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Squamish Training Berm Realignment - Wave Impact Assessment

Squamish River Watershed Society

Final Report

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Executive Summary

The Squamish River Watershed Society (SRWS) wishes to remove as much as possible of the training berm on the Squamish River as part of the Central Estuary Restoration Project (CERP). The project has the purpose of restoring and preserving the integrity of the Squamish River watershed as well as improving access and habitat in the estuary for juvenile chinook. This document summarizes a wave impact assessment of the removal of the training berm.

The objective of the current study is to provide a preliminary assessment of the wave climate impact, before (current conditions – existing training berm) and after the training berm removal, as described for the two scenarios below:

- Scenario 1: removal of training berm up to the yellow gate (approximately removal length: 1.1 km)
- Scenario 2: removal of the training berm up to Culvert 4 (approximately additional removal length: 1.3 km)

Scenario 1 wave heights were increased on the immediate east side of the berm footprint, as expected. There was also a slight increase in wave heights close to Squamish Terminals. The wave conditions close to the Squamish current coastal boundary is essentially the same for the existing scenario and for Scenario 1.

However, when the additional 1.3 km of berm is removed (Scenario 2), allowing the river to flow in the Central Channel, the assumed modification of the riverbed in this area creates larger wave heights at the upper section of the channel and close to the railway embankment.

This wave assessment was based on morphology changes estimated by SNC-Lavalin based on a preliminary assessment of available information. Detailed hydrodynamic and sediment transport modelling should be undertaken in the next design phase to better estimate the bathymetry changes before final assessment of the potential effects of the structure removal.

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APPENDICES

1. Introduction

1.1 Background

The Squamish River training berm, known locally as the Spit Road, was installed in the 1970s to 'train' the Squamish River against the west bank to accommodate a deep sea coal terminal to be built in the central estuary area. The river was also dredged at this time, and the dredge material was placed on the central estuary for the proposed terminal facility. At this time, public concern was raised on the continued industrialization of the Squamish Estuary. To address this concern the federal and provincial governments of the day halted further construction works, and started the Squamish Estuary Management Planning process with the intent to maintain a balanced approach to developments in critical habitat areas. Although construction was halted, the road that bisects the estuary and the infill remained in place. The outcome of this federal-provincial planning process is summarized in the 1982 and 1999 Squamish Estuary Management Plan, and the 2007 Skwelwil'em-Squamish Wildlife Management Area Plan wherein opportunities to restore, enhance and maintain fish and wildlife habitat in the area that had been impacted are identified.

The Squamish River Watershed Society (SRWS) has been implementing restoration and enhancement works identified through the estuary planning process. This included the successful removal of the dredge material from the central estuary, restoration of tidal channels in the estuary and re-connection of the river and the estuary through a series of nine culverts placed across the training berm (2001 – 2013). The culverts were installed to allow for freshwater-saltwater exchange in the estuary, and for fish passage for juvenile salmonids that are emerging from the river. In this rearing life stage salmonids require access to the estuary as they undergo the physiological transitions needed for their life at sea.

For the past five years, the SRWS has been undertaking fisheries assessment work to determine if the nine culverts are permitting fish access. From this work it has been determined the culverts are not effectively permitting fish access from the river into the estuary and the restored habitat in the estuary is significantly underutilized, especially by juvenile Chinook salmon. Results suggest the training berm is essentially flushing the juvenile fish out to the deep ocean, which is likely affecting stock survival rates. When compared to other estuaries, the presence of fish in the Squamish Estuary is low despite considerable and ongoing efforts to restore access and habitat since the 1970s.

Pacific Salmon, particularly Chinook species, are under considerable stress and populations have been in decline for years. In 2019, Fisheries and Oceans Canada announced that all but 1 of the 13 Chinook Salmon Fraser River Chinook salmon populations are at risk, which is consistent with local assessment findings. Fisheries and Oceans Canada outlined that the science is clear and the loss of these populations would be disastrous to resource-recreation economies, and to the fish and wildlife that depend on this species. In particular, the Southern Resident Killer Whale Population, listed as endangered under the federal Species at Risk Act, feeds on Chinook salmon as their primary food source.

To preserve and restore the integrity of the Squamish River watershed, improving access and habitat in the Estuary for juvenile chinook, the SRWS plans to remove as much of the training berm as possible within the fish and wildlife structure area and therefore support the Central Estuary Restoration Project (CERP).

1.2 Scope

SNC-Lavalin has been retained by SRWS to evaluate the impact of removal of as much as possible of training berm on the wave climate within the provincially owned fish and wildlife structure area.

SNC-Lavalin conducted a study in 2015 (Ref [6]), to define the wave climate around the perimeter of the coastal boundary of the District of Squamish (Figure 1) and provided coastal water levels expected to be concurrent with major river flooding events. Also, SNC-Lavalin found that the training berm provides protection against wave effects within Crescent Slough and in particular to the Town Dike.

The objective of the current study is to provide a preliminary assessment of the wave climate impact, before (current conditions – existing training berm) and after the training berm removal, as described for the two scenarios below:

- Scenario 1: removal of training berm up to the yellow gate (approximately removal length: 1.1 km)
- Scenario 2: removal of the training berm up to Culvert 4 (approximately additional removal length: 1.3 km)

For the purpose of this wave study, the existing 2015 wave model developed by SNC-Lavalin (Ref [6]) was updated and revalidated considering new input as summarized below:

- Identify potential areas of accretion and scour based on the available hydrodynamic and sediment transport information to define appropriate bathymetry for each Scenario;
- Model the wave propagation over the estimated bathymetry;
- Compare the results with the current scenario

Figure 1 Modelled scenarios

2. Metocean Conditions and Modelling Criteria

2.1 Reference system

Horizontal reference is UTM Zone 10N (NAD 1983). The vertical elevations or depths are referenced to either the Canadian Geodetic Vertical Datum from 1928 (CGVD 28) or the Chart Datum (CD) for the area as noted in this report. Vertical reference for modelling is Chart Datum. Chart Datum is 3.08 m below CGVD 28.

Table 1 Horizontal and vertical references specifications

Parameter	Value
Horizontal datum	UTM Zone 10 N
Vertical datum	CGVD 1928 / Chart Datum

2.2 Bathymetry

The District of Squamish is situated at the north end of the Howe Sound. The junction between the Howe Sound and the Squamish riverbed is steep, dropping from around 0 to 15 m CD in a few meters. There is regular dredging to 11 m CD to accommodate vessels at the Squamish Terminals berth pocket. The edge of the delta is unstable and changes to the bathymetry are common due to local landslides.

The Squamish River delta shows major change over time, likely due to the construction of the training berm in the 1970s (Figure 2). The river currently flows through its west branch. The thalweg of this branch migrated toward the west over time. The east part of the river in the Central Channel is currently shallower as sedimentation played an important role in the river morphology over the years. Figure 2 shows an approximate comparison of the river alignment between 1930 and 2019.

Figure 2 River alignment comparison, 1930 (left) and 2019 (right)

Appendix A summarises the additional bathymetry data obtained in the study area since the 2015 wave model study (Ref.[6]). There have been a few changes in the morphology since 2015; however the changes are primarily in the vicinity of Squamish Terminals. This comparison study uses the 2015 bathymetry to define the current situation.

The model was developed using nested and coarse grids. The model layout is shown in Figure 3 and a compiled view of the bathymetry ensemble over the Squamish Estuary is shown in Figure 4.

The bathymetry for the coarse (100 m x 100 m) model grid is based on a blend of the CHS digital coastal 500 m x 500 m model for coastal British Columbia and digitized chart-based contours close to the shorelines of Howe Sound and the various islands in the sound. The bathymetry for the fine grid model (10 m x 10 m) is based on a blend of the following data sources:

- CHS digital coastal 500 m x 500 m model for British Columbia coast
- Digitized nautical chart contours close to shoreline
- CHS Field Sheet Data
- Lidar data from the District of Squamish in 2009

