KERR WOOD LEIDAL
consulting engineers

Greater Vancouver
200 - 4185A Still Creek Drive
Burnaby, BC V5C 6G9
T 604 294 2088
F 604 294 2090

Technical Memorandum

DATE: December 21, 2018

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

CC: Al Jonsson, Fisheries and Oceans Canada

FROM: Alisson Seuarz, M.Eng., EIT.
Sarah Lawrie, M.A.Sc., P.Eng.

RE: **SQUAMISH RIVER ESTUARY ENHANCEMENT**
Squamish Estuary Qualitative Sediment Transport Assessment
Our File 3619.004

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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.

The first project that is being undertaken by the SRWS is to attempt to improve Chinook salmon juvenile access to Crescent Slough from the Squamish River by replacing one of the existing 1,000-mm diameter culverts through the training dike structure (shown in Figure 1) with a free-spanning bridge structure (Figure 2). The SRWS is proposing to install the bridge in early 2019 near the existing Culvert 3 (shown on Figure 1). The second structure is proposed for construction later.

As part of this work, SRWS retained Kerr Wood Leidal Associates (KWL) to assist with providing a qualitative sediment transport assessment to evaluate the potential difference in sediment transport into Crescent Slough between having the culverts versus the free-spanning bridge.

This technical memorandum describes:

- Sediment transport processes in the Central Estuary,
- Development of a two-dimensional hydraulic model used to compare the hydraulic connectivity of the Squamish River and Central Estuary under “normal” conditions, and
- Comparison of sediment transport into the Central Estuary between the culverts and replacing the culverts at one location with a free-spanning bridge.

1.1 Background

The Squamish River and Central Estuary experience a wide range of water levels because of tidal fluctuation and river levels. However, the existing culverts can only be used by fish during a narrow water level range: fish will not enter the culverts at high water levels when the culverts are completely submerged, while at low water levels the culverts can become dewatered.

As part of the culvert replacement work, the SWRS would like to understand the existing sediment transport conditions within the Central Estuary (with the nine culverts), and what potential changes to the sediment transport conditions would occur with the installation of a bridge structure. Of particular interest is the potential for impacts to Berth 2 at Squamish Terminals at the southern end of the slough.

In March 2018, a basic hydraulic analysis was performed to estimate the flow conveyance and sediment load through one of the culverts as well as the potential bridge opening. The calculations assumed full discharge through the culvert and a simple trapezoidal cross section for the bridge opening. The suspended sediment analysis was only done on an annual basis based on average daily flows. The preliminary results, presented in draft form, concluded that

- the existing culverts do not have the water or sediment conveyance capacity to significantly affect the morphology of the estuary; and
- the flow and sediment flux through a bridge is likely to be an order of magnitude (or more) greater than through a culvert, and it could not be said with certainty that replacing one or two of the culverts with bridges would not change patterns of sediment deposition and erosion in Crescent Slough.

Since then a two-dimensional hydraulic model of the Squamish River and Estuary was developed for the SRWS. Using this hydraulic model, the flow and sediment analysis has been updated and expanded to better understand the dynamics of the site. The new model supports a more accurate estimation of flow through the existing culverts and proposed bridge. As well, the model extent, and two-dimensional framework provides the ability to further assess the effect that potential tide conditions and flow velocities may have in the estuary with and without the proposed bridge.

1.2 Scope of Work

The purpose of this work is to provide qualitative assessment of the existing sediment transport processes in Crescent Slough and provide a professional opinion about the potential impacts to these processes from installing a bridge structure. The scope of work does not include an assessment of potential local sediment deposition within the bridge structure itself.

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2. Sediment Transport Processes

2.1 Features of Interest

There are several geographic features that are referred to throughout this assessment; these areas are shown on Figure 1 and are described as follows:

1) **Squamish River Training Dike**: a structure constructed in 1972 by BC Rail for the purpose of confining the Squamish River to the western shore of Howe Sound and allowing for the construction of a major port[1].
2) **Central Estuary**: includes the area known as Crescent Slough, and is the historic portion of the Squamish River and delta located between the Squamish River Training Dike and Squamish Terminals. The Central Estuary/Crescent Slough is the main area of interest in this assessment.
3) **Squamish River Delta**: the portion of the Squamish River seaward (south) of the end of the training dike including the outlet of Crescent Slough;
4) **Berth 2**: the Squamish Terminals berth on the west side of the facility located at the southern end of Crescent Slough within the Squamish River Delta. Berth 2 is dredged periodically to maintain water depths for vessel navigation and berthing.
5) **Berth 2 Light**: a navigational aid on the western edge of the dredged Berth 2 navigation channel.

2.2 Squamish River and Central Estuary

The Squamish River transports sediment recruited from sources within the watershed including coarser material (which typically composes the bed) and finer material, which travels suspended in the water column. As the river approaches its 'base level' (the ocean), its capacity to transport coarse material decreases. The river ultimately deposits its sediment load in Howe Sound: at the western delta front the material is generally fine to coarse-grained sand (1-2 mm) (Hickin, 1989)[2].

For the purposes of this project, a timeline of important human-induced changes to the river includes:

- **1972**: training dike constructed, confining all river flow to the western channel except for the flow through 2 culverts (Levings, 1980)[3] (at location of "Culvert 3" on Figure 1),
- **1994 to 1999**: DFO installs 7 culverts through the training dike (SRWS, 2008), and
- **2008**: SRWS installs 3 culverts through the training dike (SRWS, 2008).

Sediment transport dynamics in the Central Estuary were assessed based on existing literature and historic air photo review to assess how the human-induced changes listed above may have impacted estuary sedimentation.

[1] Squamish River Watershed Society, "Squamish River Estuary Training Dyke Culvert Improvement Project-Final Report", May 16, 2008.

[2] Hickin, E.J. 1989. "Contemporary Squamish River sediment flux to Howe Sound, British Columbia". *Canadian Journal of Earth Sciences* **26**: 1953-1963.

[3] Levings, C.D. 1980. "Consequences of training walls and jetties for aquatic habitats at two British Columbia estuaries". *Coastal Engineering* **4**: 111-136.

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Air Photo Review

Hard copies of historic air photos were obtained from the UBC Geographic Information Centre and reviewed using a stereoscope. Photos reviewed for this project are listed in the following table. A summary of observations made from the air photo review is provided below.

Table 1: Historical Air Photographs Reviewed

Date	Roll and Photo Number
1946	BC 262, #94, 96
1957 (Sep. 11, Aug. 22)	BC2358 #69-71 BC2350 #7-14
1964 (July 27)	BC5105 #89-87, 83-85
1967 (Apr. 11)	BC5226 #163-171, 181-172
1973 (Sep. 4)	BC7558 #45-43, 56-58, 99-102
1978 (Aug. 1)	15BC78130 #4-1, 11-17, 27-20, 43-39
1982 (Aug. 23)	30BC82060 #143-139
1990 (Aug. 7)	30BCB90103 #87-89, 62-60, 15-17 30BCB90109 #57-55
1994 (Aug. 1)	30BCC94122 #52-54, 96-93, 117-120
2005 (July 26)	30BCC05025 #58-60, 98-96, 206-208 30BCC05026 #23-20

The 1946 photos show that the present-day Crescent Slough was a former main channel of the Squamish River, which at that time had two main distributary channels (east and west). Crescent Slough is the former east channel. In the 1946 photos, the east channel is notably larger than the west channel.

