SALMON AND WHITE RIVER FLOOD HAZARD MAPPING

Coastal Analysis

December 3, 2021

Prepared For:
McElhanney Consulting Services Ltd.
1196 Dogwood St.
Campbell River, BC
V9W 3A2

202-2780 Veterans Memorial Parkway
Victoria, BC V9B 3S6
Phone: 778.433.2672
www.greatpacific.ca
gpinfo@greatpacific.ca

Disclaimer

GreatPacific Consulting Ltd. (GPC) has prepared this Report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professional current practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this Report. No other warranty and/or guarantee, whether expressed or implied is made, with respect to the Report, the Information, or any part thereof.

This Report has been prepared for the specific project and/or site, design objective, development and purposes described to GPC by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this Report and are not applicable to any other project or site location. GPC accepts no responsibility for any events or circumstances that may have occurred since the date on which the Report was prepared and, in the case of subsurface, marine, environmental or geotechnical conditions, is not responsible for any variability in such conditions, geographically or over time.

Except as agreed to in writing by GPC and our Client or as required by law; or to the extent used by governmental reviewing agencies for the purpose of obtaining permits or approvals, the Report and the Information may be used and relied upon only by the Client and no other party without the express written consent of GPC and payment of compensation for that consent."

Report Prepared By:

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
Dr. H. A. MIR
33642
2021-12-06

Hammad Mir, Ph.D., P.Eng.
Coastal Engineer

Reviewed By,

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
J. R. CLARKE
39072
2021-12-06

Jason Clarke, P.Eng.
Director

GreatPacific Permit to Practice 1000737

Contents

Tables

Figures

1 Introduction

This report presents data, methodology and results for the coastal water level boundary development at Sayward, BC for use in flood mapping being completed by McElhanney Consulting Services Ltd. for Strathcona Regional District.

The coastal water level boundary conditions were generated for the following four scenarios:

- 1:20 storm surge with higher high water level, large tide (HHWLT) for year 2021
- 1:200 storm surge with higher high water level, mean tide (HHWMT) for year 2021
- 1:20 storm surge with HHWLT for year 2100
- 1:200 storm surge with HHWMT for year 2100

2 Coastal Model Inputs and Methodology

2.1 Tides

The Kelsey Bay tidal station is located at the mouth of Salmon River. Mean and high-water elevations for Kelsey Bay Table 1 were obtained from Volume 6 of the Canadian Tide and Current Tables (2021).

Table 1 Tide levels for Kelsey Bay.

Site	HHWLT (m)		HHWMT (m)		MWL (m)		LLWMT (m)		LLWLT (m)	
	CD	GD	CD	GD	CD	GD	CD	GD	CD	GD
Kelsey Bay	5.3	2.4	4.4	1.5	2.9	0	1.1	-1.8	0.1	-2.8

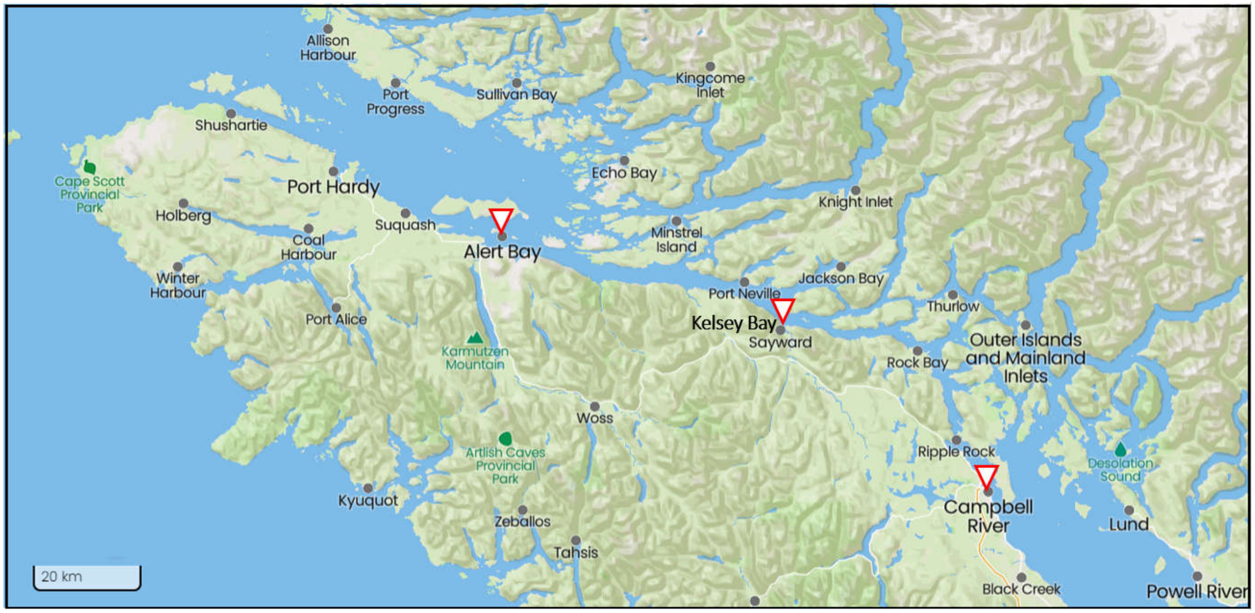
Notes: 1 - The information in this table is based on Canadian Tide and Current Tables, 2021.
2 - Tide and Chart Datum (CD) is the lowest normal tide.
3 – GD: Geodetic Datum
4 - HHWLT: Higher High Water level, Large Tide
HHWMT: Higher High Water level, Mean Tide
MWL: Mean Water Level
LLWMT: Lower Low Water Level, Mean Tide
LLWLT: Lower Low Water level, Large Tide