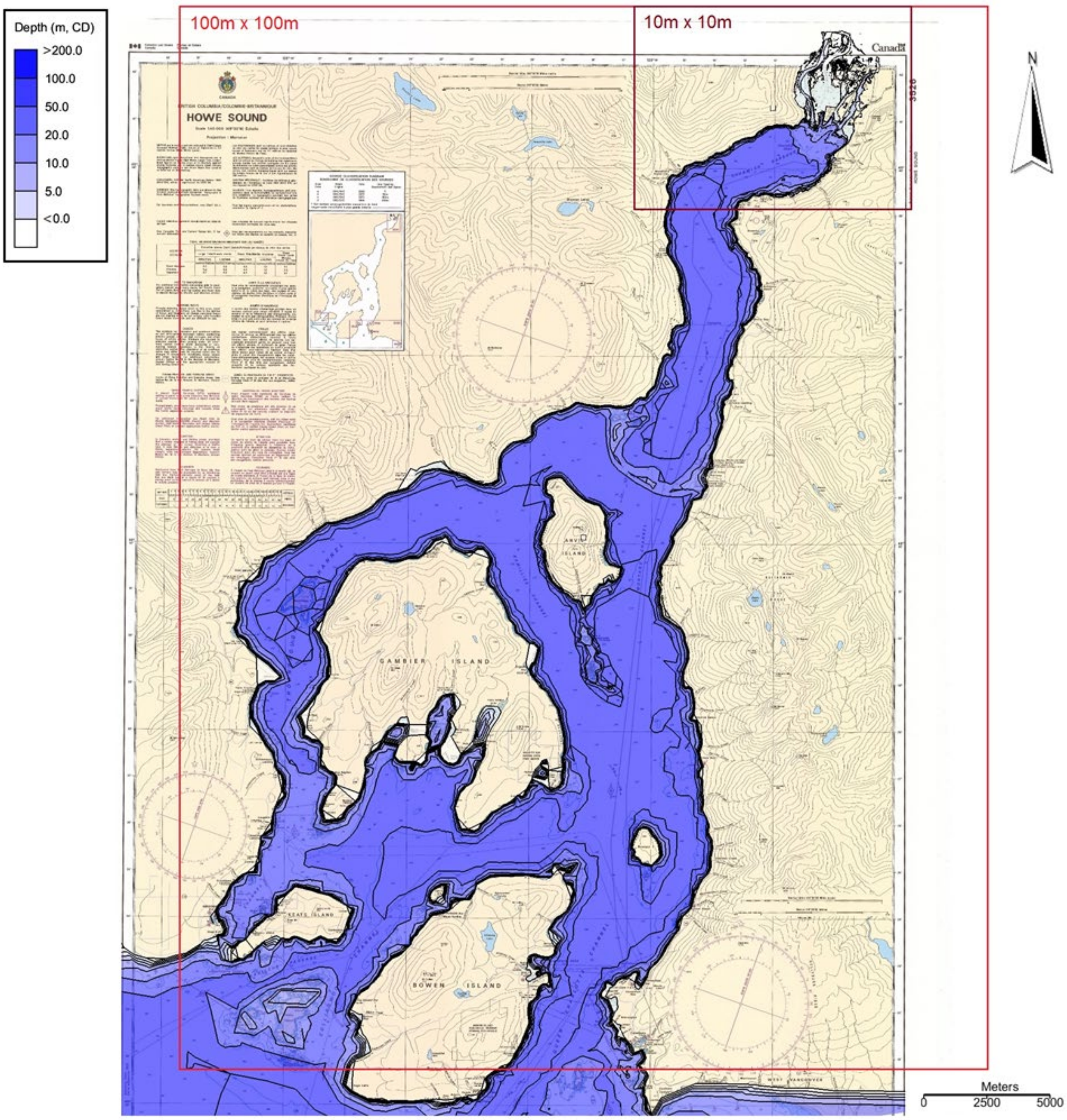

Figure 3 SWAN coarse and nested grid bathymetry used for the wave modelling

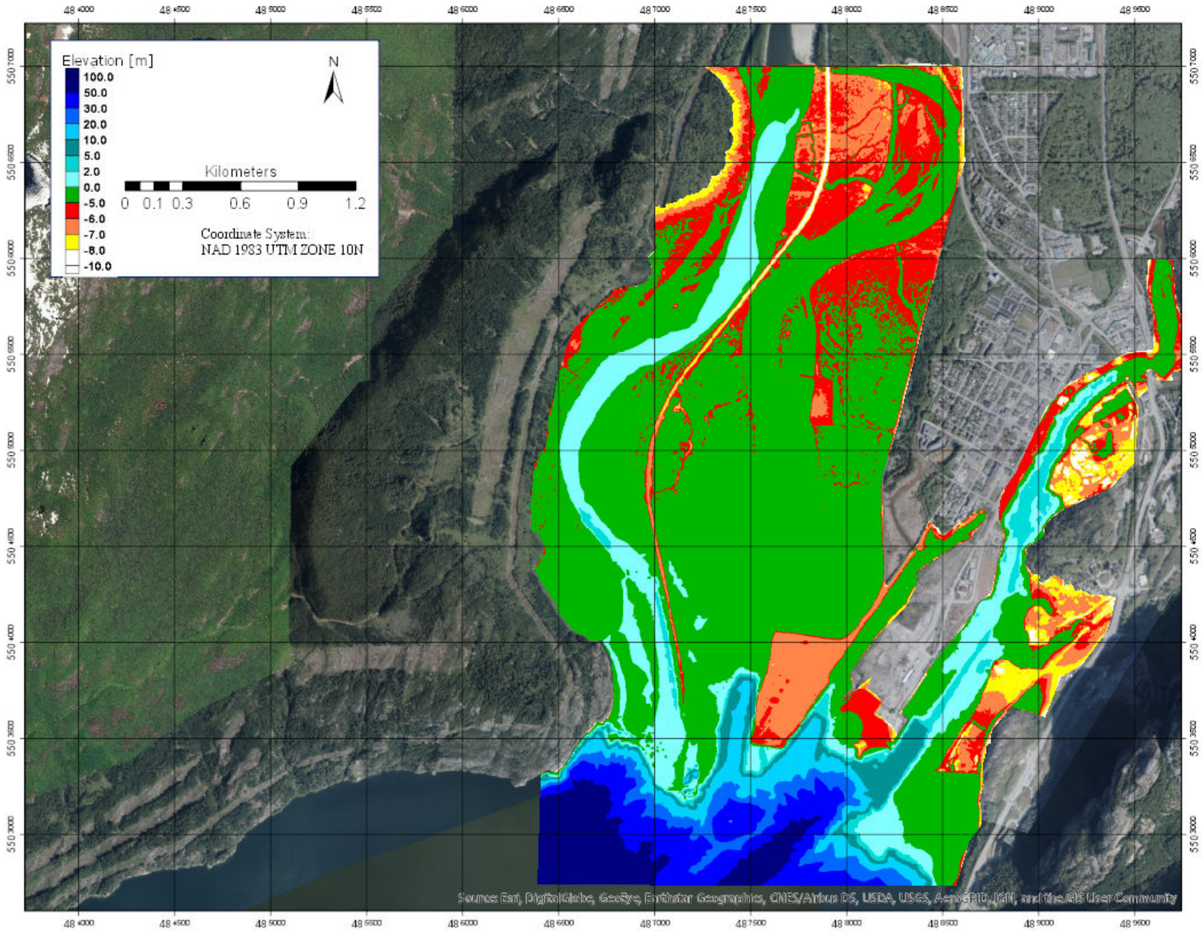

Figure 4 Assembled bathymetry for current conditions

2.3 Wind

Definition of the wave climate in the Squamish estuary requires a reliable estimate of the overwater windfield both within Howe Sound but particularly within the upper (north) reaches of Howe Sound (Ref. [6]).

Inflow wind tends to accelerate as approaching the estuary; Southerly (from) winds are expected to be stronger in the Squamish area than they are in the southern end of the Sound (Ref [8]). After analysis of available wind time series data in the area, Pam Rocks Station (ID 10459NN) was selected as the most reliable because of fewer missing data during storms and longer coverage.

The wind events Annual Exceedance Probability (AEP) were calculated using a peak over threshold analysis of the wind from the southern sector only. The minimum time between storms were 72 h to ensure independent events. Only storms lasting more than one hour was considered, assuming waves are not able to develop properly otherwise. The sample of wind speed storms followed a Generalized Extreme Value (GEV) distribution and the fitting parameters was estimated with maximum likelihood methods. The expected AEP for different return periods from south wind are given in Table 2.

Appendix A presents a preliminary observations related to the recent data (2015-2019), the storm events followed similar patterns to the previous dataset (up to 2015).

Table 2 Annual Exceedance Probability peak wind speed

Annual Exceedance Probability [1/year]	Peak Wind Speed (10m ASL)	Standard Error of Estimate
Expected Annual	41	±0.8
1/5	43	±1.2
1/10	45	±1.5
1/25	48	±2
1/100	52	±2.6
1/200	54	±3
1/500	56	±3.4

A numerical tool for the spatial interpolation of Environment Canada wind observations, independently developed by SNC-Lavalin was used to reproduce wave conditions resulting from historical storms at any location in the coastal waters of British Columbia. The resulting computed spatial or time varying wind field is provided as input to the SWAN coarse model.

The current model uses a stationary wind speed but spatial varying wind field based on the winds estimated from Pam Rock over the southern half of the model and with repeater wind stations in the reaches north of Anvil Island that echoed the wind speed at Pam Rocks but constrained the wind direction to follow the main axis of the channels between Anvil Island and Watts Point and to a direction from 215° T across Squamish Harbour. This approach is the same used in the District of Squamish Integrated Flood Hazard Management Plan.

Table 3 Designated wind storm (AEP = 1/200) for wave modelling

Parameter	Value	Comments
Wind Speed	54 knots	Based on Pam Rocks Station AEP: 1/200 (0.5%)
Wind Direction	215 deg TN	Based on Pam Rocks Station for the estuary

2.4 Water Level

The total water level input to the model is a combination of tides, local, and external storm surge. Even though recent data (2015 to 2019) was analysed (see Appendix A), the water level input for this study is the same used for the wave modelling from Ref. [6].

The scope of this study is to assess the wave impact of the berm removal for different scenarios in the present. Expected sea level rise was not included in the total water level used for this study.

External Storm Surge: Storm surge in Strait of Georgia at the entrance of Howe Sound is reported in Table 4. The expected magnitude has been provided in Section 3.2.5 of the "Sea Dike Guidelines" issued by the Province of British Columbia (Ref [1]). External storm surge of 1.25 m (AEP: 1/200) was considered to calculate the total water level input to the model.

Table 4: Exceedance probability of external storm surge (Ref. [1])

Exceedance Probability (per cent chance of being equalled or exceeded in any year)	**Exceedance Probability** (1/average recurrence interval)	**Strait of Georgia Entrance to Howe Sound**
[%]	**1/[year]**	**[m]**
50%	Annual	0.73
20%	1/5	0.83
10%	1/10	0.9
4%	1/25	1.0
2%	1/50	1.1
1%	1/100	1.2
0.2%	1/500	1.3
0.1%	1/1000	1.4

Local Storm Surge Effects: SNC-Lavalin report from 2015 (Ref. [6]) estimated 0.35 m of local storm surge from water level data during the 11 January 2014 storm. Even though the final report for the IFHMP (Ref. [4]), recommended a generic allowance of 0.3 m, the more conservative value of 0.35 m has been kept to define the local storm surge and to be consistent with the 2015 model. The difference of 0.05 m is not expected to generate significant different results for the local wave climate. A preliminary analysis of measured water level data provided by SRWS for the lower estuary suggests residuals (in relation to Point Atkinson data) are higher than 0.35 m. It is recommended that a more detailed analysis of the recent available data is undertaken in any further wave climate assessments to confirm an updated value for local effects.

Total Water Level: The total water level is calculated using extreme value analysis methods. As the sea dike guidelines suggested (Ref [1]), the 200 years storms return period should be considered for design. The surge due to that storm at Squamish is the sum of the 1:200 years external surge (1.25) with the local effect of the storm surge (0.35 m). The total water level of 3.67 m CGVD28 was considered as model input.

The summary of the different steps considered for the design water level assessment is given in Table 5.