By 1957, the head of the east channel had been largely filled in by deposition, leading to a redistribution of flow into the west channel and corresponding widening. The 1964 photos show a growth of vegetation at the head of the east channel, suggesting that the west channel remained the dominant channel. The east channel, Crescent Slough, appears to have been used for log-booming as early as 1957. There is evidence that the channel was dredged to facilitate this activity. The constructed training dike is evident in the 1973 photos, as is development at the present-day location of Berth 2.

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From 1957 onwards, there is very little change in the planform morphology of the east / Crescent Slough channel: the location and dimensions of features such as the low-flow channel (within the larger, former river channel) and sediment deposits remain largely the same over time. For example, contrast 1967 and 2005 photos below (Figure 3 and 4). This suggests that the volume of flow (and entrained sediment) that entered Crescent Slough through the culverts was not sufficient to result in morphological changes that are detectable from air photos. It should be noted that deposition of suspended sediment over shorter time horizons is difficult to detect from air photos since the changes are generally vertical, and thus hard to assess visually until deposition is sufficient to result in vegetative changes (e.g. the evolution from an intertidal sandflat to a tidal marsh).

In addition, the post-training dike photo series listed in Table 1 all show a darker water colour in Crescent Slough compared with the adjacent Squamish River channel. This suggests that the Crescent Slough water did not contain as much suspended sediment as was being conveyed in the mainstem Squamish River. (It is noted that a 2016 photo provided by SRWS shows the opposite pattern).

These observations from the historical air photo review are consistent with the finding of Levings (1980), who notes that the training dike has allowed penetration of a salt wedge into Crescent Slough, and that flow of water through culverts (2 at the time of the paper), had only a local mitigative effect. Similarly, Pettit (2017)[4] notes that the effect of the culverts cannot be detected from aerial photography.

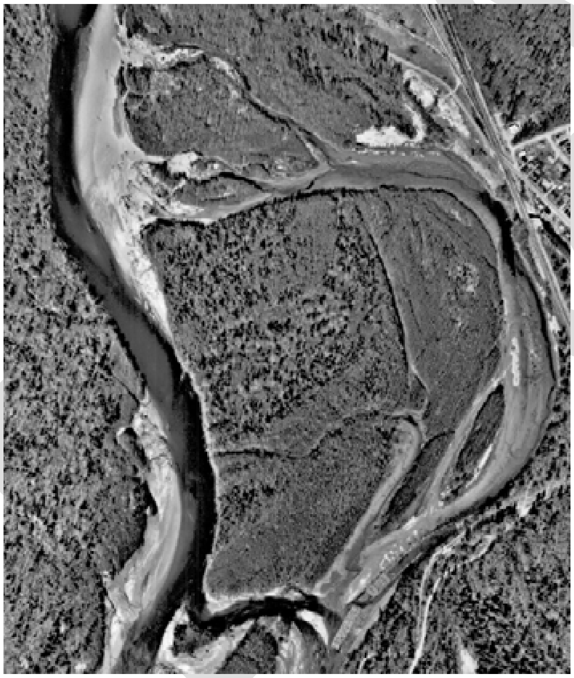

Figure 3: 1967 (BC5226 #167)

Figure 4: 2005 (30BCC05025 #97)

[4] Pettit, E. 2017. "Historical aerial photograph analysis of anthropogenic impacts to an estuary in Squamish, British Columbia". Simon Fraser University. M.Sc. Thesis.

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2.3 Historical Studies of the Squamish River Delta

Sediment transport and deposition within the Squamish River Delta has been studied frequently over the years, both through collection and analysis of bathymetric data and numerical modelling. A summary of the relevant findings of these historical studies is provided below.

J.E. Hughes Clarke et al. (2007[5], 2011[6], 2012[7] [8]): in this series of papers, historic bathymetric data and bathymetric data collected by the authors was analyzed for the purpose of studying short and long-term changes in bathymetry at the Squamish River pro-delta (the submerged section of the delta below low tide). The study area did not include the northern portion of Crescent Slough or the culverts through the training dike. The study findings are as follows:

- The Squamish River delta front pro-grades (moves towards the ocean) on average 4 m per year and accretes (rises vertically) on average 1 m per year;
- There is evidence of numerous, frequent mass wasting events (landslides) on the prodelta front. These mass wasting events are larger in volume and more frequent during high river flows (in the order of 100 definable events in the summer of 2011);
- The prograde front naturally accretes to the south and east of the end of the training dike. Were it not for dredging, access to Berth 2 by large vessels would be cut off by this accretion.
- There is evidence of a of a large mass wasting event southwest of the Berth 2 dredge pocket in the summer of 2006; this event may have been partially caused by steepening of the prodelta slope through dredging.

Tetra Tech (2017[9]): Tetra Tech performed an analysis of sediment transport and deposition in the Squamish River Delta based on both numerical modelling and an analysis of bathymetric data. The numerical model covers the Squamish River Delta only, and does not include the northern portion of Crescent Slough or the culverts through the training dike. The study findings are as follows:

- The numerical model was run for a 7-month period from April to August 2016 using recorded river flow data as an input. The model predicted both deposition and scour at the mouth of the delta, with the deposition occurring in the vicinity of the Berth 2 Light within the navigation channel to the berth. The model predicted relatively low sediment deposition within Berth 2 itself and Crescent Slough (less than 0.1 m over 5 months).

[5] Hughes Clarke et al. "Monitoring flood-related change in bathymetry and sediment distribution over the Squamish Delta, Howe Sound, British Columbia", US Hydrographic Conference, 2007

[6] Hughes Clarke et al., "The Squamish Delta Repetitive Survey Program: A simultaneous investigation of prodeltaic sedimentation and integrated system accuracy", US Hydrographic Conference, 2011

[77]Hughes Clarke et al. "The Squamish ProDelta: Monitoring Active Landslides and Turbidity Currents", Proceedings of CHC 2012, May 2012

[8] Hughes Clarke et al., "Temporal Progression and spatial extent of mass wasting events on the Squamish Prodelta Slope", Landslides and Engineered Slopes" Protecting Society through Improved Understanding, 2012

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

DRAFT

- Bathymetric data from surveys conducted in March 2015 and March 2017 was analysed to determine changes in bathymetry and patterns of sediment deposition and erosion (see Figure 5). The spatial distribution of sediment accretion predicted by the numerical model and as determined from the bathymetric data is in general agreement; however, the model locally under-predicted sediment deposition within Berth 2. The bathymetric data also showed evidence of mass wasting events at the prodelta front and at the edge of the Berth 2 dredge pocket; the numerical model cannot model this phenomenon so this discrepancy is not surprising.

