

Technical Memorandum

DATE: November 26, 2018

TO: Kimberly Armour, M.A., B.Sc.
Squamish River Watershed Society

FROM: Alisson Seuarz, EIT, M.Eng.
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RE: SQUAMISH ESTUARY MODELLING
Training Berm Bridge Opening at Chainage 2+660 – Hydraulic Modelling Results
Our File 3619.005-300

1. Introduction

The Squamish River Watershed Society (SRWS) has partnered with Fisheries and Oceans Canada (DFO), the Squamish Nation, and other stakeholders to lead the Central Estuary Reconnection Project (CERP) in Squamish, BC. The CERP is exploring options to increase hydraulic and environmental connectivity between the Squamish River and key parts of the historical estuary, with the goal of improving access to estuary habitat for juvenile Chinook and other fish species.

As part of this work, SRWS retained Kerr Wood Leidal Associates (KWL) to assist with evaluating the hydraulic performance of different options for restoring connectivity. Several of these options are described in KWL's July 2018 design criteria technical memorandum¹. After reviewing the various options, SRWS asked KWL to proceed with hydraulic modelling for a proposed bridge opening at approximate dike chainage 2+660 on the Squamish River training berm.

This technical memorandum describes development and application of the hydraulic model for a bridge opening at dike chainage 2+660. Results are compared to accepted District of Squamish (District) flood levels defined in the District's 2017 Integrated Flood Hazard Management Plan.

1.1 Background

The Squamish River generally flows from north to south and drains into Howe Sound. The training berm currently confines the lower reach of Squamish River to the westernmost portion of the historical Squamish River Estuary. The historical estuary also includes the Central Estuary (Crescent Slough and adjacent marsh and upland areas) as well as smaller water features like Bridge Pond, Cattermole Slough, Cattermole Creek and Wilson Slough.

Hydraulic modelling undertaken for SRWS is focussed on assessing the impact of proposed improvements on flood levels within the Central Estuary. The Central Estuary is bounded by the Squamish River dike / training berm in the west and Government Road / CN rail spur track to Squamish Terminals in the east.

¹ Squamish Estuary Flood Modelling – Draft Design Criteria Technical Memorandum. Prepared for the Squamish River Watershed Society. KWL File No. 3619.005.



The Squamish River dike/training berm follows the left bank of the river along the majority of its length as it passes through the District of Squamish. The regulated dike extends from the Cheekeye Fan to the upper reaches of the Central Estuary. At approximate dike chainage 2+857, the official dike (regulated under the BC *Dike Maintenance Act*) transitions to unregulated training berm. The training berm continues a further 2.9 km to its present-day terminus at Howe Sound (dike chainage 0+000). The training berm is locally known as the Squamish Spit.

The training berm was constructed in the 1970s to support development of a coal loading facility in the Central Estuary. Plans for the coal facility were abandoned; however, the training berm remains and continues to disrupt environmental connectivity between the river and the Central Estuary. Twelve uncontrolled (gravity-flow) culverts were installed at nine locations to provide some hydraulic connectivity along the training berm. Unfortunately, the hydraulic and ecological function of the culverts is limited at both low flows (where water drops below the bottom of the culvert) and high flows (where surcharging above the culvert crown limits fish utilization).

On the east side of the study area, the CN Rail spur track serving Squamish terminals further isolates the Central Estuary from other parts of the historical estuary (e.g., Cattermole Creek and Bridge Pond). The CN Rail berm also provides *de facto* flood protection for Downtown Squamish under present-day conditions. The District's official sea dike (Town Dike) defines the opposite (inland) side of Bridge Pond.

Figure 1 shows a location plan of the study area.

District of Squamish Integrated Flood Management Plan² (IFHMP)

From 2014 to 2017, KWL carried out a comprehensive flood hazard and consequence assessment for the District of Squamish. Project deliverables include three technical reports and a summary report that encompasses the IFHMP.

The IFHMP assessed a series of river dike breach modelling scenarios during the 200-year return period flood. This flood event has a 0.5% probability of being exceeded each year. Results from the dike breach scenarios were used to define Flood Construction Levels (FCLs) within the dike-protected area. Results from the dike breach model were also combined with the IFHMP's still-water coastal flood level to create an envelope map of Designated Flood Levels (DFLs) for the Central Estuary.