Table 5: Components of the total water level used in the wave model

Parameter	Value	Comments
HHWLT	5.15 m CD 2.07 m CGVD28	0 m CGVD28 = 3.08 m CD
External Storm Surge	1.25 m	Sea Dike Guidelines (Ref [1] and Ref [2]) AEP: 1/200 (0.5%)
HHWLT+ External Storm Surge	6.4 m CD 3.3 m CGVD28	
Allowance Sea Level Rise	0.0 m	Current conditions
Local Effects on Storm Surge	0.35 m	Ref. [6]
Total Water Level - Model	6.77 m CD 3.67 m CGVD28	Not including wave effects

2.5 Model Limitations

The predicted magnitude of the sea state during the designated storm is very dependent on the relationship defined for inflow wind conditions between winds at Pam Rocks, and winds in Squamish Harbour and at the entrance to the Squamish Estuary. For the purpose of this comparison it has been assumed that the winds are the same as recorded at Pam Rocks and are constant over the duration of the storm peak.

This assessment did not consider the effect of river flow on the sea state.

The model included wave breaking; however, overtopping and continuous propagation of the overtopping wave energy in the lee of the berm structure was not considered.

A summary of potential tsunami effects at Squamish and landslide generated wave events from submarine slides on the delta front of the Squamish estuary are described in Ref. [5]. Tsunami wave and landslide generated wave events and related effects are considered to be separate and independent events from a coastal storm event.

While sensitivity studies of the potential effects of wave diffraction or wave propagation around or over the offshore structures identifies were undertaken and suggest that wave diffraction effects around the structures or regeneration of waves in the lee of the structures when they are awash are relatively minor, the SWAN model is not the most suitable model for definition and assessment of these effects. Detailed modelling of the potential effects of these structures considering morphologic changes from hydrodynamic and sediment transport model should be undertaken on the next design phase.

3. Results

3.1 Current Conditions

The wave climate for the current scenario includes the complete training berm. The berm crest elevation is approximately 5.5 - 6.0 m CD, and at high water level, including a 1/200 extreme storm surge, it will likely be partially submerged (Figure 4).

The wave field results for the current conditions are shown in Figure 5. The results are similar to the "Existing Water Levels" run from Ref.[6]. There is a considerable spatial gradient in the significant wave height in the vicinity of the training berm, although its effects are mostly local due to the incident wave direction. It is observed that there is some direct incident wave energy in the central estuary area between the training berm and the Squamish Terminals berth pocket, which is not diffracted around the berm.

The model included wave breaking; however, overtopping and continuous propagation of the overtopping wave energy in the lee of the berm structure are not included. Diffraction around the berm and vertical pilled wall are approximate as are the diffraction effects around the Squamish Terminals embankment fill.

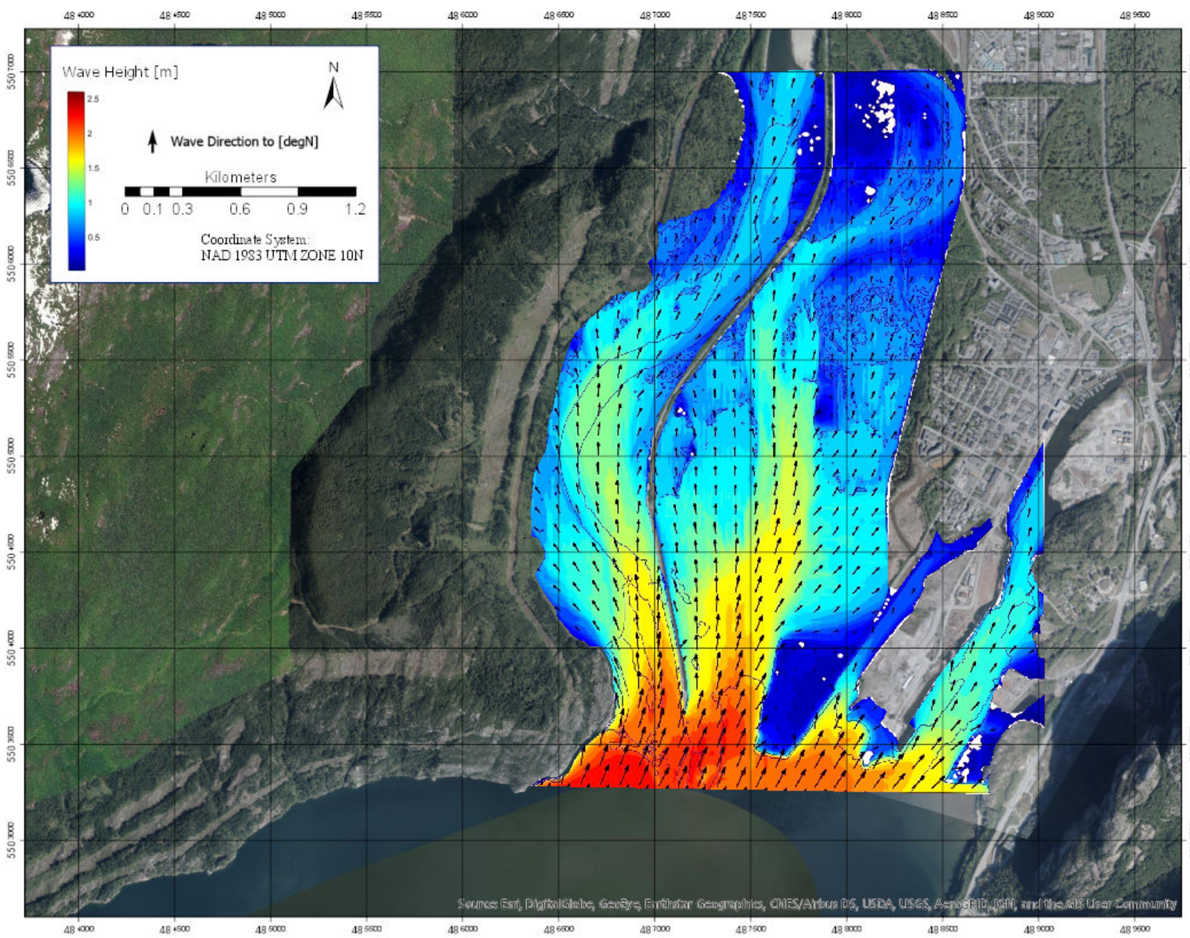

Figure 5: Current conditions wave climate results during 1/200 AEP storm

3.2 Scenario 1

3.2.1 Bathymetry Assumptions

Scenario 1 consists of removing the training berm up to “the Yellow Gate” (Figure 1), representing the removal of approximately 1.1 km of the berm length. The removal will likely modify the estuary morphology and the bathymetry for this scenario was estimated based on existing information and sediment transport models trends previously developed for the region.

Historical air photographs suggests that the main channel of the Squamish River will likely migrate eastwards at the south tip of the central Island (Figure 2) once the training berm is removed. Therefore, the bathymetry has been modified to represent the assumed new riverbed. The west bank of the existing river, from elevations higher than -1 m CD remained unchanged. East of the riverbed toward Squamish District depths were also increased to allow the interpolation of a gentle slope up to the eastern side of the central estuary. The bathymetry along the sections of the berm removal were changed to the average depths from east and west side of the berm. The proposed Scenario 1 bathymetry is presented in Figure 6.

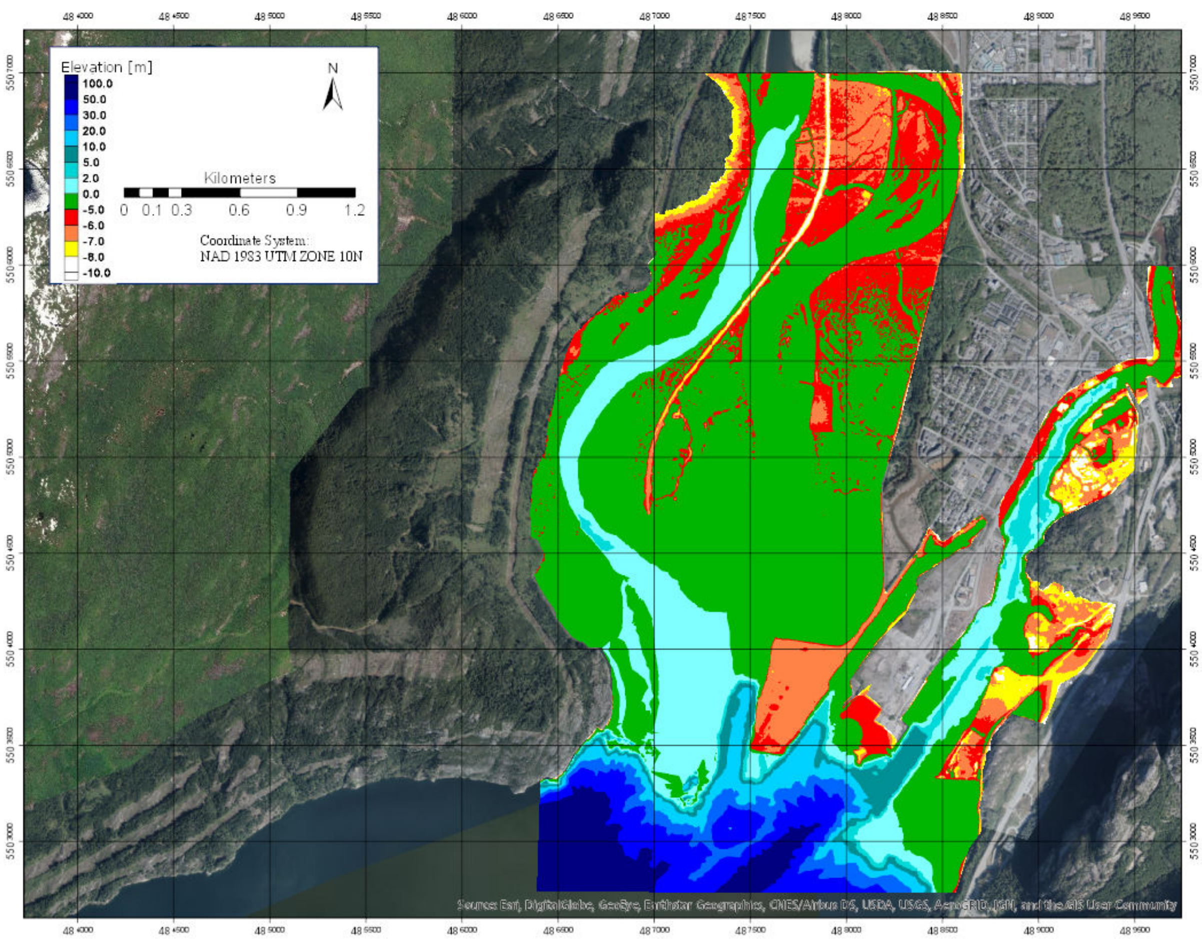

Figure 6: Scenario 1 Bathymetry

3.2.2 Results

The wave field results are show Figure 7 and show that the wave energy is increased, as expected, between the removed section of the berm and the Squamish Terminals berth pocket. The wave climate north of the Terminal is mostly the same as the present conditions with the training berm in place.