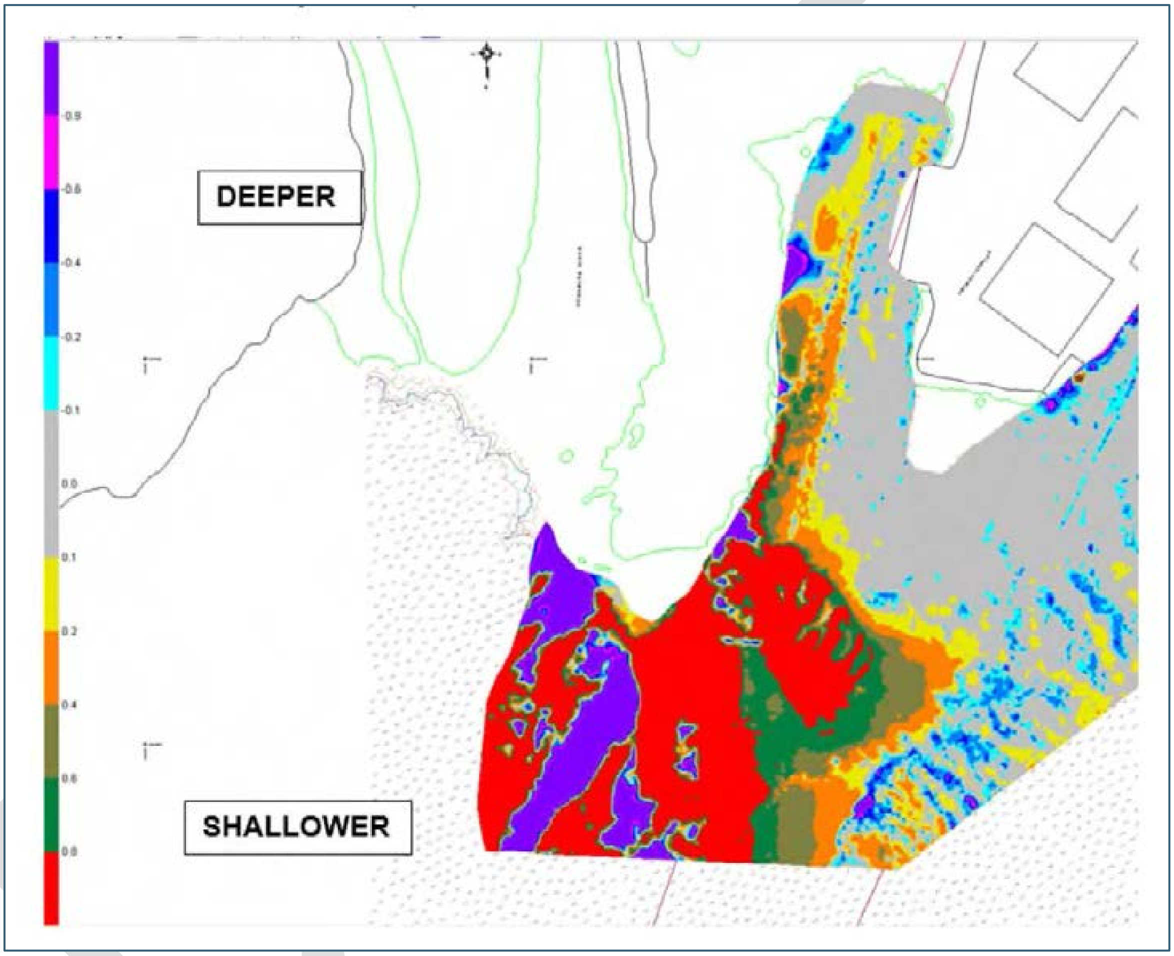

Figure 5: Depth differencing from 2015 and 2017 surveys from Tetra Tech (2017).

Implications for this Project

None of the studies performed to date on sedimentation in the Squamish River Delta have included Crescent Slough and the culverts through the training dike; as a result, they are of limited use for this study. They do, however, provide some useful insights into sediment processes in the general area:

- The studies indicate that the most active portion of the Squamish River delta in terms of both sediment accretion and erosion is a fan-shaped area extending south of the Squamish River mouth and southeast to the Berth 2 Light and navigation channel. Crescent Slough and Berth 2 itself are relatively inactive in terms of sedimentation compared to these areas.
- Based on the March 2015 and 2017 bathymetric surveys (Figure 5), the sediment deposition that does occur within Berth 2 is connected to (although much less than) the general deposition around the Berth 2 Light and the west wall of the dredge pocket. This would suggest that the primary source of sediment is the mouth of the Squamish River, rather than Crescent Slough via the culverts through the training dike.

The northward movement of sediment into Berth 2 could be caused by river or tidal currents or by wave-induced sediment transport (which is not included in the numerical model). The predominant wind directions in the Squamish River Valley are north and south (along the valley) as shown in the wind rose (Figure 6). The fetch[10] is much larger in the southern direction than the northern direction. As a result, the waves from the south are relatively larger and have the potential to cause net northward sediment transport. This sediment transport is facilitated by the shallow water depths to the south of the training dike, around the Berth 2 Light and at the perimeter of the Berth 2 dredge pocket (ground elevations at or above low tide).

In summary, review of literature regarding sediment transport in the Squamish River Delta would suggest that the Squamish River itself is the primary source of sediment in this area, including Berth 2, and that Crescent Slough is a comparatively less important, perhaps even negligible, source.

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[10] Open water distance over which waves are generated by wind.

3. Modelling Scenarios: Culverts and Proposed Bridge

3.1 Flood Modelling

Earlier this year, SWRS retained KWL to carried out modelling of the Squamish Estuary to evaluate the option of replacing the existing culverts at a location on the training berm with a bridge opening. Development and analysis of the modelling work are described in KWL's November 2018 Squamish Estuary Modelling technical memorandum[11].

The modelling scenarios of interest to this project are described as follows:

- Existing Training Berm (Scenario 0): reflects the existing condition of the training berm and 12 culverts at six different locations.
- Proposed Bridge Opening at Dike Chainage 2+660 (Scenario 2A): simulates the replacement of the two culverts at approximate dike chainage 2+660 with a ±16 m wide bridge opening.

3.2 Updated Modelling

Squamish River Flows

The flow in the Squamish River at the site was approximated using three upstream Water Survey Canada (WSC) gauges:

- Squamish River near Brackendale (08GA022);
- Cheakamus River near Brackendale (08GA043); and
- Mamquam River above Ring Creek (08GA075).

These three stations have overlapping periods of record for: 1994, 1995, 1998 to 2005, 2007 and 2009 to 2015. The daily average flows for each of these stations from this period of record were added together to estimate an average annual hydrograph at the site (downstream of the Mamquam River).

This average annual hydrograph was then used to estimate the following three flow conditions at the site:

- Annual baseflow (based on visual inspection of the hydrograph),
- Average flow condition based on the Mean Annual Discharge (MAD), and
- Average high flow condition based on the Mean Annual Flood (MAF).