2.2 Storm Surge

Coastal storm surges are primarily generated by atmospheric pressure drop and wind drag when storms are developed. While pressure induced water level changes are a broadly regional phenomenon, the wind driven water level changes are typically local events and affected by bathymetry and shoreline configuration. In a recent study, Zhai et al (2018) investigated these processes along the BC coast and statistically quantified the surge heights. Storm surges can cause a coastal flood hazard when these events coincide with high tide.

For storm surge analysis, historical water level records for three coastal stations, i.e., Kelsey Bay, Campbell River, Alert Bay, were obtained from the online database of Canadian Hydrographic Service (CHS). The station locations (Figure 1) and the length of data coverage are provided in Table 2. The Kelsey Bay station is located at the mouth of Salmon River and has only 11 years of record, which is not long enough for a reliable estimate of the 200-year extreme. The other two stations, Alert Bay and Campbell River, are 72 km West and 70 km Southeast of Kelsey Bay, respectively. The water level record for Alert Bay is 31 years and for Campbell River is 52 years.

Figure 1 Locations of water level stations



Tidal analysis was performed to separate the tidal signals from the water level record and the de-tided data included water level variations mainly caused by storm surge and also by other oceanographic phenomena including El Niño. Estimated top ten storm surge events at Kelsey Bay and corresponding storm parameters are provided in Table 3. The analysis showed that half of the storm surges took place when tide was above the MWL and only two events happened when the tide was above HHWMT. The wind data showed that most of the storm surges at Kelsey Bay were generated by the SE storms as wind over Georgia Strait pushed water through Discovery Passage into Johnstone Strait. It was also observed that in most cases, storm surges were generated both at Kelsey Bay and Alert Bay. By considering the length of data record and similarities in tidal and storm surge parameters, the water level records for Alert Bay were used for determining the extreme storm surge at the Salmon River mouth.

Annual maximum storm surges, which were estimated by removing the tide at Alert Bay for the period of 1948-1979, are given in Table 4. The table also shows the annual maximum storm surges which were estimated by removing the tide. A statistical analysis of storm surge heights was performed using the Gumbel method (Figure 2) to determine the extreme surge heights for at the Salmon River mouth (Table 5). The estimated values were found to be consistent with the extreme storm surges published by Zhai et al. (2019) for the northern BC coast. The 200-year storm surge at the Salmon River Mouth was estimated to be 1.3 m.

Table 2 Water level observation station location and data coverage.

Station (Number)	Location	Data Coverage
Alert bay (8280)	50.587º N 126.931º W	1948-1979
Kelsey Bay (8215)	50.398º N 125.961º W	1973-1978 1987-1993
Campbell River (8074)	50.042º N 125.247º W	1965-1968 1972-2021

Table 3 Estimated tide and storm surge components for top 10 historical storm surges for Kelsey Bay and corresponding storm wind conditions recorded at Alert Bay.