Wave heights increase slightly upstream in the river and close to Squamish Terminals, likely because of the assumed morphology changes in the south part of the delta. The wave height increase along the District of Squamish coastal boundary is not significant.

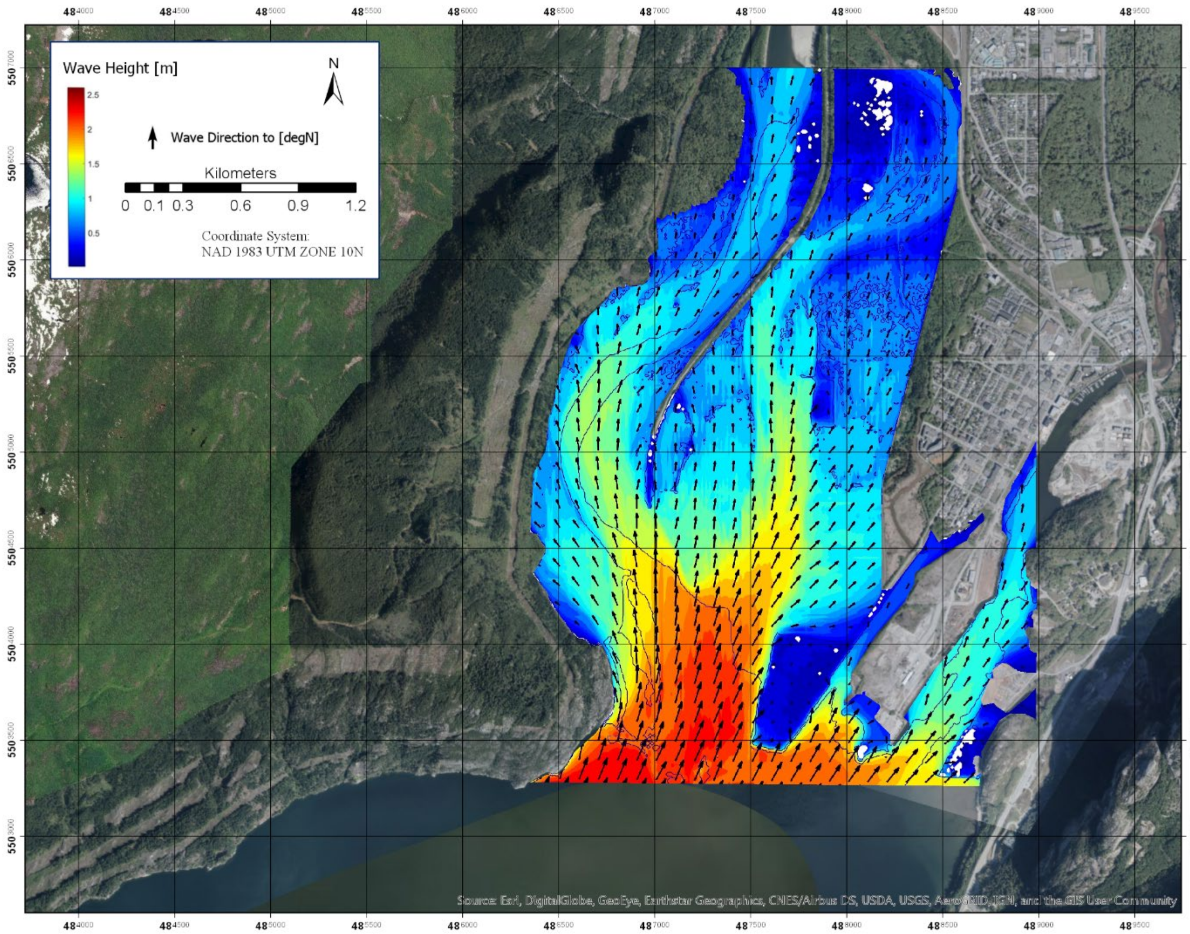

Figure 7: Scenario 1 wave climate results during 1/200 AEP storm

3.3 Scenario 2

3.3.1 Bathymetry assumptions

Scenario 2 consists of additional removal of the training berm up to Culvert 4 (Figure 1), representing the removal of approximately 1.3 km of the berm length beyond the end of the Scenario 1 removal.

Removing the training berm up to Culvert 4 could allow the river to flow into the Central Channel area instead of the current main channel, as suggested from the historical air photographs (Figure 2). The extent of river flow into the Central Channel area will be dependent on the design of the remaining culverts and the design and construction of the new terminus of the training berm.

It is assumed that when the culverts through the berm are daylighted, stream bank protection would be placed along the channels to contain bank erosion. It is also assumed that the expected increased natural flow in a daylighted channel would also increase the sediment flux.

There is a risk of a natural breach at the north end of the Central Delta area, in the vicinity of Culvert 4. The magnitude of the risk of a breach is related to the final design and maintenance of the new termination of the remaining training berm in this area, which is beyond the scope of the present assignment.

As a contingency allowance it was therefore estimated that in the event of an uncontrolled breach at the north end of the central delta, approximately one meter (vertical depth) of sediment could be removed along the low tide banks of the existing Central Slough. The depth of removal would taper to zero at the existing high water line along the existing railway berm. The estimated Scenario 2 bathymetry is shown in Figure 8.

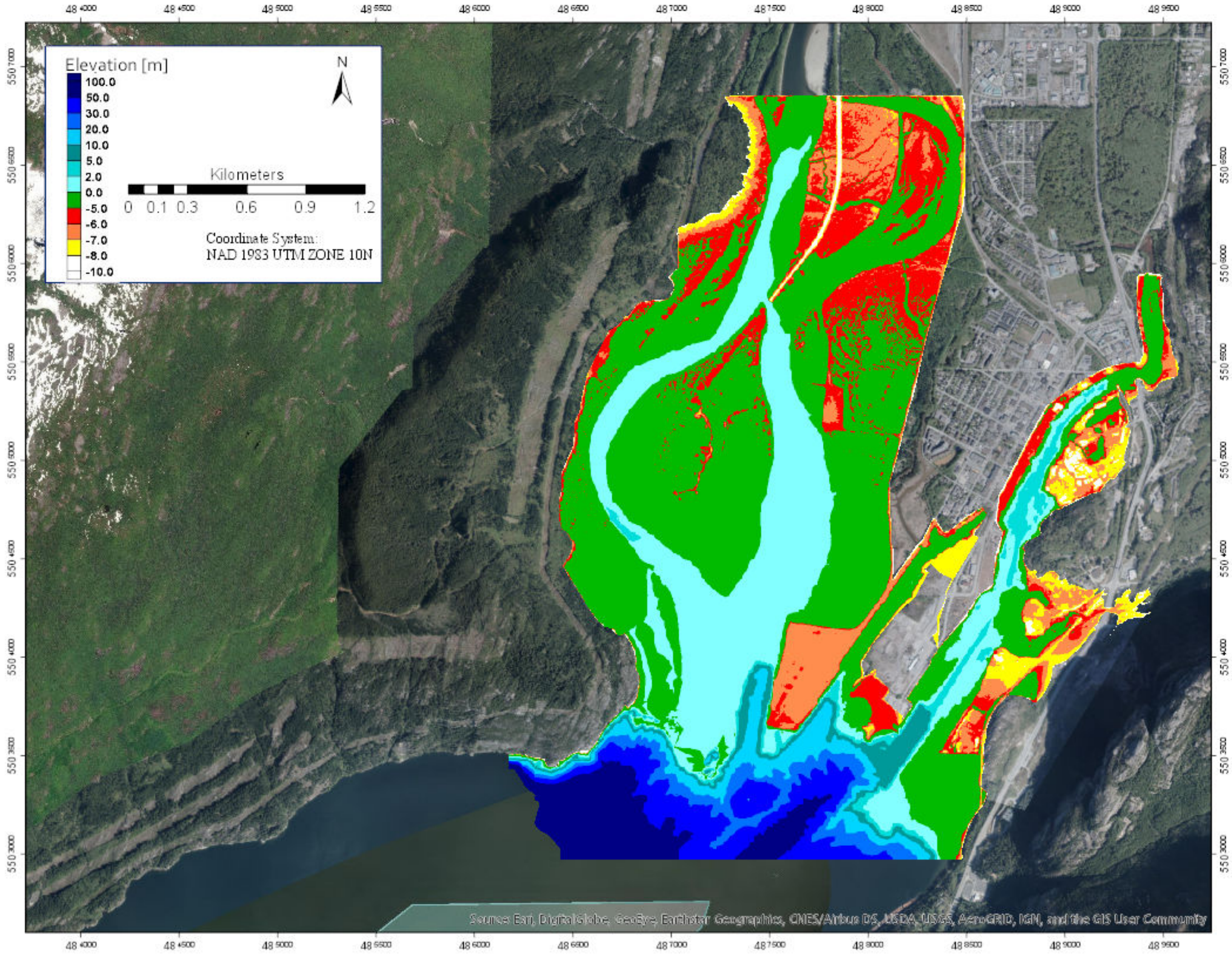

Figure 8: Scenario 2 Bathymetry

3.3.2 Results

The wave field resulting from the estimated Scenario 2 bathymetry is presented in Figure 9, which shows that the wave climate will be increased in the Central Channel area and close to the railway embankment.