The IFHMP identified the need for a more substantial sea dike to provide protection against coastal floods and future sea level rise. The District's preferred alignment for the future dike follows the Town Dike through the study reach; however, an alternate alignment is possible abutting the western slope of the CN Rail berm.

Flood assessments in coastal areas not protected by the future sea dike (including the Central Estuary) must make appropriate site-specific allowances for sea level rise, wind setup, and wave effects. The IFHMP noted that the current configuration of the training berm helps mitigate wave effects within the Central Estuary.

Figure 2-9 of the IFHMP River Flood Risk Mitigation Options Report³ shows the water levels that were used to define the IFHMP's still-water Designated Flood Level (DFL) in the Central Estuary. The IFHMP's 200-year return period still-water coastal flood level for Howe Sound (including a 1 m allowance for sea level rise) is 3.99 m geodetic elevation (CGVD 28).

² Kerr Wood Leidal, 2017. District of Squamish Integrated Flood Hazard Management Plan. Final Report. Prepared for the District of Squamish. KWL File No. 0463.278

³ Kerr Wood Leidal, 2017. District of Squamish Integrated Flood Hazard Management Plan – River Flood Risk Mitigation Options. Final Report. Prepared for the District of Squamish. KWL File No. 0463.278



Based on the limited hydraulic capacity of the existing culverts, hydraulic modelling completed for the IFHMP excluded the culverts from the model setup. The IFHMP also recognized that a 1 m allowance for Sea Level Rise (SLR) would cause large coastal floods to overtop the present-day crest of the training berm. For simplicity, the IFHMP modelled the training berm as an infinitely high structure. This assumption implies that the District will raise the training berm as high as necessary to avoid overtopping.

2. Model Setup

2.1 Software

Modelling of the Squamish River Estuary was carried out using Mike Flood software developed by the Danish Hydraulic Institute (DHI). The estuary model builds on the traditional one-dimensional river model used for the IFHMP. As such, most of the assumptions, parameters and approaches applied to the IFHMP have also been applied to this model.

Mike Flood provides a platform to dynamically link the 1D model of the river system to a two-dimensional (2D) domain within the estuary. For this study, the 1D river model passes inflow from its most downstream cross-section near Yekwaupsum I.R. No. 18 into an expanded 2D model domain that includes both the lower Squamish River and the Central Estuary.

All work was completed using Mike Flood 2017 Service Pack 1. Previous work by KWL⁴ has confirmed that results are compatible with the earlier version of the software used for the IFHMP.

2.2 Study Area

The study area includes the lower Squamish River channel and the Central Estuary. The boundaries of the 2D model area are defined as follows:

- North: Squamish River Dike Station 4+850 (corresponding to Mike 11 cross section 10920).
- West: high ground along the right bank of the Squamish River.
- East: the CN Rail spur track and 3rd Ave causeway to Squamish Terminals.
- South: Howe Sound approximately 200 m south of Dike Station 0+000.

2.3 Lower Squamish River

KWL's original 2011 river modelling study⁵ used 2005/2007 survey and bathymetric data⁶ to build a CAD-based composite surface of the Squamish River channel. Mike 11 cross-sections were extracted from the CAD surface and used to create the 1D river model.

For this project, the composite surface defining the Squamish River was retrieved from project archives and used to create 2D bathymetry for the river channel. This minimized unnecessary manipulation of the source data and maximized compatibility between the 1D and 2D models. Verification of the cross-sectional information was performed by extracting a few cross sections from the archived composite surface and comparing them to the cross sections from the one-dimensional model.

⁴ Kerr Wood Leidal, 2018. District of Squamish Quantitative Risk Assessment. Draft Report. Draft Report for the District of Squamish. KWL File No. 0463.323

⁵ Kerr Wood Leidal, 2011. Squamish River and Mamquam River Survey and Flood Assessment. Revised Final Report. Prepared for the District of Squamish. KWL File No. 0463.186.

⁶ For consistency with original data sources, models, and previous projects, all elevations are reported in CGVD28.