[11] Squamish Estuary Flood Modelling – Training Berm Bridge Opening at Chainage 2+660 – Hydraulic Modelling Results Technical Memorandum. Prepared for the Squamish River Watershed Society. KWL File No. 3619.005.

Boundary Conditions

Hydraulic modelling was performed for the three flow conditions presented above, and a representative coastal water level equivalent to the mean tide at Squamish. The selection of flows and coastal water level shown on Table 2 span a range of average conditions that would be experienced at the site.

Table 2: Flows and Coastal Water Level for Hydraulic Modelling

River Flow Condition	Squamish River Discharge m^3/s	Howe Sound Coastal Water Level m (GVD28)
Annual Baseflow	180	0.24
Average Flow	300	
Average High Flow	1500	

Tide elevation data was obtained from 2018 Canadian Hydrographic Service (CHS) tide tables[12]. The tides are provided in Chart Datum and required conversion to obtain geodetic levels.

Estuary Connectivity

The two-dimensional 'mesh' defining the model domain was modified to realistically represent the connectivity of these natural features during relatively flow conditions. Modifications were based on limited bathymetric information and available orthophotos. The intent was to allow a reasonable flow exchange through the culverts and within the estuary for the modelled conditions, which included relatively low flows.

3.3 Coastal Boundary Sensitivity Analysis

A sensitivity analysis of the coastal boundary was performed by changing the mean tide elevation to a lower and a higher value represented by the Lower Low Water Mean Tide (LLWMT) and the Higher High Water Mean Tide (HHWMT), respectively. These tide elevations were also obtained from CHS publications. Both additional coastal water elevations were only analyzed for the average high flow condition in the Squamish River since this condition is expected to provide the highest transport of sediment to the estuary.

Table 3: Flow and Coastal Water Levels for Sensitivity Analysis

River Flow Condition	Squamish River Discharge m^3/s	Howe Sound Coastal Water Level m (GVD28)
Average High Flow	1500	-1.86 (LLWMT*)
		1.54 (HHWMT**)
* Lower Low Water Mean Tide ** Higher High Water Mean Tide		

[12] 2018 Canadian Tide and Current Tables for Juan de Fuca Strait and Strait of Georgia – Volume 5, Canadian Hydrographic Service Fisheries and Ocean Canada.

4. Comparison of Culvert and Bridge Sediment Transport

In order to gain further insight into the relative importance of sediment sources in the Squamish River Delta and Crescent Slough, and potential sedimentation changes in the Central Estuary after the installation of a bridge, a comparison of the relative sediment transport rates through the culverts, the proposed free-spanning bridge and the Squamish River was performed. The comparison was based on the hydraulic modelling results coupled with estimates for suspended sediment loads within the river.

4.1 Summary of Previous Sediment Transport Results

Previous results indicated that the amount of sediment that is transported through the culvert is estimated to be approximately an order of magnitude smaller compared to what is estimated to be transported by the bridge. Furthermore, the amount of sediment that either a bridge structure or a culvert transports is small compared to the amount that is transported by the Squamish River (on the order of one to two orders of magnitude smaller).

4.2 Updated Flow Comparison

A comparison of the flow through the culverts with the flow through the free-span bridge structure was completed based on modelling results of the three different flow conditions

Assumptions to support the comparison include the following:

- A constant flow at the upstream side (Squamish River) and a constant water level at the downstream side (Crescent Slough/Central Estuary) were applied as boundary conditions.
- Replacement of the two culverts was assumed at dike chainage 2+660 of the Squamish River training berm (Culvert 3). Based on survey conducted by SRWS in August 2018, there are two culverts at this location (with diameters of 0.91 m and 1.22 m).
- The bridge opening was assumed to be ±16 m wide, and with characteristics similar to those shown in Figure 2.

Based on the comparison of modelling results for the "Existing" (culverts) and "Proposed Bridge" (bridge) scenarios presented in Table 4, during baseflow and average flow conditions the proposed bridge would divert an additional 2.6% to 2.7% of the total Squamish River flow into the Central Estuary. For the average high flow condition, the proposed bridge would divert an additional 5% to 6% of the total Squamish River flow to the Central Estuary.

For the average high flow condition, the 5% to 6% difference in diverted flow between the existing and proposed bridge scenarios represents an approximately 30% increase of flow into the Central Estuary.

Due to lack of information during the previous sediment transport analysis, flow through the culvert and the proposed bridge structure included an assumption that both were flowing at capacity. For an average daily flow equivalent to the modelled average flow condition (i.e., 300 m^3/s), the previous analysis estimated that about 1.7% and 19.2% of the flow in the Squamish River would be diverted through a culvert and a proposed bridge, respectively. Based on the updated flow comparison, this resulted in an overestimation of the flow diverted through the bridge.

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Table 4: Percentage of Total Squamish River Flow Diverted to the Central Estuary

Modelled Condition	Squamish River Flow m^3/s	Flow Diverted "Existing" Scenario	Flow Diverted "Proposed Bridge" Scenario	Difference
Annual Baseflow (with Mean Tide)	180	0.5%	3.1%	2.6%
Average Flow (with Mean Tide)	300	0.6%	3.3%	2.7%
Average High Flow (with Mean Tide)	1500	2.5%	7.8%	5.3%
Sensitivity Runs				
Average High Flow (with LLWMT)	1500	2.4%	7.5%	5.0%
Average High Flow (with HHWMT)	1500	2.3%	8.3%	6.0%
* Lower Low Water Mean Tide ** Higher High Water Mean Tide				

The flow comparison was used to support an estimate of the suspended sediment load.

4.3 Sediment Transport Comparison

Suspended Sediment Concentration

The amount of sediment being transported to the mouth of the Squamish River is proportional to the flow in the river, and the form of the relationship has been described by Hickin (1989)[13]. It was assumed that the concentration of suspended sediment in the Squamish River could also represent the suspended sediment concentration of water flowing through the culverts and the bridge structure.

Suspended Sediment Rates

The concentration of suspended sediment was estimated for the three flows using the suspended sediment rating curves for the Squamish River developed by Hickin (1989). Each sediment concentration is then used to estimate the daily sediment rates (kg/day) for:

- the Squamish River (without diversions),
- the existing culverts, and
- the proposed bridge.

[13] Hickin, Edward J. 1989. *Contemporary Squamish River Sediment Flux to Howe Sound, British Columbia*. Canadian Journal of Earth Science. Volume 26, pages 1953-1963.

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Suspended Sediment for the Existing Scenario

Model results indicate that:

- The baseflow and average flow conditions divert a very small amount of sediment to the estuary (<0.6% of the total sediment).
- The average high flow condition is expected to divert between 2.3% and 2.5% of the total sediment to the estuary depending on the tide condition.
- For the average high flow, changing the coastal boundary condition (Mean Tide, LLWMT and HHWMT) did not significantly change the flow/sediment rate through the culverts and proposed bridge. The Mean Tide coastal condition provided the highest flow (and sediment) discharge to the estuary.