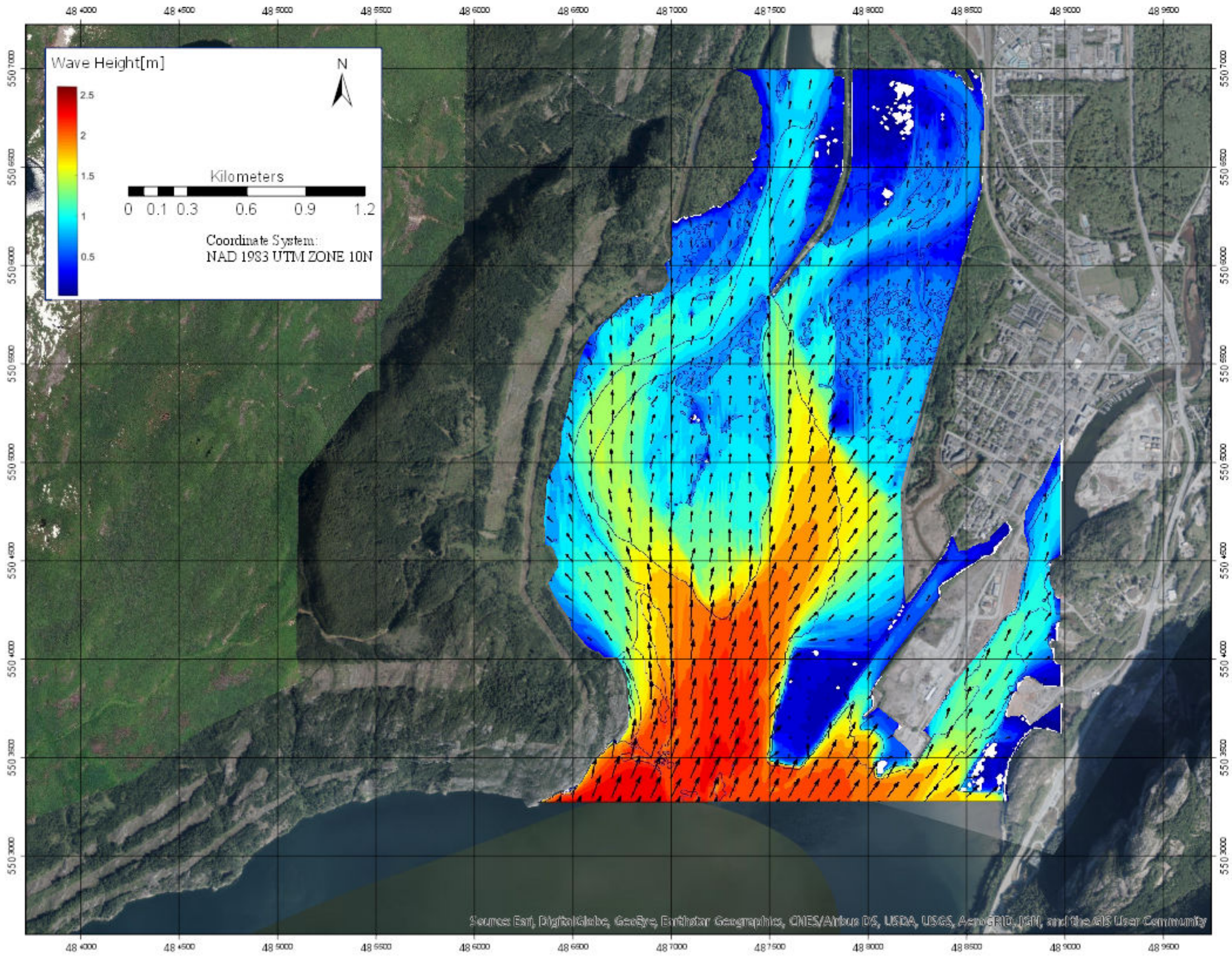

Figure 9: Scenario 2 wave results during 1/200 AEP storm

3.4 Comparison

3.4.1 Wave Field

Figure 10 shows the difference in modelled significant wave height between Scenario 1 and the present conditions with the training berm in place. Significant difference is identified on the east side of the removed berm, reducing towards the coastline.

Figure 11 shows the differences between Scenario 2 and the existing conditions with the training berm in place.

The difference in the wave climate in Scenarios 2 and 1 is shown in Figure 12.

It can be seen that that removal of the north section (Scenario 2) of the training berm, and an uncontrolled breach at the end of the remaining training berm, which might remove sediment along the Central Channel east banks still provides some wave protection to the north end of the Central Channel area and the adjacent railway embankment, except towards the south end of the railway embankment. The magnitude of the potential increase of the wave climate close to the embankment is relatively small as shown in Figure 12 and likely sensitive to the assumed erosion model expected in the event of an uncontrolled breach in the Culvert 4 area.

It is important to note that this comparison is based on preliminary estimated morphology changes due to the berm removal. A detailed sediment transport analysis should be undertaken to confirm the future bathymetry and a detailed phase resolving numerical wave model should be used to completely estimate effects of diffraction and shallow water.

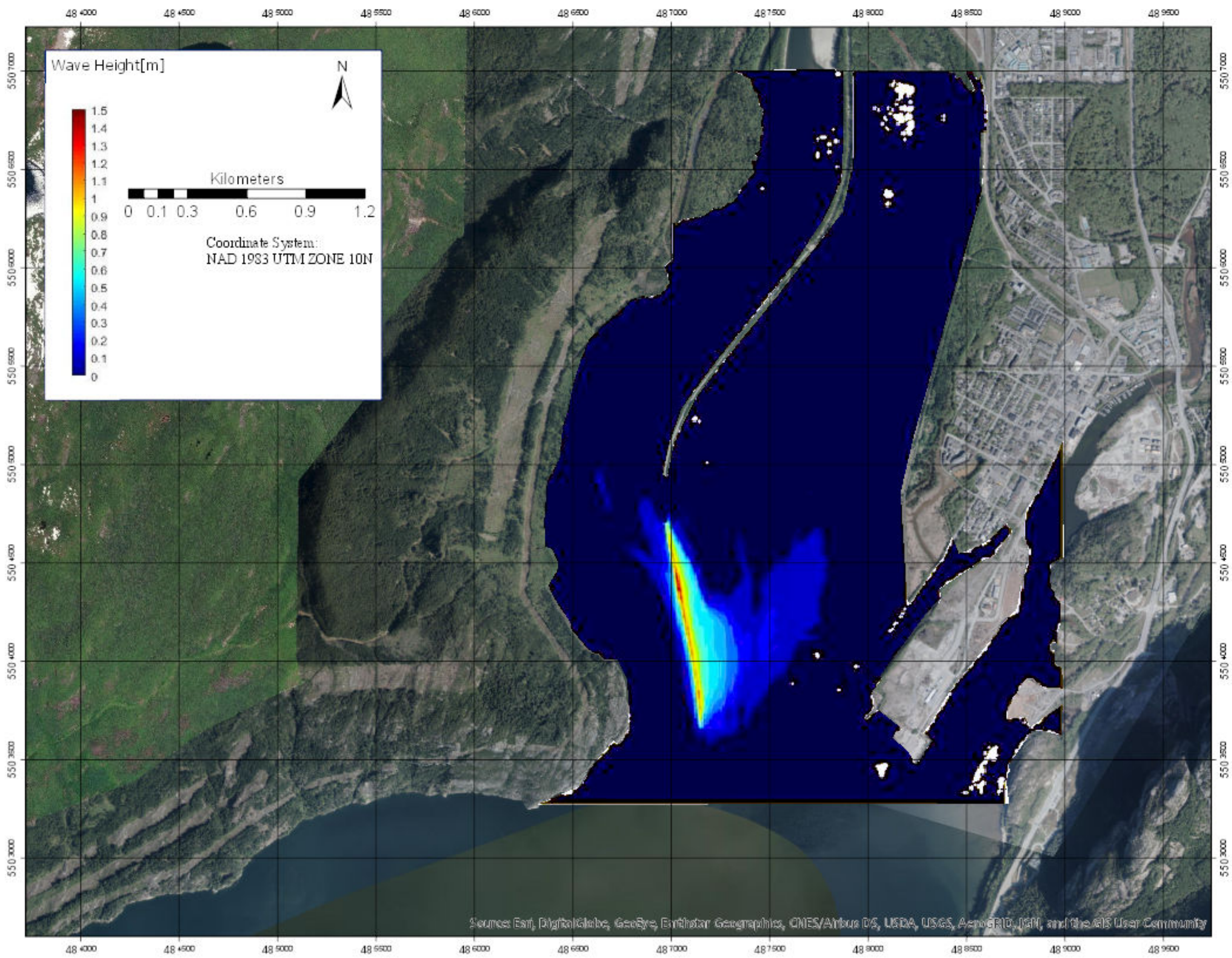

Figure 10: Difference in significant wave height between Scenario 1 and existing conditions during 1/200 AEP storm