The composite surface was exported using a XYZ format for input into the mesh generator platform and for interpolation of the 2D mesh.

2.4 Central Estuary

Ground surface elevations of the Central Estuary were defined by two main sources of data compiled in GIS as part of the IFHMP:

- 2013 LiDAR data provided by the District of Squamish; and
- Bathymetric data provided by SNC-Lavalin (coastal engineering subconsultant for the IFHMP).

Both sets of data were also extracted using a XYZ format compatible with the mesh generator and used to interpolate the mesh.

The undeveloped Central Estuary was not subject to IFHMP assumptions that modified 2013 ground elevations to account for future development under Year 2100 conditions. Maintaining 2013 elevations also implies that present-day conditions in the Central Estuary will not be affected by processes like deposition, lateral erosion, dredging, or placement of floodproofing fill.

The assumption of an infinitely high dike and training berm was acceptable for the IFHMP; however, a more accurate representation is required to support a realistic assessment of water level changes within the Central Estuary. The District's 2013 LiDAR data were used to define realistic crest elevations for the Squamish River dike and training berm.

2.5 Existing Culverts

For simplicity, the IFHMP did not incorporate the existing culverts that connect the lower Squamish River to the Central Estuary. This assumption was acceptable for the IFHMP, but a more accurate representation of local hydraulics is required for the estuary model.

SRWS provided KWL with survey information for nine of the 12 existing culverts at six locations. KWL received invert elevations and culvert dimensions in a document prepared by Bunbury & Associates - Land Surveying Limited. The culvert information is summarized in Table 1 below.

Table 1: Culvert Information

Culverts	Dimensions (m)	Inverts (m)	
		West (River)	East (Slough)
Culvert 1 (North)	H = 1.35 x W = 1.82	0.02	0.03
Culvert 1 (South)	H = 1.35 x W = 1.82	0.07	0.02
Culvert 2 (North)	H = 1.35 x W = 1.82	-0.09	-0.05
Culvert 2 (South)	H = 1.35 x W = 1.82	-0.05	-0.06
Culvert 3 (North)	H = 0.91 x W = 1.22	-0.03	-0.26
Culvert 3 (South)	H = 0.91 x W = 1.22	0.03	-0.22
Culvert 4	D = 1.22 m	-0.71	-0.65
Culvert 5	D = 1.22 m	-0.91	-0.9
Culvert 6	D = 1.22 m	-1.21	-1.22



The SRWS did not provide survey data for the three southernmost culverts shown in Figure 1 (culverts 7, 8 and 9). Without survey data, these existing culverts could not be included in the model.

The culverts are modelled using simple one-dimensional links that allow water to pass through the “high ground” of the training berm that is defined in the 2D model domain. The length of each culvert was not included in the survey data and has been estimated based on the orthophoto.

2.6 Mesh Generation

A flexible mesh representing the Squamish River and the Squamish River Estuary was generated using triangular elements to define the 2D model domain. Element sizes range from 500 m² in open areas to 5 m² in areas such as the proposed bridge opening and dike crest that require a high level of detail.

Elevations were interpolated to the final mesh geometry based on previously-described topographic and bathymetric data for the lower Squamish River and Crescent Slough.

2.7 Boundary Conditions

Peak river flows for the IFHMP’s dike breach modelling were based on the 200-year return period flood event. Peak water levels in Howe Sound were based on the 200-year return period DFL.

IFHMP analyses concluded that river and coastal floods are only partially correlated, and that 200-year return period flood events are unlikely to occur at the same time. More realistic combinations of river and coastal flood (based on the IFHMP analysis and applied for this study) are provided in Table 2 below.

Table 2: IFHMP Concurrent River and Coastal Flood Conditions

Flood Condition	Squamish River Peak Discharge	Howe Sound Peak Coastal Water Level
River Flooding	200-Year Return Period	10-Year Return Period
Coastal Flooding	10-Year Return Period	200-Year Return Period

Upstream Boundary

The upstream boundary condition applies an inflow hydrograph at the upstream end of the 1D river model. Inflow hydrographs for the 200-year return period design flood match those used for the IFHMP and are described in the IFHMP Background Report⁷. The October 2003 flood hydrograph, the largest recorded flood for the Squamish River, was used to scale up and match the peak flow estimates. All hydrograph values include an additional 10% allowance for potential climate change effects, as recommended by Engineers and Geoscientists BC⁸ and previously implemented for the IFHMP.

