

Central Squamish Estuary Restoration Project: Year 2
COA-F20-F-3067
2019 – 2020
FINAL REPORT



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Executive Summary

The Central Squamish Estuary Restoration Project (CERP) is the culmination of meetings, planning sessions, and discussions over the past twenty years to explore restoration opportunities to improve fish passage between the Squamish River and the central Squamish estuary. Over the last 100 years the estuary has been dramatically impacted with the creation of the townsite, logging, industrial development, the construction in the 1950s of a 5 km rail line to service the Squamish Terminals deep sea port (what is now referred to as the CN Spur line), and the construction from 1970 to 1972 of a road to train the Squamish River to the western side (the “Training Berm”) for a coal port development. While the coal port development ultimately was denied the Training Berm remained in place, all but restricting any fish passage between the Squamish River and estuary.

From 2001 onwards, the Squamish River Watershed Society, in partnership with the provincial government, Federal Fisheries, and Squamish Nation, has explored restoration opportunities within the estuary to improve habitat for salmon and salmonids. Funding and support from Fish and Wildlife Compensation Program (and the former Bridge Coastal Restoration Fund) factored heavily in those restoration projects as BC Hydro recognized the importance of functional estuarine habitats for the overall health of salmon on a watershed scale.

Seed funding support from Fish and Wildlife Compensation Program (FWCP) in 2017 for the Squamish River Training Dike Fish Passage Upgrades (COA-F18-F-2496) allowed for the development of the current project to restore fish passage between the Squamish River and the central estuary. The development of the project included numerous meetings, facilitated workshops, and discussions around the potential large-scale upgrades in the Squamish estuary that would improve overall fish passage and habitat between the river and estuary with a focus on restoring Chinook salmon populations (SRWS 2018). The result of those initial meetings and workshops opened the door to develop a three phased approach toward restoration: improvements along the Training Berm to upgrade or replace the existing culverts (Phase 1: Culvert Upgrades); realign or modify the lower end of the Training Berm known as the Spit (Phase 2: Spit Realignment); and install flow control structures across the CN Spur Line to re-establish fish habitat in the Bridge Pond (Phase 3: Bridge Pond Rewatering).

Work on Phase 1 commenced during the 2018/2019 fiscal year and carried into the 2019/2020 field season resulting in the replacement of a former twin 1.2m diameter corrugated steel pipe (CSP) at Location #3 with a 3m x 3m concrete box culvert. This project was supported by FWCP (COA-F19-F-2603) and work on the culvert upgrade took place from March 2019 and to October 2019. Additional shoreline stabilization (armouring), riparian planting, and installation of signage continued at Location #3 into the 2019/2020 fiscal year.

The goals and objectives completed in the 2019/2020 fiscal included:

- Monitoring fish (juvenile Chinook salmon and other salmonids) movement between the Squamish River and the central estuary with a focus on fish passage through the newly upgraded culvert at Location #3.
- Biophysical monitoring of water quality (including dissolved oxygen, pH, salinity / conductivity, and temperature) in the Squamish River, central estuary, Bridge Pond, and Cattermole Slough, as well as sediment drift and transport and vegetation surveys.
- Two modelling reports including wave modelling and modelling for the removal of the Spit for two scenarios including the removal of the lower 1 km and the lower 2 km of the Training Berm.
- Engaging with the community and government stakeholders including all levels of government, First Nation, industry, recreation, and community representatives.
- Delivering educational programming including Rivers Day events, self-guided walks, and school programs.
- Planting riparian vegetation in disturbed areas around culvert crossings at Locations #2 and #3.
- Addition of armour and rip-rap rock along intake channel at culvert Location #3 and clearing out woody debris and sediment build up from the intake of the culverts at Location #1 and #2 to improve water flows and fish passage.

To further the Phase 2: Spit Realignment component of the project, meetings, discussions, and workshops were held with decision makers, government, First Nations, and the community over the course of the year. The biggest factor affecting the Spit realignment centered around access to the southern tip by the wind sport recreation user groups. Another major factor to Phase 2 was the potential impact of sediment build-up along the western berth of the Squamish Terminals.

The work in the 2019/2020 fiscal also included plans to establish flows across the CN Spur line to improve salmon habitat in Phase 3: Bridge Pond Rewatering. To better understand how tidal flow function on either side of the CN Spur Line the SRWS implemented a biophysical monitoring program by deploying data loggers (level loggers, temperature loggers, and photo-point monitoring stations) to collect data. Several on-site meetings with the District of Squamish (DOS) staff were held to discuss the optimum locations in which flow-control structures could be installed, whether manual or automatic structures would be required to manage the flows, and who would be responsible for any long-term management of any new structures.

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Abbreviations

- CERP – Central Estuary Restoration Project
- CSEB – Canadian Society for Environmental Biologists
- CSP – Corrugated steel pipe
- DFO – Fisheries and Oceans Canada
- DOS – District of Squamish
- FWCP – Fish and Wildlife Compensation Program
- IFR – InStream Fisheries Research
- MOE – Ministry of Forests, Lands, and Natural Resources, Development and Operations
- PIT – Passive Integrated Transponder
- SNC-L – SNC Lavalin
- SRWS – Squamish River Watershed Society
- SWS – Squamish Windsports Society
- WMA – Wildlife Management Area

1.0 Introduction and Project Description

The Central Estuary Restoration Project (CERP) is a multi-year project focused on improving fish access for salmonids between the Squamish River and the central estuary. The focus is to restore declining Chinook salmon populations by improving spawning and rearing habitat within the estuary. In order to achieve this objective, the scope of the project includes three phases:

- Phase 1: Culvert Upgrades - replace culverts at key locations along Training Berm (Culvert Upgrades)
- Phase 2: Spit Realignment - realign or modify the southern end of the Training Berm, also referred to as the Spit
- Phase 3: Bridge Pond Rewatering - install flow control structures across CN Spur Line to improve water quality between the Bridge Pond/Cattermole Slough and Pretty Slough in the central estuary (in the area managed by Squamish Nation referred to as Site "A")

The Squamish Estuary, located approximately 52 km north of Vancouver, is situated at the head of Howe Sound where the Squamish River discharges a drainage area of over 3,650 square km. The Squamish estuary encompasses the tidal waters of upper Howe Sound, from the confluence of the Squamish River upstream to the Mamquam River, the Mamquam Blind Channel, and Stawamus River. The project site is located within the Skwelwil'em Squamish Estuary Wildlife Management Area (WMA) which is Crown land managed by the provincial government (MOE 2007). Access along the Training Berm Road is maintained by the DOS in agreement with the provincial government in order to provide access at the south end for wind sports activities between May and September annually. The site is within the territorial lands of Squamish Nation.

The Training Berm, an antiquated structure which was constructed in the early 1970s by BC Rail, was originally intended to "train" the Squamish River along the western edge in order to facilitate the construction of a coal port in the estuary. However, even though the federal government of the day shut this operation down the 5 km road remained in place, effectively cutting all access from the Squamish River to the central estuary for river flows and fish access. In 1994 twin CSP culverts were installed by Fisheries and Oceans Canada (DFO) at the site referred to as Location #3 (Figure 2). From 2001 until 2013 the SRWS, in partnership with DFO, installed an additional eight more culvert crossings to improve tidal exchange and provide fish access between the river and estuary. From 2013 until 2017 the SRWS commissioned a study to determine how the juvenile salmonids were utilizing the culverts. The result of the study determined that salmonids were not able to access the culverts and was likely resulting in the loss of a certain percentage of survival of salmonids as they were flushed down the Squamish River into Howe Sound (Lingard 2018).

Alignment with Cheakamus River Watershed Action Plan

The CERP project is consistent with the main priority areas identified in the Cheakamus River Watershed Action Plan (FWCP 2017) including:

- CMS.RLR.HB.14.05: high priority item to implement habitat restoration in the Squamish estuary
- CMS.RLR.HB.17.01: high priority to conduct restoration activities in the Squamish estuary to benefit Chinook salmon and other salmonids
- CMS.RLR.HB.18.01: high priority to improve fish passage between the Squamish River and the Central Estuary across the Training Berm.

Key factors the CERP project addresses are:

- I.* Restore access to estuary for juvenile salmonids, focus on providing rearing habitat for Chinook salmon. Estuary channels provide excellent rearing habitat for Chinook fry. Over 95% of the juvenile Chinook salmon captured migrating out of the Cheakamus River in the spring of 2000 were first year fry (Lingard 2018). These Chinook fry require a period of residency in estuarine waters during their first spring prior to entry into saltwater. The Squamish River estuary and its tidal channels provide a significant amount of this critical Chinook salmon rearing habitat for the Cheakamus River Chinook salmon populations. Without adequate connections between the Squamish River and the inner estuary delta the access is severely limited for fish passage, and thus the habitat is underutilized.
- II.* The loss of fundamental estuarine flow processes where fresh water moves in diverse patterns and mixes with marine waters is another factor that is addressed in all three phases of the project.
- III.* Another limiting factor addressed is the probable decrease in Chinook salmon fry growth rate due to reduced water temperatures in freshwater spawning and early life stage rearing habitat. It is suspected this result is from flow diversion at Daisy Lake and the dominance of Rubble and Culliton Creek in defining summer temperatures in the lower Cheakamus River (Lingard 2016). Decrease in spring and summer water temperatures has presumably reduced the potential growth rates and productivity of Cheakamus River Chinook salmon fry. A large component of the Chinook salmon fry produced from spawning grounds on the Cheakamus River leave the river soon after emergence and rear and feed in the mainstem Squamish River and the estuary channels for some months prior to their migration into Howe Sound. By improving Cheakamus River Chinook fry and smolt access to and use of the warm, nutrient rich waters of the Squamish River estuary their overall productivity and survival would be expected to increase in the hundreds of thousands (Lingard 2018).

- IV.** Incidental benefits are also expected for other species of interest including steelhead and cutthroat trout, and pink, coho and chum salmon. As well, bull trout and coho salmon from the Cheakamus River watershed may spend varying periods of time in the Squamish River estuary during their life cycle. Herring and other marine species will also benefit from this project.

Project Urgency

The importance to restore fish passage across the Training Berm between the Squamish River and the central estuary cannot be overstated. This project is recognized as being of high importance to Squamish Nation, the Provincial government, and Federal Fisheries who all recognize coastal Chinook salmon populations are in decline and the importance of improving habitat for survival. Chinook salmon are recognized for their importance as a source of food and cultural significance to Squamish Nation, a source of revenue for sports and recreation fishing enthusiasts, and as a vital link to the health of the south coast resident Killer Whale (SRKW) populations. In addition, Chinook salmon are considered to be of cultural and ecological importance in British Columbia and of conservation concern (COSEWIC 2019). There is also an importance to restore access between the Squamish River and the central estuary to all life stages of salmonids as it is not fully understood how the Training Berm has impacted the overall ecosystem of the watershed and health of the salmon populations. What is known is that following the construction of the Training Berm in the early 1970s many stocks, including pink salmon runs and Chinook salmon runs all but plummeted.

Benefit to Salmon

The focus of the CERP multi-year project is to improve Chinook salmon (*Oncorhynchus tshawytscha*) populations and overall health. However, the project will also benefit coho salmon (*O. kisutch*), chum salmon (*O. keta*), pink salmon (*O. gorbuscha*), steelhead (*O. mykiss*), as well as other salmonids, char, herring, and marine habitat in general.

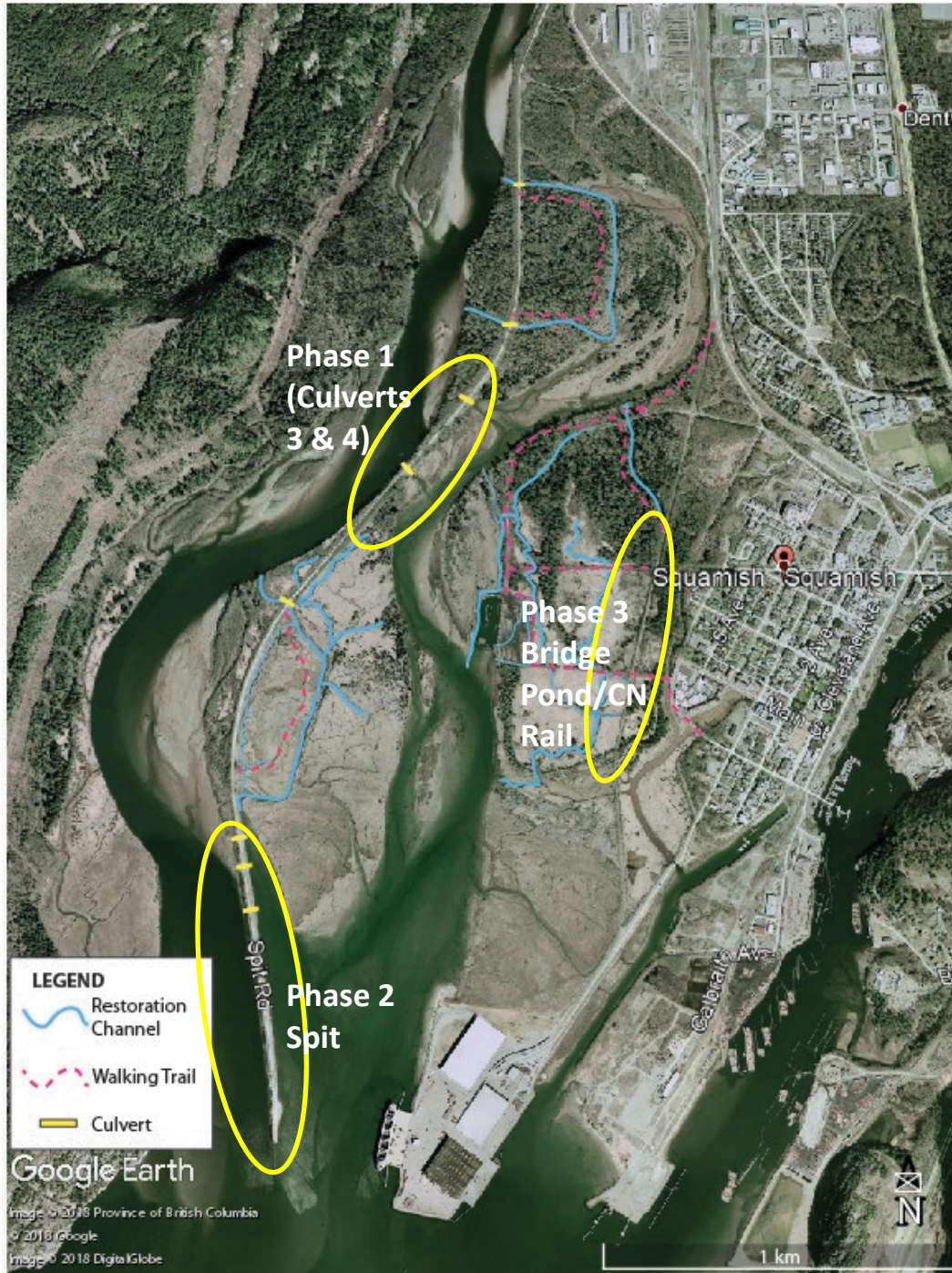


Figure 1. Central Estuary Restoration Project Phases 1 – 3

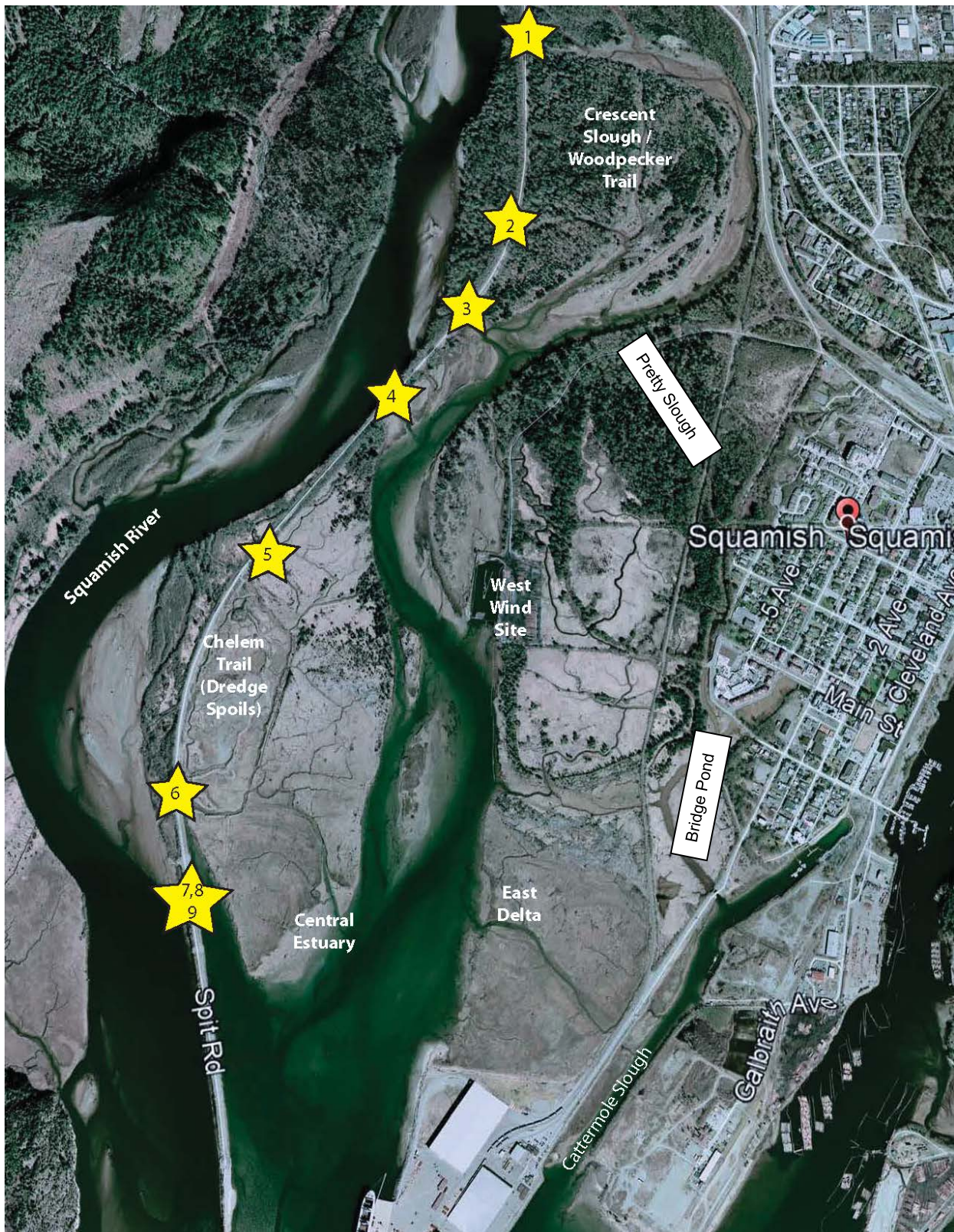


Figure 2. Location map of culvert crossings (1 to 9 in yellow stars) Squamish estuary

2.0 Goals and Objectives

When this application was developed in the fall of 2018, the intention was to be at a stage in which work on Phase 2: Spit Realignment could commence in the 2019/2020 field season. However, over the course of numerous meetings and workshops it became very clear that this ambitious component of the project would require rigorous studies, community support, and a commitment from the District of Squamish and the Province to support the Squamish Windsport Society (SWS) to establish an alternative access for wind sport recreation users to the launch site at the south end of the Spit. While there remains strong support for the CERP program by the community and agencies, the focus over the course of the year shifted more towards fisheries and biophysical monitoring as well as additional wave and spit realignment modelling.

A summary table is provided below outlining the various phases of the project, what components and phases have been completed to date, what is being planned for the upcoming year, and what the plans are for the future as the various restoration works, monitoring programs, and engineering modelling is realized.

Table 1. Summary of Project Phases & Monitoring Programs

Goal	Objective	Details	Date Achieved
Fisheries & Biophysical Monitoring	Establish baseline data followed by consistent monitoring design following physical works associated with Phases 1, 2, and 3	Fisheries monitoring using various techniques including PIT tags, acoustic tags, Gee trapping & seine netting at various locations in the Squamish River and Estuary. Biophysical monitoring for water quality, sediment transport, vegetation colonization and invertebrate populations at various locations in the Squamish River and estuary	2018 2019 2020 (underway) 2021 (pending) 2022 (wrap up)
Phase 1: improve fish accessibility across Training Berm	Replace fish passage obstructing culverts across Squamish Training Berm	Culvert replacement at Location #3	May 2019
		Culvert replacement at Location #4	Pending: August 2020
		Additional culvert replacements (Locations #1, 2, 7 – 9)	Summer 2021 & Summer 2022
Phase 2: remove or realign Spit to reopen lower 77 hectares of habitat	Realign Spit	Wave modelling & Spit Realignment modelling	Reports: 2020
		Meetings & consultation	2018 - present
		Design & Approval	Design: 2021? Approval: 2022?
Phase 3: Bridge Pond re-watering	Install a flow control structure across the CN Spur line to provide controlled flows into the Bridge Pond	Fisheries monitoring & Biophysical monitoring	Summer 2018, 2019, & 2020
		Design & Approval	Sept. 2020? Summer 2021?

2.1 Fisheries Monitoring of Juvenile Chinook Salmon Outmigration

A monitoring program was developed in 2018 by InStream Fisheries Resource (IFR) to establish baseline data prior to the culvert upgrade at Location #3 which. This program was implemented in the summer of 2018 and repeated in 2019, following the culvert upgrade. This monitoring program expanded on previous DFO efforts to collect data on salmon usage of the estuary and river including seine netting and Gee trapping. The focus of the IFR monitoring program was on the fish passage limitations at Location #3 and #4 (Figure 2). The monitoring program was intended to capture the largest movement of out-migrating juvenile Chinook salmon based on the historic data regarding the capture of Chinook salmon in the Cheakamus River Rotary Screw Traps (RST) from March to early July. The goal of this program was to recapture tagged fish and thus provide a coarse assessment of distribution of salmonids. To this end 982 Passive Integrated Transponder (PIT) tagged fish were deployed in the 2019 field season along with 100 acoustic tags at various locations in the Squamish River (Figure 3) on both wild and hatchery origin juvenile Chinook salmon. Acoustic receivers were installed in both the Squamish River and at various locations within the estuary. PIT antennas were installed in the new box culvert at Location #3 and in the channel connecting the two upper culverts at Locations #1 and #2 (Figure 2).



Photo image of acoustic array in Culvert #3 to monitor fish passage between Squamish River and estuary

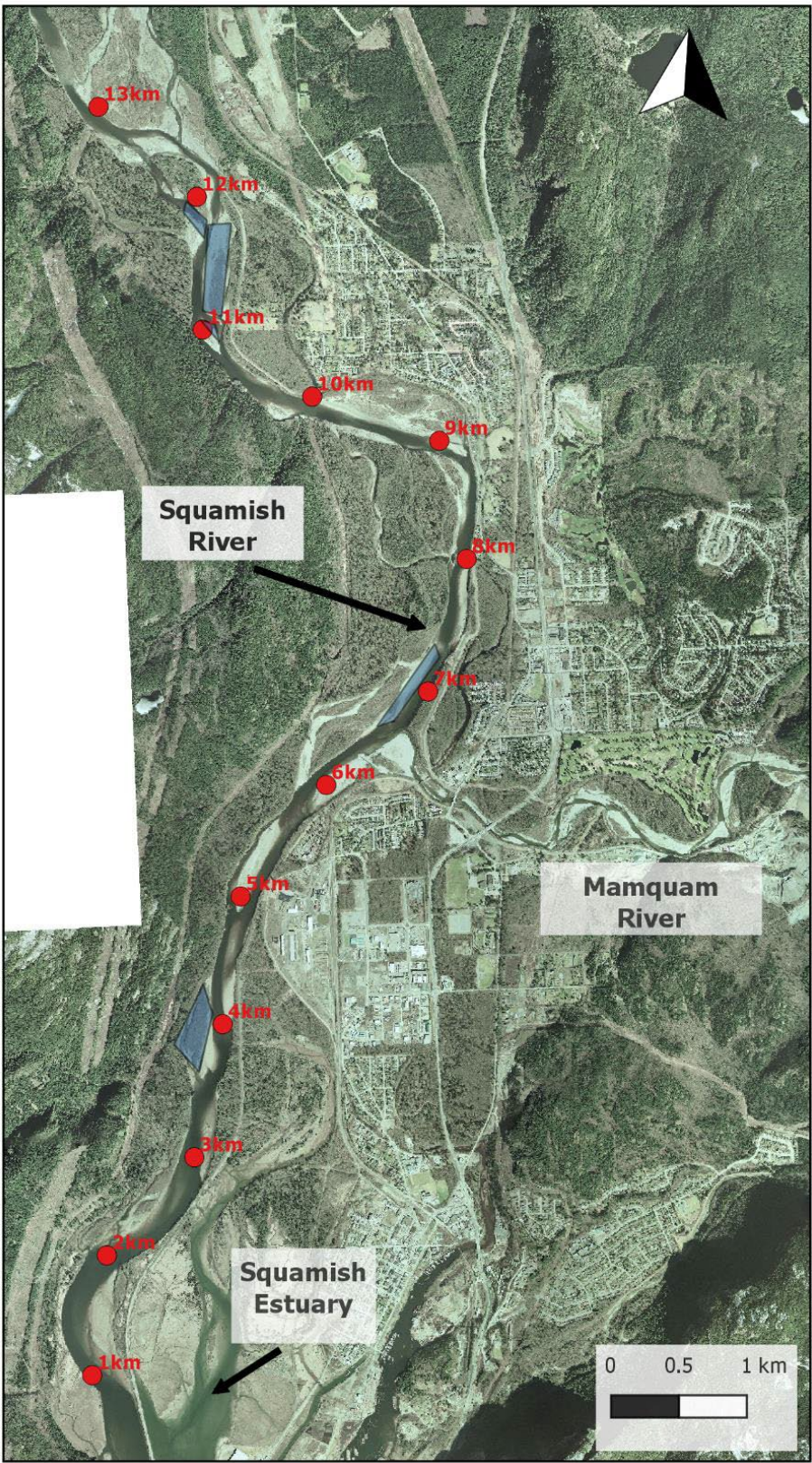


Figure 3. Fish collection locations on Squamish River (blue)

2.2 Biophysical Monitoring

Lake Trail Consulting was hired in 2018 to develop a baseline biophysical program by which to assess changes in the estuary to water quality (dissolved oxygen, pH, salinity / conductivity, and temperature), sediment transport, invertebrate assemblages, and changes in vegetation in association with Phases 1, 2, and 3 (culvert upgrades along the Training Berm and future Spit realignment, and water flow upgrades into Bridge Pond). They were able to implement the program in the summer of 2018 and repeat the methodology with additional monitoring stations in 2019 following the replacement of the box culvert.

Biophysical monitoring was an important component of the project as it provides a measure by which to evaluate the success of the restoration efforts to meet the project goal of improving fish accessibility to the Squamish estuary from the Squamish River and associated habitat improvements.

2.3 Modelling Scenarios: Wave and Spit Removal

In order to better understand potential impacts associated with the removal or realignment of the Spit as part of Phase 2 of the project, SNC Lavalin was engaged to undertake two modelling scenarios this year which included: “Wave Impact Assessment” and “Squamish Training Berm Removal”. The objective of these modelling exercises was to provide information by which to assess what, if any, impacts the realignment or removal of the Spit would have on flood impacts on the downtown, sediment accumulation that could affect operations of the Squamish Terminals, and other potential adverse effects.

2.4 Engaging with the Community, Government, and Stakeholders

The development of the Central Estuary Restoration Project is the result of over a decade of discussion and planning with the community and project partners (Squamish Nation and Fisheries and Oceans Canada). The goal of this year was to meet with the stakeholders and various parties to provide updates on the progress of the various phases of the project and to hold workshops and meetings to further along Phase 2: Spit Realignment. To this end, several meetings, workshops, media releases, and web blogs were held or posted throughout the year. The project partners, Fisheries and Oceans Canada and Squamish Nation, were central to all these meetings and workshops and engaged at all levels of discussion.

2.5 Educational Outreach Programming

The goal and objective of the educational program for this year was to provide fun and innovative experiential learning opportunities to students and the community to learn about the work the SRWS was undertaking and to engage in activities associated with the CERP.

Several events were held over the course of the year including Rivers Day (September 22, 2019). The theme of 2019 was “Year of the Salmon” and the SRWS partook in numerous guided tours and events that helped to celebrate salmon. Students and community were invited to help plant up the riparian zone at the newly replaced culvert at Location #3.

2.6 Riparian Planting

The goal of planting riparian vegetation in the areas disturbed from the culvert replacement at Location #3 and the cleaning out of the upper culverts at Locations #1 and #2 was to stabilize the embankments, prevent the spread of invasive plants, discourage public access on newly exposed areas, and to replace any disturbed vegetation. Approximately 875 native trees and shrubs were reestablished at these locations and included over 25 hours of volunteer time and support.