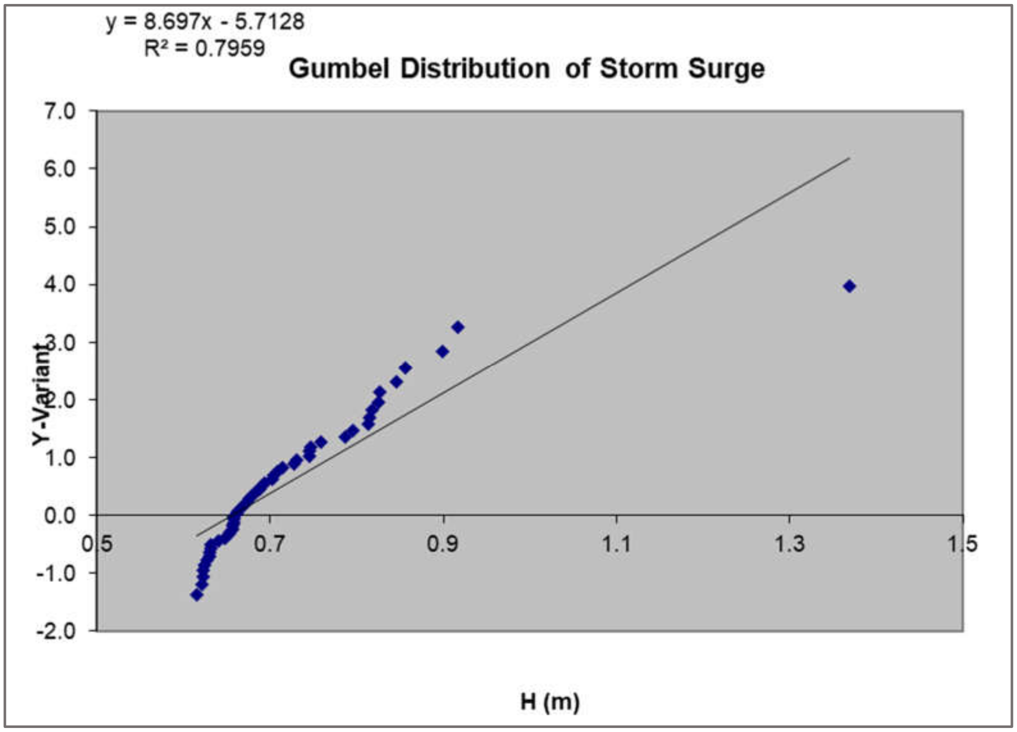
Event Date	Pure Tide (m)	Storm Surge Height (m)	Wind Speed (km/h)	Wind Direction (deg)	Pressure Fall (hPa)
1973-07-02 7:00	1.06	0.69	8	90	4.2
1973-12-12 13:00	4.50	0.90	64	140	30.6
1974-01-15 3:00	3.05	0.72	48	90	48.2
1975-11-15 8:00	3.21	0.83	74	140	41.6
1976-10-24 10:00	2.52	0.73	56	140	18.7
1977-10-30 0:00	2.08	0.70	46	140	23.8
1978-02-09 3:00	4.93	0.70	83	140	36.3
1987-12-09 14:00	4.07	0.73	46	140	37.8
1988-11-22 16:00	2.17	0.63	74	140	43.8
1990-06-10 07:00	1.26	0.61	26	270	12.9

Table 4 Annual maximum storm surge heights and annual maximum water levels at Alert Bay.

Date/Time	Annual Maximum Storm Surge Height (m)	Date/Time	Annual Maximum Water Level (m, CD[1])
1948-10-06 21:00	0.60	1948-11-02 13:00	5.40
1949-12-05 02:00	0.62	1949-03-17 03:00	5.42
1950-10-28 04:00	0.75	1950-12-09 12:00	5.64
1951-11-30 19:00	0.83	1951-11-30 13:00	5.86
1952-12-07 02:00	0.85	1952-12-30 12:00	5.55
1953-11-14 09:00	0.75	1953-11-21 13:00	5.56
1954-02-17 14:00	0.76	1954-12-09 12:00	5.70
1955-12-24 05:00	0.60	1955-11-30 13:00	5.55
1956-03-03 03:00	0.82	1956-01-26 12:00	5.30
1957-12-25 15:00	0.81	1957-12-20 12:00	5.49
1958-02-24 16:00	0.79	1958-04-04 1:00	5.49
1959-01-12 05:00	0.86	1959-01-08 12:00	5.61
1960-02-02 02:00	0.69	1960-12-18 13:00	5.55
1961-01-07 17:00	0.66	1961-01-17 13:00	5.55
1962-12-15 05:00	0.71	1962-11-12 13:00	5.52
1963-12-24 18:00	0.80	1963-12-30 13:00	5.65
1964-01-19 16:00	0.79	1964-12-19 13:00	5.67
1965-12-03 10:00	0.68	1965-12-08 12:00	5.37
1966-12-11 15:00	0.70	1966-02-05 13:00	5.52
1967-12-04 20:00	0.66	1967-12-02 13:00	5.65
1968-02-21 04:00	0.65	1968-11-21 13:00	5.81
1969-12-11 20:00	0.73	1969-12-11 14:00	5.78
1970-03-07 02:00	0.65	1970-01-08 13:00	5.41
1971-06-25 07:00	0.67	1971-12-02 12:00	5.41
1972-11-04 02:00	0.73	1972-03-18 3:00	5.34
1973-01-16 16:00	0.82	1973-12-11 13:00	5.66
1974-01-18 14:00	0.92	1974-03-10 2:00	5.36
1975-11-15 01:00	0.81	1975-11-04 13:00	5.43
1976-09-25 23:00	1.37	1976-10-24 13:00	5.47
1977-11-01 10:00	0.65	1977-12-11 13:00	5.74
1978-02-09 03:00	0.90	1978-02-07 13:00	5.83