A similar approach was used to develop inflow hydrographs for the 10-year return period flood (i.e., by scaling down the 2003 hydrograph to match the 10-year peak flow and then adding +10% for potential climate change). Table 3 below shows the peak flows for the two scenarios analyzed in this study.

⁷ Kerr Wood Leidal, 2017. District of Squamish Integrated Flood Hazard Management Plan – Background Report. Final Report. Prepared for the District of Squamish. KWL File No. 0463.278.

⁸ Engineers & Geoscientists BC, 2018. Professional Practice Guidelines - Legislated Flood Assessments in a Changing Climate in BC. 192pp.



Table 3: Summary of Year 2100 Peak Flows for Hydraulic Modelling

River/Creek	Peak Flow* (m ³ /s)		Notes
	10-Year Return Period	200-Year Return Period	
Squamish River	2,290	4,480	<ul style="list-style-type: none">• at WSC 08GA022 (2,350 km²)• Q200i from scaled 2003 hydrograph
Cheakamus River	720	1,760	<ul style="list-style-type: none">• at WSC 08GA043 (965 km²)• Q200i from scaled 2003 hydrograph
Cheekeye River	140	260	<ul style="list-style-type: none">• at mouth (64 km²)• Q200i estimated from regional analysis
Mamquam River	540	1,000	<ul style="list-style-type: none">• at mouth (377 km²)• Q200i estimated from regional analysis
Ring Creek	N/A	N/A	<ul style="list-style-type: none">• accounted for in Mamquam River flow
Mashiter Creek	N/A	N/A	<ul style="list-style-type: none">• accounted for in Mamquam River flow
Fries Creek	60	110	<ul style="list-style-type: none">• at mouth (20 km²)• Q200i estimated from regional analysis
Squamish Tributary Area 'A'	60	110	<ul style="list-style-type: none">• total area 19 km²• Q200i estimated from regional analysis
Squamish Tributary Area 'C'	45	85	<ul style="list-style-type: none">• total area 14 km²• Q200i estimated from regional analysis

* All peak flows include +10% allowance for potential climate change effects.

Downstream Boundary

The downstream boundary condition defines the water level at the downstream end of the Squamish River and Crescent Slough. Tidal cycles cause water levels at the downstream boundary to vary over time.

Water levels for the 200-year return period coastal flood are based on the December 1991 astronomic tide series. Storm surge is superimposed on the tide series so that the peak of the time series matches the Year 2100 still-water DFL). Future conditions corresponding to Year 2100 include 1 metre of Sea Level Rise (SLR) as recommended by provincial guidelines⁹.

A similar process was applied to create a time series with peak water level matching the 10-year return period still-water coastal flood. The resulting time series were applied along an open boundary defined at the south edge of the 2D model domain.

For both 200-year and 10-year return period coastal flood tide series, the timing of the series is shifted so that the peak river discharge occurs at the same time as the peak coastal water level.

Table 4 below summarizes the Year 2100 peak coastal flood levels at Howe Sound.

⁹ Flood Hazard Area Land Use Management Guidelines. May 2014. Ministry of Water, Land and Air Protection – Province of British Columbia. Amended by Ministry of Forests, Lands, Natural Resources Operations and Rural Development. January 2018.



Table 4: Summary of Year 2100 Coastal Design Flood Levels for Hydraulic Modelling

Scenario	Coastal Flood Event	Peak Water Level* (m, CGVD28)
River Flooding	10-Year Return Period	3.69
Coastal Flooding	200-Year Return Period	3.99
* Peak water levels include 1 m allowance for Sea Level Rise.		

2.8 River and Estuary Roughness

Required input for the 2D model domain includes a spatially-varied map of specified bed resistance.

Central Estuary

For consistency, bed resistance for the Central Estuary is based on the roughness values applied for the IFHMP. IFHMP Manning's n values for this area are range from 0.035 to 0.15 based on vegetation density.