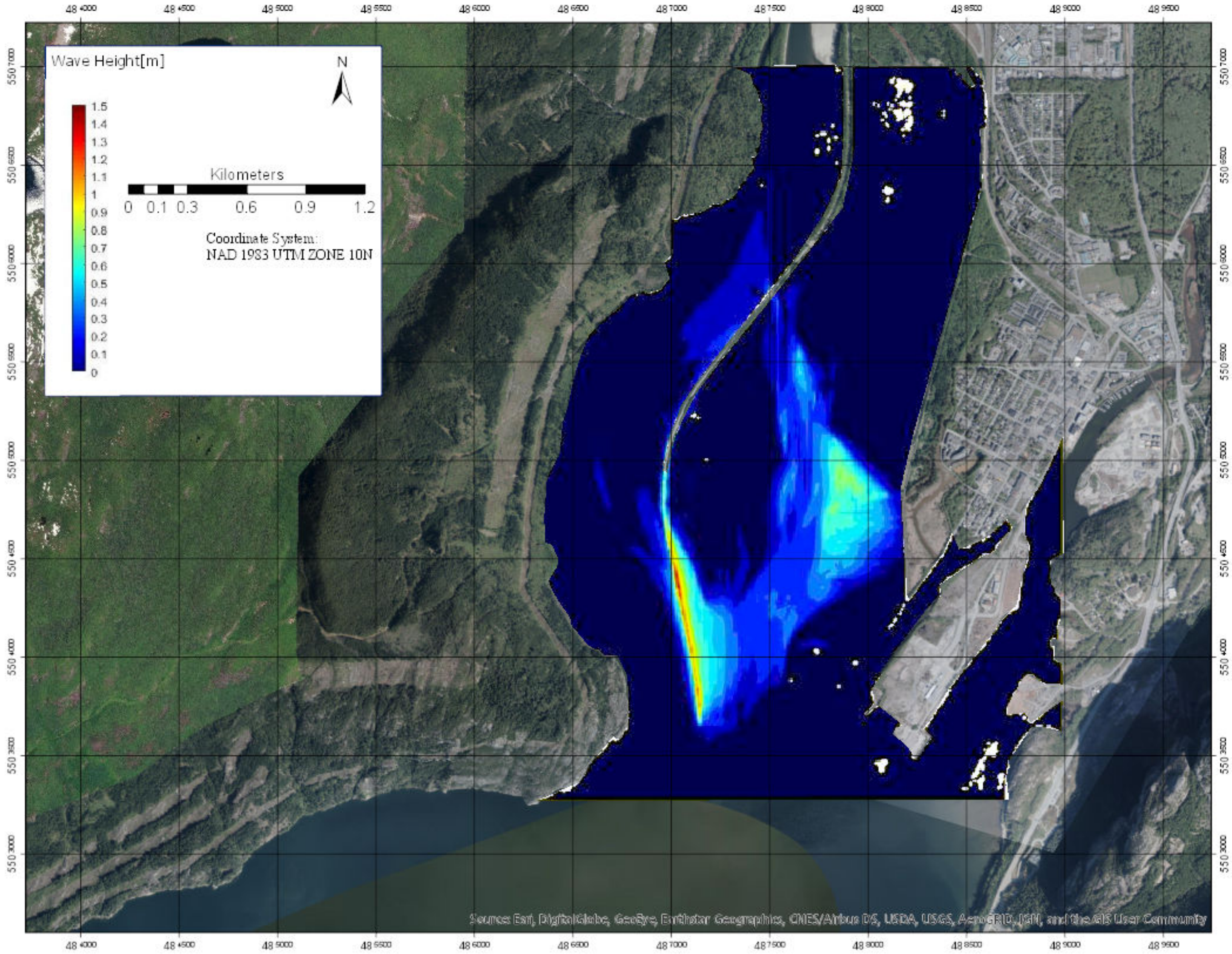

Figure 11: Difference in significant wave height between Scenario 2 and existing conditions during 1/200 AEP storm

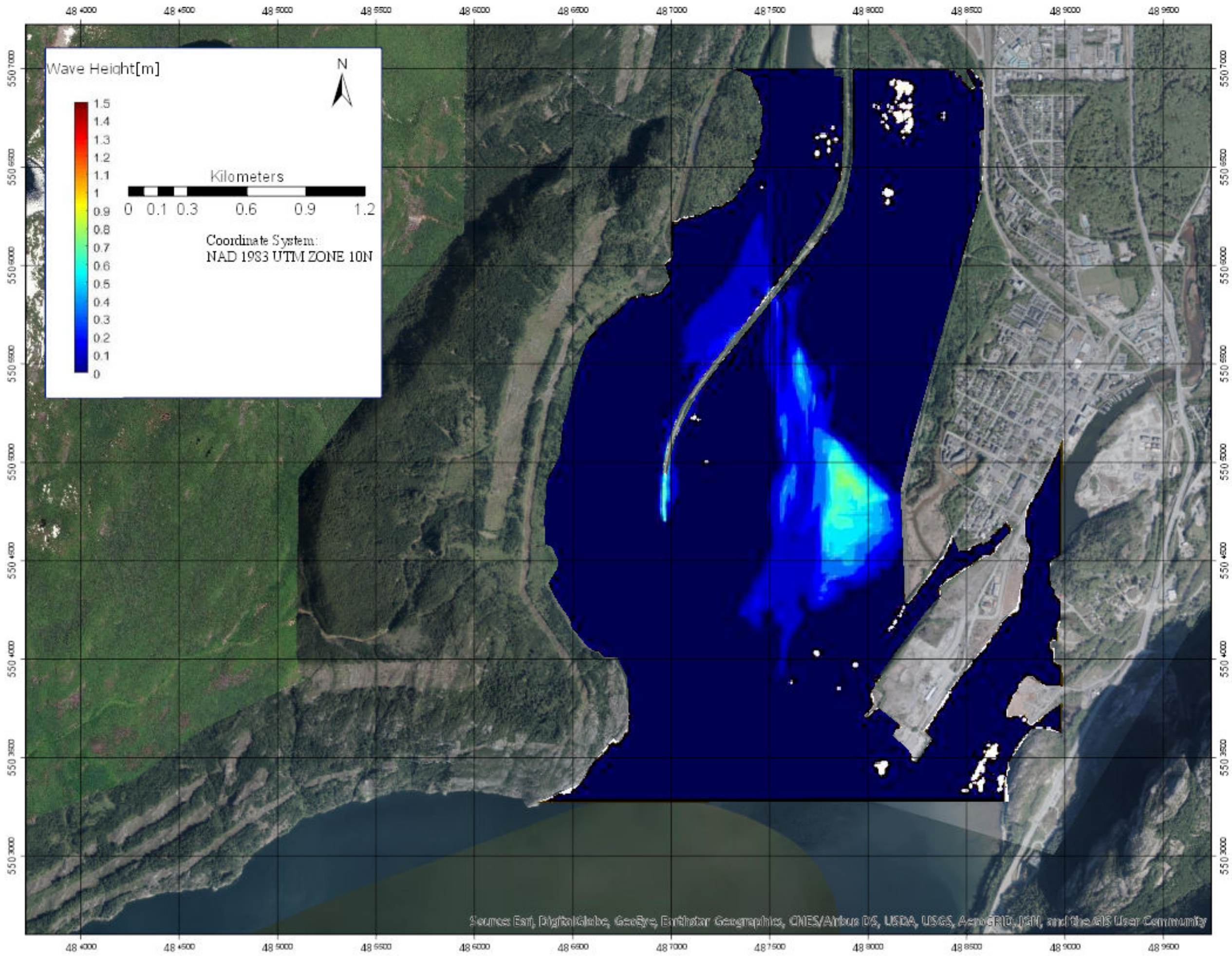

Figure 12: Difference in significant wave height between Scenario 2 and Scenario 1 during 1/200 AEP storm

3.4.2 Site Specific Summary Results

Site specific sea state results for the locations indicated in Figure 13 are summarized in Table 6.

Increases of significant wave heights are highlighted in red, while points with the same results for the different scenarios are highlighted in green. The locations are the same presented in the 2015 wave assessment (Ref. [6]).

These estimates are only representative of the sea state at the indicated location. Reference should be made to Figure 7 and Figure 9 for information in the likely variation with position in the intermediate area. The same comparison table including the depths for each point and scenario is presented in Appendix B.

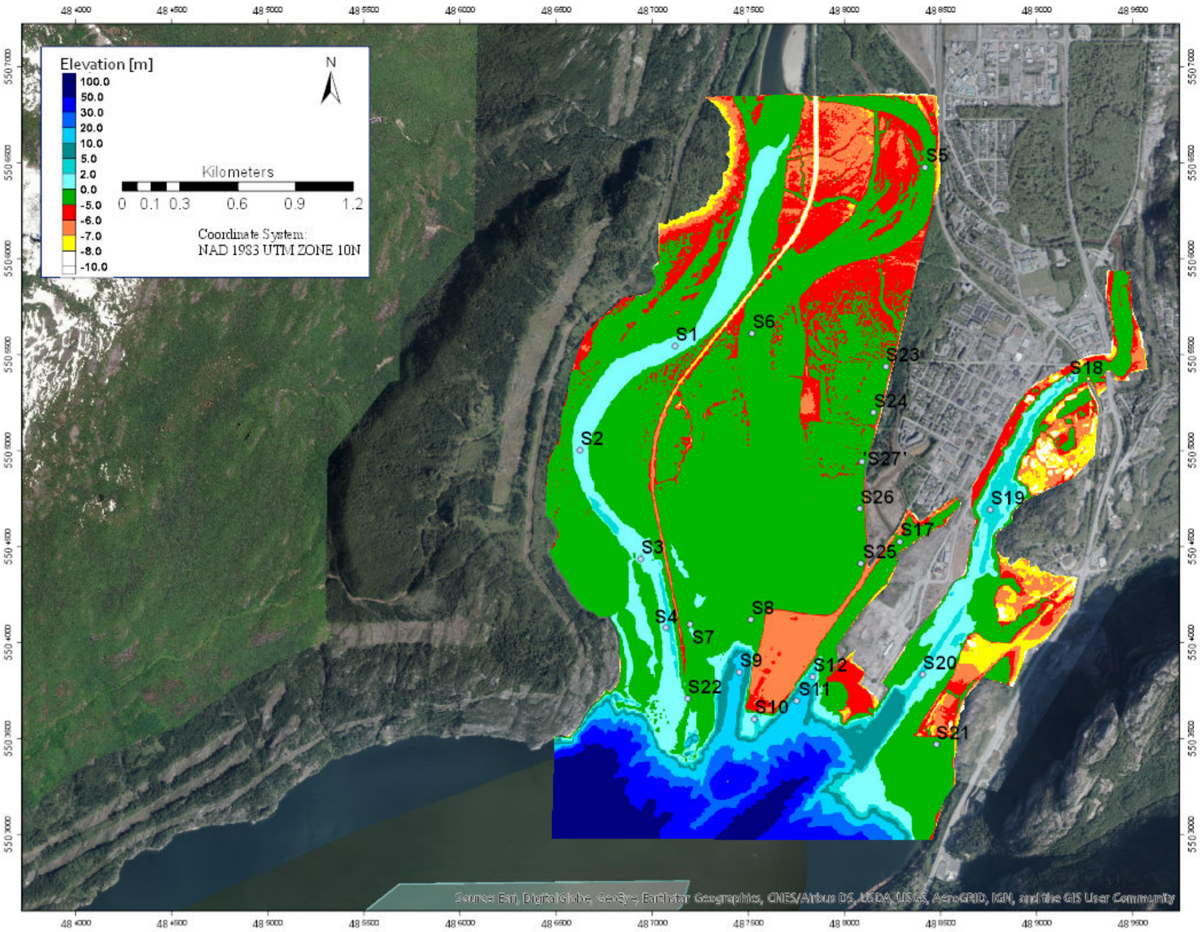

Figure 13: Locations of Site Specific Sea State Results

Table 6: Significant wave height comparison at observation points for current conditions, Scenario 1 and Scenario 2 during 1/200 AEP storm