Suspended Sediment for the Proposed Bridge Scenario

Model results indicate that:

- The baseflow and average flow conditions divert a small amount of sediment to the estuary (<3.3% of the total sediment).
- The average high flow condition is expected to divert between 7.5% and 8.3% of the total sediment to the estuary depending on the tide condition.
- For the average high flow, changing the coastal boundary condition (Mean Tide, LLWMT and HHWMT) did not significantly change the flow/sediment rate through the culverts and proposed bridge. The HHWMT coastal condition provided the highest flow (and sediment) discharge to the estuary; which is governed by the flow through the proposed bridge given that the highest discharge through the culverts is still produced by the Mean Tide condition.

Based on these comparisons, the amount of sediment that the existing scenario or the proposed bridge scenario transports into the Central Estuary is small (less than 10%) compared to the amount that is transported by the Squamish River.

These findings reinforce the conclusion that:

- the culverts have historically been a small source of sediment to the Central Estuary compared to the Squamish River, and
- sediment deposited by the Squamish River would dominate at the southern end of Crescent Slough.

The results also indicate that the replacing the culverts with a bridge will change water and sediment flows in the Central Estuary by approximately 30% under average high flow conditions. This may have potential to cause morphological changes to Crescent Slough.

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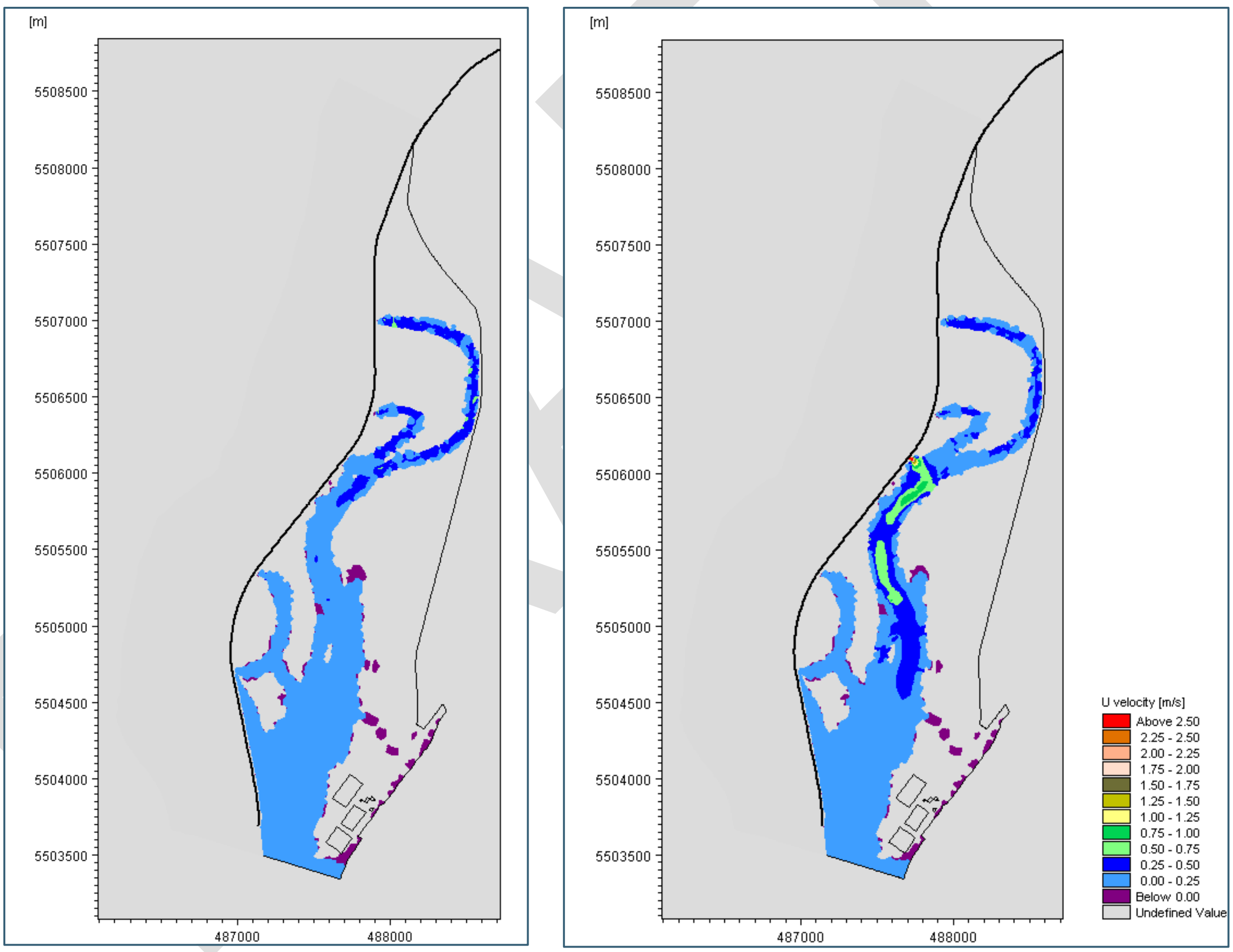
4.4 Flow Velocities Comparison

Model results also provided water velocity components in the x- and y- directions at each mesh element; a post-processing tool was used to calculate the velocity resultant for each mesh element and for each scenario. Figures below shows the velocity resultant for the average high flow condition for the existing scenario (left) and the proposed scenario (right).

As expected, velocities in the estuary are higher for the proposed bridge scenario than for the existing scenario (Figure 6). The effect of the bridge on the flow velocities extends for approximate 1500 m downstream of the bridge location and diminishes as it reaches the lower part of Crescent Slough, upstream of the terminals. For the proposed bridge scenario, the highest velocities are at the bridge location as the flow forces its way through the proposed bridge opening.