Squamish River

Results from the IFHMP's one-dimensional river model have been adopted as the District's "official" flood profile for the Squamish River. Previous sections of this memorandum describe the IFHMP's simplifying assumptions for the training berm and culverts. The new 2D model of the lower Squamish River had to be calibrated with similar assumptions so that it could approximate the IFHMP's official river profile.

This 2D modelling scenario is called the "Calibrating Scenario" and its characteristics are further explained under the Model Scenarios section.

The calibration was performed by changing the 2D roughness values until the 2D river profile converged with IFHMP 1D results. The process resulted in an acceptable calibration. Future studies may wish to update the official flood profile using a more realistic 2D model calibrated to high water marks from historical flood events.

The calibrated 2D roughness values range from about 0.018 to about 0.1 and were applied for all other model scenarios.

2.9 Model Parameters

The IFHMP included sensitivity analysis of hydraulic model parameters (e.g., fluid viscosity, Navier-Stokes approximation, etc.). The IFHMP concluded that model results were not overly sensitive to parameter changes and recommended values for each parameter. For consistency and efficiency, the estuary model adopts recommended parameter values from the IFHMP.

2.10 Initial Water Levels

For simplicity, a uniform initial water level was applied to the entire 2D model domain. For model stability, the initial water level matches the water level at the first time step of the downstream boundary condition.

To allow the model to equalize water levels in the river section, each model simulation allows for two hours of "spin up" before producing useable results.



3. Model Scenarios and Results

This section describes each modelled scenario and summarizes the model results.

3.1 Calibrating Scenario

The purpose of the calibrating scenario was to compare the 2D model's river profile against the District's "official" 1D river profile. Both profiles represent the 200-year river flood condition with a concurrent 10-year coastal flood condition; however, they solve different equations and can produce slightly different results. The objective of model calibration for this project is to produce a close approximation rather than recreate near-identical values.

To approximate the IFHMP profile in a 2D environment, this scenario had to match the IFHMP's modelling assumptions that contained the 200-year return period flood fully within the river channel:

- The crest of the dike/training berm was raised well above expected water levels to avoid overtopping during the simulation.
- The existing culverts through the dike/training berm were excluded to avoid flow relief from the river to the Central Estuary.

As previously explained, the 2D Squamish River model was "calibrated" to the IFHMP's 1D model by changing the roughness values defining the bed resistance of the river area (west of the dike / training berm).

Calibrated 2D roughness values are considered somewhat less realistic than the calibrated values applied in the IFHMP's 1D model. Where discrepancies exist (e.g., around the transition from dike to training berm), the difference will tend to increase water levels in the river. Higher water levels in the river will tend to drive more flow through the bridge opening, producing slightly conservative results for flood assessment in the Central Estuary.

Having a 2D estuary model that approximates the "official" river profile under similar assumptions enables the direct comparison of 2D model results against corresponding IFHMP flood maps. Any change in water levels between the IFHMP and SRWS models can then be attributed to changes in the model setup (e.g., introduction of culverts, berm overtopping, and proposed bridge openings) rather than the change from a 1D to 2D modelling domain.

The 2D model obtained from this "Calibrating Scenario" became the starting point for all subsequent modifications described below.

3.2 Existing Training Berm (Scenario 0)

This scenario is described as Scenario 0 in the design criteria technical memo and begins with the final model from the "Calibrating Scenario". The two major changes imposed for this scenario include:

- The crest of dike/training berm was lowered to reflect its existing elevation.
- Nine of the 12 existing culverts through the dike/training berm were added at 6 different locations (culverts 1 through 6 on Figure 1).

Model results were post-processed in GIS to produce the maximum Year 2100 water surface elevations shown in Figure 2 (200-year return period river flood) and 3 (200-year return period coastal flood). As expected, the river flooding condition resulted in the largest peak flows in the Central Estuary while the coastal flooding produced the highest peak water levels.



Table 5 below provides the Year 2100 maximum water level and flow in the Central Estuary as well as the maximum change in water level when compared to the corresponding IFHMP coastal flood level. The river flood produced a larger change in water level, but the absolute water levels are still below those of the coastal flood. Introducing a more realistic representation of the training berm increased coastal flood levels from the IFHMP by 0.03 m, from the IFHMP's nominal 3.99 m to elevation 4.02 m.