Note: 1. Local Chart Datum for Alert Bay

Figure 2 Gumbel distribution of peak water level at Alert Bay.



The y-axis is *ln(ln(1/P)* where P is the probability of exceedance. The water level on the x-axis is shown against the Chart Datum (CD) which is 2.9 m below the GD.

Table 5 Statistically estimated extreme storm surges at the mouth of the Salmon River.

Return Period (Year)	Storm Surge Height (m)
2	0.8
10	1.0
20	1.1
50	1.2
100	1.2
200	1.3

2.3 Climate Change

2.3.1 References and Guidelines

Sea-level rise predictions for sites on the West Coast are provided by James et al. (2014; 2015), from the Geological Survey of Canada (GSC).

The BC Government published an amendment to the 2011 guidelines entitled “Flood Hazard Area Land Use Management Guidelines” (BC MOE, 2018), which states that sea-level rise, before accounting for regional uplift or subsidence, should be allowed for as follows:

- 0.5 m by the year 2050,
- 1.0 m by the year 2100, and
- 2.0 m by the year 2200.

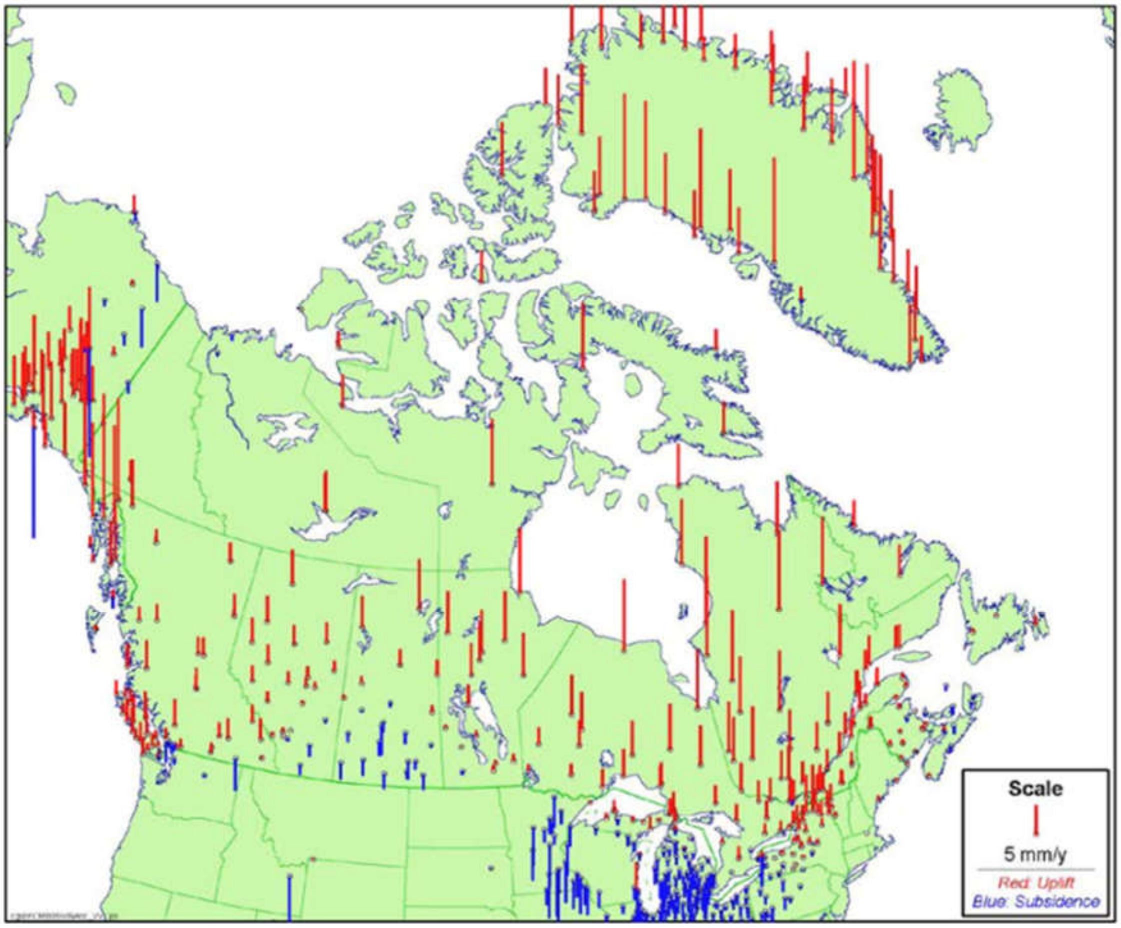
The provincial guidelines were used in comparison with the published information by the Geological Survey of Canada (GSC). It should be noted that sea level rise projections are estimates, and depending on how the analysis is carried out, and what assumptions are made, there are a range of values and level of uncertainty in the projections for any given timeframe.