2.7 Armouring of River Intake at Culvert #3 and Maintenance of Upper Culverts

The goal was to clean out the upper two culverts at Locations #1 and #2 and restore fish access across these culverts to improve overall water flows between the Squamish River and the Crescent Slough (upper estuary). Over the winter months several storms resulted in an accumulation of woody debris that plugged up the trash racks and the culverts themselves. Maintenance and cleaning out these culverts occur every three to seven years on average, although the culvert at Location #2 has only had to be cleaned out once before in the 20 years since it was installed. The two upper culverts may be the location of potential upgrades with either arch culverts or larger box culverts as a continuation of Phase 1.

The goal of adding additional armour to the river side of the newly upgraded box culvert at Location #3 was to stabilize the banks and prevent erosion. There was an excess of rock left over from the installation of the culvert and the probability of erosion was considered significant. The additional rock is intended reduce future maintenance at this location.

3.0 Study Area

The Squamish Training Dike is a 5 km structure that extends from the confluence of the Mamquam River downstream to Howe Sound and confines the Squamish River to the western bank. The focus of this phase of the project was to improve fish passage across Culvert #3 located at latitude 49.707275 longitude -123.170656 (Figure 1).

4.0 Methods

The focus of the year was to continue monitoring the changes and improvements along the river and estuary following the replacement of the culvert at location #3 (Figure 2) and to undertake any additional modelling as required.

4.1 Fisheries Monitoring¹

A total of 982 PIT tags were implanted into both wild and hatchery origin Chinook salmon juveniles captured in-river. As well, 100 acoustic tags were implanted into wild and hatchery raised juvenile Chinook salmon. Acoustic receivers were installed in both the Squamish River and at various locations within the estuary. PIT antennas were also installed in the new box culvert and in a channel connecting the two northern culverts to the Central Estuary.

The program was delayed by the construction of the culvert in early May 2019, resulting in a shorter monitoring season.

Additional areas were also fished to collect baseline species assemblage data along Pretty Slough, Bridge Pond, and Cattermole Slough (Figure 2) through the use of Gee trapping.

For a detailed summary of the fisheries monitoring methodology, results, and recommendations please refer to the report prepared by InStream Fisheries “Squamish River Central Estuary Restoration Effectiveness Monitoring; Implementation Year 2019” (IFR 2020).

4.2 Biophysical Monitoring²

Monitoring of water quality and biophysical components in the estuary was for carried out during the two-year period from 2018 to 2019 to establish a baseline of habitat conditions for Chinook salmon and a post culvert upgrade study. Metrics on water quality, sediment dynamics, vegetation, soils, and channel morphology were collected to reflect the current status of fish habitat in the estuary and to capture changes associated with the restoration works.

4.2.1 Water quality monitoring methodology

1. Conductivity

- Type: automatic using a conductivity logger
- Objective: To detect changes in the physico-chemical environment as a result of restoration activities.
- Rationale: Conductivity can be used to evaluate the degree of mixing of freshwater and salt water that is expected to increase as a result of restoration.

2. Dissolved Oxygen

- Type: Instantaneous measures taken manually with a YSI meter
- Objective: To detect changes in the physio-chemical environment as a result of restoration activities.

¹ Cook, K., et.al. “Squamish River Central Estuary Restoration Effectiveness Monitoring; Implementation Year #1 (2019)”. October 15, 2019.

² Tryon, L., Alyssa Togado. “Central Estuary Monitoring Program: 2018 – 2019 Interim Report” March 31, 2020.

- Rationale: This will evaluate if restoration activities prolong the duration of acceptable DO levels for Chinook rearing during the summer period
3. Temperature
- Type: automatic with tidbit loggers and level loggers
 - Type: Instantaneous when D.O. measures collected
 - Objective: To detect changes in the physio-chemical environment as a result of restoration activities.
 - Rationale: This will evaluate if improved mixing from restoration will prolong the duration of acceptable temperatures for Chinook rearing during the summer period
4. Nutrients
- Type: Water sample sent in for laboratory analysis (Phosphorus and Nitrogen)
 - Objective: To detect changes in the physio-chemical environment as a result of restoration activities.
 - Rationale: Nutrients in estuaries are important for production and are often cited as a key factor in supporting critical life stages for salmon. However, studies indicated the Squamish estuary in poor in nutrients. Monitoring dissolved phosphorus, nitrogen and will evaluate if improved mixing from restoration actions will result in nutrient concentrations beneficial for salmon productivity.

4.2.2 Physical Habitat (flows, channel dimensions)

Monitoring of physical habitat for critical estuarine life stages of Chinook salmon (smolting and upstream migration) to include:

1. Tidal channel dimensions
 - Type: Rod and level survey of channel dimensions prior to and following restoration activities.
 - Objective: To detect changes in the physical environment as a result of restoration activities.
 - Rationale: This will evaluate if restoration activities result in improvements (e.g. increased pools) or degradations (increased widening, decreased pools) in tidal channel morphology as it relates to chinook salmon habitat.
2. Flows through channels and culverts
 - Type: Direct measurements of water flow velocities through culverts and tidal channels using a flow meter
 - Type: Indirect measurements of flow velocities through culverts by measuring water depth and relating to culvert dimensions and slope
 - Objective: To assess range in flow velocities against known flow thresholds for critical life stages of Chinook:
 - i. smolting - for culverts and tidal channels
 - ii. adult migration - for culverts only

Table 2: Sites for permanent monitoring stations

Site	Site Name	Location Description	UTM ¹	Water Level	Conductivity	Temperature	Sediment	Channel	Soils	Vegetation
A	River Station	Logger station installed along left bank of Squamish River 600m upstream of Culvert 1	10U 487884 E 5507607 N	X	X					
B	Culvert 1	Monitoring site is ~300m downstream (east side) of culvert 1. Includes logger station in tidal channel, 2 sediment stations in marsh, 2 channel cross sections, and 4 soil/veg transects adjacent to tidal channel	10U 488177 E 5506994 N	X	X	X	X	X	X	X
C	Bailey Street	Area adjacent to Wilson Slough Intake. Logger Station in Crescent Slough adjacent to Bailey Street and 330m downstream (south) of intake. Two sediment stations and one channel cross section station across main channel.	10U 488530 E 5506410 N	X	X	X	X			
D	Culvert 2	No longer a monitoring station - loss of staff gauge. Possible future monitoring.	10U 487895 E 5506375 N							
E	Culvert 3	Area east of Culvert 3. Includes logger station 70m upstream main tidal channel from where culvert 3 tidal channel enters. Logger station removed for winter season and re-set in spring. Also includes 4 sediment stations-2 in marsh (2018 install), 2 in mudflat (2019 install), and one cross section across culvert 3 tidal channel. 4 veg/soil transects perpendicular to and east of Spit road.	10U 487901 E 5505991 N	X	X	X	X	X	X	X
F	Culvert 4	Area east of Culvert 4. Logger station in Culvert 4 pool. Culvert 4 tidal channel has 2 cross-sections and main channel has 1 cross section 70m downstream (south) of culvert 4 tidal channel confluence. Also includes 4 sediment stations-2 in marsh (2018 install), 2 in mudflat (2019 install). One vegetation transect north and perpendicular to C4 tidal channel.	10U 487530 E 5505810 N	X	X	X	X	X	X	X
	Culvert 7	Hobo tidbit loggers installed on either side of culvert	10U 486995 E 5504561 N		X					
	Culvert 9	Hobo tidbit loggers installed on either side of culvert	10U 487038 E 5504352 N		X					
G	Lower Estuary	Logger station installed on a piling complex (dolphin) in lower estuary approximately 500m east of Culvert 8. 4 sediment stations: 2 in marsh (2018 install) and 2 in mudflats (2019 install), all on northeast side of main tidal channel in vicinity of logger station.	10U 487516 E 5504466 N	X	X	X	X		X	
H	Cattermole Slough	Logger station installed June 2019 in Cattermole Slough below stinky pond.	10U 488382 E 5504457 N	X	X	X				

¹ UTM location is central to all stations at monitoring site.

A detailed summary of the methodology deployed can be found in greater detail in the report prepared by Lora Tryon, Lake Trail Environmental Consulting (Tryon 2020).

It is expected with increasing connectivity between the river and the estuary, there will be greater flushing of estuarine habitats and improved water quality within preferred ranges for smolting Chinook salmon. Seven stations, including one in the river and six in the central estuary, were established to monitor temperature with automatic data loggers. Of those stations, six also collect water level data and five collected conductivity data (for calculation of salinity).

Greater periods of marsh inundation and increased area of marsh coverage are also expected to be improved in association with the culvert upgrades as the pathways for sediment to enter the estuary from the river are opened. Sediment, vegetation, and soil surveys will provide a measure by which to monitor changes in marsh communities and coverage, as well as changes in soil carbon and sediment accretion rates. In 2018 and 2019, metrics were collected at 17 sediment stations, 10 vegetation transects, 39 vegetation plots, and 20 soil plots (Figure 4).

Greater flows from the river into the estuary are expected to deepen tidal channels, resulting in more wetted habitat available during low tide periods for Chinook salmon.

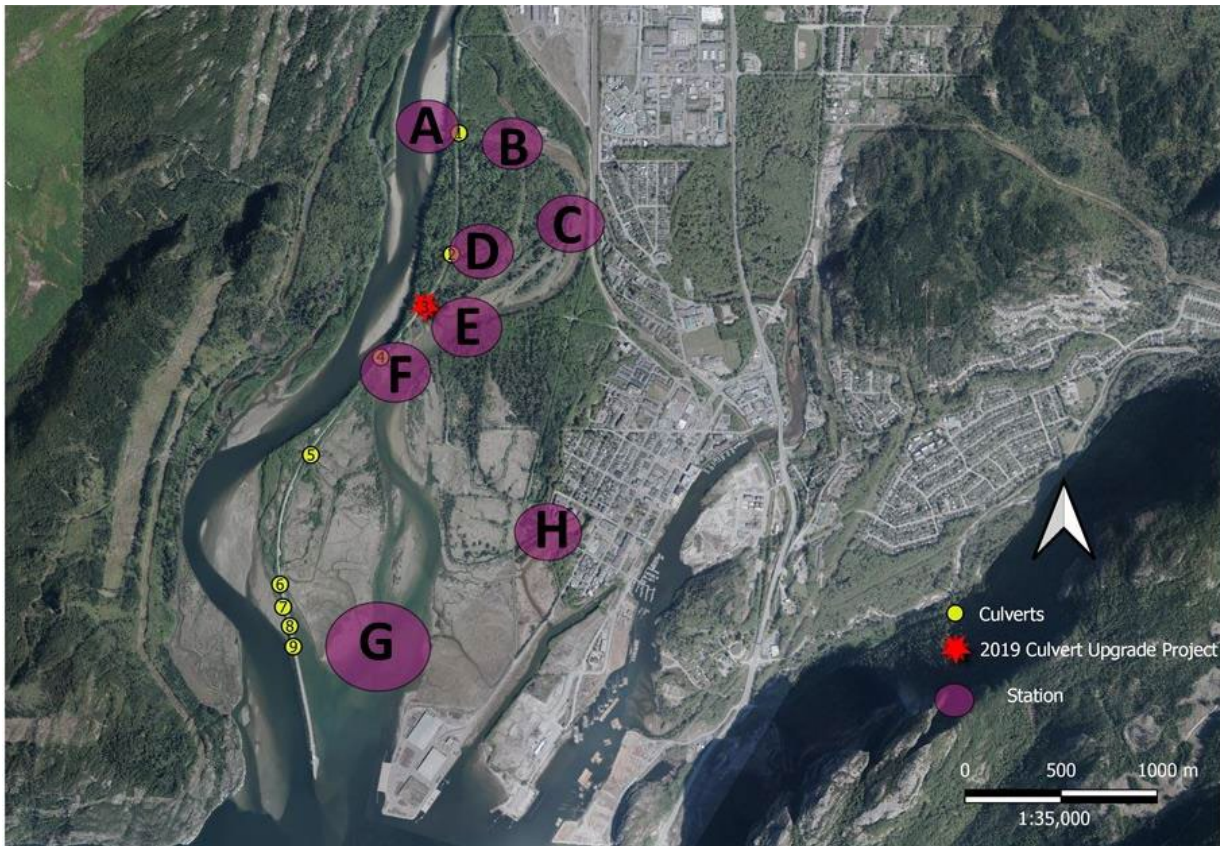


Figure 4. Monitoring Stations Site Locations

4.3 Wave Modelling and Spit Removal Modelling

Additional modelling for the year included: wave modelling to identify how the existing Spit functions and what role, if any, it performs to deflect wave action that could result in flood risk to the downtown; and modelling for the Spit removal. SNC Lavalin was hired to undertake both modelling scenarios and a summary of the methodology can be found in the respective reports: “Squamish Training Berm Realignment Wave Impact Assessment” (SNC-L February 2020) and the draft report “Squamish Training Berm Removal Progress Report” (SNC-L June 2020).

4.4 Engagement with the Public, Stakeholders, and Community

Numerous meetings were held throughout the year, along with stakeholder workshops, blog postings, and media releases.

4.4.1 Meetings

- December 18, 2019: DOS – SWS Interim Access Engagement Plan (District of Squamish)
- January 31, 2020: Windsports Access Interim Options Workshop, Meeting Summary Report (District of Squamish)
- February 26, 2020: Squamish Training Berm Realignment Wave Impact Assessment (SNC-Lavalin)
- February 28, 2020: Facilitated Stakeholder Workshop (CERP Stakeholder Meeting #3 appended)
- March 4, 2020: Squamish Training Berm Realignment Technical Proposal (WSP)
- March 31, 2020: Central Estuary Monitoring Program 2018-2019 Interim Report (Lake Trail)
- March 31, 2020: Squamish River Central Estuary Restoration Effectiveness Monitoring (InStream)

4.4.2 Media Releases

- March 13, 2020: District of Squamish weekly newsletter:
<https://squamish.ca/yourgovernment/news/collaborative-effort-to-achieve-long-term-balance-of-environmental-economic-and-recreation-interests-in-the-squamish-estuary-and-spit-is-underway/>
- March 18, 2020: Salmon News

4.5 Education Outreach Programming

Several programs were held throughout the year in celebration of the 2019 “Year of the Salmon” with a focus on the work being undertaken as part of the CERP. Over 25 students and a dozen volunteers came out to help with the riparian planting and keeping the newly planted sites watered and cared for. Events, such as Rivers Day, helped to raise awareness in the community on the importance of estuary restoration and provided an opportunity for the community to learn more about this exciting project and the plans for the coming year.



Rivers Day Poster



Matt Foy leading Year of the Salmon tour, Dec 2019



Wild for Salmon Outreach program, May 2019

4.6 Riparian Planting

Over 800 native riparian plants were established around Culvert #3. Much of the planting took place in September 2019 with the assistance of volunteer support from the BC Institute of Technology Ecological Restoration program. An additional 75 native riparian vegetation were planted around Culvert #2 in April 2020 following the cleaning out of woody debris buildup.

The estuary facing east slope of Culvert #3 was predominantly planted up with sword fern and a mix of various riparian plants were placed along the disturbed areas on the west side (river facing) of Culvert #3.

Table 3: Riparian Species Planted at Culverts #2 & #3

Plant Description for Culverts #2 & #3			
<u>Plant Name</u>	<u>Common Name</u>	<u># plants</u>	<u>size</u>
<i>Cornus stolonifera</i>	Red osier dogwood	25	1 gal pots
<i>Mahonia nervosa</i>	Dull Oregon grape	100	1 gal pots
<i>Myrica gale</i>	Sweet gale	50	1 gal pots
<i>Polystichum munitum</i>	Sword ferns	300	1 gal pots
<i>Rosa nutkana</i>	Nootka rose	25	1 gal pots
<i>Rubus parviflorum</i>	Thimbleberry	100	1 gal pots
<i>Rubus spectabilis</i>	Salmonberry	100	1 gal pots
<i>Salix sitchensis</i>	Sitka willow	25	1 gal pots
<i>Spirea douglasii</i>	Purple spirea/hardhack	100	1 gal pots
<i>Thuja plicata</i>	Western red cedar	50	1 gal pots
Total		875	

4.7 Armouring of River Intake at Culvert #3 and Culvert Maintenance

In October 2019, the extra stockpile of armour rock left over from the installation of the box culvert at Location #3 was placed along the river intake channel to stabilize the banks and prevent future erosion. The equipment used for this work included two 300 series excavators (one excavator used to load the rock into the truck and the other to place the rock material) along with a rock truck provided by John Hunter and Company. Each piece of armour rock was carefully placed into the embankment in a layered manner that would be able to withstand storm events or large woody debris collisions. The work took place over a 9-day period.

During low flow conditions in May 2020 a 300 series excavator was used (John Hunter and Company) to physically remove woody debris build up along the trash racks and plugged up the culverts at Locations #1 and #2. The river intake channels were also deepened out to the Squamish River, and sediment was removed and side cast along the embankment to restore unobstructed river flows through to the culverts. The work took place over three days and was restricted to low-tide periods on each day. The temporary access road was blocked off (in order to prevent pedestrian access) and planted up with native riparian vegetation. Additional signage is intended to be placed at each of the two culverts to acknowledge funding support and provide information on the purpose of the culverts and their importance in conveying water and fish passage between the Squamish River and the Crescent Slough (upper estuary).

The outcomes of adding the additional armour rock at Culvert #3 resulted in stabilizing 250 square metres of habitat. The outcomes of cleaning out woody debris build up at Culverts #1 and #2 resulted in restoring 250 linear meters of channel flows and over 700 square meters of habitat for the passage of salmonids between the Squamish River and the upper estuary.

5.0 Results and Outcomes

The outcomes for this fiscal year varied from the original plans due to the need for additional studies and community engagement. The plans to move forward with Phase 2 still need more details worked out but in the interim the focus for the coming field season will be to replace a second culvert (Location #4) as part of Phase 1 and develop detailed engineering plans and surveys to install an intake structure across the CN Spur Line (Phase 3). The outcomes from the year included meetings, reports, engineering and hydraulic modelling, educational programming, and ongoing networking and outreach.

5.1 Fisheries Monitoring³

Telemetry data from the PIT antennas installed in the new box culvert and at various locations in the central estuary (Figure 5) showed seven juvenile Chinook salmon passed through the new box culvert at Location #3. Another thirteen of the 100 fish implanted with acoustic tags, and two PIT-tagged fish (one wild and one hatchery) were also observed to have accessed the estuary, presumably by migrating around the Spit (IFR 2019).

Tagged hatchery fish accessing the estuary were detected for several weeks making use of the estuary, confirming the use and importance of the estuary for juvenile Chinook salmon. The remaining 86% of the hatchery Chinook salmon implanted with acoustic tags were never detected on receivers in the estuary and were assumed to have migrated directly into Howe Sound. There was no way to determine the survival of either the juvenile salmonids that had a residency time in the estuary versus those that migrated directly into Howe Sound.

Use of estuarine habitat was also assessed through a capture program in the estuary using seine nets and traps. The goal was to recapture tagged fish and to provide a coarse assessment of distributions of salmonids. Juvenile Chinook salmon were primarily captured in the southern portions of the estuary and no PIT tagged fish were recaptured⁴. Additionally, specific areas of interest for future restoration activities (Pretty Slough, Bridge Pond, and Cattermole Slough) were also fished to collect baseline species assemblage data. The result of this additional trapping was salmonids were only observed in Cattermole Slough. These results, combined with previous years of capture data from the estuary, suggested that improvements to estuarine habitat access are still needed. However,

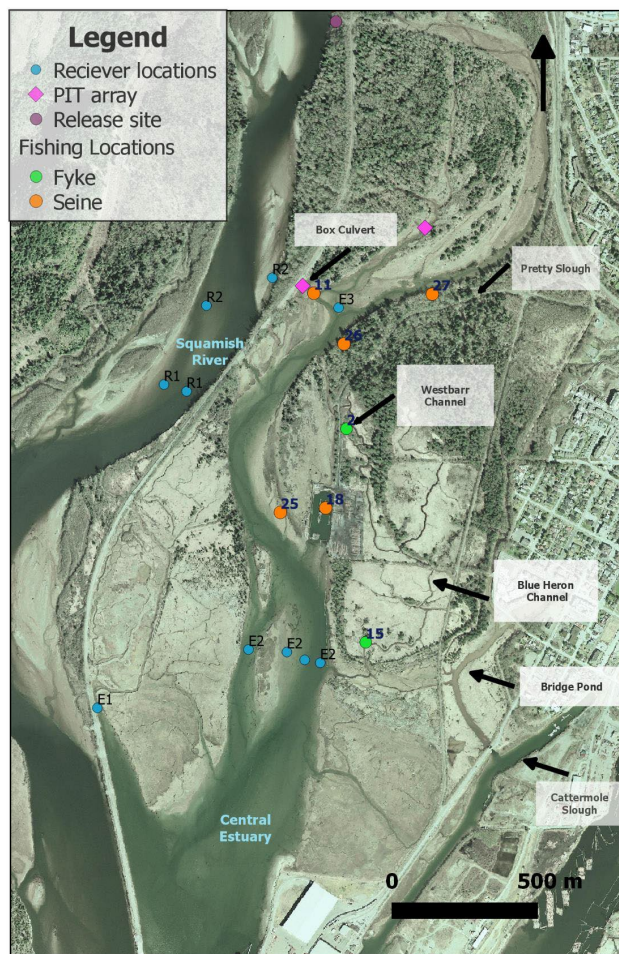


Figure 5: Map of CERP fisheries monitoring project locations

³ Cook, K., et.al. "Squamish River Central Estuary Restoration Effectiveness Monitoring; Implementation Year #1 (2019)". October 15, 2019.

⁴ It should be noted that the field season only started at the end of May 2019, after the culvert upgrade had been completed, which was likely the cause of no PIT tagged fish being captured.

it should be noted that less fishing effort was allotted to the estuary in the 2019 field season relative to the effort dedicated to the Squamish River around the culverts.

The results from the 2019 field program were inherently biased due to delays in the culvert construction (delayed from March to May due to the change in plans from designing of a bridge to a box culvert). It should also be noted that most of the fish tagged were hatchery raised fish which may be more motivated to migrate directly to marine environments than wild fish. As such, the recommendation for the 2020 field season is to tag wild fish at the start of the migratory season in early March.

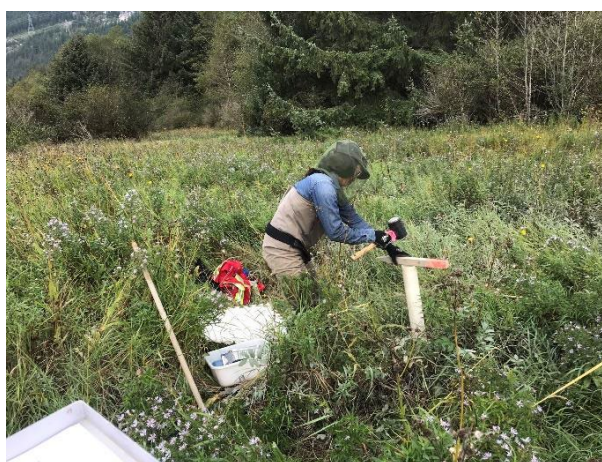
Overall, the 2019 monitoring program indicated the installation of the box culvert was a successful step in restoration activities to improve fish passage along the Squamish River into the estuary.

5.2 Biophysical Monitoring⁵

Monitoring stations were established at several locations throughout the estuary to capture various parameters. These parameters included the deployment of temperature loggers at 7 sites and conductivity loggers at 5 sites (Figure 4). To study physical habitat, 6 tidal channel cross sections were surveyed at 4 sites (Figure 4). Six level loggers were deployed along the Squamish River and the central estuary to establish tidal variations. In order to study sediment dynamics, a total of 17 sediment stations were established at 5 locations. To assess vegetation and soils, a total of 10 vegetation transects, and 39 vegetation plots were established, along with 20 soil plots. Invertebrate populations were studied at several locations with the use of Hester Dendy's. A total of 23 photo-points were established to study changes in vegetation. The summary results of these monitoring stations are still being assembled and will be shared in a later report.

Some preliminary findings from comparing the baseline monitoring undertaken in 2018 and 2019 (pre culvert replacement) and contrasted with the post culvert upgrade suggest that greater flows from the river into the estuary are expected to deepen tidal channels resulting in more wetted habitat available during low tide periods for Chinook salmon. Furthermore, greater periods of marsh inundation and increased area of marsh coverage are also expected to be improved upon as a result of the culvert upgrades which will provide pathways for sediment to enter the estuary from the river. Monitoring the changes in sediment, vegetation, and soil through surveys will help to determine the extent which marsh communities and coverage, as well as change in soil carbon and sediment accretion rates, are improved upon by the culvert upgrades along with the resultant improvements for outmigrating juvenile Chinook salmon.

⁵ Tryon, L., Alyssa Togado. "Central Estuary Monitoring Program: 2018 – 2019 Interim Report" March 31, 2020.



Photos of various monitoring and surveying. Upper left: station on estuary side of Culvert #4. Upper right: station at southern end of Crescent Slough downstream of Culvert #2. Lower left: Alyssa Togado measures vegetation growth. Lower right: Lora Tryon installing biophysical station

6.0 Discussion

This project has been developed in partnership with Fisheries and Oceans Canada and Squamish Nation and is of importance to improve the overall health of Chinook salmon stocks and restore the estuary to previous pre-development conditions. Support has also been recognized from the local sports fish advisory board, recreation fishing groups, Ministry of Forests, Lands, and Natural Resource Operations, and other community stewards. Squamish Nation manages portions within the estuary, Site “A”, adjacent to the Bridge Pond, that will directly benefit from improved water quality and tidal flows resulting from this project. This in turn will add to Squamish Nation’s ability to harvest local salmonids, as well as provide educational programming. The project allows for engagement with local universities, technical institutes, and local schools in hands-on experiential learning opportunities including tree planting, mapping, monitoring, and the development of long-term post-graduate research

studies. In addition to allowing community and student engagement, the SRWS has been able to sponsor a University of British Columbia Master's student to study Chinook salmon behaviour associated with the restoration efforts. Students from School District #48 regularly participate in special events, programs, and activities directly associated to this project including studying wildlife and fish movement, planting native riparian vegetation, undertaking tree and bird surveys, and learning about the natural habitat and environment (for more on these programs check our website: <https://www.squamishwatershed.com/outreach-program.html>).

The project restoration completed in the 2019 field season was published in the Fall 2019 issue of the Canadian Society of Environmental Biologists⁶ (CSEB 2019).

7.0 Recommendations

There were numerous challenges to face in the 2019/2020 fiscal year regarding strategic planning and modelling requirements. The better part of the fall of 2019 was spent in discussions between the project partners (SRWS, DFO, and Squamish Nation) and the Squamish Windsports Society (SWS), the District of Squamish (DOS), and the Squamish Terminals around Phase 2 Spit realignment. The DOS required modelling of wind impacts and Spit removal to better understand if any modifications to the Spit would impact flood levels or sediment accretion issues, the result of which SNC-L was engaged to provide two engineering modelling reports: "Squamish Training Berm Realignment Wave Impact Assessment" (SNC-L February 2020) and the "Squamish Training Berm Realignment Model Progress Report" (SNC-L June 2020). The District of Squamish flood gauges at the Third Avenue flood gate (which would have provided valuable information on tidal flows for Phase 3 of the project to install flow control structures across the CN Spur Line) were not in operation, resulting in the SRWS having to set up level-loggers and monitoring stations on either side of the CN Spur Line.

While the year was extremely important in moving the project forward, the intended work on Phase 2 had to be deferred for a later date and remains indefinite as the scope of the realignment of the Spit needs to include alternate access for the SWS, which is beyond the ability of the SRWS to achieve alone. Physical works for this year were refocused on providing additional armour stabilizing along the river intake at Culvert #3 and the maintenance of Culverts #1 and #2 that were blocked with woody debris buildup. The plans moving forward for the 2020 field season are to focus on additional culvert upgrades as part of Phase 1 of the project while continuing to have discussion and planning for Phase 2: Spit Realignment and Phase 3: Bridge Pond Rewatering.

⁶ CSEB Fall 2019 issue: https://cseb-scbe.org/wpmarine/wp-content/uploads/2019/11/CSEB_Vol76-3-Fall-2019-Email-Final.pdf

8.0 Acknowledgement

We would like to thank our project partners Fisheries and Oceans Canada and Squamish Nation and Fish and Wildlife Compensation Program for funding and supporting this project.