Table 5: Peak Flow and Water Level Results for Scenario 0

Flood Condition	Maximum Flow to Estuary ¹ (m ³ /s)	Max Water Surface Elevation in Estuary (m)	Change from IFHMP Water Level ² (m)
River	1,150	3.74	+0.05
Coastal	750	4.02	+0.03
Notes: 1. Represents net flow into estuary from all river sources (overtopping and culverts). 2. Change in Water Level is based on comparison between Scenario 0 and corresponding IFHMP coastal flood level at Howe Sound.			

Changes in maximum water level are relatively small but consistent for both river and coastal flood scenarios. The magnitude of these changes confirms that the simplifying assumptions made for the IFHMP were appropriate for that project; however, the impact of the CERP's proposed bridge should be evaluated against the more accurate baseline criteria produced under this scenario.

Figure 4 shows the maximum difference in water level between the governing scenario (i.e., coastal flooding) and the IFHMP DFL map for the Central Estuary. It should be noted that IFHMP DFLs incorporate outflow from potential dike breaches along the Squamish River dike and training berm. IFHMP DFLs can therefore be greater than SRWS water levels in localized areas at or near the dikes, resulting in the negative differences shown on Figure 4. The CERP's proposed bridge will not have any effect on governing flood levels in areas where Figure 4 shows negative differences.

For the river flooding, the peak river discharge entering the upstream end of the 2D domain is approximately 6,840 m³/s. Of this total flow, about 1,150 m³/s (17%) is diverted into the Central Estuary by overtopping 1080 m³/s (16%) and through the culverts 70 m³/s (1%). The balance of flow continues down the river.

For the coastal flood scenario, the peak river discharge entering the 2D domain is approximately 3,340 m³/s, reflecting the reduced magnitude of the concurrent river flood. Of this total flow, about 750 m³/s (22%) gets diverted into Crescent Slough by overtopping 700 m³/s (21%) and through the culverts 50 m³/s (1%).

The existing culverts were implemented in 1D using artificial channels and connected to 2D via standard links. Model results such as flow capacity and peak velocity are captured from the 1D setup for each culvert. More detailed information about hydraulic parameter results for the culverts, such as peak discharges and velocities, are summarized in Table 6.



Table 6: Modelling Results of Existing Culverts for Scenario 0

Culvert Branch	River Flooding		Coastal Flooding	
	Peak Discharge (m ³ /s)	Peak Velocity (m/s)	Peak Discharge (m ³ /s)	Peak Velocity (m/s)
Culvert 1 (two barrels)	28.6	5.8	21.2	4.3
Culvert 2 (two barrels)	22.9	4.7	14.3	2.9
Culvert 3 (two barrels)	6.5	3.7	5.1	3.2
Culvert 4	4.8	4.1	3.8	3.6
Culvert 5	3.5	3.0	2.4	2.1
Culvert 6	3.0	2.6	1.7	1.4

3.3 Bridge Opening at Dike Chainage 2+660 (Scenario 2A)

This scenario was described as Scenario 2A in the design criteria technical memo. It introduces a ±16 m wide bridge opening at approximate dike chainage 2+660. The opening is located downstream of the regulated dike and within the unregulated training berm.

Updates to the model commenced with the changes made for Scenario 0 and applied the following further modifications:

- Removal of the two culvert barrels and 1D link channel at Culvert 3.
- Lowering the elevation of a ±16 m long section of the training berm (the proposed bridge opening) to a representative river/estuary bed elevation.
- Lowering the elevation of mesh elements adjacent to the training berm toe where necessary to create approach channels.
- Modifying bed resistance values for the bridge opening and approach channels to reflect bank and channel bottom conditions (instead of training berm crest and slopes).
- Increasing the elevation of mesh elements at the bridge approaches to grades that will allow traffic to cross the bridge while providing freeboard to the low chord of the bridge deck.

Model results were post-processed in GIS to produce the maximum Year 2100 water surface elevations shown in Figure 5 (200-year return period river flood) and 6 (200-year return period coastal flood).