2.3.2 Sea Level Rise

The relative sea-level rise is defined as the global sea-level rise, plus or minus isostatic rebound or settlement from post glacial effects and is based on the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The sea-level rise estimates provided herein are relative to the period 1986 to 2005, commonly referenced as the year 2000.

The global mean sea-level rise projection for RCP8.5, the largest emission scenario, at the year 2100 is 74 cm (the 5% to 95% range is 54 cm to 98 cm; James et al 2014). On the West Coast of Canada, most relative sea-level rise projections are smaller than the global mean due to the isostatic rebound movement of land as shown in Figure 3.

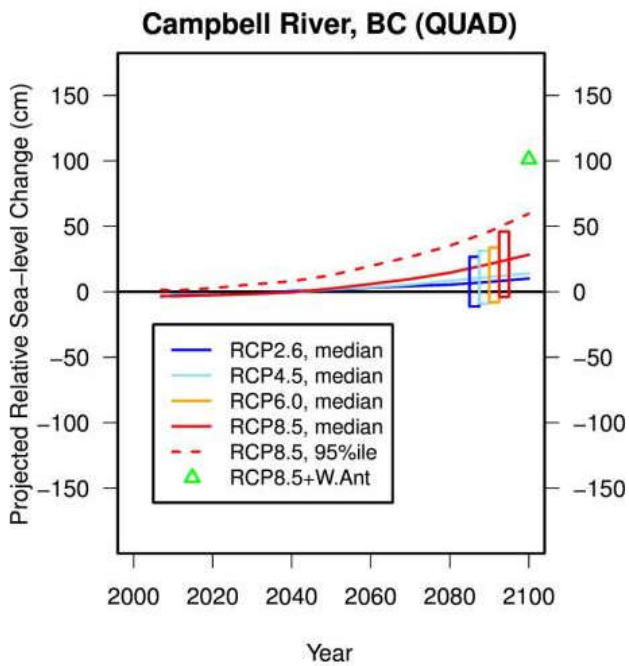
Figure 3 Isostatic rebound of sites in Canada (GSC 2014)



Campbell River, BC (south of Sayward) and Beaver Cove, BC (near Alert Bay) are the nearest relevant sites to Sayward presented in the investigations by James et al. (2014, 2015) that considered the combined effects of global sea level rise and land movement. Figure 4 shows the sea-level rise projections relative to land for Campbell River and Beaver Cove. For the year 2100, the predicted elevation changes at Campbell River, corresponding to 5% and 95% range are -2.9 cm to 59.6 cm (with median of 28.3 cm). For the year 2100, the predicted elevation changes at Beaver Cove, corresponding to 5% and 95% range are 14.4 cm to 70.5 cm (with a median of 42.5 cm).