Project Team:

- Edith Tobe, Project Manager, Squamish River Watershed Society
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- Dave Nanson, Restoration Biologist, Fisheries and Oceans Canada
- Murray Manson, Fisheries Protection Biologist, Fisheries and Oceans Canada
- Katrina Cook, Stephanie Lingard, and Cole Martin, InStream Fisheries Research Inc
- Lora Tryon, Lake Trail Environmental Consulting

We would also like to take this time to thank:

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- Mayor Karen Elliot & Councillor Doug Race, District of Squamish
- Kim Stegman, Paul Morris, Emma Jarret, Squamish Terminals
- DOS engineering department
- Judith Cullington, JCA and Associates
- Squamish Windsports Society
- Squamish Environment Society, and
- Squamish Streamkeepers

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10.0 Photos
Culvert #1 Clean-up

Before



After



Facing twin culverts from west side of Training Berm (river side): note build up on left photo



Trash rack at river confluence; note build-up of sediment and woody debris before then after



Clean-out of intake channel at river; note build-up before and clean-up after

Culvert #2 Clean-up



Facing upstream towards Squamish River from Training Berm

Culvert #3



Facing east from river side towards Training Berm



March 15, 2020. Facing west from Training Berm (towards Squamish River intake); note placement of additional rip rap along banks leading towards river to provide erosion protection

September 21, 2019 volunteer support with riparian planting from BCIT Ecological Restoration program:





Students from BCIT ER program after a full afternoon of planting riparian vegetation



Signage warning water sport users to use caution if moving through culvert (signage installed at both sides of the culvert)



Information signage on kiosk/bench

CENTRAL ESTUARY RESTORATION PROJECT

2019 Culvert Upgrade Site

Restoring fish access and habitat for juvenile
salmon in the Squamish River Estuary.



In partnership with Squamish Nation and
Fisheries and Oceans Canada.

Funding support from:



Fisheries and Oceans
Canada

Pêches et Océans
Canada



Detail of signage

Squamish River Central Estuary Restoration Effectiveness Monitoring

Implementation Year 1 (2019)

Reference: SQUAMISH ESTUARY

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Executive Summary

A new box culvert was installed in a training berm that divides the Squamish River and its estuary in May 2019 as part of the Central Estuary Restoration Project (CERP). To evaluate success of the box culvert in terms of fish passage and gather baseline data for future CERP activities, movement of juvenile Chinook Salmon in the Squamish River and the Squamish River Estuary was monitored using both Passive Integrated Transponder (PIT) and acoustic telemetry. The research aimed to understand if CERP restoration activities improve habitat access for juvenile Chinook Salmon and how they may impact species richness of specific habitats of interest.

Fish collected from the Tenderfoot Creek Hatchery were implanted with acoustic tags ($n = 100$) and released at river kilometer 3 of the Squamish River to determine if and how fish access the estuary, or if they go directly to Howe Sound (i.e., do not use the estuary). A total of 982 PIT tags were also implanted into both wild and hatchery origin Chinook Salmon juveniles captured in-river. Acoustic receivers were installed in both the Squamish River and at various locations within the estuary. PIT antennas were installed in the new box culvert and in a channel connecting two northern culverts to the Central Estuary. Telemetry data shows that seven juvenile Chinook Salmon passed through the box culvert. Another 13 of the 100 fish implanted with acoustic tags and two PIT-tagged fish (one wild and one hatchery) accessed the estuary, presumably by migrating around the spit and into the estuary from Howe Sound. Tagged hatchery fish accessing the estuary were detected using estuarine habitat for up to several weeks, emphasizing the importance of estuaries even for larger hatchery fish. The remaining 86% of hatchery Chinook implanted with acoustic tags were never detected on receivers in the estuary and are assumed to have migrated directly into Howe Sound and not used any estuarine habitat.

Use of estuarine habitat was also assessed through a capture program in the estuary using seine nets and traps. The goal was to recapture tagged fish, and to provide a coarse assessment of distributions of salmonids. Chinook Salmon were primarily captured in southern portions of the estuary and no PIT tagged fish were recaptured. Additionally, specific areas of interest for future restoration activities (i.e., Pretty Slough, Bridge Pond and Cattermole Slough) were fished to collect baseline species assemblage data; salmonids were only encountered in Cattermole Slough. These results, combined with previous years of capture data from the estuary, suggest that improvements to estuarine habitat access are still needed. However, less fishing effort was allotted to the estuary in this initial year of research relative to that dedicated to the Squamish River. We propose to increase and strategically structure estuary fishing efforts in future years to improve recapture probability and knowledge of fish distributions.

Results from this first year of research are inherently biased due to delays in culvert construction and because hatchery fish were used for most tagging. Hatchery fish may be more motivated to migrate directly to marine environments than wild fish, and fish may also be less attracted to estuarine habitat later in the Spring. To increase relevancy of results to wild Chinook populations, we propose to tag wild fish starting at the beginning of the migration period in 2020.

Overall the 2019 monitoring program indicated the installation of the box culvert was a successful step in restoration activities to improving fish passage in the Squamish River Estuary, but most fish still migrated directly to Howe Sound and were not able to access estuarine habitat. Additional restoration efforts are still needed to improve fish passage between the Squamish River and its estuary.

Introduction

The Squamish River is a glacial, salmon bearing watershed on the south coast of British Columbia, located within the traditional territory of the Squamish First Nation. The Squamish Nation harvests salmon in the Squamish River and its tributaries for food, social and ceremonial purposes and the watershed also provides opportunities for commercial anglers, raft guiding outfitters and recreation.

Chinook Salmon (*Oncorhynchus tshawytscha*) populations have been in decline along the Pacific coast since the 1980's (Slaney et al. 1996; Heard et al. 2007). Although data are sparse for Squamish River Chinook Salmon, recent research suggests the population is also in decline. Monitoring of juvenile Chinook Salmon abundance on the Cheakamus River for BC Hydro was conducted between 2000 and 2018 as part of a water use planning process. Fry abundance estimates resulting from that research ranged from 137,000 to 800,000 between 2000 and 2013 and from 16,000 to 114,000 between 2014 and 2018 (Lingard et al. 2018). Coast-wide declines in Chinook Salmon abundance have been attributed to poor ocean survival, overharvest and habitat losses (Slaney et al. 1996; Walters and Martel 2004; Heard et al. 2007; Beamish et al. 2012). In the Squamish River, salmon populations may also be impacted by these regional stressors as well as local stressors including loss in estuarine habitat, a major flood in 2003, and a caustic soda spill in 2005 in the Cheakamus River, a tributary of the Squamish River (McCubbing et al. 2005).

Estuarine habitats are important transition zones for both the juvenile and adult stages of their life history and juvenile Chinook Salmon use estuaries to a greater extent than other species of salmon (Sibert 1975; Levy and Northcote 1982; Levings et al. 1991; Korman et al. 1997; Bottom et al. 2005; Hering et al. 2010; Moore et al. 2016). Estuarine access and the quality and quantity of estuarine habitat in the Squamish River has been significantly reduced by both industrial and urban development. Of specific concern is a training berm that separates the Squamish River from its estuary. Installed in the 1970s to accommodate a coal port that was never realized, the training berm restricts the river to the west bank. Beginning in the mid-1990's, restoration work began on the estuary through the Squamish River Watershed Society (SRWS) in partnership with Squamish Nation, Fisheries and Oceans Canada (DFO) and the Province of British Columbia. Restoration projects in the estuary have included removing dredge spoils and contaminated soils, re-grading and vegetating areas to form tidal marshes and natural flood-plain habitats, and construction of tidal channels and culverts in the training berm. The construction of ten culverts began in the early 2000's to enable the passage of river water and fish into the estuary. However, monitoring of these culverts in 2018 revealed that they do not provide adequate fish access to the Squamish River estuary (Lingard et al. 2018).

In response to these findings, SRWS started the Central Estuary Restoration Project (CERP) in partnership with Squamish Nation and DFO. CERP is focused on reconnecting and restoring habitat to support the outmigration of Pacific salmon, particularly rearing juvenile Chinook Salmon. The goal of CERP is to improve rearing conditions for juvenile salmonids in the Squamish estuary by: 1) upgrading existing culverts in the training berm to improve fish access; 2) modifying the lower section of the training berm to reconnect the lower estuary; and 3) installing a flow control device under the CN rail spur to re-water historical channels.

These actions align with three distinct phases of CERP. Phase 1 was implemented in 2019 with the replacement of twinned 3-foot culverts with a three-meter box culvert. Phases 2 & 3 are currently in the planning phase. InStream Fisheries Research (IFR) was contracted by SRWS to assess the effectiveness of Phase 1 by monitoring passage of juvenile Chinook Salmon through the new box culvert. This report summarizes these results and further provides an assessment of movements patterns and presence of juvenile Chinook Salmon in the Squamish River and its estuary. Two management questions guided the monitoring program:

1. Are CERP restoration activities improving habitat access for juvenile Chinook Salmon?
2. Does improving water quality in Pretty Slough and Bridge Pond through CERP restoration activities alter species richness of these habitats?

Methods

To monitor movements of juvenile Chinook Salmon between the Squamish River and the estuary, tagging and tracking technologies (i.e., telemetry) were used in addition to surveys for fish presence in specific estuary habitats.

Study Site

The Squamish River watershed, located in the Coastal Mountain range of southern British Columbia, covers an area of 3650 km². The Squamish River is the largest tributary of Howe Sound and forms the northern terminus of the glacial fjord. The Squamish River watershed has four main tributaries (Mamquam, Cheakamus, Ashlu and Elaho Rivers) and is home to nine species of Pacific salmon (Chinook, Coho, Chum, Sockeye, and Pink Salmon) and trout (Dolly Varden, Cutthroat, Rainbow/Steelhead and Bull trout).

The Squamish River is bound by a training berm on its eastern bank beginning at the confluence of Howe Sound (river kilometer [rk] 0) that separates the river from its historical estuarine flood plain between rk 0 and rk 4. The width of the river channel along the training berm varies between 200 and 500 m. Ten culverts of approximately 1.2-meter diameter in the berm connect the river to the estuary which are numbered in ascending numerical order from north to south. At culverts 1, 2 and 5, side channels lead to and from the training berm on both the river and estuary sides of the road. At culverts 3 and 4 the central estuary channel butts directly against the training berm. At culverts 6 through 10 the structures connect the deep Squamish River channel to a short channel on the estuary side of the berm, but it is not well connected to the central estuary and most estuarine habitat. Culvert 3 was selected for upgrade to a larger box culvert.

Monitoring activities covered a large area and encompassed all areas of interest identified by SRWS (Figure 1). For the telemetry component, fish implanted with PIT and acoustic tags were detected at key locations by PIT arrays and acoustic receivers, respectively. All hatchery fish were released upstream of the box culvert in the Squamish River, while wild-caught fish were released at their capture location. Fish presence in the estuary was also determined by seine netting and various types of trapping throughout the Central Estuary.

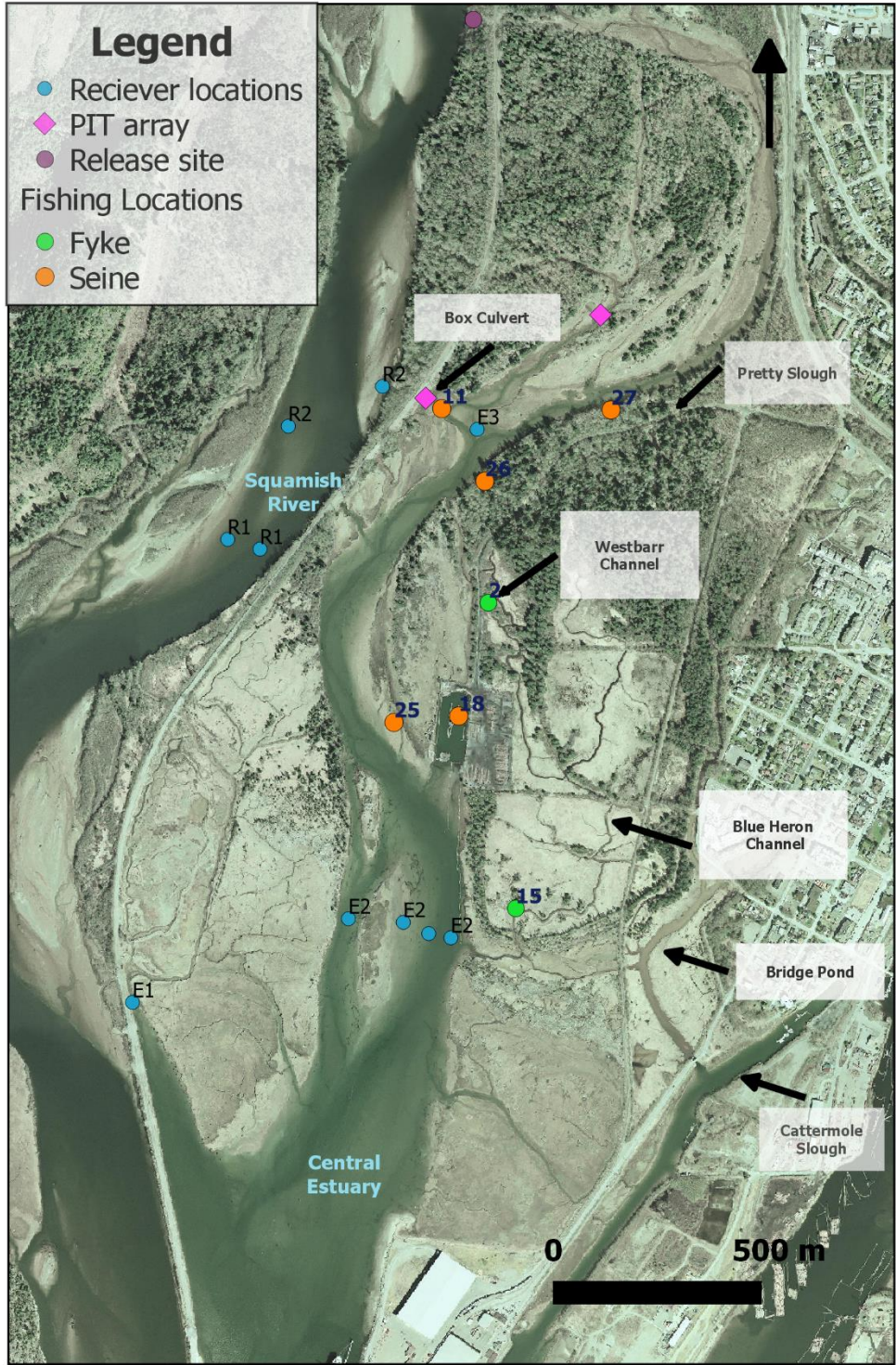


Figure 1. Map of CERP monitoring project locations including: acoustic receiver locations, PIT arrays, fishing sites within the Squamish River estuary and the release location for tagged hatchery fish.

Hydrological conditions within the Squamish River and Estuary are highly dependent on river discharge and tidal cycles. The Squamish River typically experiences low discharge periods in both winter and late summer/early fall, and high discharge periods in spring and late fall. High discharge events in the spring result from a combination of snow melt and storm events, while high discharge events in fall are generally due to storm events. Squamish River discharge values were obtained from the Environment Canada gauge at Brackendale (08GA022) and tidal times and heights from location #7811 (Howe Sound, Squamish) from DFO. The study period ranged from May 15, when the first fish were tagged, to June 20, when the last tagged fish was detected. Discharge showed regular diurnal cycles and ranged from 183 to 644 m³/s. Water levels dropped with a hot dry spell in early June but increased again after a rain event (Figure 2). Tide heights ranged from 0.3 to 4.9 m; large tidal cycles were observed in late May and early June (Figure 2). Other environmental and water quality variables such as temperature and water levels within the estuary were monitored by Laketrail Environmental and are not included in this report.

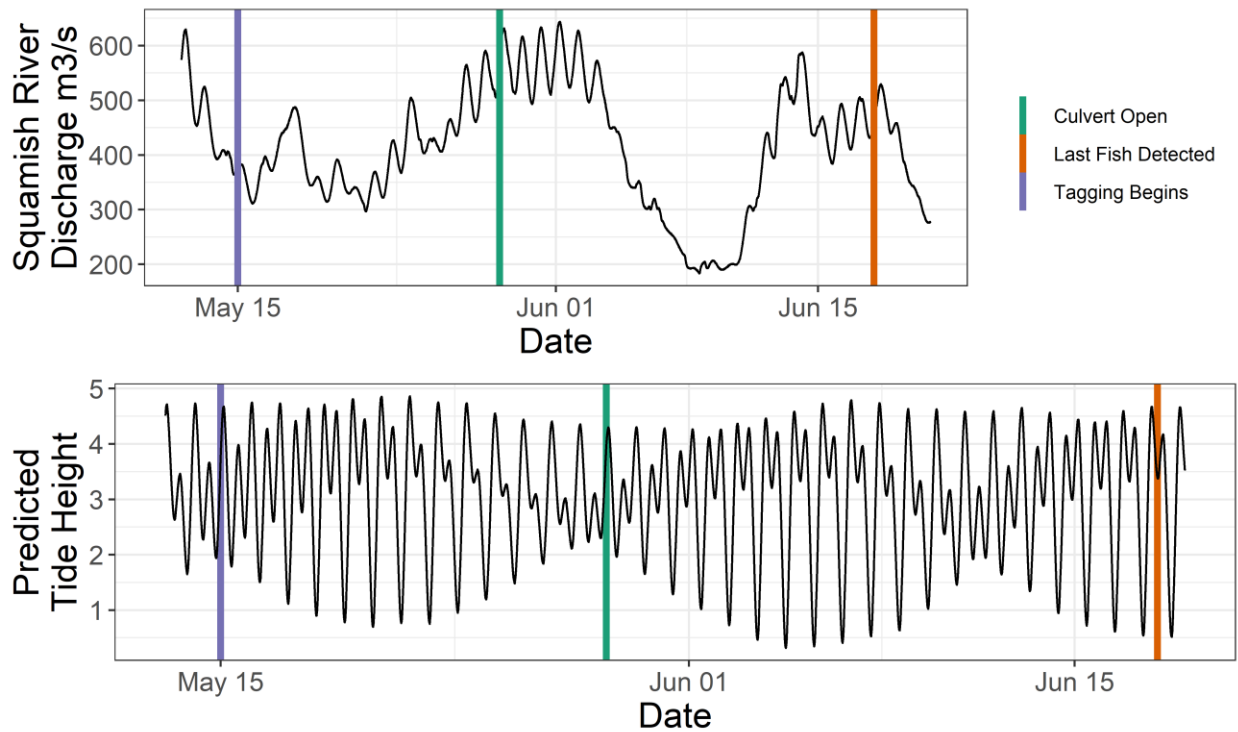


Figure 2: Discharge in Squamish River and predicted tide heights in Howe Sound throughout the study period. Coloured vertical bars represent the study period dates (between pink and blue) and when the box culvert opened (green).

Fish Capture

Fish were captured in the Squamish River and estuary for tag application and recapture monitoring. Additional capture efforts were focused in specific areas of the Central Estuary to determine presence of salmonids. All fish were identified to species and enumerated. Very abundant and non-target species (e.g., sculpins) were not enumerated and numbers were estimated when caught in large numbers (e.g., >20 chum in one set).

Squamish River

Juvenile Chinook Salmon were the target species and capture sites were selected according to documented habitat preferences for this species (Garland et al. 2002, Holecek et al. 2009). Fish were captured in the Squamish River using a 1/4-inch mesh beach seine deployed from a raft. Fishing occurred two to three times per week between May 17th and June 13th, 2019. Two additional trips were made after dark on May 24th and June 13th. There were five seining sites on bar edges in the main channel of the Squamish River between rk 2.4 and rk 12, all dominated by sand or small gravel substrates (Figure 3). Seining occurred between discharges of 200 and 650 m³s⁻¹.

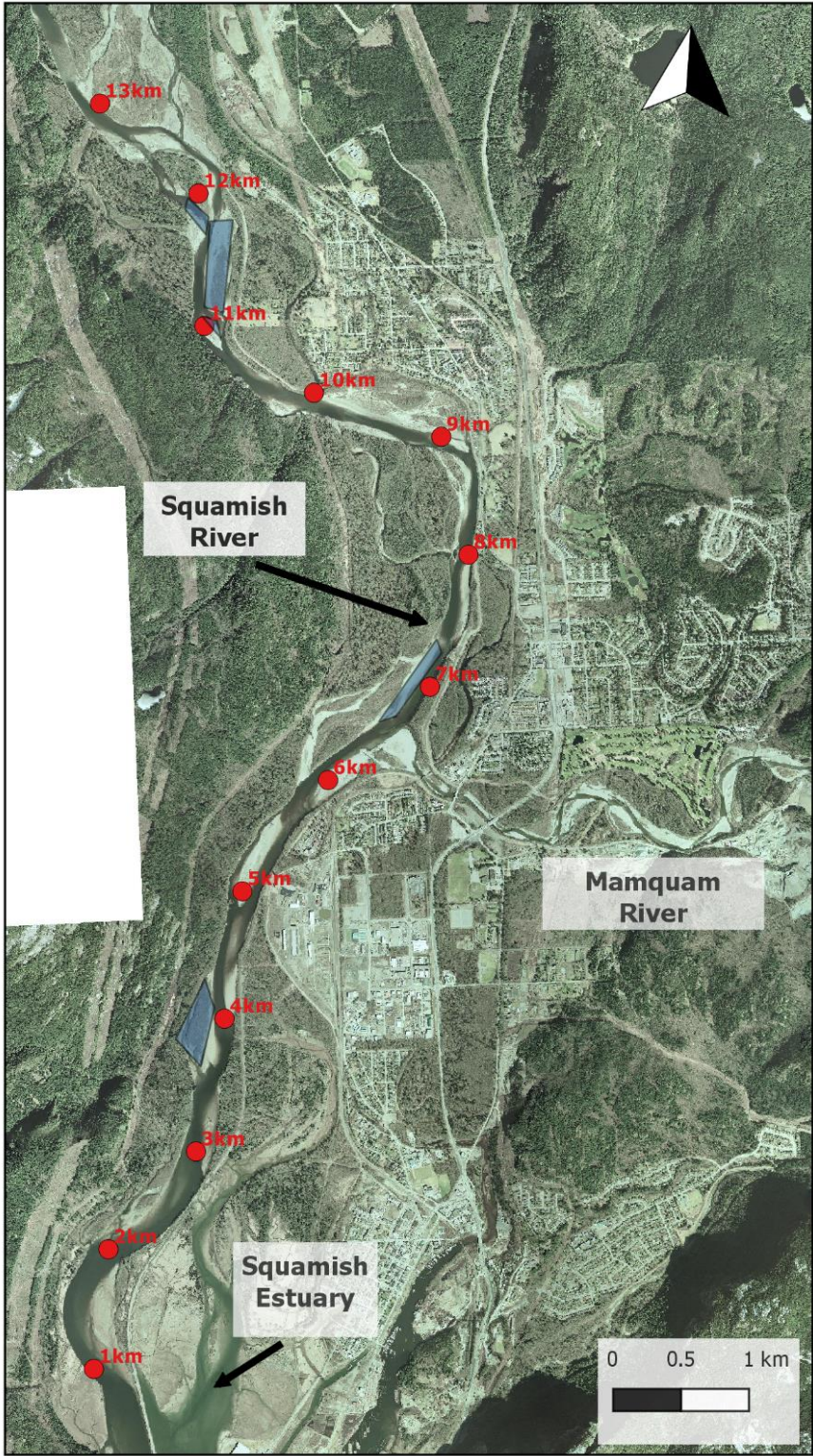


Figure 3. The Squamish River with river kilometers marked and fish capture locations identified by shaded blue.

Central Estuary

Monitoring of juvenile Chinook Salmon from 2013-2016 identified six sites suitable for capturing Chinook juveniles (Lingard 2018), five of which were sampled in 2019. Two sites were in tidal channels and fished with fyke net traps and three within the main Central Estuary fished by seining (Figure 1). A fishing site at the terminus of the Squamish River was not sampled due to lack of access during culvert construction.

To capture fish by seine in the Central Estuary, a crew of three technicians set the seine net (100 ft long x 4 ft deep with ¼ inch mesh) either by hand or boat. Conditions are only appropriate for seining at tides > 1.5 m, and boat access is only possible at high tide. The goal was to seine sites twice a week between May 17 and June 13.

To capture fish in the two constructed tidal-channels, referred to as Blue Heron and Westbarr Channels (Figure 1), custom constructed Gee-trap style fyke nets (Redden Nets, Langley, BC) were fished two nights per week between May 17 and June 7. The rectangular nets had ¼ inch mesh and measured 1 m x 1 m x 2 m. A directional codend at each end prevented fish from escaping the main chamber.

Additional specific sites of interest were fished to collect baseline fish species assemblage data. Several activities form the basis of CERP; Activity 3 aims to improve water quality and flow from the upper estuary through Bridge Pond towards Cattermole Slough. Activity 3 proposes to install culverts under the rail line between Pretty Slough and Bridge Pond, allowing water to flow from Pretty Slough in the upper estuary to Bridge Pond. Prior to construction, baseline assessment of species assemblages in Pretty Slough and Bridge Pond was requested by SRWS. Using methods appropriate to each area (Table 1), sites in Pretty Slough, Bridge Pond (between the tide gate and flap gate) and Cattermole Slough were each fished once for this component of the work (Figure 4). Sampling at these sites will be continued as restoration activities in the Bridge Pond Complex progress.

Table 1. Area and types of traps selected for evaluating baseline species assemblages in Site A and Cattermole Slough of the Squamish River Estuary

Area	Selected Trapping Modality
Pretty Slough	Electrofishing and minnow trapping
Bridge Pond	Minnow trapping
Cattermole Slough	Beach Seine



Figure 4. Fishing locations in the Pretty Slough, Bridge Pond, and Cattermole Slough to collect baseline fish species assemblage data.

Biological Sampling

Fork length (FL) was recorded to the nearest millimeter for all salmonids, and weight to a tenth of a gram for a subset of Chinook Salmon. Scale samples were also obtained from a subset of Chinook Salmon to archive and determine age if there is future interest. Scales were collected from above the lateral line posterior to the dorsal fin using a scalpel blade. To ensure accuracy of measurements and reduce handling stress, fish were anesthetized in a water bath of clove oil and ethanol mixed at a ratio of 1:10 prior to sampling.

Tagging Procedures

PIT and acoustic telemetry were used, both of which provide fish with an individual ID that can be detected remotely. Combining the two technologies maximizes data quality while minimizing costs. PIT telemetry is best suited to confined waterways and has limitations in saline environments, whereas acoustic telemetry is best for tracking in open, dynamic and saline environments (Thorstad et al. 2013). Conversely, acoustic tags are expensive, require surgical implantation, and are larger than PIT tags (~0.1g for PIT and 0.43 g for acoustic), typically leading to higher mortality relative to PIT-tagged fish (Brown et al. 2013, Hockersmith et al. 2003).

PIT tags were implanted in both wild-captured fish and fish collected from the Tenderfoot Creek Hatchery. Because culvert construction timelines were uncertain in this initial year of study, we limited the acoustic telemetry component to hatchery fish that could be held on site if culvert construction extended beyond the peak juvenile outmigration period.

Hatchery releases were spread throughout the field season to encompass a variety environmental conditions (e.g., river discharge, tide magnitude) from May 15 to June 7. Our experimental design adapted to delayed culvert construction timelines; half of the hatchery releases occurred prior to culvert construction completion, and half after.

Implanting PIT Tags

Wild-caught and hatchery fish were tagged according to the same protocols, following the recommendations of a size threshold of 65 mm FL (Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee, 1999). Prior to tagging, fish were anesthetized in a water bath of clove oil and ethanol mixed at a ratio of 1:10 until loss of consciousness (Stage 2; Summerfelt and Smith 1990). For tagging, fish were held ventral-side up and a 12 x 2.12 mm half duplex (HDX) PIT tag (Oregon RFID) loaded within a tagging needle was implanted into the ventral cavity. Fish were recovered in aerated buckets. Wild-caught fish were released at their capture location once recovered and all fishing at that site was complete. Recovery buckets were covered to provide shade, water quality was monitored, and water changed as necessary. In the hatchery, once tagging was complete fish were relocated to hatchery holding facilities until release with fish implanted with acoustic tags (see 'Surgery Recovery and Release').

Surgical Implantation of Acoustic Tags

Hatchery fish for study were held in 8' diameter 3220 L circular tanks with continuously recirculating water. Untagged fish were all held in one tank and fed weekly according to standard hatchery protocols. Qualified and experienced IFR staff conducted the surgeries and practiced suturing techniques on the study population prior to tagging. For surgery, fish were brought to stage 3 anesthesia (Summerfelt and

Smith 1990) using clove oil emulsified in alcohol (1:10 ratio). After obtaining FL and weight, fish were placed ventral side up on a surgical board lined with padding. A 4-5 mm incision was made on the linea alba anterior to the pelvic girdle with a surgical scalpel for tag insertion (V4-180kHz, InnovaSea Marine Systems Canada Inc; weigh 4.2 g). Monocryl absorbable 5–0 monofilament sutures (Monocryl; Ethicon, Somerville, NJ, USA) were used to close incisions with one simple interrupted suture using square knots with two wraps on the first row and a single wrap on the second row. Gills were continuously irrigated throughout the procedure, first with the prepared clove oil mixture and then with water once suturing began. Individual fish were monitored in buckets until recovered from anesthesia (i.e., swimming and responding to stimuli).