Similar to Scenario 0 (no bridge opening), the river flooding condition resulted in the largest peak flows in the estuary while the coastal flooding produced the highest peak water levels.

Table 7 below summarizes Year 2100 maximum water level and flow in the estuary as well as the maximum change in water level when compared to Scenario 0 (no bridge opening). The river flood produced a larger change in water level, but the absolute water levels are still below those of the coastal flood. The proposed bridge opening increases the governing coastal flood levels by 0.02 m, from 4.02 m to elevation 4.04 m.



Table 7: Model Results of Peak Estimate for Scenario 2A.

Flood Condition	Max Flow to Estuary ¹ (m ³ /s)	Max Flow through Bridge Opening (m ³ /s)	Max Water Surface Elevation in Estuary (m)	Change from Scenario 0 Water Level ² (m)
River	1,370	360	3.81	+0.07
Coastal	880	210	4.04	+0.02
Notes: 1. Represents net flow into estuary from all river sources (overtopping, culverts and proposed bridge opening). 2. Change in Water Level is based on maximum difference between Scenario 2A and Scenario 0 water surface elevations.				

Figure 7 shows the maximum difference in coastal flood levels between Scenario 2A (with bridge opening) and Scenario 0 (without bridge opening).

For the river flood scenario, the peak river discharge entering the 2D domain is approximately 6,840 m³/s. Of this total, about 1,370 m³/s (20%) gets diverted into the Central Estuary by overtopping 950 m³/s (14%), through the culverts 60 m³/s (1%), and through the proposed bridge opening 360 m³/s (5%). The balance of flow continues down the river.

For the coastal flood scenario, the peak river discharge entering the 2D domain is approximately 3,340 m³/s, reflecting the reduced magnitude of the concurrent river flood. Of this total, about 880 m³/s (26%) gets diverted into Crescent Slough by overtopping 630 m³/s (19%), through the culverts 40 m³/s (1%) and through the bridge opening 210 m³/s (6%).

After replacing two existing culverts with the proposed bridge opening, only seven culverts were modelled at five different location of the dike. Table 8 below summarizes the results for the main hydraulic parameters of the culverts modelled. Under both flood scenarios (river and coastal), the proposed bridge opening conveys four to five times as much flow as all culverts combined.

Table 8: Modelling Results of Existing Culverts for Scenario 2A.

Culvert Branch	River Flooding		Coastal Flooding	
	Peak Discharge (m ³ /s)	Peak Velocity (m/s)	Peak Discharge (m ³ /s)	Peak Velocity (m/s)
Culvert 1 (two barrels)	27.2	5.5	20.9	4.3
Culvert 2 (two barrels)	22.0	4.5	13.2	2.7
Culvert 4	4.4	3.9	3.7	3.4
Culvert 5	3.5	3.0	2.4	2.0
Culvert 6	2.9	2.5	1.6	1.4



4. Analysis of Present-Day Conditions

Present-day conditions can be approximated by subtracting the 1 m allowance for SLR from the Year 2100 water surface elevation results described in Section 3. The “present day” approximations will remain somewhat conservative since they still include the climate change +10% peak flow allowance.

A preliminary freeboard assessment was completed by comparing LiDAR-based profiles of Government Road and the CN Rail embankment against “present day” coastal flood levels for Scenario 2A at adjacent locations in the Central Estuary.

Results from this comparison show that:

- “Present-day” coastal flood levels with the proposed bridge opening (i.e., Scenario 2A still-water surface elevations excluding 1 m SLR) remain at least 0.8 m below the LiDAR profile of Government Road.
- “Present-day” coastal flood levels with the proposed bridge opening (i.e., Scenario 2A still-water surface elevations excluding 1 m SLR) remain at least 0.3 m below the LiDAR profile of the CN Rail embankment.

The above comparisons exclude wind setup (estimated by the IFHMP as up to 0.2 m for the northern half of the Central Estuary and 0.1 m for the southern half of the Central Estuary under Year 2100 conditions with 1 m SLR). The IFHMP did not assess wind setup for present-day conditions.

The above comparisons also exclude wave effects. Wave effects are expected to vary along the CN Rail embankment, and would likely result in some amount of white water or green water overtopping the embankment into Bridge Pond.