Scenario	Current Conditions			Scenario 1			Scenario 2		
Observation Points	Hs (m)	Tp (s)	Dir (⁰T)	Hs (m)	Tp (s)	Dir (⁰T)	Hs (m)	Tp (s)	Dir (⁰T)
S1	0.8	2.9	218	0.8	2.9	218	0.8	2.9	218
S2	1.1	3.3	168	1.1	3.3	166	1.1	3.3	165
S3	1.7	4.3	172	1.7	4.3	170	1.7	4.3	170
S4	1.9	4.3	191	2.0	4.3	187	2.0	4.3	187
S5	0.7	2.6	196	0.7	2.6	196	0.7	2.6	196
S6	1.2	3.3	183	1.2	3.3	183	1.4	3.8	180
S7	1.4	4.3	174	2.1	4.8	193	2.1	4.8	193
S8	1.7	4.8	210	1.9	4.8	213	1.9	4.8	212
S9	2.0	4.8	2 10	2.1	4.8	210	2.1	4.8	210
S10	2.1	4.3	205	2.1	4.3	205	2.1	4.3	205
S11	1.8	4.3	199	1.8	4.3	200	1.8	4.3	199
S12	1.6	4.3	198	1.6	4.3	198	1.6	4.3	198
S17	0.5	2.3	211	0.5	2.3	211	0.5	2.3	211
S18	0.6	2.6	222	0.6	2.6	222	0.6	2.6	222
S19	0.9	3.3	195	0.9	3.3	195	0.9	3.3	195
S20	1.2	3.8	214	1.2	3.8	214	1.2	3.8	214
S21	1.6	4.8	229	1.6	4.8	229	1.6	4.8	229
S22	2.1	4.8	203	2.2	4.8	201	2.2	4.8	201
S23	0.8	3.3	213	0.8	2.9	213	0.8	3.3	214
S24	0.8	3.3	214	0.8	3.3	214	0.8	4.8	216
S25	0.8	2.6	238	0.8	4.8	238	0.7	2.6	243
S26	1.0	3.3	221	1.0	4.8	222	**1.1**	4.8	230
S27	0.8	3.3	213	0.8	3.3	214	0.8	4.8	224

4. Conclusions and Recommendations

The removal of the existing Squamish training berm is part of SRWS plans to restore the Squamish estuary. The objective of this study was to investigate the impact of the berm removal on the wave climate in the region using a numerical wave model.

The wave model is based on the model developed in 2015 for the District of Squamish Integrated Flood Hazard Management Plan – Ref. [4] and Ref. [6]. In this study, the model bathymetry was modified to reflect potential expected morphology changes after the removal of approximately 1.1 (Scenario 1) and 2.4 km (Scenario 2) of the training berm.

Scenario 1 considered the removal of approximately 1.1 km of the training berm up to the existing yellow gate. The second scenario considered an additional 1.3 km of berm removal, up to Culvert 4.

In Scenario 1, significant wave heights were increased on the east side of the removed berm as expected. There is also a slight increase of wave heights close to Squamish Terminals. The wave conditions close to the Squamish coastal boundary was very similar in both the current and Scenario 1 model runs. However, when the additional 1.3 km of berm is removed (Scenario 2), which allows the Squamish River to flow in the Central Channel, the assumed modification of the riverbed in this area creates larger wave heights at the upper section of the channel and close to the railway embankment. The effects (run-up / overtopping) of waves were not estimated in this preliminary assessment. It is recommended to calculate these effects during the next phases of the study to verify the potential impact of increased overtopping to the District's drainage system.

This wave assessment was based on morphology changes estimated by SNC-Lavalin for a preliminary assessment based on available information. Detailed hydrodynamic and sediment transport models should be undertaken on the next design phase to better estimate the bathymetry changes before assessing the potential effects of the structure removal.

While sensitivity studies of the potential effects of wave diffraction or wave propagation around or over the offshore structures identified were undertaken, and suggest that wave diffraction or wave regeneration around or in the lee of the structures are relatively minor, the SWAN model is not the most suitable model for definition of these effects. The use of a phase resolving nearshore wave model is recommended in the next design phase.

5. References

[1] "Sea Dike Guidelines – Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use", BC Ministry of Environment, 27 January 2011.

[2] "Guidelines for Management of Coastal Flood Hazard Land Use – Climate Change Adaptation Guidelines for Sea Dikes and Coastal Flood Hazard Land Use", BC Ministry of Environment, 27 January 2011.

[3] "Squamish Terminals Hydrodynamic and Sediment Transport Modelling", Tetra Tech, 4 July 2017

[4] "Integrated Flood Hazard Management Plan – Coastal Flood Risk Mitigation Options", Final Report, September 2017

[5] "Review of Tsunami and Landslide Wave Hazards", SNC-Lavalin, (Document 618897-3000-41EN-0001), 12 February 2015

[6] "District of Squamish Integrated Flood Hazard Management Plan", SNC-Lavalin, (Document 618897-3000-41EB-0001), 12/02/2015

[7] Flood hazard area land use management guidelines", May 2004, ministry of water, land and air protection, province of British Columbia amended by: ministry of forests, lands, natural resource operations and rural development, January 1, 2018

[8] Buckley, J. R. (1977). The Currents, Winds, and Tides of Northern Howe Sound. PhD thesis submitted to the Department of Physics and Institute of Oceanography, University of British Columbia.

[9] Thomson, R. E. (1981). Oceanography of the British Columbia Coast. Ottawa: Dept. of Fisheries and Oceans.

[10] Devore, J.L. (1995). Probability and Statistics for Engineering and the Sciences. International Thomson Publishing, Inc.

6. Revision Index and Signatures

Issue Code	Rev. No	Date (yyyy-mm-dd)	Description of Changes	Initials
RR	PA	2020-01-08	Issued for Internal Review	GMJ
RR	PB	2020-01-13	Draft for Client Review and Comments	GMJ
RI	R0	2020-02-26	Final Report	GMJ

Issue Codes:

RC Released for Construction
RD Released for Design
RF Released for Fabrication
RI Released for Information
RP Released for Purchase
RQ Released for Quotation
RR Released for Review and Comments

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Appendix A

Recent Data

This Appendix presents a preliminary analysis of recent relevant data obtained for the assessed area.

Bathymetry

The following bathymetry datasets were available and used by other studies since 2015:

› Tetra Tech (Ref. [3]) used the combination of 2015 CHS bathymetric survey and 2017 bathymetric survey by the Canadian Coast Guard for the Squamish Harbour Model. Bathymetry data from 2017 was provided by Squamish Terminals and it is shown in Figure A- 1

› The most recent data from a 2019 survey (CCOM: Center for Coastal and Ocean Mapping) covers the river and the delta. The data was provided by John Hughes Clarke and it is shown in Figure A-2. Preliminary comparison with the 2015 data set indicates that:

  - a landslide might have a happened at the edge of the delta
  - the river alignment has continued its slight migration west.