Surgery Recovery and Release

Tagged fish were provided with ample recovery and river acclimatization time, and release procedures aimed to optimize survival probability (Table 2). Following surgery and initial recovery from anesthesia, all tagged fish were placed in a segregated holding pen within a recovery tank for > 48 hours. If fish did not recover during this time (e.g., were pale or showing erratic swimming behavior) they were euthanized by cerebral percussion. The goal was to tag 10 fish with acoustic tags and 50 fish with PIT tags per tagging day, but final daily numbers varied slightly (e.g., due to mortalities). We had concerns of low survival among fish with acoustic transmitters (see Melnychuk 2009), especially when released later in the season as a small group. Research has shown Bull Trout predation on juvenile Chinook is lower when fish migrate in large groups (Furey et al. 2016). Therefore, to improve survival probability of tagged fish, additional untagged hatchery fish were released concurrently.

Table 2: Timeline of the process of starvation to release for hatchery fish implanted with PIT and acoustic tags.

Timeline of Surgeries and Release	
Starvation	Fish fed 1x per week as per hatchery protocols
Surgery	>48 hours post-feeding
Recovery	>48 hours post-surgery in segregated holding pens in hatchery
Acclimation	6-12 hours in a submerged and closed in-river tank
Release	Released at civic Twilight on day of transport to river

Following recovery, fish were transported in a transport tank equipped with a continuous supply of dissolved oxygen to the release site in the lower Squamish River (*rk* 2.5; ~25-minute drive). Fish were then netted out of the tank into buckets and carried to a closed holding tank submerged in the river to acclimate to river conditions. Fish were released that same day at civic twilight in a single group to best

align with migration patterns of wild fish thought to reduce predation (Furey et al., 2016). The release site was located on river left (same side as box culvert), approximately 1 km upstream of the box culvert (Figure 1).

Telemetry Arrays

PIT and acoustic technologies each require their own arrays to detect tagged fish. Arrays underwent extensive testing under varying environmental conditions prior to and during deployment to ensure appropriate read range (maximum distance that a receiver or antenna can effectively decode a transmitter) and efficiency (the probability of detecting a passing tagged individual), not all of which is detailed here.

PIT Array

The PIT array consisted of 'pass through' rectangular antennas that detect tags as fish pass through or over antennas. Two antennas were installed within the box culvert and another two within a channel just downstream of the confluence of channels leading from culverts 1 and 2 (Figure 1). The dual antenna design at each location allowed for determination of efficiency and directionality of movements. Antenna construction and configuration differed slightly between the two locations. In the box culvert, antennas were built within a (1.06 x 4.3 m) rectangular PVC housing installed approximately 1.5 m apart.

Antennas were both connected to a remote Oregon RFID tuner box and multi-reader via twin-axial cable and powered by two deep cycle 6V batteries in series that were changed twice per week. In the Central Estuary, flexible antenna approximately 2 m apart were suspended over the channel by rope and secured in position with sandbags such that they conformed to channel geometry. At this location, each antenna was connected to an Oregon RFID remote tuning box and single reader via twin-axial cable. The 12V system was powered by four 6V deep cycle batteries (two each in a series) continuously charged by a solar panel (no battery changes required).

At both locations, antenna function was tested weekly by manually passing a test tag through each antenna. If the test tag was not detected by both antennas, they were tuned accordingly; this procedure ensured optimal performance throughout the deployment period.

Efficiency Testing

The goal of array testing was to identify the probability of detecting a passing fish. With each array having two antennas, detection efficiency for upstream antennas is a ratio of detections shared on both relative to upstream detections. Because detection efficiency of upstream detection sites is determined using downstream data, arrays must be directional, and the reliability of estimates will increase with the number of detection points. Performance was also assessed by comparing numbers of fish detected by antenna and overall fish numbers relative to the number released during controlled releases, whereby a

known number of PIT-tagged fish were released within the vicinity of the PIT antennas. In the Central Estuary, fish were released at the exits of culvert 1 and culvert 2 and in the immediate vicinity of the antennas (Table 3). At the box culvert, three releases were conducted at various distances from the culvert to additionally provide insight into culvert attraction.

Detection efficiency is measured at the first antenna encountered based on detections at the second (i.e., the proportion of fish detected on both antennas). As an additional efficiency test, fish were individually forced through the box culvert antennas using a release tube. With this release we know that fish passed through both antennas and can calculate a true efficiency for each antenna.

Fish collected from the Tenderfoot Creek hatchery were used for all controlled releases and tagging was conducted as detailed above.

Table 3: Details of controlled releases of PIT-tagged hatchery Chinook Salmon to test efficiency of the Central Estuary and Box Culvert PIT antennas.

Location	Date	Release Location
Central Estuary	June 4	Culvert 1
	June 4	Culvert 2
	June 18	1 m from antennas
Box culvert	June 16	0 m from culvert
	June 5	10 m from culvert
	June 5	50 m from culvert
	June 16	Forced through both antennas

Acoustic Array

The acoustic array consisted of nine 180 kHz receivers that made up four ‘gates’. An acoustic gate is a checkpoint, designed such that tagged fish are unlikely to pass that point without being detected. Tags emitted two types of ID transmissions: High Residence (HR; 8-12 s burst rate) and Pulse Position Modulation (PPM; 15-25 s burst rate). The array contained both HR2 (n = 3) and VR2W (n = 7) receivers (InnovaSea Marine Systems Canada Inc). HR2s provide measures of acoustic noise and position (which both affect detection efficiency), can decode both tag ID transmissions, and emit PPM and HR self-transmissions, providing a continuous test of array performance. The VR2W only detects PPM transmissions and provides no other data. HR2s were split between the river and the estuary. Gate locations were established to determine whether fish enter Howe Sound prior to entering the estuary, if they access the estuary through the box culvert, or if they use the estuary at all. The 30-day tag life

additionally allowed gathering of some information regarding residence time in the estuary and lower Squamish River.

In the river gate, two receivers were deployed on either side of the river near the box culvert (R2) and two downstream of the box culvert (R1; Figure 1). Fish detected on the downstream river receivers (R1) failed to find and pass the box culvert. Estuary receivers were deployed away from Squamish terminals to reduce potential boat traffic noise and within natural constrictions not dewatered at low tide. There were three estuary gates: Spit Estuary-side (E1), Central Estuary (E2), and Culvert Exit (E3; Figure 1). Fish first detected on river receivers but then detected on either the Spit Estuary-side or Central Estuary gates (E1 or E2) likely entered the estuary from Howe Sound. Fish detected on the Culvert Exit gate (E3) but not previously detected on other estuary gates can be categorized as having entered the estuary through the box culvert. Fish only detected on the River Gate are assumed to have not accessed the estuary.

Deployment method varied with receiver location. In the river where high flows and debris were a concern, an anchor was built by pouring a 50 cm² slab of concrete over a rebar frame. Two pieces of rebar extended 50 cm from each side of the slab, preventing the anchor from rolling in high flows. A PVC housing was attached to the anchor to hold receivers. In the estuary some deployment sites were dewatered at low tide and others up to 4 m deep at high tide. The top of acoustic receivers emits a 'listening cone' that detects tagged fish as they pass through. If the top of the receiver became exposed at low tide, fish would go undetected. To ensure fish were still detected at low tide, estuary receivers were buried at a very low tide. Receivers were held within a PVC housing with just the top exposed. A rebar frame was built around the top of the housing and it was buried to the level of the frame so that it remain level with the substrate. The unit was attached to an anchor located ~1 m away to prevent interference with detections.

The first receivers were deployed on May 13 and the last retrieved on July 17. Three river receivers were presumably lost in a high-water event, one of which was downloaded prior (Table 4).

Table 4: Details of deployed acoustic receivers. Individual or multiple receivers made up several acoustic gates, or a checkpoint at which tagged fish are unlikely to undetected upon passing.

	Receiver Position	Gate	Receiver Number	Date Deployed	Date Removed
River	River left, upstream	R2	461372	May 13	June 10
	River right, upstream	R2	302547		Not retrieved
	River left, downstream	R1	461370		May 23 (download only)
	River right, downstream	R1	302546		Not retrieved
Estuary	Culvert exit	E3	302549	May 27	July 17
	Central estuary, east	E2	461374	May 10	
	Central estuary, center-east	E2	302552		
	Central estuary, center-west	E2	302551		
	Central estuary, west	E2	302548		
	Spit Estuary-side	E1	302550	May 21	

Testing Receiver Range and Array Performance

A range testing tag affixed with an end cap attachment was used for all array testing. Considerable range testing was conducted prior to array deployment to select optimal locations and determine detection range under various environmental conditions. For initial testing, a line of six receivers (three each of VR2Ws and HR2s) was deployed in both the estuary and river for at least 24 hours with a range testing tag affixed to a receiver on the farthest end of the line. Receiver range at both high and low tides was determined by assessing the maximum distance the range testing tag was detected, and the maximum distance HR2 self-transmissions were detected. Working with scientists at InnovaSea Marine Systems, receiver range was estimated to be approximately 80 m. Therefore, receivers in a line were deployed at a conservative maximum distance of 60 m apart.

To test array performance in the final deployment configuration, a series of passes were conducted with the range testing tag. The test tag was affixed to a weighted line extending from a float with an attached GPS unit. The float was deployed from an upstream point expected to be outside of the detection range of the gate and left to float to a downstream point expected to be outside of the detection range. Having an independent float ensured no interference with acoustic signals (e.g., from a vessel).

Several passes were conducted at each gate. The goal over the study period is to conduct 3 passes per receiver location at each tidal condition (i.e., ebb, high and low tide). In 2019 considerable testing was conducted (Table 5), and results will be expanded on in 2020. In the Squamish River we only conducted

testing at an ebb tide. This is the most important time as preliminary testing revealed it to be very noisy; results therefore represent a worst-case scenario. For the estuary gates, our concern was water levels rather than noise and they were tested at high and low tides to have full representation of all water levels.

Table 5: Summary of efficiency testing passes conducted with the range testing tag over the four acoustic gates.

Gate	# of Receivers	Number of passes		
		Ebb tide	High tide	Low tide
Squamish River	4	6	NA	NA
Central Estuary	4	NA	6	7
Spit – Estuary Side	1	NA	3	4
Culvert Exit	1	NA	5	5

Analyses

Analysis of telemetry data was completed in R Project Software. For PIT data, the PITR package developed by InStream Fisheries Research (Harding et al. 2018) was used to collate data and summarize fish movements. We also determined the detection efficiency for each culvert array (i.e., three antennas) for fish moving from the Squamish River into the estuary. Detection efficiency is a measure of accuracy for a PIT antenna based on the number of tags detected by subsequent downstream antennas. Calculating the efficiency of each receiver requires a full spatial analysis whereby the proportion of tag transmissions detected relative to those expected to be detected is calculated at various distances. This analysis will be conducted to inform deployment of receivers in 2020. For 2019, we use three parameters to determine performance of the acoustic array: 1) results from test tag passes (i.e., detected or not), 2) detections of HR2 receivers on neighboring receivers, and 3) levels of acoustic noise.

Results

Fish Characteristics and Distributions

Wild-caught Salmonids

In the Squamish River, 95 beach seine sets were completed between May 15 and June 13 at 5 sites between rk 2.5 and rk 12. Of the 517 Chinook Salmon captured (Mean FL \pm SD = 73.6 \pm 15.5), 332 were tagged. It is apparent from size distributions over time that Chinook are larger earlier in the season; every fishing week the number of fish > 80 mm declined from the previous week (Figure 5).

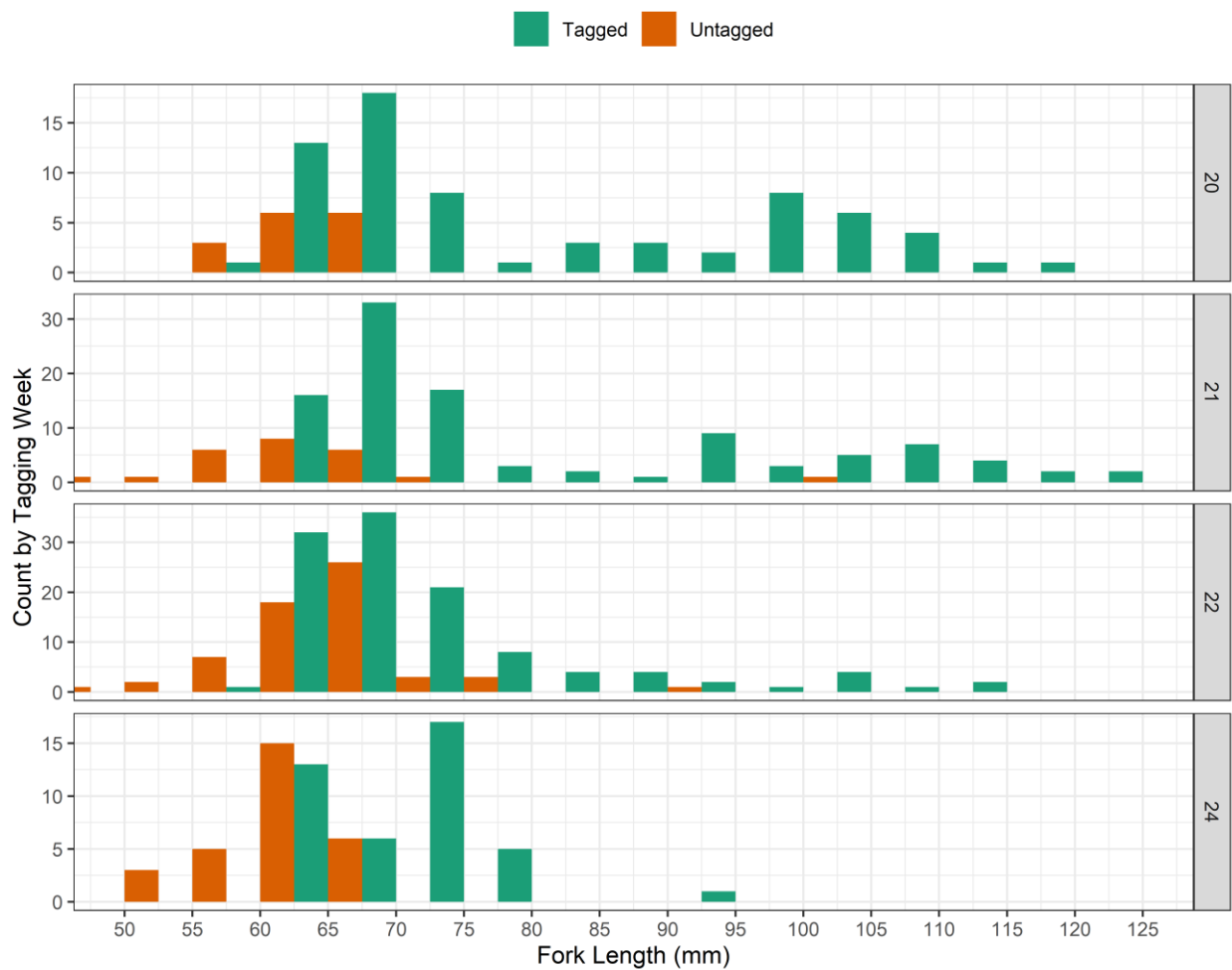


Figure 5. Size distribution of Chinook Salmon juveniles captured in the Squamish River by beach seine in spring 2019. Week 20 = May 13; 21 = May 20; 22 = May 27; 24 = Jun 10

In the estuary, 30 capture attempts were completed by trap (n = 14, 24-hour periods) and beach seine (n = 16 sets) between May 17 and June 13. Across all fishing events, 97 juvenile Chinook Salmon were captured of which 47 were tagged. No Chinook Salmon were captured in the tidal channels, and no PIT tagged fish were recaptured in the estuary. Chinook Salmon were captured by beach seine in the southern portions of estuary (i.e., between Westbarr and the box culvert) while Coho Salmon fry (*O. kisutch*; < 50 mm) dominated catches north of the box culvert (Figure 6).



Figure 6: Total number of Chinook, coho, and other salmonids captured by sine at the five capture sites within the Squamish River Estuary

Several other species were captured during fishing. Notably, Bull Trout (*Salvelinus confluentus*) and Steelhead Trout (*O. mykiss*) were often captured in the Squamish River. and Chum Salmon (*O. keta*) fry and Coho Salmon fry and smolts were commonly captured in the estuary (Table 6). Species composition and fish size cannot be directly compared between the two locations as different methods and nets were used (e.g., mesh size of 1/2" in river versus 1/4" in estuary).

Table 6. Catch composition and size of fish captured in the Squamish River and Estuary by beach seine in Spring 2019.

Species	River Seining		Estuary Seining	
	n	FL (mm) ± SD	n	FL (mm) ± SD
Bull Trout	13	217.3 ± 89.5	NA	
Chinook Salmon	473	73.6 ± 15.5	96	70.3 ± 11.9
Chum Salmon fry	2	NA	26	54.7 ± 5.6
Coho Salmon fry	3	62 ± 6.1	31	43.7 ± 8.9
Coho Salmon smolts	3	77 ± 9.5	57	86.8 ± 9.5
Cutthroat Trout	3	211 ± 29.4	1	157
Starry Flounder	1	NA	2	72
Gunnel Fish	NA		1	NA
Lamprey	1	64	2	83
SFL	1	NA	1	NA
Steelhead Trout	67	117.1 ± 29.7	7	77.5 ± 36.1
Staghorn sculpin	NA		2	NA
Three-spine stickleback	NA		6	NA

Sizes cannot be compared between the Squamish River and estuary given differences in mesh sizes of nets used within each location.

Hatchery Chinook Salmon

Chinook Salmon collected from the hatchery were implanted with either PIT or acoustic tags and released at the release site above the box culvert (Figure 1). Hatchery fish were larger than wild-caught Chinook; mean (± SD) FL was 121.9 mm ± 11.1. Mean tag burden of for fish implanted with acoustic tags was 2.2 % (SD = 0.6 %).

Chinook Salmon Movement in Squamish River and Estuary

Movement results primarily focus on acoustic telemetry data, as this is more robust than PIT data and had various detection sites throughout the Squamish River and Estuary. However, the larger sample size of PIT-tagged fish further informs if juvenile Chinook Salmon used the box culvert or upper culverts (i.e., culvert 1 or 2), and information regarding movement and residency times can be derived from the recapture of tagged individuals.

Fish of both tag types were released before and after the culvert opening. All fish tagged at the hatchery were released at the release site above the box culvert and wild-caught Chinook implanted with PIT tags were released at location of capture (Table 7).

Table 7. Table of location, number and timing (before= before culvert open, after=after culvert open) of fish releases in the Squamish River in spring, 2019.

Release Site	PIT		Acoustic	
	Before	After	Before	After
At site of Capture (wild-caught Chinook)	206	126	NA	
~1 rkm above box culvert (hatchery Chinook)	250	401	48	52

Of the 100 fish implanted with acoustic tags, 69 were detected. Undetected fish (n = 31) likely migrated to Howe Sound but were missed by the river receivers.

In-River Movement

River residency times for hatchery fish were low, as determined by acoustic detections; the mean time between release to last detection on river receivers approximately 1 rkm downstream was 7.3 hours (SD = 21.7). Most fish detected on river receivers travelled that distance in < 9 hours, but five fish remained at the release site for an extended period (i.e., ~ 1.9 to 5.5 days; Figure 7). Of the 30 PIT tagged fish recaptured, the time between tagging and recapture was up to 17 days (mean \pm SD = 6.6 \pm 4.7 days; Figure 7). Chinook captured in the Squamish River were of both wild and hatchery origin, and the three hatchery fish recaptured in-river had longer residency times than fish released from the hatchery.

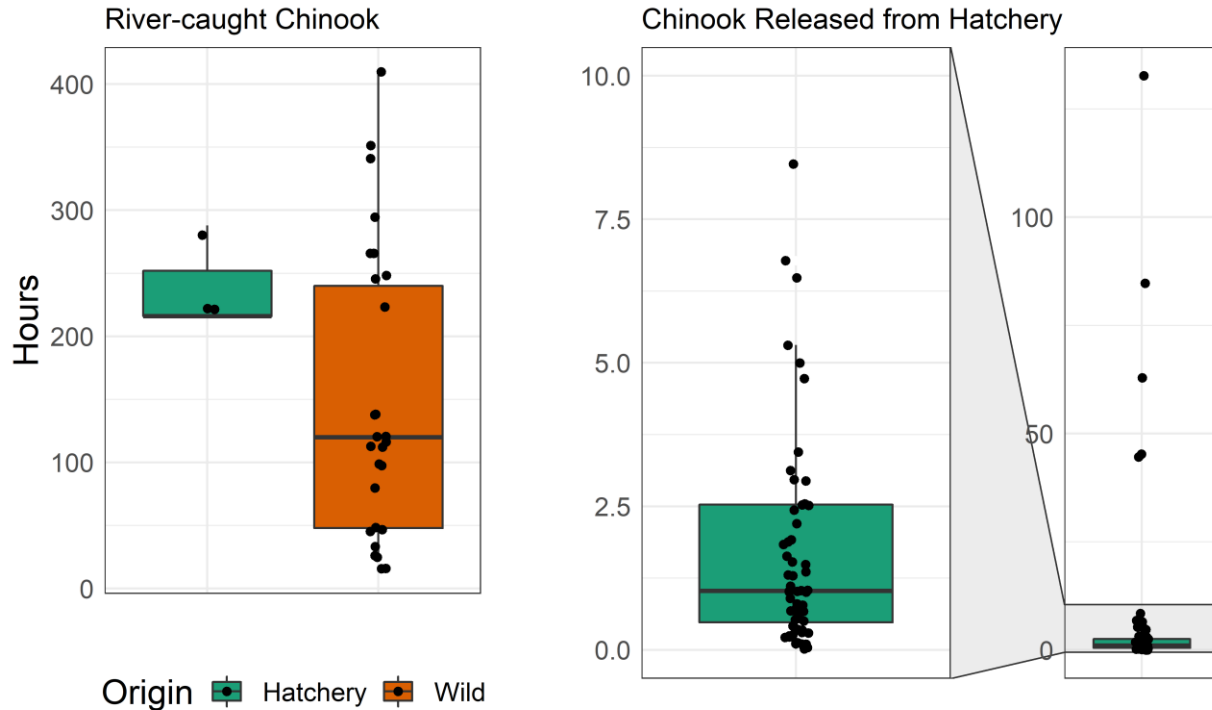


Figure 7: Minimum river residency times as determined by recapture data (for wild-caught Chinook; left panel) or detection data (for Chinook released from the hatchery; right panel). Each point represents an individual fish. Whiskers of boxplots represent the interquartile range, outside of the box the 25th and 75th percentiles, and the line in the middle the median.

Tagging began on May 15, but the box culvert wasn't flowing until May 29. Most wild-caught fish were tagged prior to the culvert opening (67%), but if they remain in-river for several days, as this limited data suggests, the culvert would have been available for a greater proportion of tagged fish than reflected by tagging dates.

The apparent differences in mean minimum river residency times from the tagged hatchery population (~160 vs. 6.8 hours) highlight how the observed behavior of the hatchery fish may not represent that of wild-caught fish. However, any wild fish not residing in-river for long durations are unlikely to be recaptured and therefore estimates of river residency for wild-captured fish are undoubtedly biased high.

Accessing the Squamish River Estuary

Of the tagged study population (n = 957), 22 individuals accessed the estuary from the Squamish River (14 with acoustic and 8 with PIT tags), all but one were collected from the hatchery (and thus released above the box culvert). More of these fish accessed the estuary prior to the culvert opening (9 of 48; 18.8%) than after (5 of 52; 9.6%; Figure 8). The most successful release group in terms of estuary access was on May 24, from which 50% of fish navigated into the estuary prior to the box culvert opening

(Figure 8). This release occurred on an incoming tide and the river had increased 100 m³/s over the previous 24 hours to ~500 m³/s. Of the five fish detected in the estuary after completion of the box culvert, one was detected passing through it.

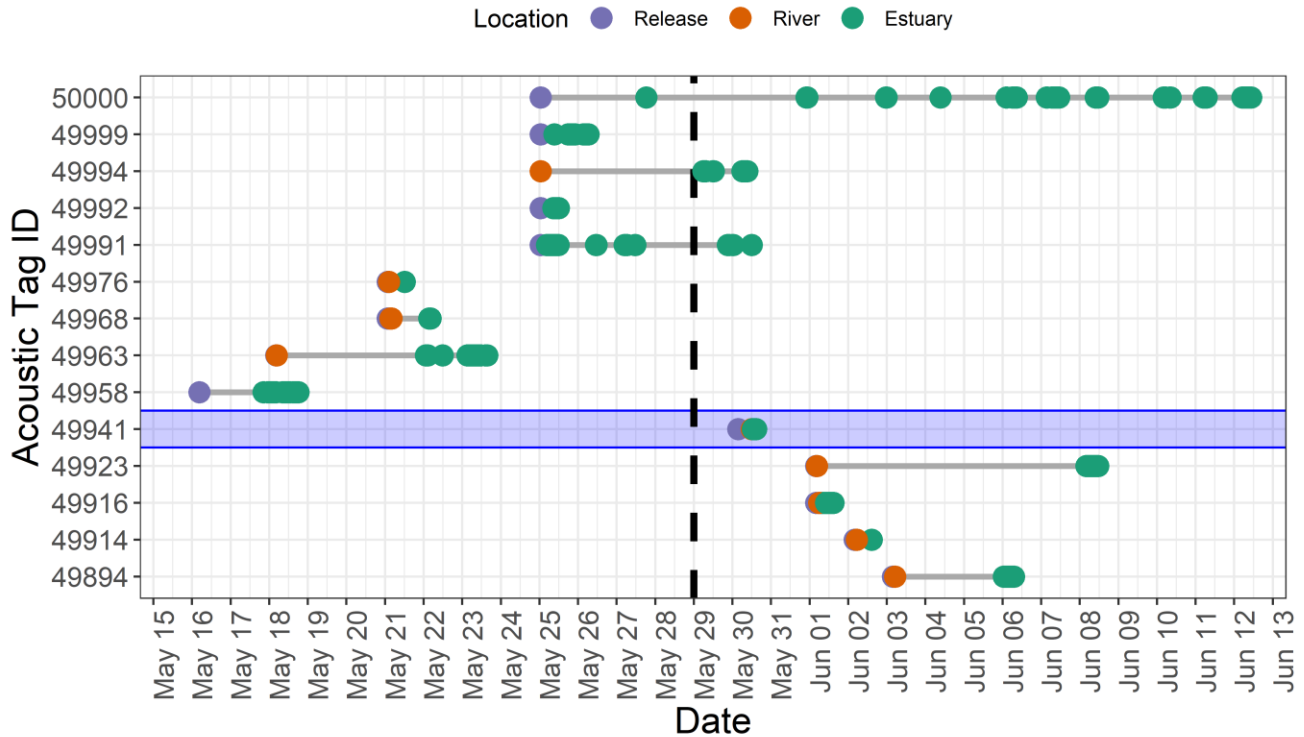


Figure 8: Timeline of movement from the Squamish River to the estuary for hatchery Chinook Salmon implanted with acoustic tags. Each point represents an individual tagged fish, with the colour representing the location of detection. The vertical dotted line indicates when the culvert opened, and the individual highlighted in blue is the only fish to have used the culvert.

There was considerable variation in travel times from the river to estuary (Figure 8). Among hatchery fish implanted with acoustic tags, two travelled from release to first detection in under four hours (Fish 49994 and 49916) whereas one fish took over a week (Fish 49923; median = 18.3 hours). Two fish (49976 and 49914) were only detected once on one estuary receiver.

No wild-caught fish implanted with PIT tags were recaptured in the estuary, but one was detected on the Central Estuary array.

Box Culvert Passage

The box culvert was opened on May 29. Seven hatchery fish (one with an acoustic tag and six with PIT tags) from three release groups entered the culvert between tide heights of 2.5 and 3.4 m and river discharges of 514 and 594 m³/s (Table 8; Figure 9). Five fish were detected on both antennas and are thus confirmed to have entered the estuary via the culvert and another two fish with PIT tags were only detected on the first antenna. We can confirm these fish entered the culvert but cannot confirm they passed through it, though it is likely. All fish detected on the culvert antennas were released at the release site above the culvert on river-left. No wild-caught fish, released at site of capture, used culverts.