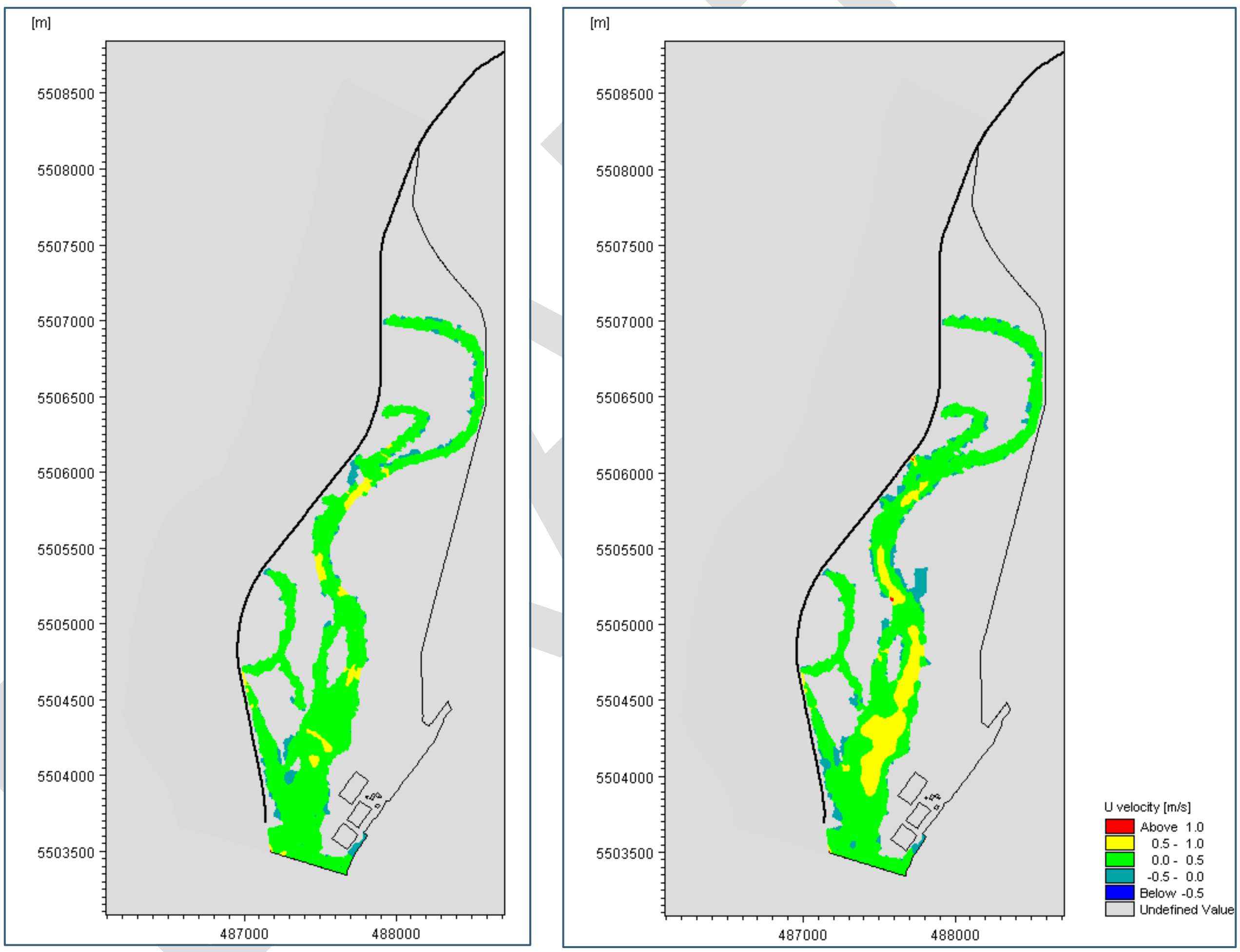


Existing Scenario *Proposed Bridge Scenario*

Figure 6: Model Velocity Results in Crescent Slough / Central Estuary (Average High Flow Condition with Mean Tide)

The sensitivity analysis conducted for the average high flow condition showed that the LLWMT coastal boundary provided higher velocities than the mean tide boundary condition. Conversely, the HHWMT coastal boundary provided much lower velocities than the mean tide boundary condition. Figure 7 shows the difference between the LLWMT and HHWMT coastal boundaries for the existing and proposed scenarios.

The highest velocity difference in the main channel of Crescent Slough occurs downstream of the Culvert 3 / proposed bridge location for both the existing and proposed bridge scenarios. For the proposed bridge scenario, as more water flows to the estuary, the highest velocity difference extends to the south end of Crescent Slough.



Existing Scenario *Proposed Bridge Scenario*

Figure 7: Model Velocity Sensitivity Results in Crescent Slough / Central Estuary (Average High Flow Condition with LLWMT Compared to HHWMT)

Velocity Thresholds

The stability of the river bed was evaluated using the permissible (or critical velocity) as defined by Fischenich, 2001[14]. It is assumed that there is a potential for bed erosion / movement of sediment if the water velocity exceeds the permissible velocity. A permissible velocity of 0.5 m/s to 1.0 m/s has been selected as a reasonable value based on the sediment bed composition of Crescent Slough / Central Estuary.

For the purpose of this study, the velocity resultant from the model has been compared to the permissible velocity to identify areas that may be prone to bed movement. Velocity results for the average high flow condition and mean tide coastal boundary indicate that flow velocities near the proposed bridge structure and extending approximately 1000 m downstream are higher than the velocity threshold; however, flow velocities in the larger Central Estuary are less than 1.0 m/s for both scenarios.

Based on the velocity results and the selected allowable velocity, erosion of the estuary bed is unlikely to occur for the scenarios modelled. It is important to note that these results of velocity referring to the potential movement of sediment are meant to be indicative, rather than conclusive.

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[14] Stability Thresholds for Stream Restoration material. Craig Fischenich, 2001.

5. Summary of Findings

A qualitative assessment of the existing sediment transport processes in Crescent Slough was conducted for the purpose of providing a professional opinion about the potential impacts of replacing the two culverts structures at Culvert 3 with a free-span bridge structure to improve fish habitat. The assessment was based on a review of available literature and air photos, and hydraulic modelling of the estuary.

We have concluded that **the existing culverts have not had the water or sediment conveyance capacity to significantly affect the morphology of Crescent Slough or Berth 2** based on the following evidence:

1. Review of historical air photos taken before and after culverts were installed in the Squamish River Training Dike indicates that the culverts through the dike have not led to planform changes in Crescent Slough. This would suggest that the water flow, and by inference, the sediment flow, through the culverts is relatively low.
2. Also based on an analysis of historical aerial photos, water in Crescent Slough typically has less suspended sediment than water in the Squamish River. These observations are consistent with the finding that the training dike has allowed penetration of a salt wedge into Crescent Slough, and that flow of water through the culverts had only a local mitigative effect. This also suggests that the flow through the culverts is relatively low and they are not a major source of sediment to Crescent Slough.
3. In the southern portion of Crescent Slough, where it interfaces with the Squamish River Delta, available evidence indicates that the dominant sediment source is the Squamish River rather than the culverts through the training dike. This conclusion is consistent with preliminary sediment transport calculations performed by KWL which indicate that the Squamish River conveys a sediment volume two orders of magnitude larger than the culverts through the training dike.

The potential impact of replacing the existing culverts with a proposed bridge structure was assessed by performing hydraulic modelling and sediment transport calculations. **The analysis indicates that the flow and sediment flux into the Central Estuary with a bridge is likely to be approximately 30% greater than through the existing culverts at the average high flow and mean tide conditions**.

Based on results of flow velocities in the Central Estuary, **replacement of the culverts at Culvert 3 with a bridge is unlikely to change patterns of sediment deposition and erosion in Crescent Slough or Berth 2.**

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6. Recommendations

Although hydraulic modelling was done to estimate the flow rates through the existing culverts and proposed bridge, there is uncertainty regarding the actual amount of sediment flowing to the estuary. The assumption that the sediment in the river is proportional to the flow may not apply as the water transitions through the bridge structure and enters the Central Estuary.