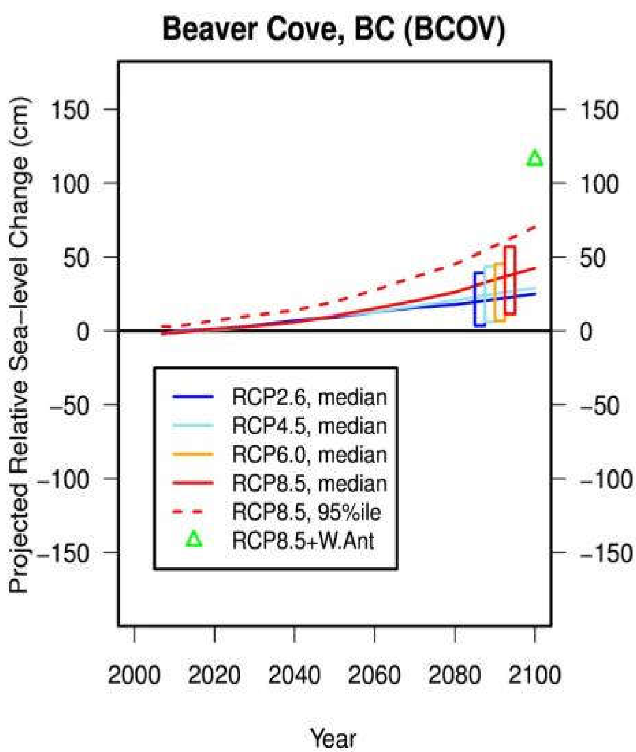
For this study, the sea-level rise for the year 2100 was considered equal to the 95% percentile of the RCP8.5 projections for Beaver Cove or 71 cm.

Figure 4 **Sea-level rise projections relative to the period 1986 to 2005 for Campbell River and Beaver Cove (James et al., 2015).**



RCP8.5

year	5%	median	95%
2007	-7.8	-3.1	1.6
2010	-7.9	-3.5	0.9
2020	-8.0	-2.6	2.8
2030	-9.3	-1.8	5.6
2040	-9.1	-0.5	8.0
2050	-7.8	2.4	12.6
2060	-8.0	5.9	19.7
2070	-7.2	9.7	26.7
2080	-6.1	14.5	35.1
2090	-3.7	21.1	46.0
2100	-2.9	28.3	59.6



RCP8.5

year	5%	median	95%
2007	-6.3	-1.6	3.2
2010	-5.8	-1.4	2.9
2020	-4.5	1.3	7.1
2030	-4.1	3.3	10.7
2040	-2.0	5.9	13.8
2050	0.5	10.1	19.7
2060	2.5	15.1	27.7
2070	4.3	20.3	36.4
2080	7.4	26.3	45.2
2090	11.9	34.7	57.5
2100	14.4	42.5	70.5

By considering the uncertainty in the prediction the relatively higher value predicted for Beaver cove is use for the current study. Projections beyond year 2100 were not made as part of this study, and it should be noted that sea levels are likely to continue to rise beyond year 2100. As scientific knowledge develops regarding future rates of sea level rise, this analysis should be updated.