Table 8: Details of fish passage events at the box culvert

Release Date	Passage at Box Culvert			Fish ID	Tag Type	Tide		Discharge (m ³ /s)
	Date	Time	Confirmed			Height (m)	Direction [†]	
May 29	May 30	12:09	Yes	49941	Acoustic	2.487	↑	542
May 31	May 31	23:04	Yes	461929	PIT	3.083	↑	583
		23:14	Yes	461966		3.139	↑	586
		22:31	Yes	461877		2.931	↑	574
		23:50	No*	461755		3.346	↑	594
Jun 2	June 2	21:42	Yes	461965		3.453	↓	514
		22:30	No*	461818		3.269	↓	523

* Only detected on river-side culvert antenna and not estuary-side antenna

[†] Up arrow represents flooding and down ebbing tides

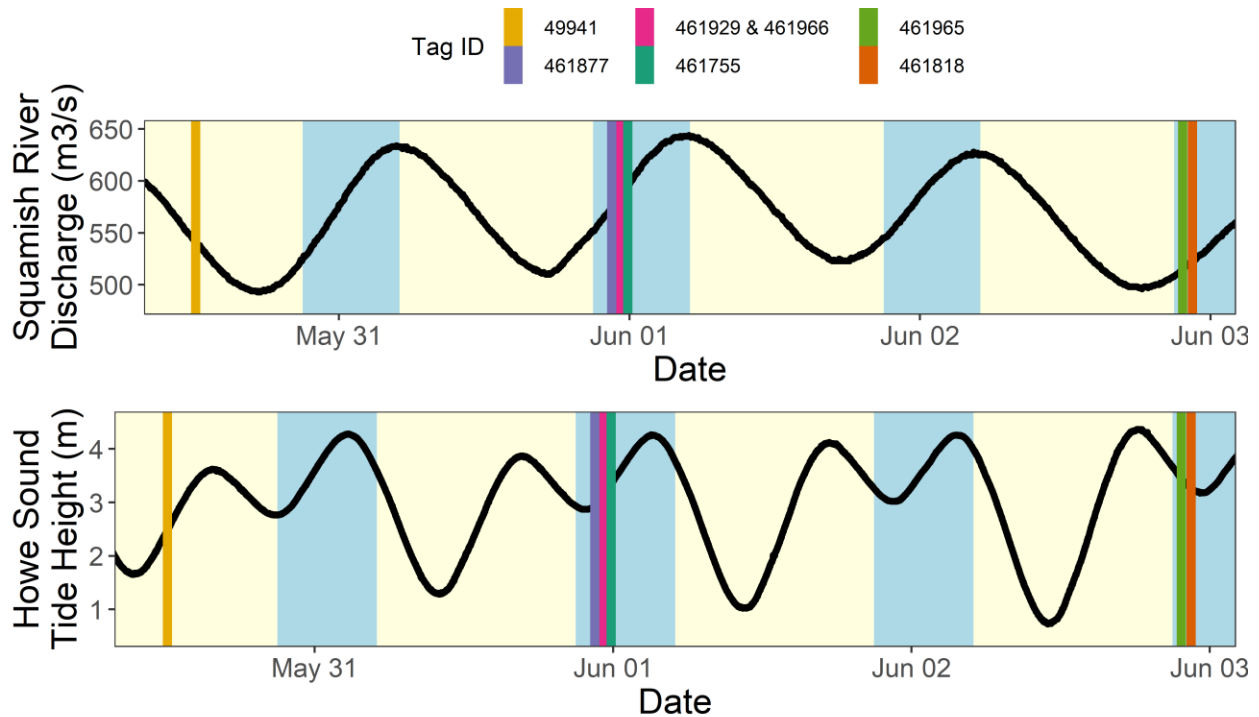


Figure 9: Squamish River discharge (top) and tide heights for Howe Sound (bottom) during the period of box culvert passage. Vertical lines are displayed at times of culvert passage events. The pink line represents two fish that passed the culvert within 10 minutes of each other. Shading indicates approximate daylight hours (dark = blue; 6PM-5AM; light = yellow; 5AM-9PM). All fish were released at civic twilight and detected the evening of release, except for 49941 which passed the day after.

Accessing the Estuary by Other Means

Tagged fish detected in the estuary but not by antennas and receivers in the box culvert ($n = 15$) are assumed to have entered from Howe Sound. Acoustic receivers deployed in-river downstream of the culverts were lost in a high-water event. One of these receivers was downloaded on May 23, after which in-river fish presence downstream of culverts cannot be confirmed. Use of the old culverts (i.e., culverts 1, 2, 4-9) is unlikely, as previous research has found them to be ineffective for fish passage (Lingard 2018; Lingard et al. 2018). Although entrance from Howe Sound cannot be confirmed without downstream river receiver data, we have strong evidence for four individuals prior to culvert completion:

- Two fish (acoustic tags 49968 and 49976) detected on river receiver downstream of the culverts.
- Two fish (acoustic tags 49991 and 49999) first detected on the Spit – Estuary Side receiver and then detected on the central estuary receivers. It is most likely that these fish contoured around The Spit prior to continuing into the estuary. Fish 49991 later returned to The Spit.

Two PIT tagged fish were detected on the Central Estuary antennas. One hatchery fish from the June 1st release group was detected on the on the morning of June 2nd and the direction of travel for this fish is unclear. One wild fish released on June 3rd was detected numerous times on the downstream Central Estuary antenna on the evening of June 19th and morning of June 20th, suggesting it moved into the area from the South.

Estuary Residency

Estuary residency and habitat use was limited by battery life of acoustic tags (~30 days), however, the area alongside The Spit was used more often than expected, with fish often moving between here and the Central Estuary gate. Detection histories reveal small movements among the deployed estuary receivers over the course of days and weeks (Figure 10). Minimum estuary residency times, the time elapsed between first and last detection on estuary receivers, ranged from less than 1 hour to nearly 16 days for the 11 fish with multiple detections within the estuary (mean = 1.9 days; Figure 10). These estimates are considered minimums because fish may move beyond acoustic gates (i.e., into the northern portion of Central Estuary) or reside in the estuary longer than the battery life of the tag.

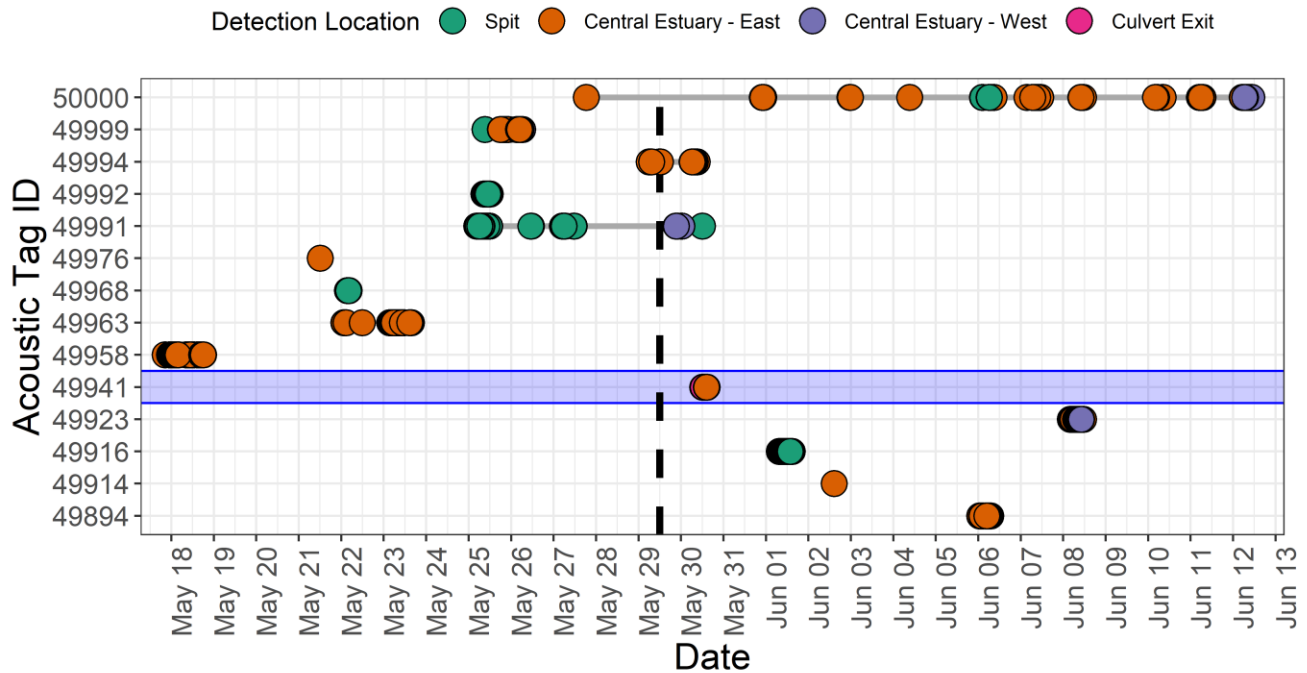


Figure 10: Positional data for tagged hatchery Chinook Salmon fish detected on acoustic receivers in the Squamish River Estuary. Each point represents a detection event at a given receiver location, as identified by colour. The vertical dotted line indicates when the culvert opened, and the individual highlighted in blue is the only fish to have used the culvert. Some fish resided in the estuary for several weeks (e.g., Fish 50000) and most were detected at multiple receiver locations.

Performance of Telemetry Arrays

PIT Array

Performance was measured through detection efficiency of upstream antennas (i.e., the ratio of detections shared on both antennas relative to upstream detections) and by comparing numbers of fish detected by each antenna and overall, relative to the number released during controlled releases.

Box Culvert Antenna

Detection efficiency for study fish (i.e., excluding controlled releases) was 67%. Six study fish were detected, four of which were detected by both antennas. The other two fish were only detected by the upstream (river side) antenna and were either missed by the downstream antenna, as the measure of detection efficiency assumes, or entered but not passed through the culvert. Likewise with controlled releases, where measures of detection efficiency among groups released in front of the culvert ranged from 0.29 to 0.72 (Table 9), fish may have milled around the entrance of the culvert (detected only on upstream) and not passed through, inaccurately reducing detection efficiency.

Assessing the percentage of fish detected relative to the number released during controlled releases were variable, ranging from 28% to 70% (Table 9). When fish were forced through the culvert antennas in a release pipe detection probability was 69.4 % for the downstream antennas, 95.9% for the upstream antennas and 98% for both combined (Table 9). In future years, efficiency should be determined through forced passage events at various environmental conditions.

Table 9: Performance testing results from for PIT antennas in the box culvert for study fish (i.e., excluding controlled releases) and by each controlled release trial. Detection efficiency is provided for the upstream antenna given detections shared among both antennas.

Release Group		n	Upstream Antenna Detection Efficiency	Individuals Detected (%)		
				Up Ant.	Down Ant.	Combined
All study fish			0.67	NA	NA	NA
Controlled Releases	At culvert entrance	50	0.29	12.0	28.0	32.0
	10 m from culvert	50	0.72	36.0	36.0	46.0
	50 m from culvert	41	0.53	51.2	41.4	70.7
Forced through antennas		49	NA	95.9	69.4	98.0

Central Estuary

The central estuary antennas were not tested as extensively as the box culvert; fish were not forced through antennas to test efficiency. With only two study fish detected, antenna efficiency cannot be reliably estimated. Controlled releases do provide some information and suggest good performance. Detection efficiency from the releases at the exit of Culvert #2 and at 1 m upstream of the antennas was 0.65 and 0.46, respectively (Table 10). None of the fish released at the exit of Culvert #1 were detected.

Table 10: Performance testing results from PIT antennas in the Central Estuary for study fish (i.e., excluding controlled releases) and by each controlled release trial. Detection efficiency is provided for the upstream antenna given detections shared among both antennas.

Release Group		n	Upstream Antenna Detection Efficiency	Individuals Detected (%)		
				Up Ant.	Down Ant.	Combined
Controlled Releases	Culvert 1 exit	49	NA	0	0	0
	Culvert 2 exit	49	0.65	30.6	34.7	42.9
	1 m from antennas	101	0.46	41.6	80.1	85.1

Acoustic Array

Performance at each receiver location was determined with: 1) results from passes of a testing tag, 2) detections of HR2 receivers on neighboring receivers, and 3) levels of acoustic noise. Note that the range testing tag has a higher burst rate than study tags and is therefore more likely to be detected than a tagged fish. Test tag data is best used to create a distance matrix of efficiency whereby efficiency is calculated for varying distances from each receiver. The spatial analysis required to calculate true efficiency of the array will be conducted prior to deployment of receivers in 2020. Results are discussed by area.

Estuary Receiver Gates

Performance of estuary receivers was excellent. Test tag passes were 100% successful; the test tag was detected on all test passes of individual estuary receivers and by all three receivers at the eastern Central Estuary site during each of the three passes.

Examining the proportion of HR2 PPM self-transmissions detected by the two neighboring VR2 receivers at the Central Estuary site also suggests good performance. Although there was some daily variation, HR2 self-transmissions were consistently detected by the closer VR2 (60 m away; 50-95% of self-transmissions emitted were detected per day) and were also detected by the VR2 130m away on most days (up to 27% of self-transmissions emitted were detected per day; Figure 11). These values are higher

than expected because both VR2s were dewatered and unable to detect any signals at low tide. Dewatering of receivers wasn't monitored, but the farthest VR2 was deployed in a shallow tidal flat and was likely out of water 50% of the deployment time.

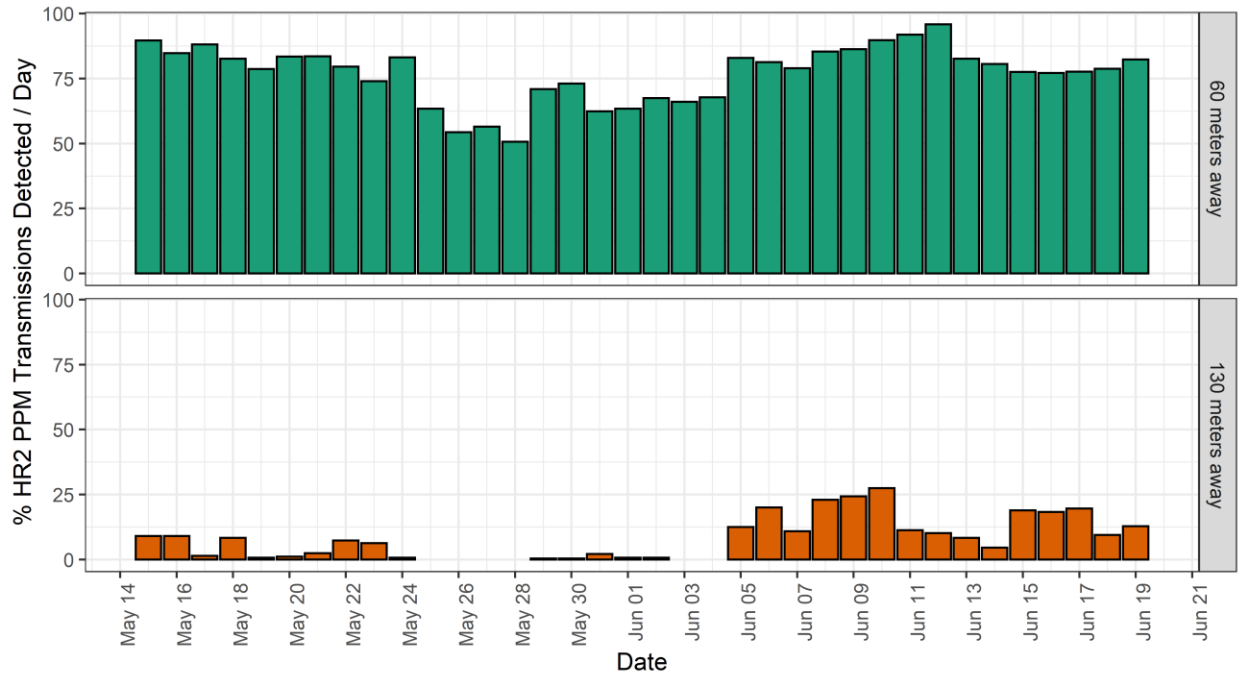


Figure 11: The proportion of PPM transmissions emitted by the HR2 detected by the two neighboring VR2 receivers at the Central Estuary site

Together, the test tag passes and detections of HR2 PPM self-detections indicate overlapping coverage between receivers. It is therefore unlikely that a fish passing within 60 m of estuary receivers would go undetected, and detection range of receivers may have exceeded 130 m under some conditions. Ultimately detection range is dependent on environmental condition. Performance of the array did appear to drop between May 24 and Jun 4 (i.e., the percentage of HR2 transmission detected dropped; Figure 11). Reasons for this drop are unknown, and it is not associated with tides, discharge, or noise levels.

Squamish River Receiver Gates

River receivers did not perform as well as estuary receivers. The Squamish River is a difficult environment for deployment and testing, and thus testing was not as extensive as in the estuary. A fast river environment produces high levels of acoustic noise, especially during freshet. We have diagnostic data from the two river receivers deployed on river left, one until May 23 and the other for the entire deployment period. Acoustic noise, as measured by HR2 receivers, mimicked tidal cycles and was highest on an outgoing tide (Figure 12). Above noise levels of 30 dB performance will markedly decrease

(InnovaSea, personal communication). At the upstream receiver, noise levels were rarely above this 30dB threshold but at the downstream receiver, acoustic noise approached 60 dB on an outgoing tide daily (Figure 12). Conversely, acoustic noise never exceeded 16 dB on the HR2 receiver in the estuary.

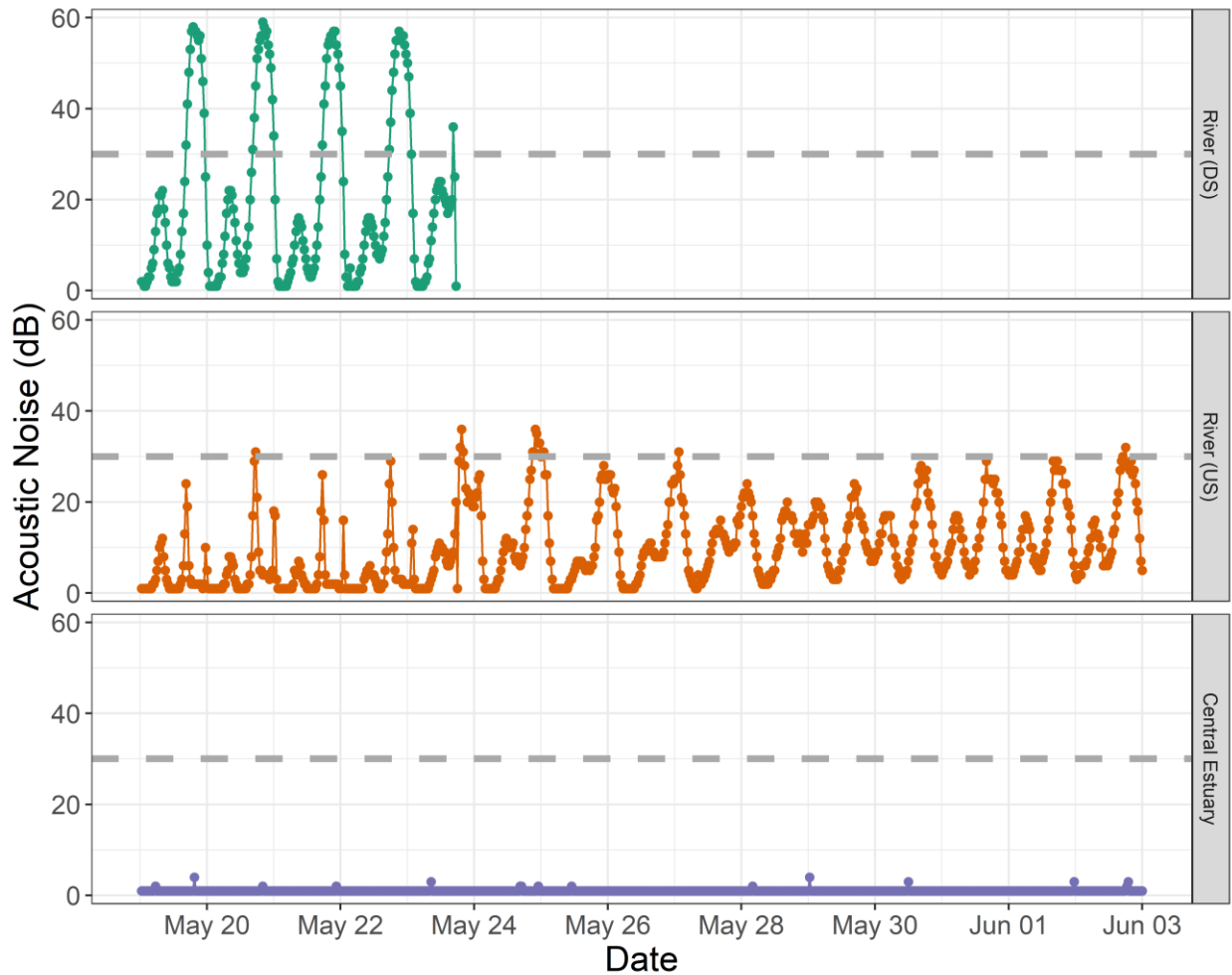


Figure 12: Levels of acoustic noise recorded by HR2 receivers deployed near the East bank of the Squamish River [Downstream (DS) and at (Upstream; US) the box culvert; two top plots] and in the Central Estuary (bottom plot). Noise levels in the Squamish River mimic tidal cycles, being noisiest during an ebbing tide. When noise levels exceed 30 dB, as indicated by the grey dashed line, receiver performance (i.e., ability to detect passing tagged fish) decreases.

The test tag was detected on two of the three passes conducted over river left receivers. The two VR2s on river right were never found or downloaded after deployment. Preliminary testing suggested that range of river receivers was approximately 50 meters. That river receivers detected 69% of tagged fish after release indicates functionality despite some poor performance measures.

Fish Capture in Pretty Slough, Bridge Pond, Cattermole Slough

Three different methods of fish capture were used to sample Bridge Pond, Pretty Slough and Cattermole Slough in 2019. Bridge Pond was sampled near the tide gate with 10 minnow traps set over night. The catch in bridge pond was dominated by stickleback and both Staghorn and Coast Range Sculpin (Table 11).

Juvenile Chinook, Coho and Chum Salmon and Staghorn Sculpin were captured by seine in Cattermole Slough. Pretty Slough was sampled using minnow traps and electrofishing. Neither method successfully captured fish, but fish were observed (Table 11).

Table 11. Results from fishing efforts in Bridge Pond, Pretty Slough and Cattermole Slough in the eastern portion of the Squamish River estuary in spring 2019. CAL= Cottus alueticus, STAG= Leptocottus armatus, CH=O. tshawytscha, CO= O. kisutch, CM= O. keta, Gunnel= Pholis laeta.

Site	Method	# Sets	Species	Catch
Bridge Pond	Minnow Trap	1	CAL	11
Bridge Pond	Minnow Trap	1	GUNNEL	1
Bridge Pond	Minnow Trap	1	STAG	24
Bridge Pond	Minnow Trap	1	STB	503
Cattermole Slough	Seine	3	CH	6
Cattermole Slough	Seine	3	CMF	1
Cattermole Slough	Seine	3	CO	5
Cattermole Slough	Seine	3	STAG	5
Pretty Slough	EF & Minnow	1 each	NA	0

Discussion

During this first year of research, over 1000 Chinook Salmon were tagged to monitor movement between the Squamish River and its estuary. Tagged juvenile Chinook Salmon were detected using the newly constructed box culvert, but more Chinook accessed the estuary by other means. However, the overall proportion of fish detected in the estuary was small; most study fish migrated to Howe Sound from the Squamish River without entering the estuary.

Fish Passage at the Box Culvert

It is promising that juvenile Chinook Salmon were detected using the culvert to access the estuary. Seven hatchery fish passed the culvert from the Squamish River to the estuary, whereas in 2018 when the twinned 3-foot culverts were in the same location, no fish other than those released at the entrance for testing were detected using the culvert (Lingard et al. 2018). However, the passage effectiveness detailed herein should be interpreted as a maximum or best-case scenario. All fish detected using the culvert were released ~1 km upstream of the culvert on the same side of the river as the culvert, a contrived situation created to improve survival of tagged fish that substantially improved probability of locating the culvert. No tagged wild-caught fish, released at the location of capture, were able to locate the culvert, suggesting that culvert attraction for fish traveling in the center or right side of the river channel may be limited.

Throughout the monitoring period anecdotal observations of water and flow conditions within the culvert were made and a time-lapse camera was installed. It is evident from these observations and the photos that the culvert is not wetted at all discharges and tide elevations. The seven fish that did pass the culvert did so in three groups and conditions were similar for each passage event. All fish passage through the culvert occurred at higher tides (>2.5 m) and high river discharge (500-600 m³/s). Therefore, it appears locating the culvert may be difficult and the correct river elevation conditions need to occur at the time fish are passing the culvert approach channel for the culvert to be effective.

Use of the Squamish River Estuary

Despite limited potential for fish passage through culverts, our results confirm that the Squamish River Estuary is an important rearing area for juvenile Chinook Salmon. Both young of the year and yearling wild Chinook Salmon were captured in the Squamish River estuary, the majority (97%) of which were wild fish. Capture data from the estuary indicates a decrease in captures of Chinook Salmon juveniles from south to north in the central estuary, a pattern also documented by a previous trapping study in the estuary (Lingard 2018). Reasons for this distribution are unknown. If most fish enter the estuary from Howe Sound, as our data suggests, it may be difficult to locate and access these protected Northern

portions of the estuary. Alternatively, lack of flow from the Squamish River into the Northern estuary could cause conditions not suitable for rearing and feeding (e.g., elevated temperatures, low dissolved oxygen). Continued monitoring in these areas as restoration activities progress will inform these uncertainties.

Although none of the over 1000 Chinook implanted with PIT tags were recaptured during estuary fishing efforts, acoustic data shows that 14% of hatchery fish implanted with acoustic tags used the estuary (one of which used the box culvert). Fish detected on the estuary receivers spent up to two weeks in the estuary before their tags either went silent or they migrated to Howe Sound. In the Skeena River watershed, juvenile Chinook Salmon have been demonstrated to spend weeks to months in the estuary prior to marine residence (Moore et al. 2016). It is well established that estuaries are important for sub-yearling Chinook, but our results add to the evidence that larger yearling (i.e., >100mm) Chinook Salmon may rear for extended periods of time in estuaries (Bottom et al. 2005; Moore et al. 2016). Potential survival benefits of estuarine access for this population is unknown. However, a study comparing juvenile to adult survival for Chinook Salmon between altered and natural estuaries found that decreases in the availability of natural estuarine habitat negatively influenced survival (Magnusson and Hilborn 2003).

Among hatchery fish implanted with acoustic tags, 86% did not access the estuary and it is suspected these fish migrated directly to Howe Sound. Although it is possible some study fish died prior to having the opportunity to access the estuary, particularly the 31 undetected fish. However, the short distance between release and river receivers was travelled quickly making it conceivable for fish to have been missed by river receivers, especially during ebb tide. Fish move quickly downstream; there may only be seconds for a receiver to detect the tag. Out-migrating fish will move even faster during ebb tides, when levels of acoustic noise are high (and probability of detection low). Conversely, performance of estuary receivers was very high and it's unlikely a tagged fish entering the estuary would have gone undetected.

Few (14%) individuals were able to successfully navigate to the estuary. All study fish were released close to the estuary, increasing their chances of surviving to the estuary over wild fish migrating greater distances from upstream tributaries. Given limitations of using hatchery fish and the one release location, this percentage cannot be extrapolated to the wild Chinook population. Therefore, the proportion of wild Chinook able to access the Squamish River estuary is unknown, but if it is as low as our research suggests for hatchery fish, negative impacts to juvenile survival given lack of estuarine access is likely.

Results from this year and previous years of monitoring clearly show that estuary access could be improved for juvenile Chinook Salmon. Further breaches in the Spit are required to improve fish access. Aerial photographs of the estuary show several locations where the Squamish River would naturally braid

into the estuary. For example at culvert 4, just downstream of the box culvert, the river and central estuary both abut the training berm. Given that the box culvert is not wetted at all tide and river elevations, designs for future breaches or fish passage structures in the spit should strive to expand windows of passage to a wider range of environmental conditions (i.e., tide and discharge).

Limitations and Future Directions

This study was successful in determining proportion of hatchery reared Chinook Salmon entering the Squamish River estuary via the new box culvert and from Howe Sound (i.e., around The Spit). Behavioural differences between wild and hatchery fish are well established (see Melnychuk et al. 2009 for an example from the Squamish River), and thus we do not suggest our results provide an accurate representation of wild fish behavior. For example, river residence times differed substantially between wild-caught and hatchery and suggest wild fish will reside in the river for several days or weeks, whereas most of our study population consisting of hatchery fish migrated downstream within hours of release. However, estimates of river residence time are highly uncertain and inferences have been derived from a small sample of fish. Residence times for wild-caught fish are based on recaptures of few individuals (e.g., ~5% of tagged population), and recapture probability is inevitably higher for fish with higher residence times (i.e., fish migrating downstream shortly after tagging won't be recaptured).