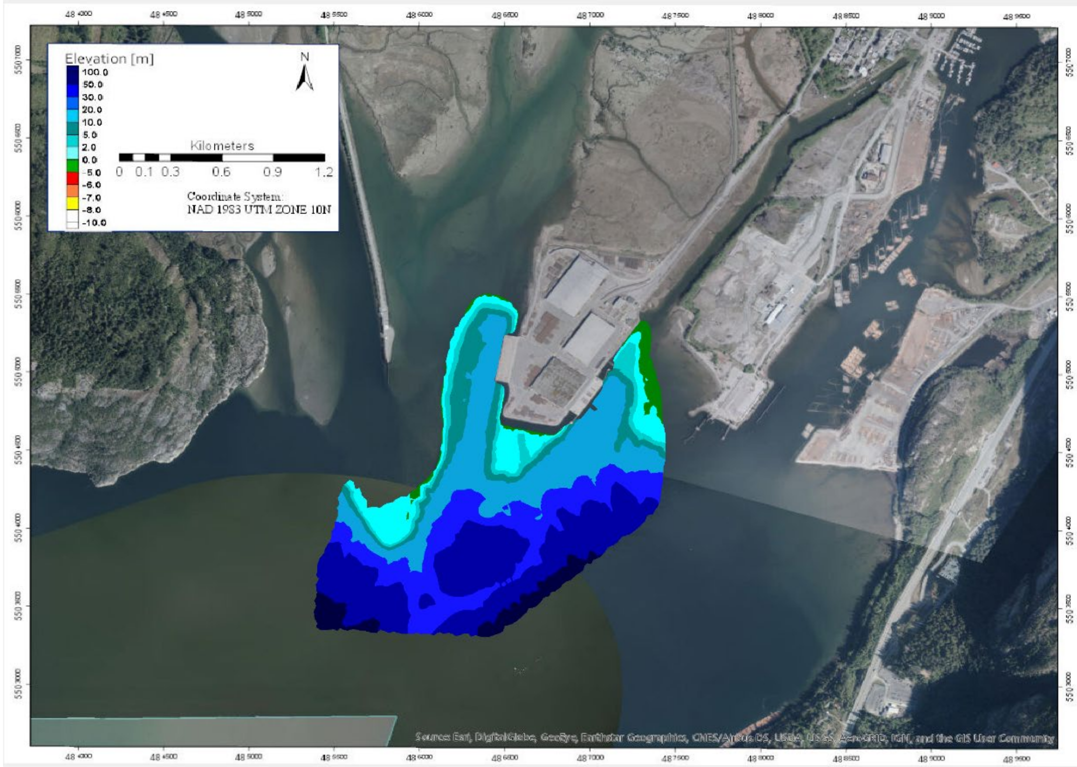

Figure A- 1 Bathymetry dataset provided by Squamish Terminals – 2017 survey

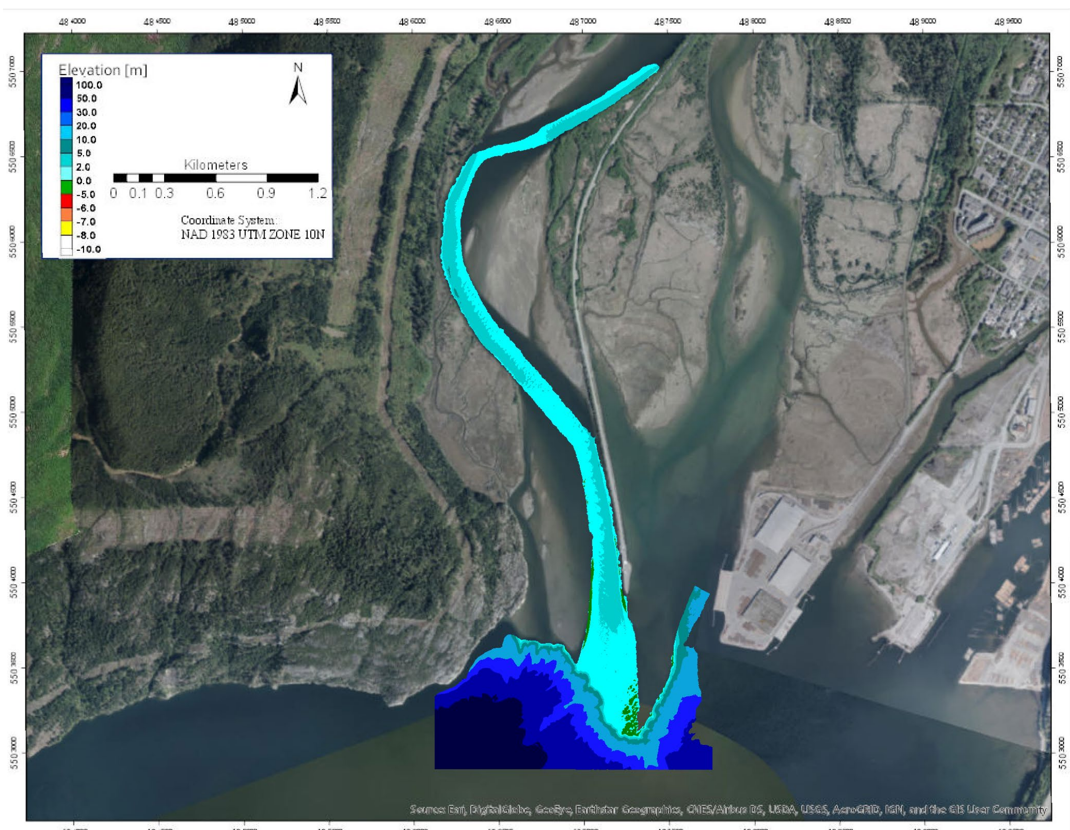

Figure A- 2 Bathymetry provided by CCOM – 2019 survey

Wind

Wind data from Pam Rock Station was updated to include information from 2012 to 2019. Figure A- 3 shows the top 40 wind storm events from 1994 to 2012 (Ref. [6]) and 2012 to 2019. It is observed that the recent wind storm are in the middle range of the previously considered storms for the 2015 model study. The current comparison assessment was carried on with the same wind speed and direction from the prior model.

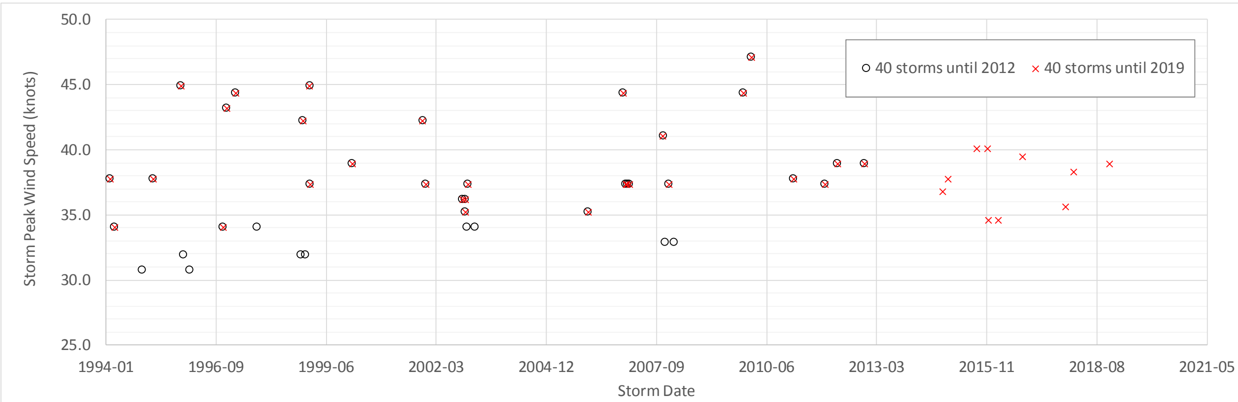

Figure A- 3 Storm comparison 1994-2012 and 2012-2019

Water Level

Astronomical Tides - Table A- 1 shows the comparison between predicted tides based on the Canadian Hydrographic Services (CHS) – Canadian Tide and Current Tables from 2014 and 2019. It is recommended to include the small difference in HHWLT in the next design steps and numerical models.

Table A- 1: Adjustment of tide tables for Squamish and its reference port (Point Atkinson) for 2014 and 2019

Tidal Level (m, CD)	Reference Port		Secondary Port	
	Point Atkins		Squamish	
	2014	2019	2014	2019
HHWLT Higher High Water, Large Tide	5.1	5.0	+0.1	+0.1
HHWMT Higher High Water, Mean Tide	4.4	4.5	+0.1	+0.1
MWL Mean Water Level	3.1	3.1	+0.1	+0.0
LLWMT Lower Low Water, Mean Tide	1.2	1.2	+0.0	+0.0
LLWLT Lower Low Water, Large Tide	0.0	0.1	+0.0	+0.0

Note: Conversion of tidal water levels (CD) to water levels relative to CGVD28 based on 3.08 m.

Measured data – SRWS has been measuring water level data at two locations since May 2018. The stations are located at Culvert 4 and lower estuary. Figure A- 4 shows a sample of the measured data at the Lower Estuary Station for the second half of December 2018.

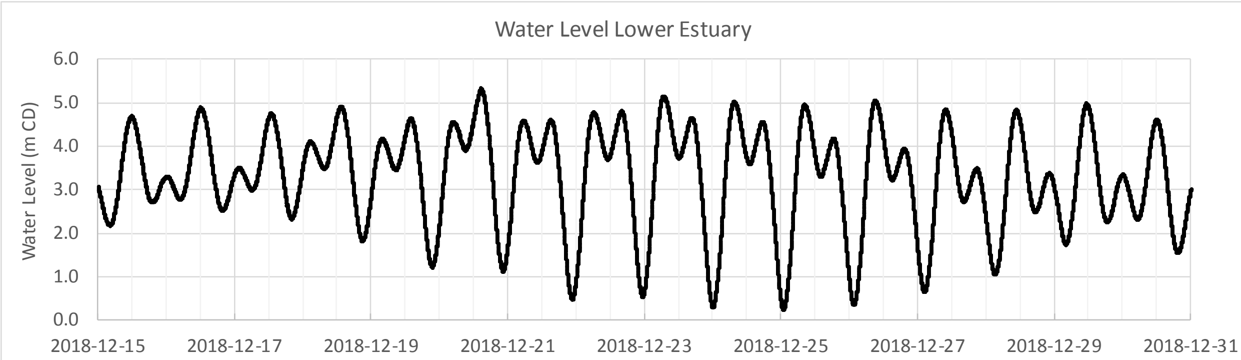

Figure A- 4 Sample of water level measured by SRWS at the lower estuary station

Preliminary comparison with Point Atkinson Station measurements shows residuals over 0.4 m. It is recommended a deeper analysis of the water level and comparisons to wind data to identify storms and reliability of the measurements. The comparison will also check the value assumed in Ref.[6] for external storm surge.

Appendix B

Comparison Table

Figure B-1 Comparison at observation points for current conditions, Scenario 1 and Scenario 2

Scenario	Current Conditions				Scenario 1				Scenario 2			
Observation Points	Hs (m)	Tp (s)	Dir (^{0}T)	Depth (m)	Hs (m)	Tp (s)	Dir (^{0}T)	Depth (m)	Hs (m)	Tp (s)	Dir (^{0}T)	Depth (m)
S1	0.8	2.9	218	7.8	0.8	2.9	218	7.8	0.8	2.9	218	7.8
S2	1.1	3.3	168	7.9	1.1	3.3	166	7.9	1.1	3.3	165	7.9
S3	1.7	4.3	172	7.2	1.7	4.3	170	7.2	1.7	4.3	170	7.2
S4	1.9	4.3	191	8.6	2.0	4.3	186	8.0	2.0	4.3	187	8.0
S5	0.7	2.6	196	3.8	0.7	2.6	196	3.8	0.7	2.6	196	3.8
S6	1.2	3.3	183	5.5	1.2	3.3	183	5.5	1.4	3.8	180	7.8
S7	1.4	4.3	174	6.6	2.1	4.8	193	7.8	2.1	4.8	193	7.8
S8	1.7	4.8	210	6.0	1.9	4.8	213	6.0	1.9	4.8	212	7.8
S9	2.0	4.8	2 10	18.5	2.1	4.8	210	18.5	2.1	4.8	210	18.5
S10	2.1	4.3	205	9.2	2.1	4.3	205	9.2	2.1	4.3	205	9.2
S11	1.8	4.3	199	18.6	1.8	4.3	200	18.6	1.8	4.3	199	18.6
S12	1.6	4.3	198	9.6	1.6	4.3	198	9.6	1.6	4.3	198	9.6
S17	0.5	2.3	211	5.1	0.5	2.3	211	5.1	0.5	2.3	211	5.1
S18	0.6	2.6	222	9.3	0.6	2.6	222	9.3	0.6	2.6	222	9.3
S19	0.9	3.3	195	9.8	0.9	3.3	195	9.8	0.9	3.3	195	9.8
S20	1.2	3.8	214	8.9	1.2	3.8	214	8.9	1.2	3.8	214	8.9
S21	1.6	4.8	229	5.0	1.6	4.8	229	5.0	1.6	4.8	229	5.0
S22	2.1	4.8	203	6.2	2.2	4.8	201	7.4	2.2	4.8	201	7.4
S23	0.8	3.3	213	2.1	0.8	2.9	213	2.1	0.8	3.3	214	2.1
S24	0.8	3.3	214	2.1	0.8	3.3	214	2.1	0.8	4.8	216	2.1
S25	0.8	2.6	237	2.9	0.8	4.84	238	2.9	0.8	2.6	243	2.9
S26	1.0	3.3	221	2.3	1.0	4.8	222	2.3	1.1	4.8	230	2.6
S27	0.8	3.3	213	2.1	0.8	3.3	214	2.1	0.8	4.8	224	2.1