Numerical sediment transport modelling was not done as part of this work. It is important to recognize the limitations of numerical sediment transport modelling in this complicated estuarine location. A large amount of effort could be spent on numerical sediment transport modelling and it would still provide results that are only indicative.

There are several options open to SRWS to increase the level of certainty regarding impacts of the proposed bridges and to manage potential adverse consequences:

1. Implement a sediment deposition and erosion monitoring program. Any changes in the morphology of the Central Estuary and Crescent Slough are likely to be gradual, and therefore it will likely be possible to anticipate adverse consequences if a robust monitoring program is put in place. From a sediment transport perspective, this monitoring program would involve collecting detailed topographic and bathymetric data within the estuary on a regular basis, documenting changes in elevation and verifying that erosion and accretion are not occurring in undesirable areas. The monitoring program could proceed immediately to establish a baseline prior to construction.
2. Include flow control structures in the bridge design, or design the bridges such that flow control can be readily added. This is a risk management option that would allow flows to be controlled to manage adverse impacts. Flow control structures would need to be selected considering ease of fish passage, cost, ease of operation and reliability.

It is recommended that SRWS consider these options as the design of the proposed bridge proceeds.

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7. Closing

We trust that this qualitative sediment assessment meets your needs at this time. If you have any questions, please contact the undersigned at 604-294-2088.

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:

Alisson Seuarz, M.Eng, EIT
Project Engineer

Sarah Lawrie, M.A.Sc., P.Eng.
Project Engineer

Reviewed by:

Erica Ellis, M.Sc., P.Geo.
Fluvial Geomorphologist

David Sellars, M.Sc., P.Eng.
Senior Water Resources Engineer

ASB/SJL

Encl.: Figures

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Revision History

Revision #	Date	Status	Revision Description	Author
B	December 21, 2018	Draft	Updated to include hydraulic model results and updated sediment transport analysis	EM / EE / ASB / SJL
A	March 2, 2018	Draft	Submitted to client for review	EM / EE

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Squamish River Watershed Society

Squamish Estuary Sediment Transport Assessment

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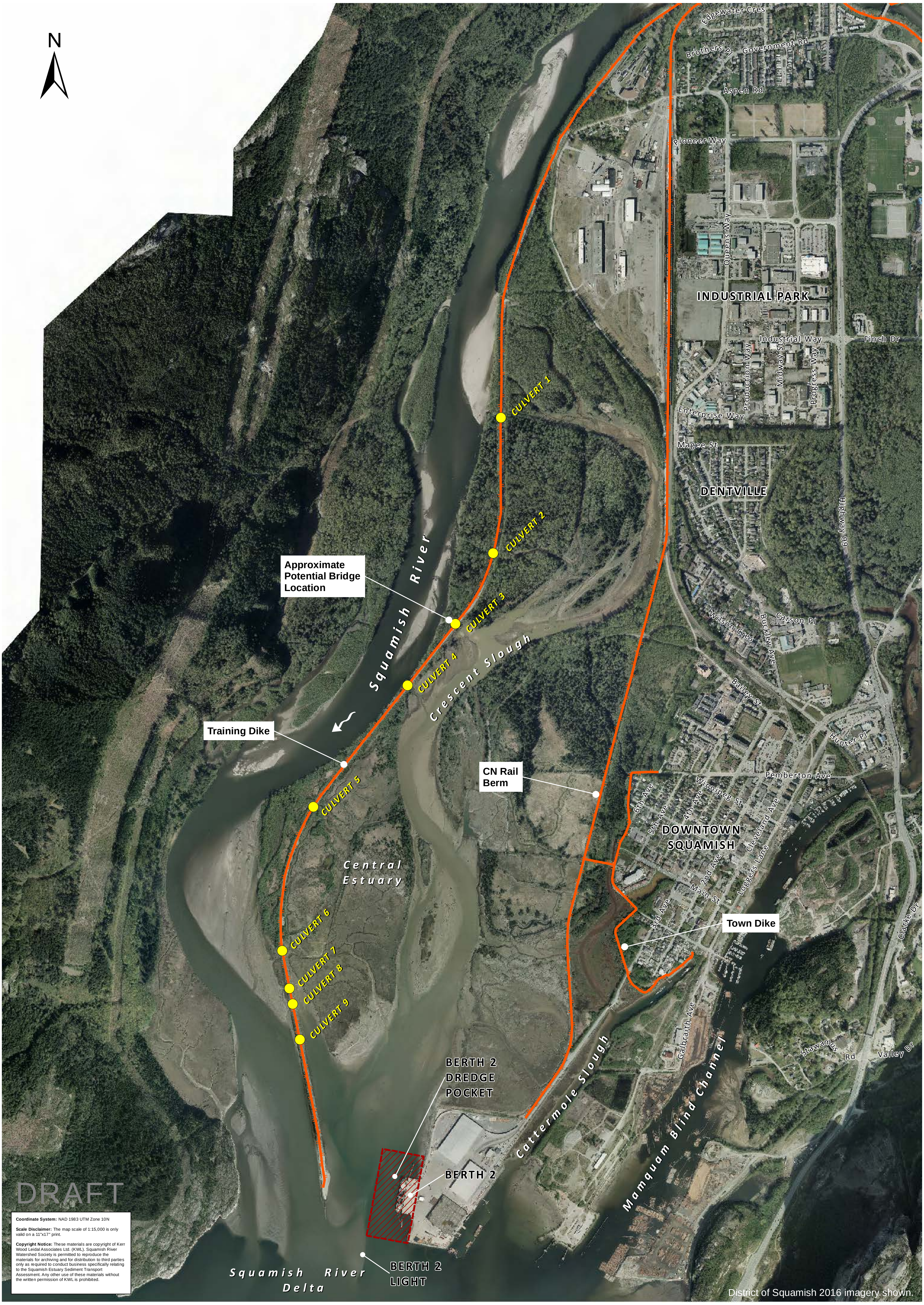
consulting engineers