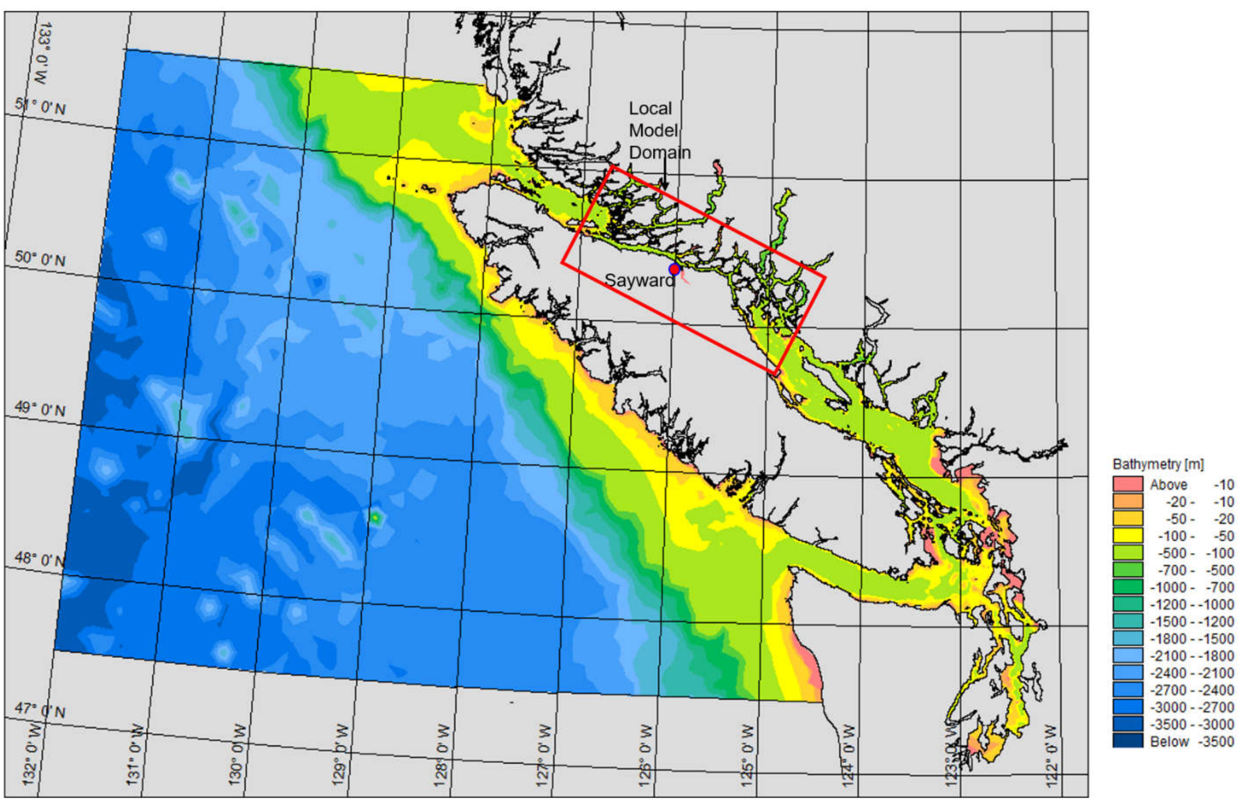
3 Modelling

3.1 Tidal Simulation

A regional hydrodynamic model for the Southern BC Coast and adjacent ocean was used for the simulation of tide (Figure 5). The model was constructed using a two-dimensional modelling package, MIKE 21 HDFM, developed by DHI Water and Environment. Additionally, a local hydrodynamic model covering Johnstone Strait and Discovery Passage was used for the simulation of water level dynamics at the Salmon River mouth. A refined bathymetric grid at the Salmon River mouth and adjacent surroundings was used in the local model. The regional model provided the boundary forcing to the local model.

A tidal simulation was performed for a 7-day period covering the largest spring tide occurring in 2021 spring-neap tidal cycles. The simulated water level was extracted just beyond the mouth of the Salmon River to provide the coastal boundary for subsequent into the river model.

Figure 5 The regional and local model domains used for hydrodynamic simulation.



3.2 Storm Surge Simulation and Derivation of Boundary For River Model

The coastal model was also applied to simulate the wind generated water level change in the coastal channels. The simulation was performed for the peak storm event on 16 November 1991 recorded at Alert Bay. The water level change due to atmospheric pressure fall during the peak storm was estimated using an empirical method published by WMO (2011). The relationship between pressure fall during a storm event and associated surge height is given by the following equation:

$$\eta_p = (p-1013) \times 0.033$$

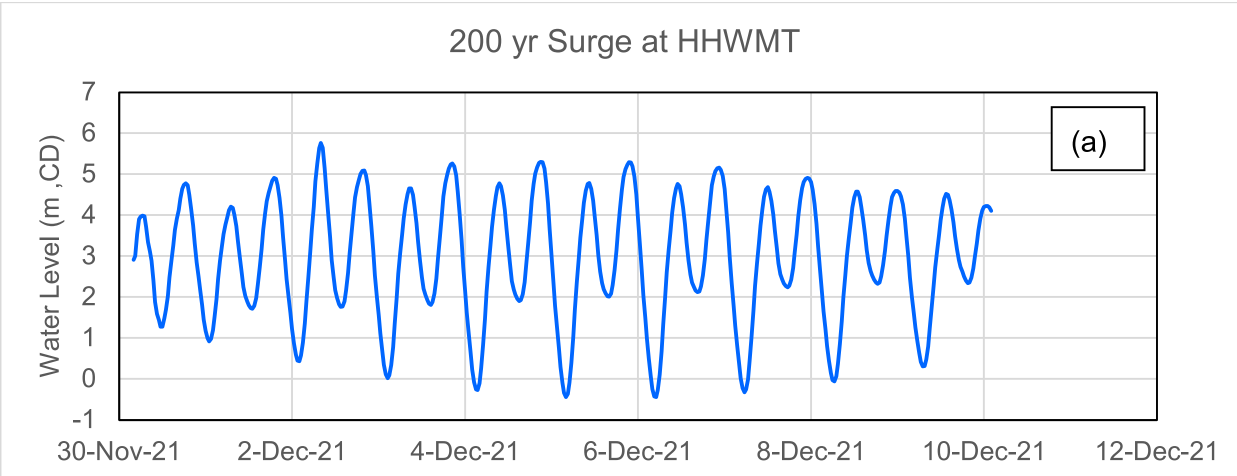
Where η_p is the surge height in ft, and p is atmospheric pressure in hectopascals (hPa).