5. Model Uncertainty

A bridge opening at approximate dike chainage 2+660 is expected to increase governing coastal flood levels in the Central Estuary by a maximum of 0.02 m.

When considering flood levels in absolute terms, a difference of 0.02 m is well within the bounds of uncertainty for the hydraulic model and its constituent assumptions. Uncertainty in the IFHMP’s peak flow hydrology alone could likely result in changes an order of magnitude larger than those described herein. However, the estuary model is consistent with the IFHMP model that produced the District’s official flood levels. Consideration of uncertainty therefore shifts to whether the model is able to produce a realistic *relative* change in water level.

The modest increase in water levels associated with the proposed bridge opening is internally consistent (i.e., consistent within the model domain). It is also fully consistent with theoretical expectations for a modest increase in flow through the estuary. As such, it is reasonable to support the model’s findings: that the proposed bridge opening will result in a small but measurable *relative* increase in water level.

A policy decision will likely determine whether the various benefits of the estuary reconnection project justify a marginal increase in local flood levels outside the *de facto* and official flood protection perimeters. Complicating factors for the policy decision are expected to include:

- freeboard along the *de facto* protection that is less than the provincial standard for dikes (0.6 m);
- the absence of a direct hydraulic connection between Crescent Slough and Bridge Pond;
- the lack of a detailed assessment of potential stormwater inflow and wave overtopping into Bridge Pond; and



- dike crest elevation deficiencies along the Town Dike that separates Bridge Pond from Downtown Squamish.

Modelling described herein is specifically intended for assessing flood levels and has neither identified nor explored potential design scenarios. As such, the model results presented herein should not be used for bridge design purposes.

6. Conclusions

Hydraulic modelling completed for the IFHMP made simplifying assumptions that neglected hydraulic connectivity between the lower Squamish River and Central Estuary. In this study, the hydraulic model was refined to allow river flow to reach the Central Estuary by overtopping of the training berm or passing through a number of existing culverts. The updated model produced Year 2100 coastal flood levels in the Central Estuary that are 0.03 m higher than those established by the IFHMP. These updated coastal flood levels provide an appropriate baseline for evaluating the impacts of a potential bridge opening in the Squamish River training berm.

This study modelled a ± 16 m wide bridge opening in the Squamish River training berm at approximate dike chainage 2+660. **Results show that the bridge opening would increase coastal flood levels in the Central Estuary by up to 0.02 m.**

Although the modelling assessment focussed on Year 2100 conditions, “present day” conditions can be approximated by subtracting the 1 m SLR allowance from model results. “Present day” water levels in the Central Estuary were compared to the 2013 LiDAR profile of the CN Rail embankment. **The comparison shows that “present day” still-water flood levels (i.e., excluding wave effects) will not overtop the *de facto* flood protection provided by the CN Rail embankment.**

7. Closure

We trust that the analysis and results submitted in this technical memorandum encompasses the modelling scenarios requested by the SRWS and provides direction to achieve the ultimate goals of the Squamish Estuary Modelling project. Please do not hesitate to contact the undersigned if you have questions or need further clarification.



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- Encl.: Figure 1: Location Plan
Figure 2: Maximum Water Surface Elevation for Squamish River and Estuary Year 2100 River Flooding Condition - Scenario 0
Figure 3: Maximum Water Surface Elevation for Squamish River and Estuary Year 2100 Coastal Flooding Condition - Scenario 0
Figure 4: Difference in Water Elevation between Year 2100 Coastal Flooding Condition Scenario 0 and IFHMP Scenario
Figure 5: Maximum Water Surface Elevation for Squamish River and Estuary Year 2100 River Flooding Condition - Scenario 2A
Figure 6: Maximum Water Surface Elevation for Squamish River and Estuary Year 2100 Coastal Flooding Condition - Scenario 2A
Figure 7: Difference in Water Elevation between Year 2100 Coastal Flooding Condition Scenario 2A and Scenario 0.

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Revision History

Revision #	Date	Status	Revision Description	Author
0	November 26, 2018	Final	Issued as final for client copy	ASB / DR