The timing of the study (mid-May to mid-June) was relatively late in the known Chinook Salmon migration period, which begins in April for larger fish (> 65 mm; Lingard & Melville 2017). Examining fish size by date also indicates large fish (> 100 mm) tend to migrate earlier than smaller fish (60-80 mm). All hatchery fish tagged in 2019 were over 100 mm; the delayed study period may have added additional bias as the hatchery fish may have been motivated to leave the river to a greater extent than smaller wild fish.

There are several methodology changes that could be made to reduce biases in study design. The primary limitations from 2019 is the use of hatchery fish, and the late start, both of which were required with the delayed construction timelines of the box culvert. For the 2020 study year, wild fish will be implanted with acoustic tags. Beginning the study in early April and extending through June will allow for evaluation of estuary access and residence across a wider range of environmental conditions.

More strategic effort should also be spent in the estuary to improve chances of recapture in future monitoring years. Recapture effort in the estuary was roughly 60% less than the effort expended to capture fish in the Squamish River. The reduced fishing effort is likely a considerable factor in the lack of recaptures in the estuary. Fishing conditions are very specific in the estuary as much of the habitat is only accessible by boat, and it was not feasible to move the seine net around by hand. In future years, a

concentrated and systematic period of recapture (e.g., fishing every day for 7-10 days) could be implemented to evaluate whether greater effort results in re-capture of fish.

The estuary was a low risk location for the acoustic receivers compared to the Squamish River and their performance was greater than expected. Additional effort and distribution of acoustic arrays in the estuary could be used to improve knowledge of fish passage and habitat usage. The resulting data could potentially be used to identify key areas that juvenile Chinook Salmon use for rearing. Conversely, the river acoustic telemetry gate was challenging to deploy and maintain, and several receivers were lost in high flows; research goals can be achieved in future years without receivers in the Squamish River.

Conclusions

Chinook Salmon exhibit a continuum of juvenile life history types (Miller et al. 2010; Volk et al. 2010; Bourret et al. 2016). Estuaries are important transition habitats for all life history types of Chinook Salmon, with both young of the year and larger yearling known to rear for extended periods of time in estuaries of other watersheds of British Columbia and Washington state (Bottom et al. 2005; Moore et al. 2016). In this study, findings are restricted to fish meeting the tagging threshold of 65 mm. However, given the importance of estuaries to all Chinook Salmon juveniles and the low catches of Chinook Salmon in 2019 and previous years of trapping (Lingard 2018), an assumption can be made that smaller fish likely have an equally difficult time accessing the estuary as the larger wild fish monitored in this study. Continued seining in the estuary and an acoustic tagging program targeted at wild Chinook Salmon (size threshold of 85 mm) in 2020, will provide a much more accurate representation of the population.

Despite potential biases associated with using hatchery fish and the timing of the 2019 monitoring program, results indicate that additional fish passage improvements are required between the Squamish River and its estuary. The installation of the box culvert appears to be an improvement from the previous 1.2 m culvert installed at the same location, but fish access to the structure is limited to a select range of tidal and river discharge conditions. Future restoration efforts should strive to provide more options for fish access to estuarine habitat across a wider range of river discharge and tidal elevations. Additional years of monitoring wild fish will enhance our knowledge of the system and restoration needs.

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Central Estuary Monitoring Program: 2018-2019 Interim Report

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Submitted to:

The Squamish River Watershed Society

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Introduction

The Squamish River Watershed Society (SRWS) is implementing restoration efforts to help return the Squamish estuary to its original functioning condition to support salmonids, particularly chinook salmon. Three main components to the restoration project includes:

1. Replacing a culvert along the Squamish Training Berm with a box culvert to improve fish passage between the Squamish River and estuary. **Completed May 2019**
2. Restoring connections along the spit portion of the training berm (one kilometer) where it extends into the outer estuary to open the entire southwestern end of the estuary to tidal and river flow, and thus expanding key estuarine habitat where juvenile salmonids can rear prior to ocean migration **Planned for 2020-2021**
3. Installing an intake structure (or series of culverts) across the CN Rail spur line where it services Squamish Terminals to allow flows to pass between the Central Estuary and Cattermole Slough/Bridge Pond. **Timing TBD**

The Central Estuary Restoration Project was implemented in 2019 and is planned for completion in 2022. Monitoring is required to evaluate the success of the restoration project to meet the project goal of improved fish passage and habitat conditions. The monitoring objectives for this project are:

1. To estimate the changes in passage of juvenile chinook between the river and the estuary before and after restoration activities
2. To document changes in fish habitat and water quality in the estuary as a result of restoration activities.

The first objective is addressed in studies by Instream Fisheries Research; results of these studies are provided in Cook, Lingard, & Martin, 2019 and in Lingard (2018) and summarized in this report (see *Fish Passage and Use Monitoring*).

The second objective is addressed in studies by Lake Trail Environmental Consulting, and covered in this report and in the 2018 interim monitoring report by McAuley & Togado (2019). This report provides a 2018-19 summary for Objective 2 of activities completed to date, lessons learned and monitoring plans for 2020. Much of the monitoring provides baseline information to evaluate long term and future restoration success. This report also provides an early assessment of water quality, sediment and channel morphological changes that occurred pre and post the 2019 Culvert 3 Upgrade Project component of the CERP.

Combined, the two monitoring components provide a comprehensive picture of the ability for fish to access, utilize, and ultimately benefit from fish habitat in the Central Estuary as a result of restoration activities.

Background

Study Area

The Squamish estuary is the marine/freshwater interface between the Squamish River and Howe Sound, British Columbia (Figure 1). The estuary covers an expansive combination of riverine riparian, shrub meadow, estuarine salt marsh and brackish marsh, tidal channel, mudflat and anthropogenically modified channels and ponds. The Squamish River flows south into the estuary, draining approximately 3600 km² of watershed area including numerous tributaries, the largest being the Elaho and the Ashlu. All five species of salmon utilize the watershed as well as steelhead, coastal and resident cutthroat trout, resident rainbow trout, Dolly Vardon, and bull trout.

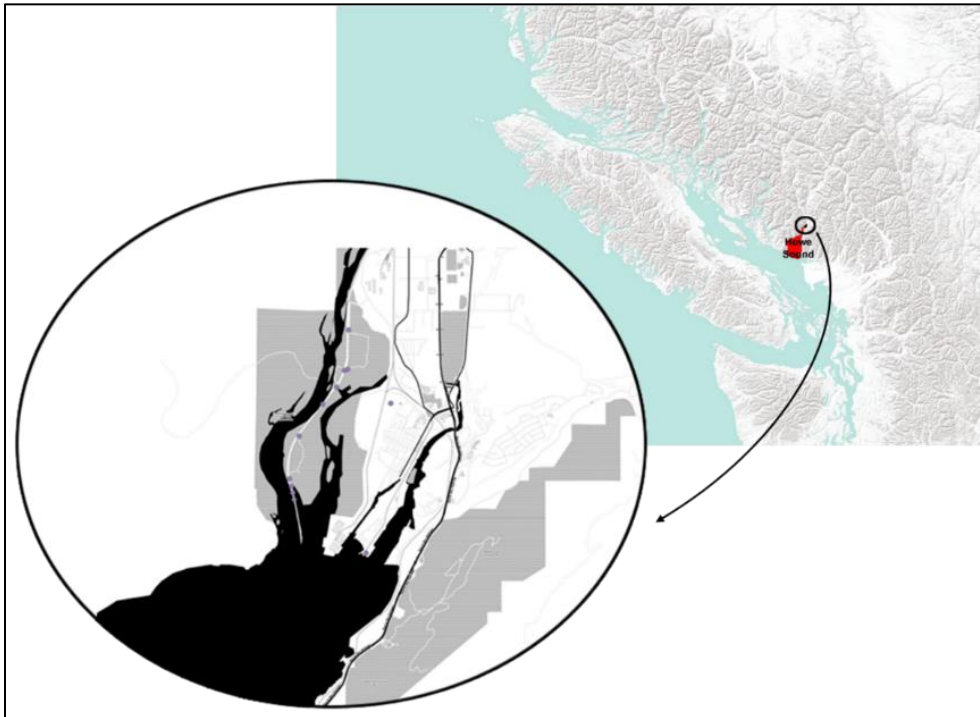


Figure 1: Inset of the Squamish River estuary in relation to Howe Sound, British Columbia.

History

The Squamish estuary is known as Skwelwil'em by the Squamish Nation. The Squamish Nation were the first people to settle the valley and establish villages alongside the estuary. The first European settlers arrived in the late 1800's with the advent of the Union Steamship Company of British Columbia. The Squamish estuary was used for agriculture and log transport; the markets for both were fueled by industrial development in Burrard Inlet. Over the past 150 years less than 50% of the original estuarine habitat remains intact due to logging, infilling and development. What remains of the Squamish estuary has been modified by roads, rail, dikes, and river berms that have restricted flows from the Squamish River into the estuary. Of the former numerous villages inhabited by Squamish Nation historically in the estuary, only the site of Stawamus remains inhabited.

One of the major impacts to the estuary was the construction in 1971 of a 5 km road/berm that was intended to “train” river flows to allow for construction of a coal port by BC Rail (Figure 2). While the coal port development ultimately never received approval, a five-kilometer berm that separated the river from the estuary was left intact. The new berm presented implications for survival of juvenile salmonids migrating to the ocean as it prevented direct access to the upper estuary. Estuaries are a critical staging ground for salmonids, in particular chinook salmon, providing food, refuge and a salinity gradient that allows them to slowly acclimate to salt water. The impacts of rapid increases in salinity can result in slowed growth and increased mortality in chinook (Taylor, 1989). Indeed, escapements of adult chinook returning to the Squamish River exhibited a marked decline shortly following the construction of the training berm (Wada & Sander, 2005).

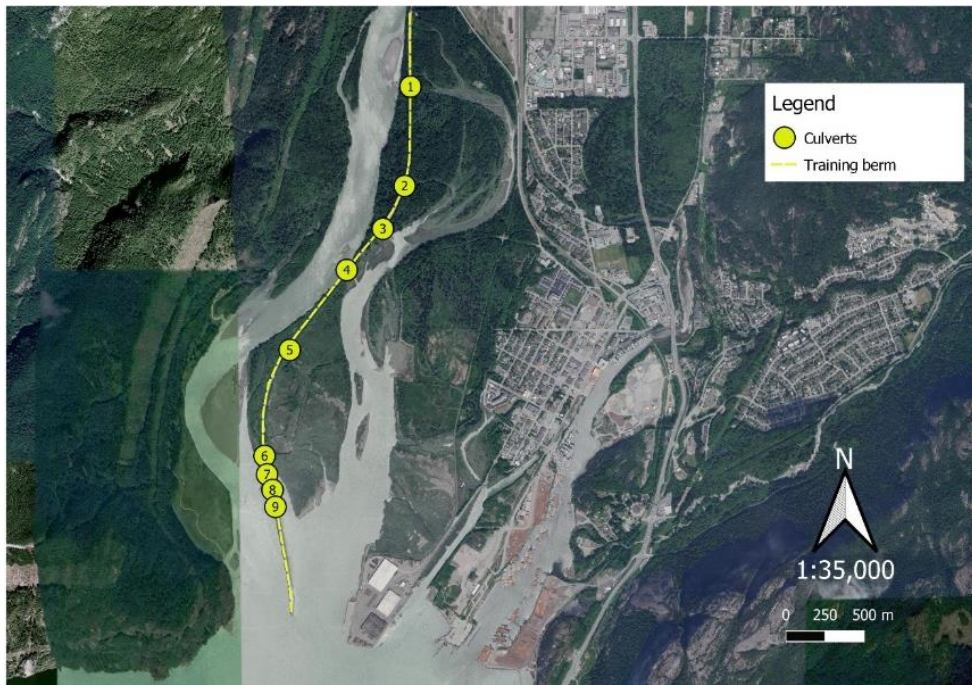


Figure 2: Overview of the Squamish estuary showing location of training berm and culverts, numbered 1 through 9 from north to south along the berm.

From the mid-1990s until 2013, nine culvert crossings of various sizes were installed across the lower three kilometers of the berm to improve water exchange fish access between the river and the estuary (Figure 2). A study of the effectiveness of the culverts for fish passage from 2013-2016 indicated that juvenile chinook salmon were likely not utilizing the culverts to enter the estuary (Lingard, 2018). This, along with studies in other systems that indicate dike removal is beneficial for chinook (e.g. Bottom, et al., 2005) identified a need to improve access for juvenile chinook to the estuary.

As a result of this study the SRWS, in partnership with Fisheries and Oceans Canada (DFO) and Squamish Nation, embarked on a project to improve access and flow between the river and the estuary. In 2019 the first phase of restoration was implemented. This involved replacing twin 1.2 m corrugated steel pipe culverts (CSP) with a 3m x 3m box culvert. The culvert upgrade was intended to improve mixing of cold freshwater from the river with the saline water of the ocean during the late spring and summer periods, thus attenuating temperature and salinity extremes during estuarine rearing. As well, the box culvert,

with a lower design invert elevation than the CSP culverts and its much larger volume, would enable better passage of juvenile salmonids into the inner estuary (Figure 3).



Figure 3: A new 3m x 3m box culvert was installed in May of 2019 providing improved access to juvenile salmonids between the river and the estuary. Note acoustic arrays (for Instream fish monitoring study in 2019) and gap in concrete baffles to right to allow fish passage.

Fish Use and Passage Monitoring

Fish use and passage studies provided rationale and baseline information for estuarine restoration, as well as the first year of success monitoring for the new box culvert installed in late May of 2019 at Culvert 3. Results are summarized below; for a full account of the studies and the limitations please refer to Lingard (2018) and Cook, Lingard, & Martin (2019).

Squamish Estuary Juvenile Chinook Salmon Habitat Usage Survey (Lingard, 2018a)

Juvenile chinook salmon use of the Squamish estuary was investigated in a multi-year study by Instream Fisheries Research for the years 2013, 2015 and 2016 (Lingard, 2018). Juvenile chinook were captured in the estuary using trap and seine gear and sampled for age, size and genetic structure. Estuarine captures occurred between March and July, with peak captures occurring in May and June. Three size classes of Chinook were measured (<50mm, 50-80mm, and >80mm), with overlap between three age classes (Ages 0, 1, and 2). DNA analysis of estuarine captures found chinook originated from several lineages, including the Cheakamus River (a tributary to the Squamish River) the Capilano River, the Chilliwack River and three rivers on the east coast of Vancouver Island. Only one of 61 samples from the Squamish estuary had a lineage from the Squamish system outside of the Cheakamus River lineage.

Results from the different habitat types sampled indicated tidal channels were underutilized in the Squamish estuary compared to tidal flats, and the majority of captures occurred near the terminus of

the estuary along the exposed spit portion, indicating access to areas higher up in the central estuary were inhibited despite culvert connections across the training berm. These results support the rationale that restoration actions that increase opportunities for fish to access the estuary from the river channel across the training berm will be beneficial to chinook and other species that use the estuary.

Squamish River Central Estuary Restoration Effectiveness Monitoring (Cook et al., 2019)

The objectives of 2019 fish monitoring activities by Instream Fisheries Research were to provide baseline information for future restoration activities and to evaluate fish access to the estuary through the new box culvert at Culvert 3.

Chinook juveniles of both wild and hatchery origin were marked with PIT and acoustic tags which allowed individuals to be detected through direct capture and remotely with PIT receivers and with acoustic arrays. Although only seven of 1000 tagged fish were detected at the box culvert, tagging and detection did not begin until part way through the chinook migration period. All fish detected at the box culvert were of hatchery origin and occurred over a span of three days immediately after the box culvert opened (May 29), usually during evening hours. As numbers in 2019 were too low to conclude there was an improvement in fish passage with the new culvert, the results are promising compared to 2018 results when the original culvert was monitored with a similar PIT array and no fish were detected.

This study also allowed for investigation into the water levels and river discharges favorable for juvenile chinook passage through the box culvert. Their detection occurred on a rising tide that ranged between 2.5m to 3.4m and when Squamish River discharges ranged from 514 cms to 594 cms. Considering the narrow range in tide and water levels through which chinook accessed the box culvert, further improvements that allow for access during lower tides and discharges would be beneficial.

Movement of fish tagged in the river to the estuary or Howe Sound were also investigated. Results indicated that most of the chinook tagged in the river and detected in the estuary moved around the spit rather than through the culverts. Most of the acoustic tagged fish (86%) were not detected in the estuary, indicating the majority moved straight from the river to Howe Sound. Minimum estuarine residencies of tagged fish ranged from 1 hour to 16 days.

Fish monitoring plans for 2020 will also involve acoustic and PIT tagging and field sampling of juvenile chinook. Limitations in this study will be addressed by tagging only wild fish to avoid uncertainties associated with using hatchery fish to assess wild fish migratory behavior. Monitoring will begin early to capture the entire known chinook migration period. It is expected that 2020 sampling will allow for greater certainty in estuarine residence and habitat utilization by sampling across a wider range of habitats and environmental conditions.

Water Quality and Biophysical Monitoring

Monitoring of the water quality and biophysical components in the estuary for 2019 build upon monitoring results from 2018, and reported in McAuley & Togado (2019). Activities in 2018 involved establishing stations in the estuary and river for long term monitoring of impact (restoration) and control sites as well as the collection of baseline data prior to restoration. Monitoring metrics related to the following:

- Water Quality
- Physical Habitat
- Hydrology; and
- Sediment Dynamics

2019 Monitoring Summary

Activities in 2019 involved monitoring established stations and setting up new stations in the estuary and river for long term monitoring of impact (restoration) and control sites as well as the collection of baseline data prior to restoration. Monitoring metrics relate to the following:

- Water Quality
 - Temperature logging at 7 sites
 - Conductivity logging at 5 sites
- Physical Habitat
 - 6 tidal channel cross sections at 4 sites
- Hydrology
 - Water level logging at 1 river site and 5 estuary sites
- Sediment Dynamics
 - 17 sediment stations measured at 5 sites
- Vegetation and Soils
 - 10 vegetation transects and 39 vegetation plots
 - 20 soil plots
- Invertebrate Communities
 - Invertebrate settlement on Hester Dendy's preserved from 2018 deployment in (month) (not analyzed)
- Establishment of 15 new Photopoints for a total of 23 Photopoints for 2018-2019

Activities completed in the spring/summer of 2019 are summarized below and detailed in the following

section:

- Ongoing monitoring of six permanent logger stations in the estuary and river to monitoring water levels, temperature and conductivity;
- Installation of a new logger station at the Cattermole Slough (Area H)
- Removal of Station E loggers for winter
- One water quality profile along the estuary gradient during a high tide;
- Tidal channel dimension surveys;
- Sediment accretion pin installs and measurements;
- Survey and mapping of sampling locations.
- Vegetation and soil surveys
- Photo-point monitoring
- Complete the survey of logger stations to relative to a new elevation benchmark (Installed by Bunbury)

Monitoring Sites and Stations

Monitoring in the estuary was conducted at and near seven sites. Six of these sites were permanent sites established in 2018, with another added at the Cattermole Slough in 2019. A summary of monitoring site locations is presented in Figure 5 and Table 1. Coordinates and descriptions of individual monitoring stations at each site is provide in Table A-1, Appendix 1. Appendix 1 also provides large scale maps of all CEMP monitoring stations for 2018-2019. Photos of field activities associated with monitoring is provided in Figure 4.

Changes in 2019 include the addition of new stations for water quality, hydrology, sediment and tidal channel dimension monitoring and the removal of invertebrate and Tidbit temperature monitoring stations. In summary, changes to monitoring from 2018 to 2019 were as follows:

- A new logger station was installed at the Cattermole Slough to collect baseline information for the proposed project to connect the Central Estuary with the Cattermole Slough. A Hobo levellogger and conductivity logger were installed there on June 19, 2019.
- Eight new sediment stations were installed for a total of 16 sediment stations in the estuary
- One new tidal channel dimension survey station was successfully established at Site C in 2019 for a total of six in the estuary
- 2018/19 winter storms knocked over the Area E logger station (near Culvert 3); this was re-installed in May, 2019 and removed for the following winter season in October, 2019 with plans to reinstall again in the spring of 2020.
- The River logger (Site A) was lost in the winter of 2019-20, and will be replaced in 2020. Debris is suspected as the cause; as such, starting in the fall of 2020 this logger will also be seasonally

removed.

- A conductivity logger was installed at Area E (culvert 3) in April 2019.
- Hester Dendy Invertebrate Samplers set in 2018 were retrieved in the spring of 2019 and invertebrate samples were preserved in formalin but not yet analyzed due to time/budget constraints. No further Hester Dendy's were deployed after the spring retrieval.
- Tidbit loggers were retrieved, but failed to download temperature data and were therefore not reinstalled.
- The staff gauge at Culvert 2 disappeared over the winter and was not re-located or re-installed. As a result there is currently no monitoring occurring at Site D (Culvert 2).

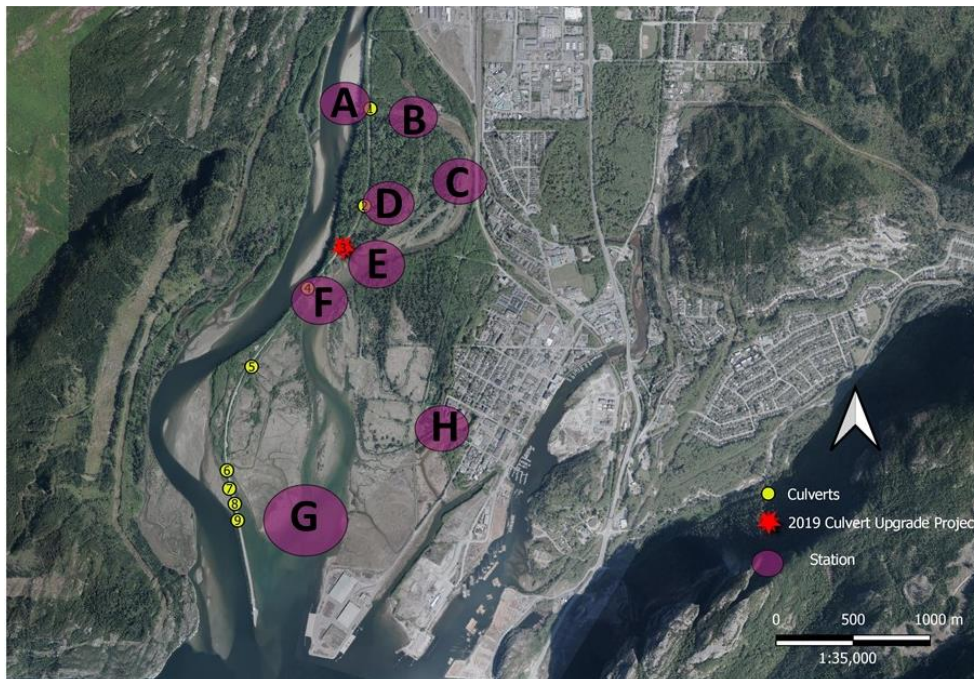


Figure 5: Site locations where monitoring stations were installed in 2018 and 2019 and location of 2019 Culvert 3 Upgrade Project. Large scale maps with monitoring station details for each site are provided in Appendix 1.



Table 1: CEMP Monitoring site locations and metrics collected at each site.

Site	Site Name	Location Description	UTM ¹	Water Level	Conductivity	Temperature	Sediment	Channel	Soils	Vegetation
A	River Station	Logger station installed along left bank of Squamish River 600m upstream of Culvert 1	10U 487884 E 5507607 N	X	X					
B	Culvert 1	Monitoring site is ~300m downstream (east side) of culvert 1. Includes logger station in tidal channel, 2 sediment stations in marsh, 2 channel cross sections, and 4 soil/veg transects adjacent to tidal channel	10U 488177 E 5506994 N	X	X	X	X	X	X	X
C	Bailey Street	Area adjacent to Wilson Slough Intake. Logger Station in Crescent Slough adjacent to Bailey Street and 330m downstream (south) of intake. Two sediment stations and one channel cross section station across main channel.	10U 488530 E 5506410 N		X	X	X	X		
D	Culvert 2	No longer a monitoring station - loss of staff gauge. Possible future monitoring.	10U 487895 E 5506375 N							
E	Culvert 3	Area east of Culvert 3. Includes logger station 70m upstream main tidal channel from where culvert 3 tidal channel enters. Logger station removed for winter season and re-set in spring. Also includes 4 sediment stations-2 in marsh (2018 install), 2 in mudflat (2019 install), and one cross section across culvert 3 tidal channel. 4 veg/soil transects perpendicular to and east of Spit road.	10U 487901 E 5505991 N	X	X	X	X	X	X	X
F	Culvert 4	Area east of Culvert 4. Logger station in Culvert 4 pool. Culvert 4 tidal channel has 2 cross-sections and main channel has 1 cross section 70m downstream (south) of culvert 4 tidal channel confluence. Also includes 4 sediment stations-2 in marsh (2018 install), 2 in mudflat (2019 install). One vegetation transect north and perpendicular to C4 tidal channel.	10U 487530 E 5505810 N	X		X	X	X	X	X
	Culvert 7	Hobo tidbit loggers installed on either side of culvert	10U 486995 E 5504561 N		X					
	Culvert 9	Hobo tidbit loggers installed on either side of culvert	10U 487038 E 5504352 N		X					
G	Lower Estuary	Logger station installed on a piling complex (dolphin) in lower estuary approximately 500m east of Culvert 8. 4 sediment stations: 2 in marsh (2018 install) and 2 in mudflats (2019 install), all on northeast side of main tidal channel in vicinity of logger station.	10U 487516 E 5504466 N	X	X	X	X		X	
H	Cattermole Slough	Logger station installed June 2019 in Cattermole Slough below stinky pond.	10U 488382 E 5504457 N	X	X	X				

1 UTM location is central to all stations at monitoring site.

Monitoring Activities and Results

Water Quality and Levels

Conductivity, Level and Temperature

Hobo loggers used to collect conductivity, water levels and temperature at 30-minute intervals on the hour and half hour. Onset HOB0 dataloggers were used. A barometric logger located at low elevation approximately 5km north of Site A was used to compensate water level data for barometric pressure. Periodic water level measurements collected onsite and used to compare with logged sensor depths, which were used along with the surveyed elevation of the station to correct for water elevation. Logger data was downloaded and compensated using HOB0 ProWARE V 3.7.18 Data Assistants (HOB0ware, n.d.). The loggers used to monitor conductivity were HOB0 U24 model, and those for water level and temperature were the HOB0 U20-04 model. Details on loggers, sites, parameters and compensation parameters are presented in Appendix 2.

Preliminary Analysis 2018-2019

Salinity

The frequency of low, mid and high salinity ranges measured at four stations in the estuary from May 2018 to November 2019 is presented in Appendix 3. Frequencies were calculated based on the number of data points when salinities occurred within the specified ranges within each week of data collected at 30-minute intervals using RStudio software (Version 1.2.5001). Low-range salinity is from 0-5 parts per thousand, mid-range is 5-10 parts per thousand, and high range is > 10 parts per thousand. Observations of frequencies of low, mid and high range salinities for 2018/2019 are below:

- **Station B (Culvert 1):**
 - High range salinities dominated from January through to April, 2019, with mid- and low range salinities as the subdominant condition.
 - Mid-range salinities dominated from April to May, 2019, with very low frequencies of low and high salinities.
 - Low range salinities dominated from June (time of install) to September in 2018, and from May to September in 2019. Mid-range salinities were the subdominant condition during these periods.
 - A high level of mixing occurred between October 2018 to January, 2019
- **Station C (Bailey Street)**
 - The period between January and March was dominated by mid- range salinities, with low range as the subdominant condition.
 - Low range salinities dominated from June (time of install) to October in 2018, and from May to September in 2019. Mid-range salinities were subdominant during these periods, yet occurred infrequently.
 - Two periods of mixing occurred between October, 2018 and January, 2019, and another March and May, 2019.

- **Station D (Culvert 3)**
 - Mixing dominated the salinity profile from April (time of install) to May, 2019.
 - Low range salinities dominated the profile from May to September, 2019. High and moderate salinities occurred infrequently during this period.
 - A transition to high salinities dominating the salinity profile was evident after September, 2019 to the time of dismantling the station in October 2019.
- **Station H (Cattermole Slough)**
 - Low range salinities dominated from the time of install in June to August, 2019. A period of mixing followed until the last logger download for this period in October 2019.

The salinity profile during the spring chinook smolt migration (March to June) is largely influenced by the spring snowmelt freshet in the Squamish River. Before the freshet in 2019, mid-range salinities dominated at Stations B and C. Results for all stations indicate that chinook that time migration with the freshet will experience a dominance of low range salinity conditions during their estuarine residence at Stations B and C.