The simulated pattern of storm surge development was used to generate the water level change by the combined effect of tide and surge. The simulated tide was scaled to obtain the 20 year and 200-year storm surges which were statistically estimated using field records. Subsequently, the surge history was superimposed to the specific phases of tide for the desired flood condition scenarios to obtain the time series of water level change combining tide and surge.

3.3 Results

Sea water levels, for inputting to the river model were predicted for four specific events (Table 6) using tide, and storm surge. These scenarios include both current and future (under climate change) marine conditions. The water levels were extracted at 5588000 N 290000 E, an offshore location outside the Salmon River mouth (Figure 6a and 6b).

Figure 6 Water level for (a) 1:20 storm surge at HHWLT and (b) 1:200 storm surge at HHWMT, for year 2021.



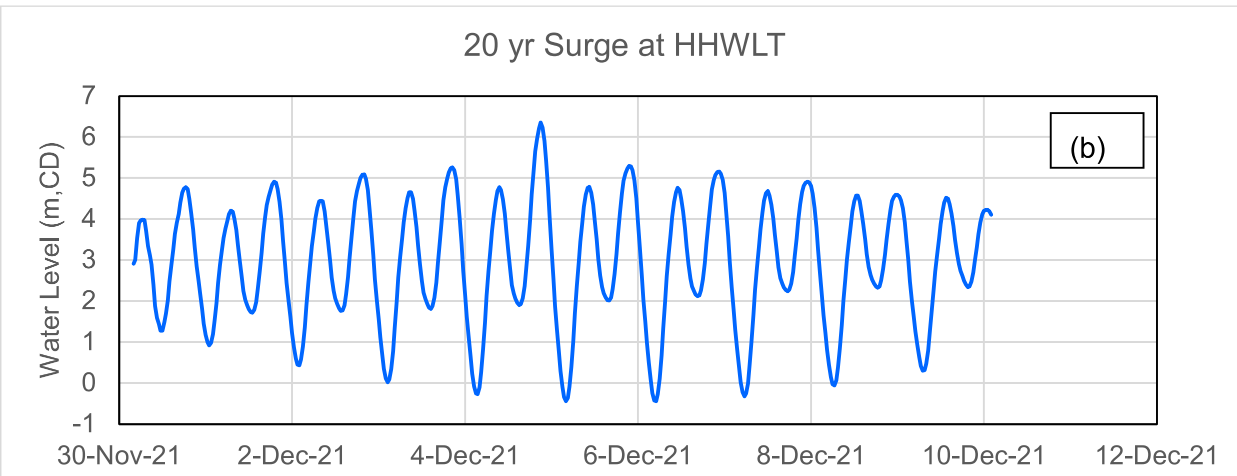


Table 6 Predicted extreme water levels for four scenarios.

Scenario	Year of Prediction	Peak Water Level (m, CD)
1:20 storm surge with HHWLT	2021	6.36
1:200 storm surge with HHWMT	2021	5.73
1:20 storm surge with HHWLT	2100	7.07
1:200 storm surge with HHWMT	2100	6.44

3.4 Assumptions

Assumptions used for this study were as follows:

1. The analysis did not address landslide or avalanche events
2. The analysis did not address tsunami events
3. No freeboard allowance was added to the marine water levels
4. The conversion from chart datum to geodetic datum was -2.9 m.
5. The analysis did not consider projections beyond year 2100.

4 References

BC Ministry of Environment (2018). "Amendments to Flood Hazard Area Land Use Management Guidelines, 2011". Province of British Columbia. Section 3.5 and 3.6

Fisheries and Oceans Canada (DFO). 2021. Canadian Tide and Current Tables – 2021 – Volume 6. Discovery Passage and West Coast of Vancouver Island. Canadian Hydrographic Service. Cat No. Fs73-6/2021-PDF.

James, T.S., J.A. Henton, L.J. Leonard, A. Darlington, D.L. Forbes and M. Craymer. (2014). Relative sea-level projections in Canada and the adjacent mainland United States, GSC Open File 7737.

James, T.S., J.A. Henton, L.J. Leonard, A. Darlington, D.L. Forbes and M. Craymer. (2015). Tabulated values of relative sea-level projections in Canada and the adjacent mainland United States, GSC Open File 7942.

Zhai, L., B. Greenan, R. Thomson, and S. Tinis, 2019. Use of Oceanic Reanalysis to Improve Estimates of Extreme Storm Surge. Journal of Atmospheric and Oceanic Technology, 36, 2205-2219, https://doi.org/10.1175/JTECH-D-19-0015.1

.