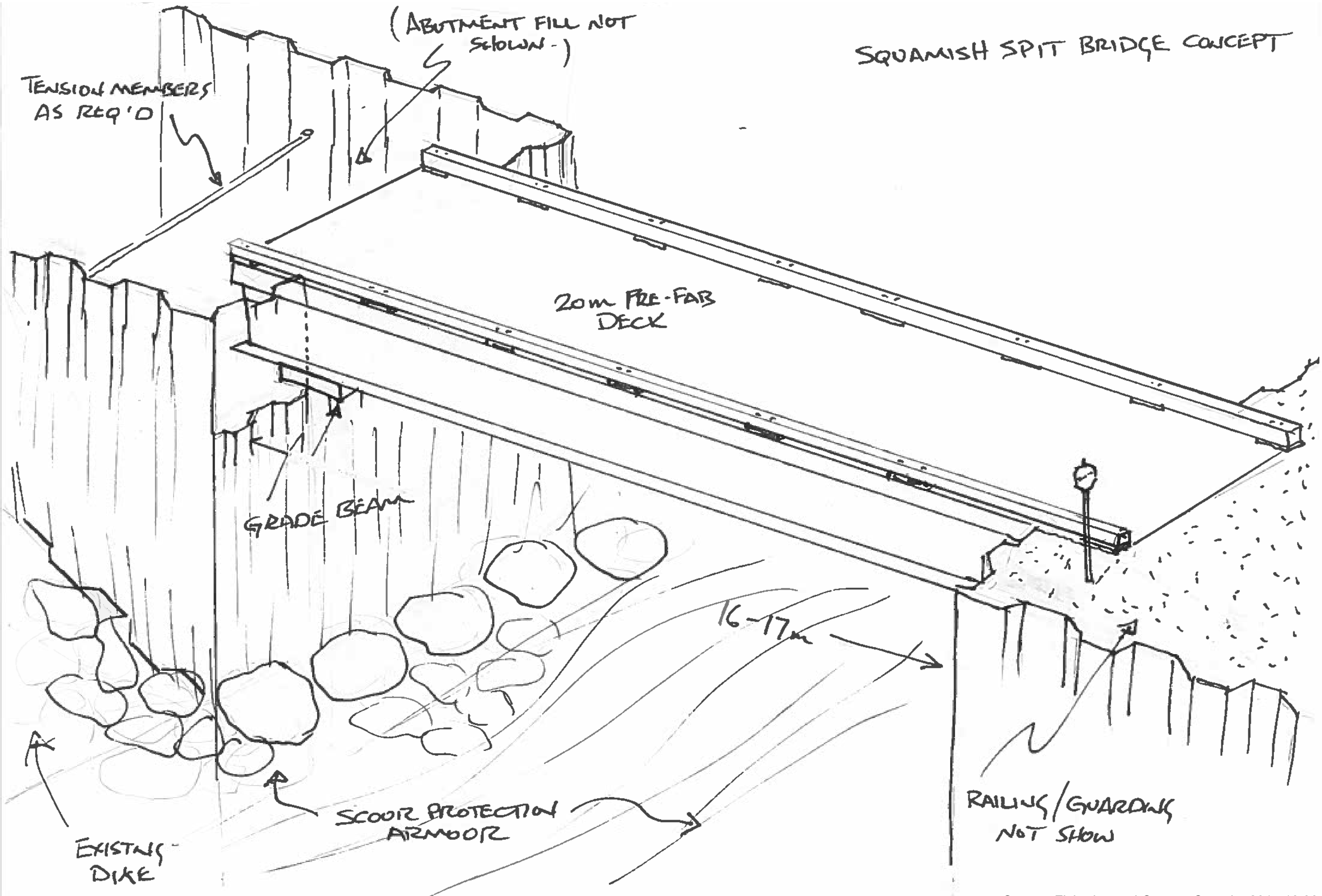
Project No. 3619.004

Date December 2018

Scale 1:15,000

Project Location and Features of Interest

Figure 1



Source: Fisheries and Oceans Canada, 2017.10.30

Squamish River Estuary Bridge Concept

Figure 2

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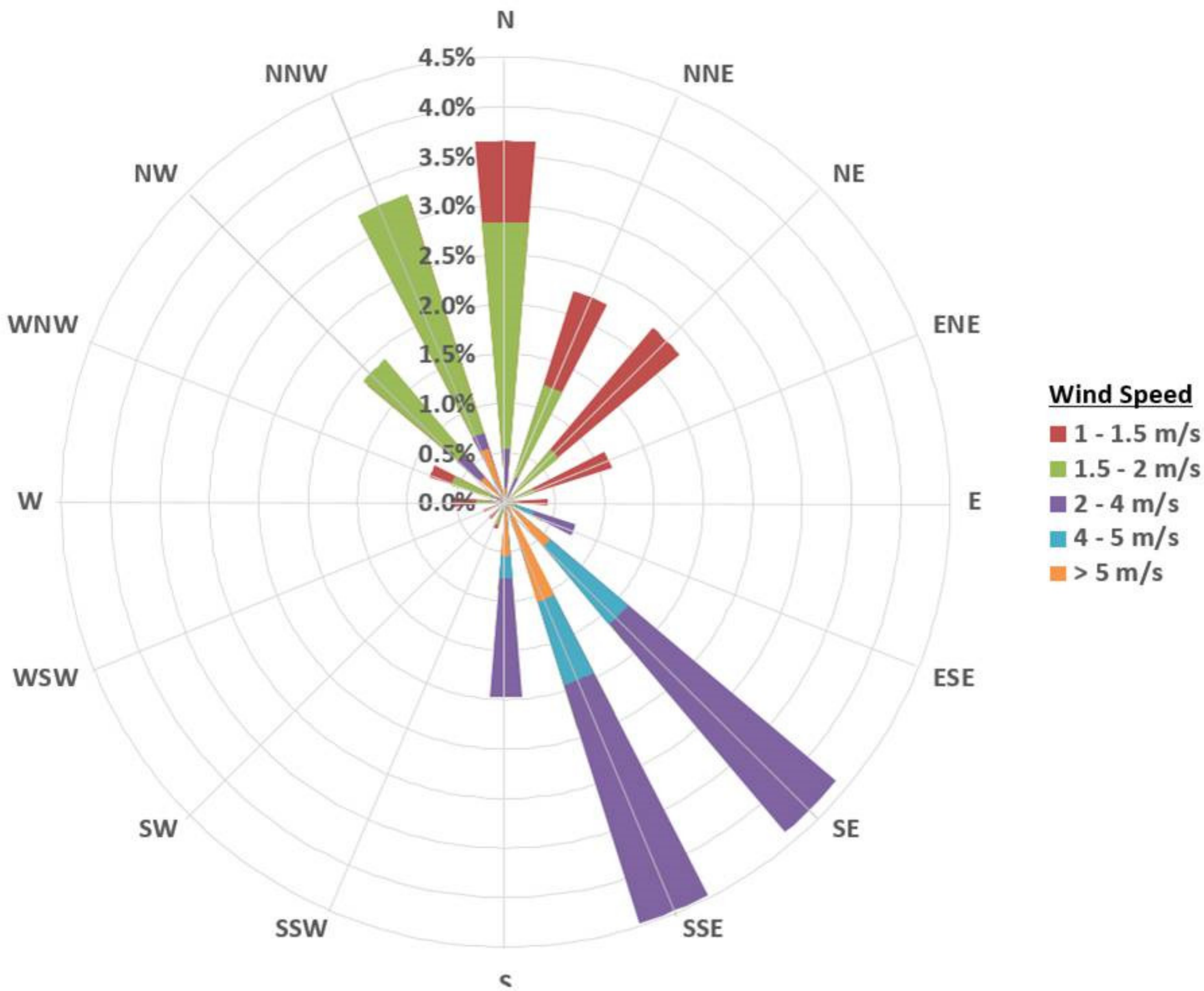

Figure 6: Squamish Airport Wind Rose (Date from 1983-2014)

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