Temperature and Water Levels

- Weekly minimum, mean and maximum temperatures were investigated during different stages of inundation for three stations (Stations B, F, and G) in Appendix 4. In these charts, “Dry” refers to there being less than 50% of the channel depth wetted, “Tidal Channel Wetted” refers to the frequency of inundation when the tidal channel was >50% wetted up to the marsh edge, and “Wetted” refers to the frequency in which the marsh was inundated.
 - The range in temperatures during different periods of inundation during the known chinook migration period were below the threshold for smoltification impairment in chinook (17°C, Richter & Kolmes (2005))
 - A spike in temperatures during 2019 occurred at all stations and inundation periods in July
 - The greatest range in temperatures appear to occur during periods of marsh inundation at Stations B and F.

Water Profile Monitoring

Water quality profiles at four sites was conducted in the estuary on July 12, 2019 after a period of hot dry weather (Tables 2 and 3, below). The results indicate that the sites most influenced by the river near culvert 3 and 4 (WQ Sites 2019-3 and 4) respectively, overall had colder temperatures and lower salinities. Otherwise stratification in the profiles was not evident, and results indicated high oxygen concentrations and moderate temperatures throughout the water column.

Table 2: Locations where water quality profiles were collected during July 12th, 2019 sampling in the estuary. Sites 2019-1 to 2019-4 follow a north to south trajectory from Station C to Station F.

Date	2019-07-12	2019-07-12	2019-07-12	2019-07-12
Site	2019-1	2019-2	2019-3	2019-4
Location	Crescent Slough near tide gate	South of Station C	lower crescent slough, purple martin box 27	Approx C3 tidal channel
UTM	10U 488545 5506758	10U 488546 5506410	10U 488210 5506112	10U 487815 5506040
Time	15:30	15:53	16:17	16:52
max depth		1.6	2.3	
secchi depth	0.29		0.18	0.19

Table 3: Results of water quality profile sampling in the estuary on July 12th, 2019.

Depth	0	0.5	0	0.5m	1.0m	1.5m	0	0.5	1	2	0	0.5m	1.0m	1.5m
Site	2019-1	2019-1	2019-2	2019-2	2019-2	2019-2	2019-3	2019-3	2019-3	2019-3	2019-4	2019-4	2019-4	2019-4
Temperture (°C)	17.7	17.7	16.6	16.7	16.6	16.7	15.5	15.4	15.4	15.4	13.3	13.3	13.3	13.3
Specific Conductance	5430	5458	3223	3260	3392	3566	2248	2239	2245	2345	964	924	1205	1239
Salinity	2.9	2.9	1.7	1.7	1.7	1.9	1.2	1.2	1.2	1.2	0.5	0.5	0.6	0.7
% DO	97	96	106	103	102	107	110	110	109	104	116	115	114	112
DO ppm	9.0	9.0	10.2	10.0	9.9	9.8	11.0	10.9	10.9	10.3	12.1	12.0	11.7	11.7

Tidal Channel Dimensions

Tidal channel dimensions were surveyed along cross sections with rod and level at low tide. Re-bar pins were installed to permanently mark the termini of each cross section on the tidal channel banks. Right and left tidal channel banks (denoted as RB and LB) are defined by the tidal channel bank location when facing downstream, or with the outgoing tide. Cross sections established in 2018 were re-surveyed in 2019 at Sites A, E, and F. A new cross section was established in 2019 at Site B. Details of locations of cross sections and their profiles are provided in Appendix 1. Table 4 provides an overview sampling effort. Results of tidal channel measurements corrected for elevation are provided in Appendix 5.

Table 4: Tidal channel dimensions surveys sampling dates.

Station	Name	2018 Survey	2019 Survey
B	C1-CS1	10-Aug	27-Aug
B	C1-CS2	10-Aug	27-Aug
C	BS-CS1		29-Aug
E	C3-CS1	25-Jun	14-Jun
F	C4-CS1	14-Jun	15-Aug
F	C4-CS2	15-Jun	15-Aug

Sediment Stations

Sediment stations were installed in 2018 and 2019 to monitor changes in sediment elevation in tidal marsh and mudflat habitats throughout the central estuary (Table 5). Appendix 1 provides the locations of sediment stations. Sediment stations involve rebar pins placed approximately 1.1m apart and levelled. Each year they are surveyed and re-set if not level, and measures are taken from pin height to ground surface every 10cm between the pins. Results are corrected for elevation for comparison to previous years. Results to date are presented in Appendix 6.

Table 5: Summary of Sediment Stations installed in the Squamish estuary from 2018-2019. All stations measured annually except LE-SS5 (due to access constraints).

Site	Site Name-Other	Station Name	Date Installed
B	Culvert 1	C1-SS1	2018-08-10
B	Culvert 1	C1-SS2	2018-07-04
C	Bailey Street	BS-SS1	2019-08-26
C	Bailey Street	BS-SS2	2019-08-26
E	Culvert 3	C3-SS1	2018-06-25
E	Culvert 3	C3-SS2	2018-06-25
E	Culvert 3	C3-SS3	2019-08-16
E	Culvert 3	C3-SS4	2019-08-16
F	Culvert 4	C4-SS1	2018-06-14
F	Culvert 4	C4-SS2	2018-06-15
F	Culvert 4	C4-SS3	2019-08-14
F	Culvert 4	C4-SS4	2019-08-14
G	Lower Estuary	LE-SS1	2018-08-15
G	Lower Estuary	LE-SS2	2018-08-15
G	Lower Estuary	LE-SS3	2019-08-02
G	Lower Estuary	LE-SS4	2019-08-02
G	Lower Estuary	LE-SS5	2018-08-15

Soils and Vegetation Plots

The first vegetation and soil surveys were conducted in salt marsh ecosystems of the Central estuary in 2019. This involved mapping the perimeter of saltmarsh ecosystems, surveying vegetation and soil plots and conducting vegetation transects. A total of 11 transects, 39 vegetation plots, and 20 soil plots were assessed from June to August, 2019 (Table 6, Table A-1). All transects had vegetation zonation information collected, while eight also had vegetation and soils plot data. The methods of soil and vegetation sampling are described here.

Table 6: Vegetation and soils sampling effort for 2019

Station Sampled	Strata	Number of Transects	Number of Soil Plots	Number of Vegetation Plots	Vegetation Polygons
B	S9	4	9	14	No
E	S8.1	5	11	25	No
F	S8.2	1	0	0	Yes
G	S7	1	0	0	No

Transect locations were determined differently for each area:

- In Area B, four transects were set, each perpendicular to the tidal channel from the channel cross section pegs installed in 2018. The end of each the transects in Area B occurred where it met the terrestrial ecosystem.
- In Area E, five transects were set parallel to one another, starting from the edge of the Spit road, spaced 50m apart and projecting 125° towards the estuary. These transects ended where they met extended mudflat or tidal channel.
- In Area F, a single transect that collected only zonation data extended parallel to the terrestrial area. It began at the edge of a new vegetation zone not included in Area E transects and ended where it met the Culvert 4 tidal channel.
- In Area G, a single transect that collected only zonation data extended between the terrestrial area adjacent to Spit Road to the mudflats.

The areas assessed for soils were focused at Area B (control), and Area E (Culvert 3 Upgrade project site). Vegetation was assessed at Areas B, E, F, and G. Vegetation and soil survey locations are provided in Appendix 1.

Saltmarsh Community Delineation

On May 30th, 2019, the perimeter of saltmarsh habitats was delineated using the track function on a Garmin Csx GPS at Station F. Station F was done in the area of Culvert 4, south of the 2019 Culvert 3 culvert upgrade. Saltmarsh communities were mapped using the track feature on a Garmin GPSMap 64st (record method set at Auto) while the operator walked the perimeter of each polygon. The perimeter of vegetation communities were determined where mudflat transitioned to >50% vegetated, or along the midpoint at the transition from one community type to another.

Vegetation Zone Transects

All transects were assessed for dominant and subdominant vegetation during peak growing season from June through to August. This involved marking a waypoint at transitions where vegetation changed significantly to a different community type, or zone. Where transitions were not clear, the boundaries were determined to be midway between one community type to another. Zones were assessed along a 5m strip along each transect. Transects in Areas B and E were assessed with a measuring tape, and in Areas F and G using GPS and compass.

Vegetation and Soil Plots

Vegetation and soils are expected to change over time and with restoration efforts. Vegetation information was collected to identify baseline conditions and to monitor changes in the extent and type of vegetation communities. Soil cores were collected for each vegetation plot to characterize organic content associated with each vegetation type.

It is expected that improving river and estuarine connectivity will increase the area and diversity of saltmarsh ecosystems, and in turn will increase carbon storage in estuarine soils. Salt marsh habitat is beneficial for fish and wildlife for forage and refuge opportunities offered by it when the marsh is inundated. A diversity of salt marsh vegetation types is expected to support a diversity of forage

opportunities for chinook and other species. Carbon sequestration has wider benefits as it helps to alleviate climate change. In general success of restoration activities for salmon will be measured and monitored according to the guidelines in

Table 7: Measures of restoration success for vegetation and soils, including monitoring period after restoration is complete.

Metric	Measure	Monitoring Period
Total salt marsh area	m2	Years 1, 5, and 10
Salt Marsh Diversity	Community diversity	Years 1, 5, and 10
	Species diversity	Years 1, 5, and 10
Soil carbon	bulk density	Years 1, 5, and 10
	TOC in top 20cm of soil	Years 1, 5, and 10

Plot establishment

Plots were established in the saltmarsh zones. Plot locations were pre-determined based on zonation and their starting point. The starting point for determining plot locations was either:

- At the start of the transect, unless the first zone of the transect had terrestrial vegetation
- At the start of the saltmarsh habitat
- At the start of a new vegetation zone, or community type.

Plots were determined for each vegetation zone as follows:

- Soil plots were surveyed after the first 10m into the zone, then every 50m after that, until a new zone was encountered.
- Vegetation Plots were surveyed after the first 10m into the zone, then every 15m after that, until a new zone was encountered.

Vegetation Plots

At each vegetation plot, species and coverage within a 1m² quadrat were documented. Where unknown species were encountered, they were labelled with a unique number and photos were taken for later identification.

Soil Plots

A 3" PVC soil core tube was used to extract up to 50cm of soil for analysis. The core was sharpened on one edge to help cut through near-surface root systems. To account for sample compression, measurements of the bore hole depth relative to penetration depth was done periodically at 5cm, 10cm, 20cm, 30cm, and 50cm depths (or the maximum depth attained if less than 50cm). The core tube was penetrated first with a twisting motion to cut roots and pushed in by hand until there was too much resistance. Then a rubber mallet was used to pound the core in the remaining depth. Prior to extraction, the core tube was capped and sealed, then pulled out with a twisting motion, taking care not to lose any out the bottom. Once extracted, a plunger was used to push the soil core from the tube onto a tray. The sample was laid out, measured and photographed. One or more samples were then collected for lab analysis, followed by field sampling.

Samples collected for laboratory analysis targeted the organic layer. Where the organic layer did not fluctuate in colour before it met the inorganic layer, one sample of 3-5cm in length was collected.

Where the colour changed throughout the organic layer but without any abrupt transition, two samples of 3-5cm length were collected. Samples were placed in labelled metal containers for later analysis. Immediately after each days' sampling, soil samples were placed in a dry area and allowed to air dry before sealing. This often took several weeks and required periodically breaking up the sample to enhance air drying.

Samples were dried in an oven and weighed to determine bulk density. Subsamples of select transects were then sent to the Provincial Chemistry Analytical Lab in Victoria to be tested for Total Organic Carbon. Results were unavailable for the time of this report from this lab.

Results

- Maps showing vegetation and soil sampling is provided in Appendix 1. A map of vegetation polygons determined using saltmarsh delineation and vegetation transects (described above) is presented in Appendix 1.
- Vegetation community data will be assessed in 2020
- Baseline soil bulk density and Total Organic Carbon results for Stations B and E are provided in Appendix 6 Table A-3.

Photopoint Monitoring

Photopoints of locations along the Central estuary from Station B to Station E were collected in 2018 and 2019. In 2019, 15 new photopoints were established for a total of 23 for 2018 and 2019 at Sites B, D, E, and F. Table A-4 in Appendix 7 provides details on photopoint locations and descriptions.

Plans for 2020 Biophysical Monitoring

- Repairs and maintenance to logger stations as necessary
- Reinstallation of Station E loggers for spring and summer
- Download and relaunch loggers
- Installation of new reference station (Fries Creek)
- Install water level logger at Station C
- Install surface temperature loggers at Stations G and new reference station
- Assess extent of salinity wedge in river at high tide prior to freshet
- Water quality profiles along estuarine gradient in Central estuary during spring and summer high tides before and after freshet
- Re-survey loggers against new benchmarks (to be established by Bunbury)
- Tidal channel dimension surveys;
- Sediment accretion pin measurements;
- Updates on mapping as required

- Photopoint monitoring

Also planned for the 2020 monitoring season is the first evaluation of the effects of the Culvert 3 upgrade project on water temperature and salinity by comparing 2018 (before culvert upgrade) results to 2019 and 2020 salinity and temperature data using salinity and temperature data from Station B as a control, and from Station E as a treatment. This report provides a preliminary analysis of this data with 2018 and 2019 data. Other metrics (channel dimensions, sediment stations, and vegetation/soils) are expected to require longer term monitoring to identify changes as a result of the 2019 Culvert 3 upgrade project.

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Conclusions

2018-2019 Summary

2019 was a successful monitoring season for the Central Estuary Restoration Project. Stations installed in 2018 were resurveyed, with very few problems of damage or loss over the winter season. The culvert installation at Site E was successful and provides an early opportunity to monitor restoration success. Surveying of all stations has allowed for comparison between stations and will be useful for other studies that are modeling sediment and water level characteristics before and after proposed restoration options. The information collected covers the range of information required to understand how changes from restoration will affect refuge, forage, and physico-chemical environment for juvenile Chinook as they move through and reside in the estuary. Results have also informed biophysical monitoring activities for 2020, including the establishment of a reference station on the west side of the Squamish River at Fries Creek. Results have not been fully compiled and analyzed as of the time of this report, however early analysis indicates opportunities to compare baseline conditions to future restoration in all areas of the monitoring program.

Outreach and Education

The CEMP has also provided opportunities to engage and educate others. Estuary tours of the monitoring components have been provided to university classes, stakeholders, and the public through on-site queries and the SRWS AGM. A digital presentation that summarizes the 2018-2019 monitoring program has also been uploaded to the Salish Sea Conference website. The Central Estuary Monitoring Program provides a showcase of ecosystem-based management that will help inform restoration success and opportunities to expand the monitoring program into future restoration projects.



Figure 6: Oblique view north of the Squamish River Estuary in June, 2017. Photo courtesy of John Buchannan.

Appendices

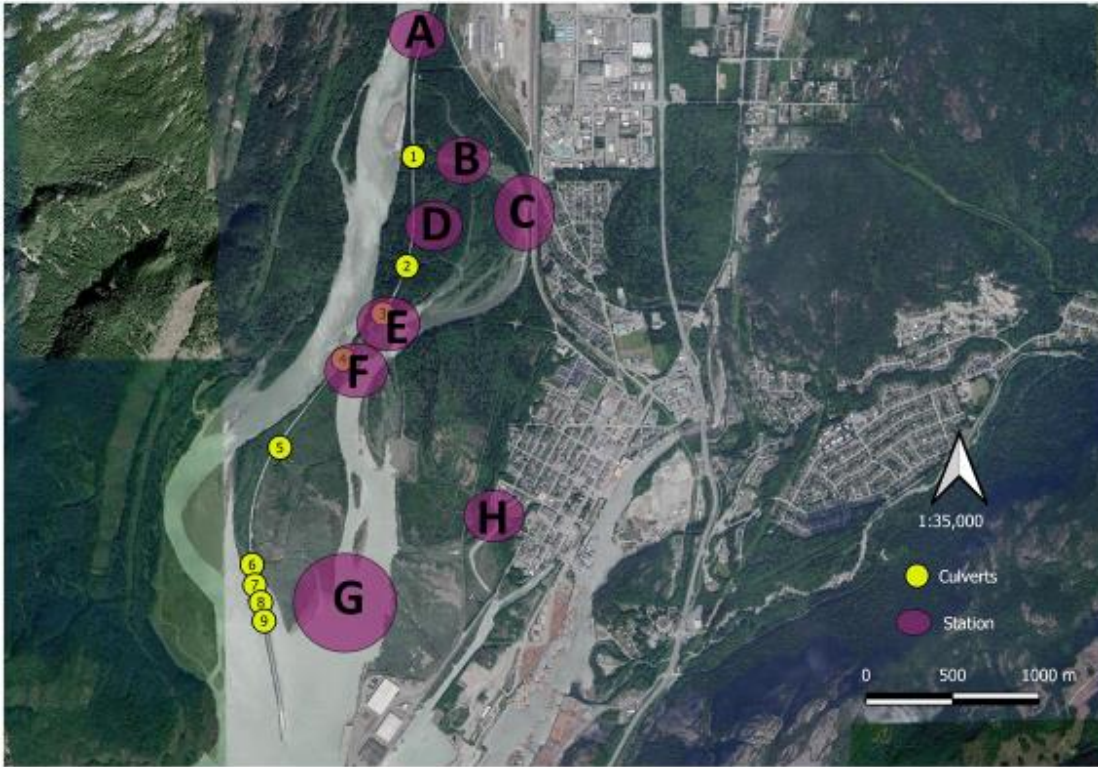
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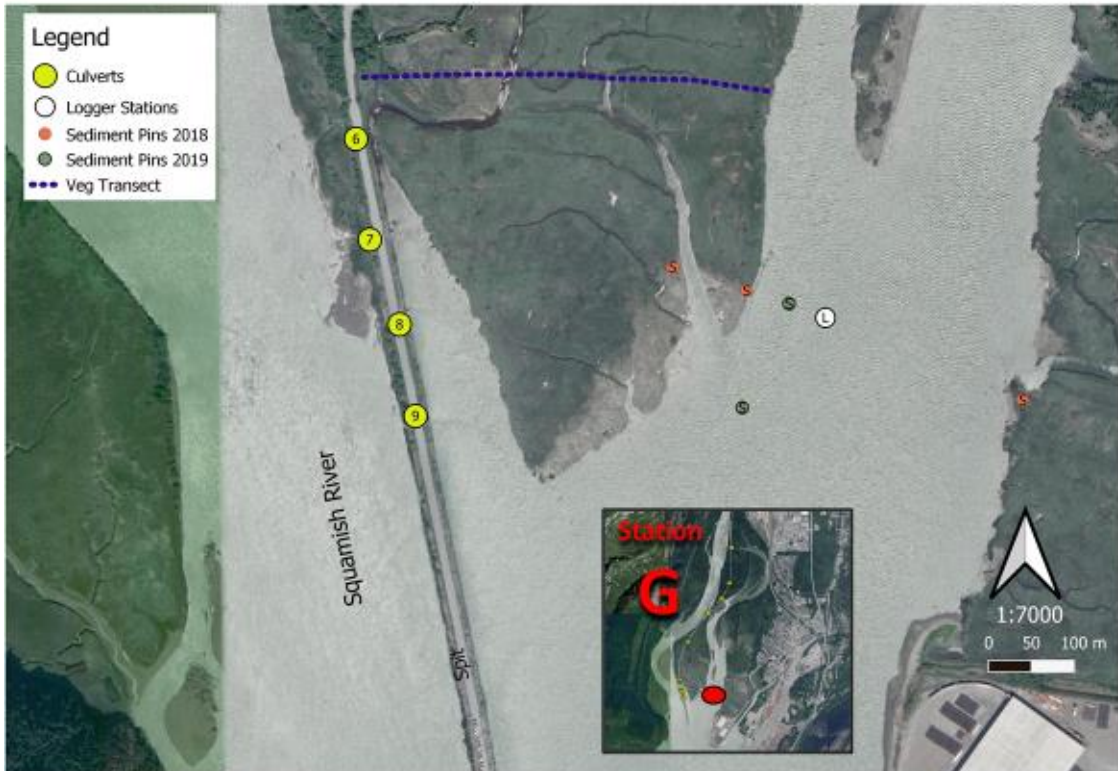
Appendix 1: Monitoring Stations: Site locations and Maps

Table A- 1: Monitoring site codes, descriptions and coordinates for 2018-2019 CEMP activities.

Station	Monitoring Location	Name Code	Type	Description	UTM
A	River Logger	RL	Level/temp logger in river	Left bank of river 600m upstream from Culvert 1	10 U 487884 5507607
B	Culvert 1	C1	Culvert Location	Culvert at road crossing	10 U 487904 5507015
		C1-LL, C1-CL	Logger Station	In pool downstream of culvert. Both Level Logger (LL) and Conductivity Logger (CL)	10 U 488177 5506994
		C1-SS1	Sediment Station 1	In marsh on LB long tidal channel downstream of culvert	10 U 488224 5506994
		C1-SS2	Sediment Station 2	In marsh on RB long tidal channel downstream of culvert	10 U 488220 5506972
		C1-CS1-LB	Channel Cross Section 1 LB	Along tidal channel downstream of culvert	10 U 488148 5506973
		C1-CS1-RB	Channel Cross Section 1 RB	Along tidal channel downstream of culvert	10 U 488151 5506970
		C1-CS2-LB	Channel Cross Section 2 LB	Along tidal channel downstream of culvert	10 U 488199 5506992
		C1-CS2-RB	Channel Cross Section 2 RB	Along tidal channel downstream of culvert	10 U 488197 5506985
		S9T1	Veg/Soil Transect 1	67 m in length at 130 degrees from C1-CS2-RB Pin	10 U 488197 5506985
		S9T2	Veg/Soil Transect 2	40 m in length at 310 degrees from C1-CS2-LB Pin	10 U 488199 5506992
		S9T3	Veg/Soil Transect 3	40 m in length at 190 degrees from C1-CS1-RB Pin	10 U 488151 5506970
		S9T4	Veg/Soil Transect 4	40 m in length at 10 degrees from C1-CS1-LB Pin	10 U 488148 5506973
		C	Bailey Street	BS-CL	Logger Station
BS-SS1	Sediment Station 1			on mudflat west of main tidal channel across from Wilson Slough Intake	10 U 488525 5506627
BS-SS2	Sediment Station 2			on mudflat west of main tidal channel and south of BS-SS1	10 U 488521 5506576
BS-CS1	Channel Cross Section 1 LB			In marsh on LB (east) of tidal channel upstream of Wilson Slough pump station. LB Pin is 8.4m and 200° to the middle piling.	10 U 488562 5506659
BS-CS1	Channel Cross Section 1 RB			In marsh on RB of tidal channel upstream of the yellow gated pump station. RB Pin is 4m and 270° to second spruce from north end of terrestrial island on RB.	10 U 488527 5506662
E	Culvert 3	C3	Culvert Location	Culvert at road crossing	10 U 487708 5506108
		C3-LL	Logger Station	In Crescent Slough upstream of Culvert 3 tidal channel outflow. Level Logger (LL) only.	10 U 487901 5505991
		C3-SS1	Sediment Station 1	In marsh on RB long tidal channel downstream of culvert. 35m @ 195° from C3-LB Pin	10 U 487779 5506081
		C3-SS2	Sediment Station 2	In marsh on LB long tidal channel downstream of culvert	10 U 487739 5506053
		C3-SS3	Sediment Station 3	In mudflat northeast of C3 channel confluence with main channel	10 U 487844 5506009
		C3-SS4	Sediment Station 4	In mudflat southwest of C3 channel confluence with main channel	10 U 487820 5505985
		C3-CS1-LB	Channel Cross Section 1 LB	Along tidal channel downstream of culvert	10 U 487782 5506100
		C3-CS1-RB	Channel Cross Section 1 RB	Along tidal channel downstream of culvert	10 U 487749 5506057
F	Culvert 4	C4	Culvert Location	Culvert at road crossing	10 U 487494 5505851
		C4-LL	Logger Station	In pool downstream of culvert. Level Logger (LL) only.	10 U 487512 5505828
		C4-SS1	Sediment Station 1	In marsh on RB long tidal channel downstream of culvert	10 U 487567 5505786
		C4-SS2	Sediment Station 2	In marsh on LB long tidal channel downstream of culvert	10 U 487532 5505777
		C4-SS3	Sediment Station 3	in mudflat	10 U 487586 5505740
		C4-SS4	Sediment Station 4	in mudflat	10U 487574 5505719
		C4-CS1-LB	Channel Cross Section 1 LB	Along tidal channel downstream of culvert	10 U 487545 5505812
		C4-CS1-RB	Channel Cross Section 1 RB	Along tidal channel downstream of culvert	10 U 487532 5505793
		C4-CS2-LB	Channel Cross Section 2 LB	Along tidal channel downstream of culvert	10 U 487561 5505791
		C4-CS2-RB	Channel Cross Section 2 RB	Along tidal channel downstream of culvert	10 U 487537 5505785
G	Lower Estuary	LE-LL, LE-CL	Logger Station	On a piling complex (dolphin) in lower estuary	10 U 487516 5504466
		LE-SS1	Sediment Station 1	In marsh on RB long tidal channel downstream of culvert	10 U 487338 5504526
		LE-SS2	Sediment Station 2	In marsh on LB long tidal channel downstream of culvert	10 U 487424 5504498
		LE-SS3	Sediment Station 3	In mudflat north of tidal channel	10 U 487474 5504483
		LE-SS4	Sediment Station 4	In mudflat south of tidal channel	10 U 487419 5504362
		LE-SS5	Sediment Station 5	on east side of central estuary tidal channel adjacent ~330m north of Squamish Terminals	10 U 487746 5504370
H	Cattermole Slough	CS-LL	Logger Station	In Cattermole Slough 50m downstream (south west) of s/w pond tide gate	10 U 488382 5504894









Appendix 2. Logger Station Specifications and Download Schedule

Table A- 2: Logger locations, measurement parameters (PARA1, PARA2), compensation parameters, and serial numbers. All level loggers, including the barometric logger were Onset Hobo U20L-04 Model. All conductivity loggers were HOBO U24 Model.

Site	Site Name	Para1	Para2	Compensation Parameters	Serial	Notes
A	River Station	level	temperature	Fluid Density = 1000.000kg/m3 (freshwater)	20452130	Logger missing after Oct 2019 download/relaunch date: scheduled for replacement in spring 2020
B	Culvert 1	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	20297575	
B	Culvert 1	level	temperature	Fluid Density = 1010.000kg/m3 (brackish water)	20331503	removed on Aug 8/2018 for warranty, replaced with new logger
B	Culvert 1	level	temperature	High Range, non-linear Sea Water (PSS-78)	20292488	new logger install
C	Bailey Street	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	10888814	
E	Culvert 3	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	20539332	removed for winter season 2019/2020
E	Culvert 3	level	temperature	Fluid Density = 1010.000kg/m3 (brackish water)	20292490	removed for winter season 2019/2021
F	Culvert 4	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	10888815	Logger failed after July 17, 2018 . Not replaced.
F	Culvert 4	level	temperature	Fluid Density = 1000.000kg/m3 (freshwater)	20331502	
G	Lower Estuary	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	20297576	
G	Lower Estuary	level	temperature		20331336	
H	Cattermole Slough	conductivity	temperature	High Range, non-linear Sea Water (PSS-78)	20539331	
H	Cattermole Slough	level	temperature	Fluid Density = 1010.000kg/m3 (brackish water)	20508109	
N/A	Brackendale	barometric pressure	temperature	n/a	20292489	

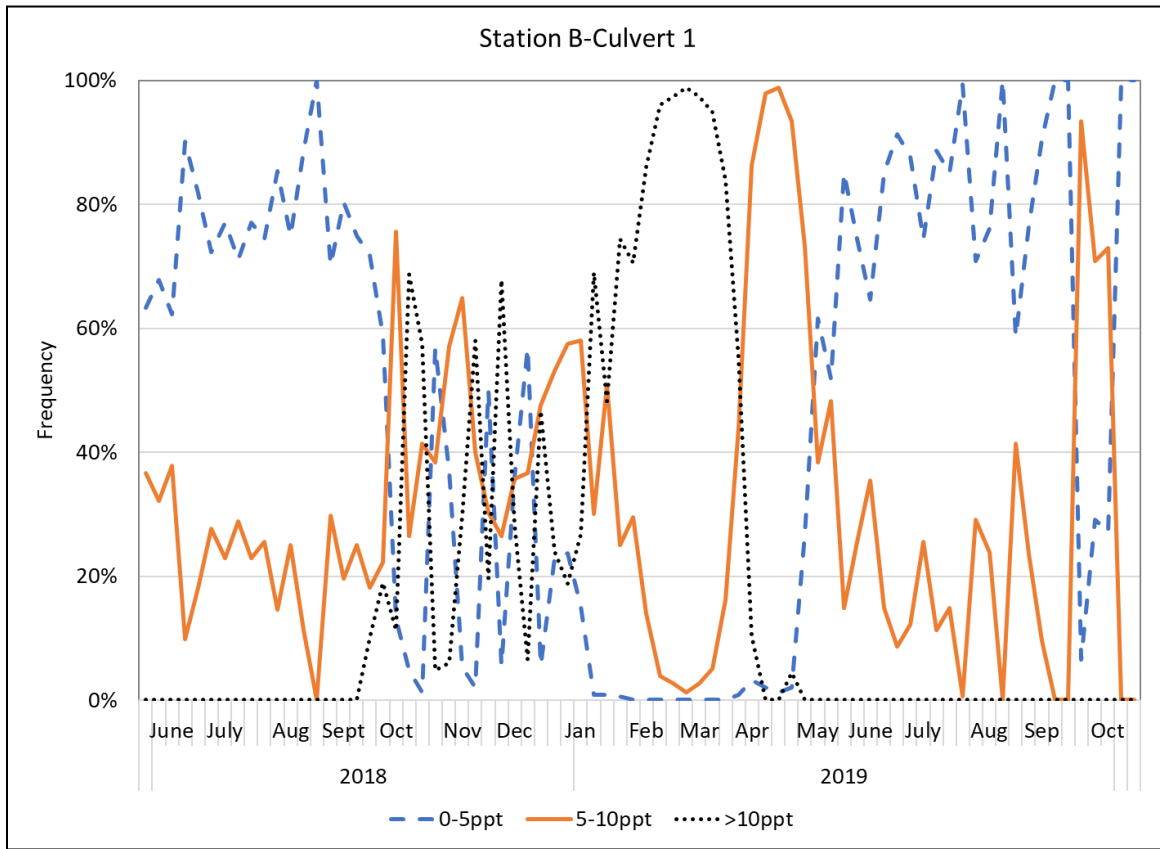
Table A- 3: Table of conductivity logger launch, download and retrieve dates for 2018 and 2019. Each subsequent logger date refers to a download and relaunch between logging intervals. Retrieve dates refer to dates when the logger was retrieved for download. If a retrieved logger was re-launched at a later date, this is indicated in a new row under "Logger Launch Date".

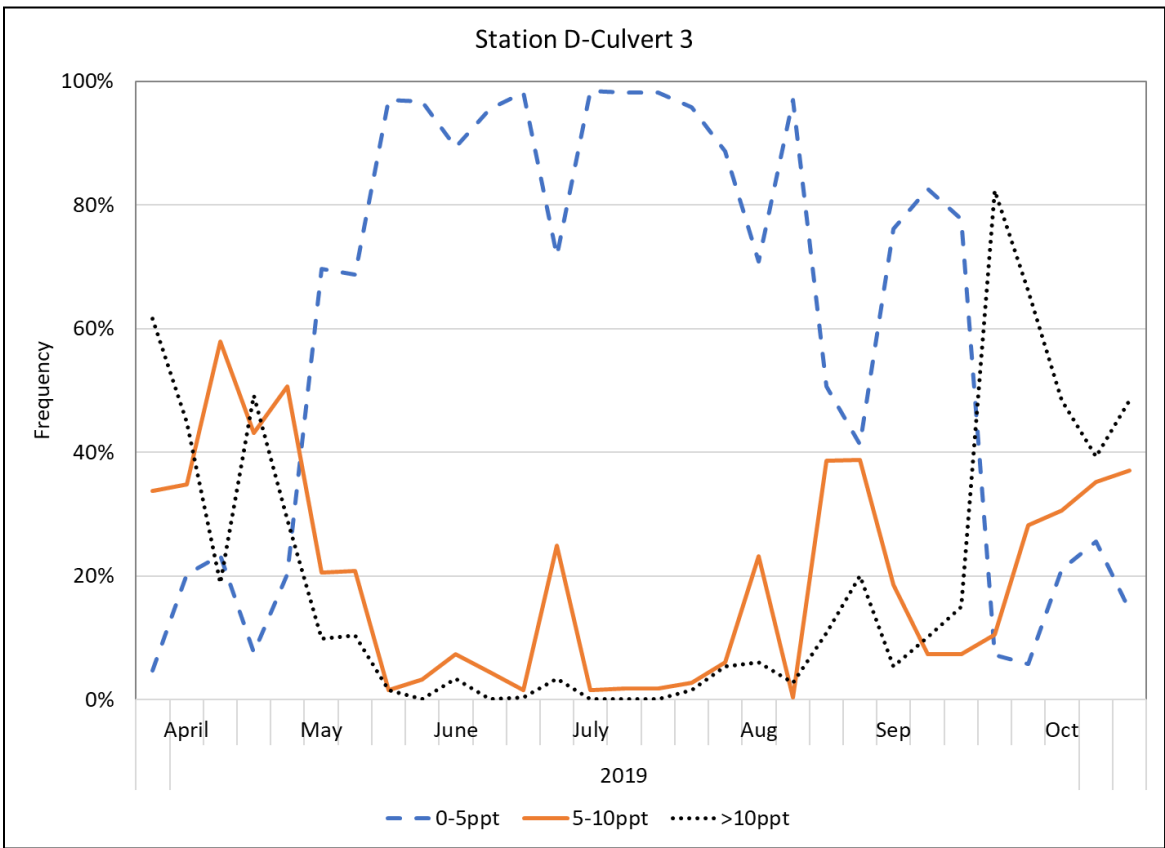
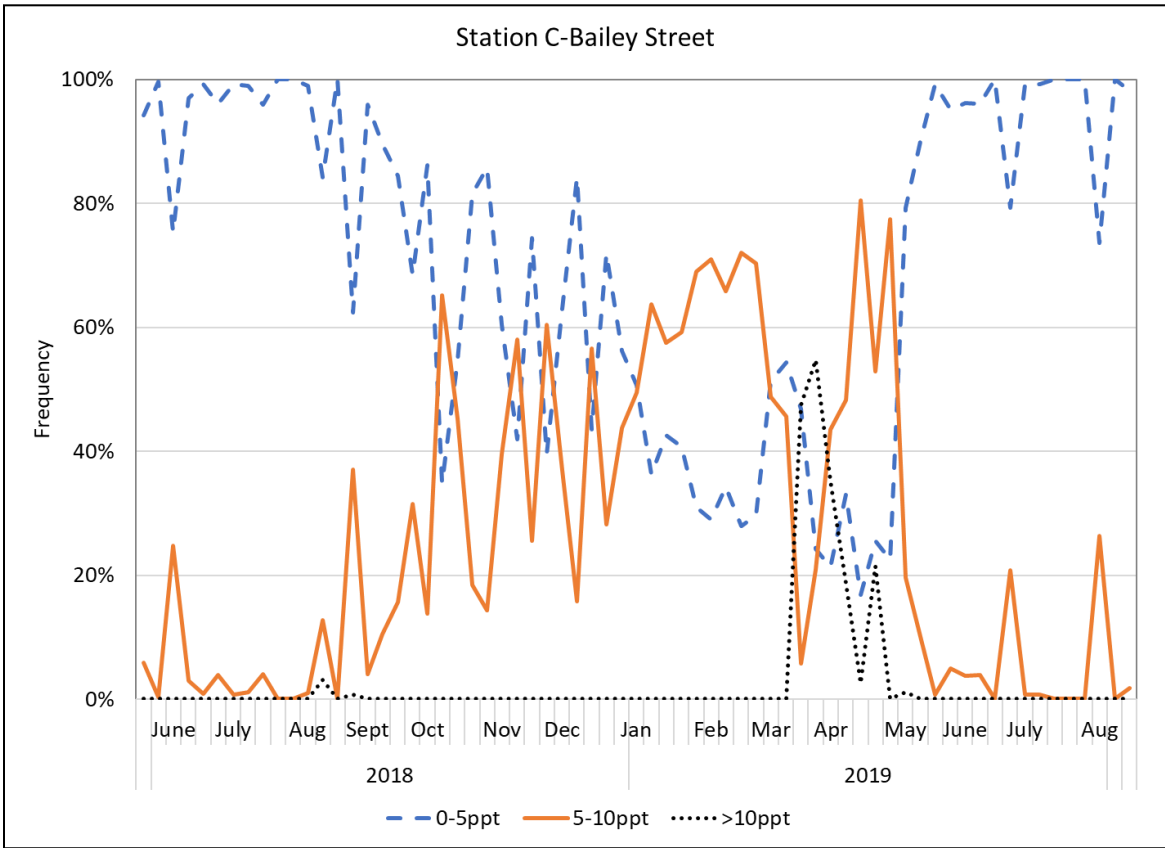
Name	Site	Logger Launch Date	Logger Date1	Logger Date2	Logger Date2	Logger Date4	Logger Date5	Logger Date6	Logger Retrieve Date	Notes
C1-CL	B	2018-05-29	2019-06-13							
BS-CL	C	2018-05-13	2019-03-26	2019-06-13	2019-08-27					
C3-CL	E	2019-04-08	2019-06-13	2019-08-27	2019-10-28					
C4-CL	F	2018-05-28							2018-07-17	Logger battery stopped, not replaced after July 17, 2018 download
LE-CL	G	2018-05-29	2018-08-10						2018-10-04	download and relaunch
LE-CL	G	2018-10-05	2019-01-19	2019-03-25	2019-06-14	2019-08-28	2019-11-16			
CS-CL	H	2019-06-19	2019-07-15	2019-08-28	2019-10-28					

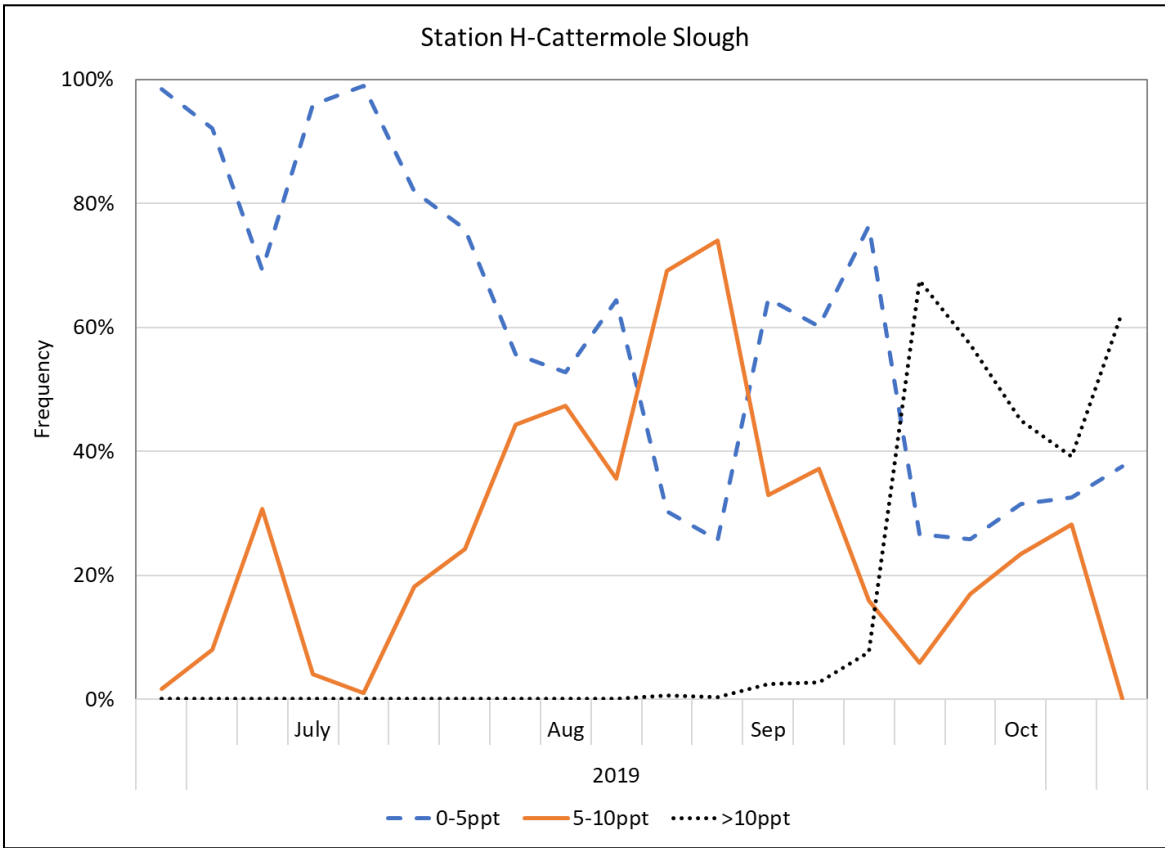
Table A- 4: Table of level logger launch, download and retrieve dates for 2018 and 2019. Each subsequent logger date refers to a download and relaunch between logging intervals. Retrieve dates refer to dates when the logger was retrieved for download. If a retrieved logger was re-launched at a later date, this is indicated in a new row under “Logger Launch Date”.

Name	Site	Logger Launch Date	Logger Date1	Logger Date2	Logger Date2	Logger Date4	Logger Date5	Logger Date6	Logger Retrieve Date	Notes
Baro	N/A	2018-05-28	2018-07-17	2018-10-04	2019-03-26	2019-07-15	2019-09-03	2019-12-06	2019-12-06	
R-LL	A	2018-10-11	2019-01-16	2019-03-25	2019-07-15	2019-08-28	2019-10-27			Logger gone after last retrieve data, scheduled for replacement in 2020
C1-LL	B	2018-05-29	2018-07-17	2018-08-08					2018-08-08	removed on Aug 8 for warranty, replaced with new logger
C1-LL	B	2018-10-05	2019-06-13	2019-10-27						
C3-LL	E	2018-05-28	2018-07-17	2018-10-04	2019-01-19				2019-03-25	Missing data between March 25 and April 8, 2019
C3-LL	E	2019-04-08	2019-06-13	2019-08-27					2019-10-28	Logger removed for season Oct 28, 2019
C4-LL	F	2018-05-28							2018-07-17	logger stopped for download
C4-LL	F	2018-07-17							2018-10-04	logger stopped for download
C4-LL	F	2018-10-05	2019-03-25	2019-06-14	2019-08-28	2019-10-28				
LE-LL	G	2018-06-13	2018-08-10						2018-10-04	download and relaunch
LE-LL	G	2018-10-05	2019-01-19	2019-03-25	2019-06-14	2019-08-28	2019-11-16			
CS-LL	H	2019-06-19	2019-07-15	2019-08-28	2019-10-28					

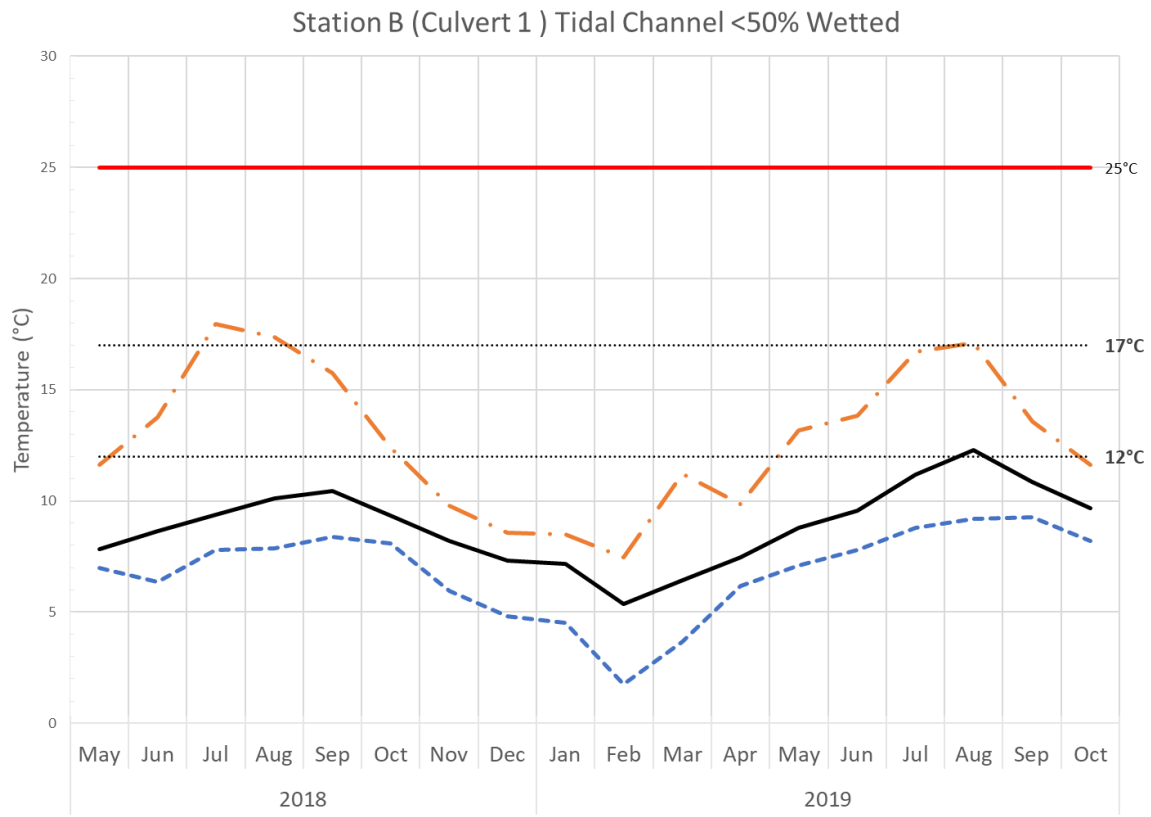
Appendix 3: Salinity Charts for Stations B, C, E, and G



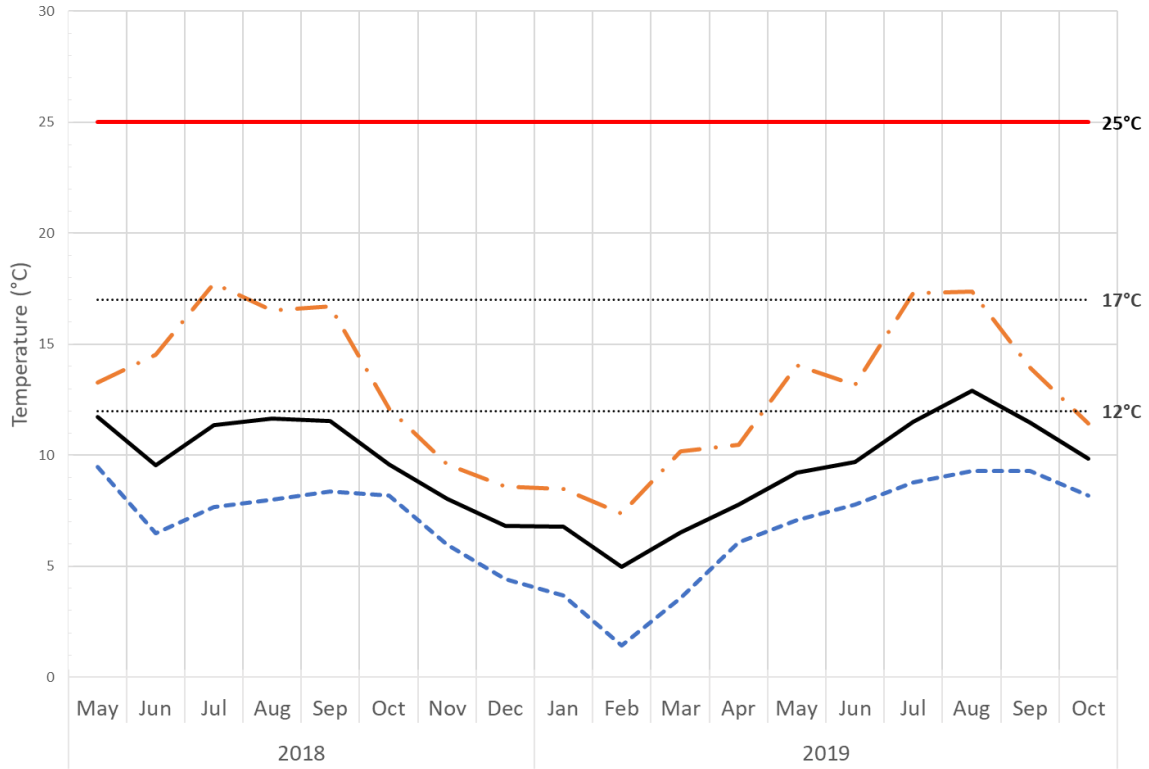




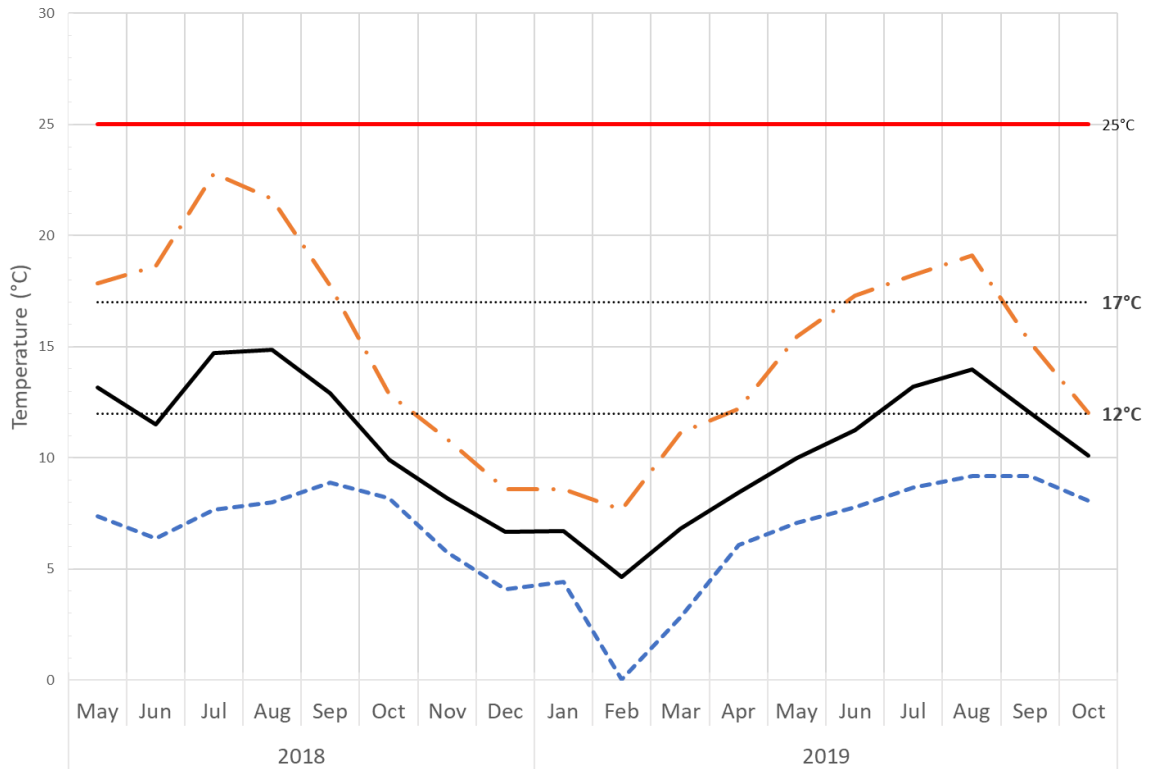
Appendix 4: Temperature and Water Level Charts for Stations B, E, and F



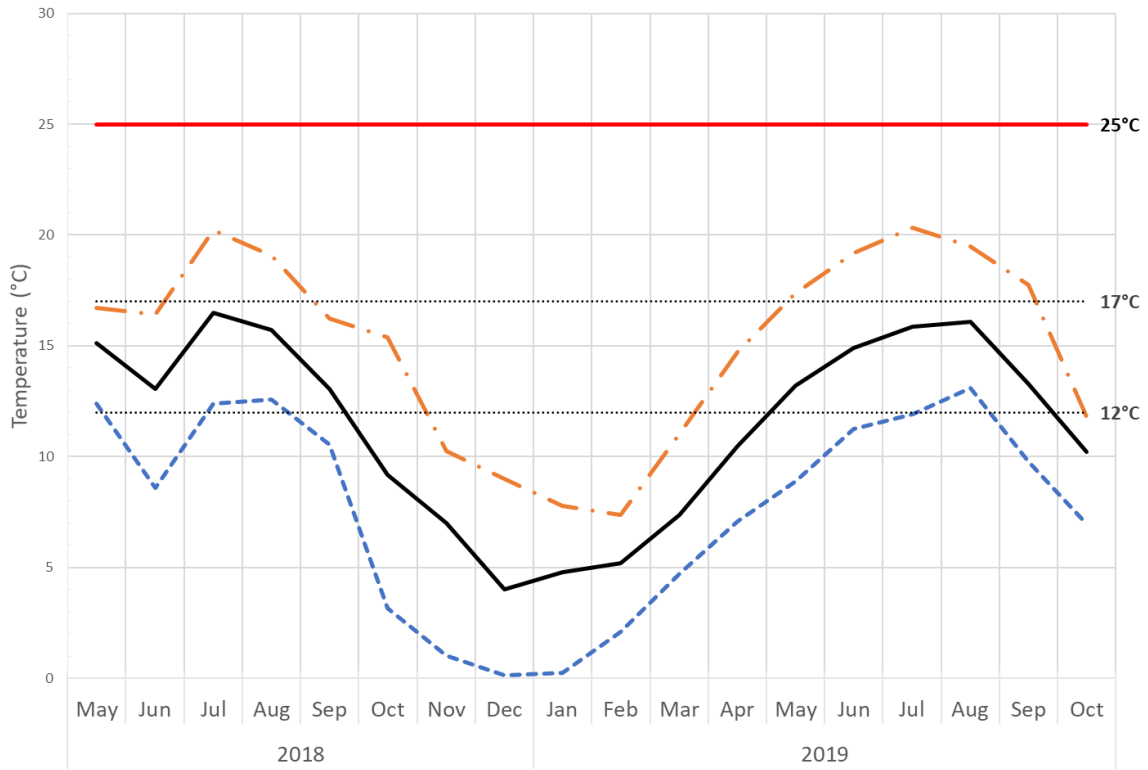
Station B (Culvert 1) Tidal Channel Wetted



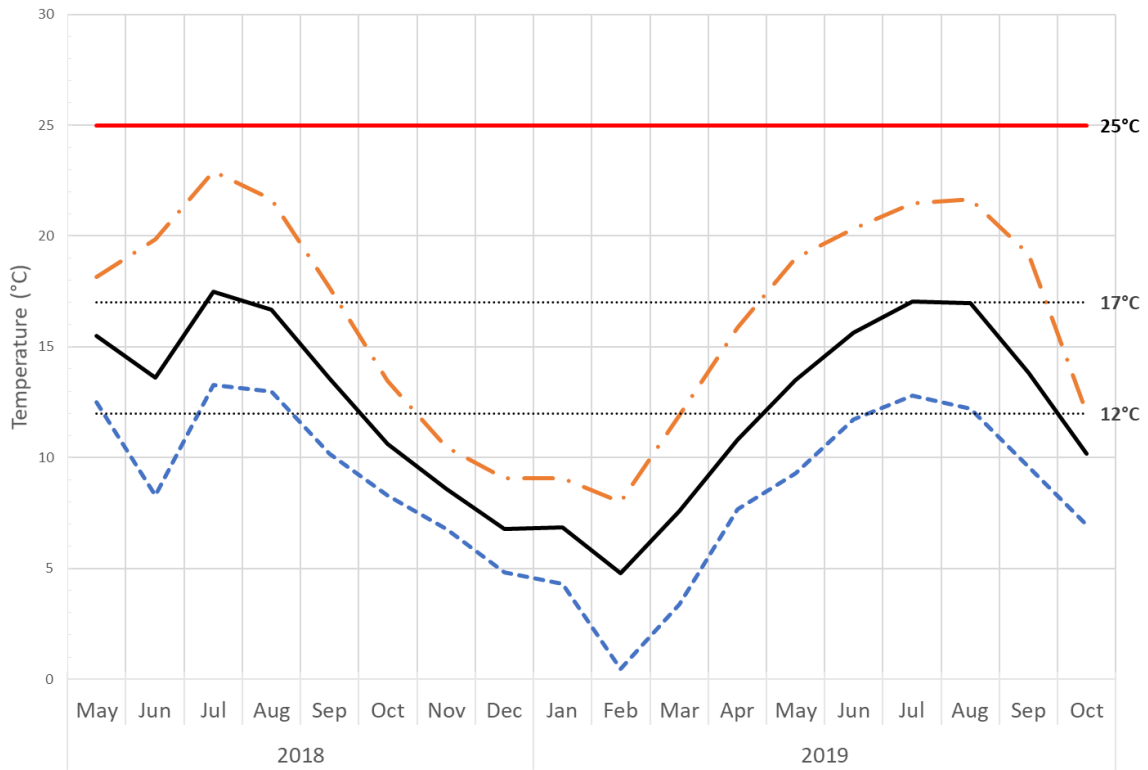
Station B (Culvert 1) Marsh Wetted



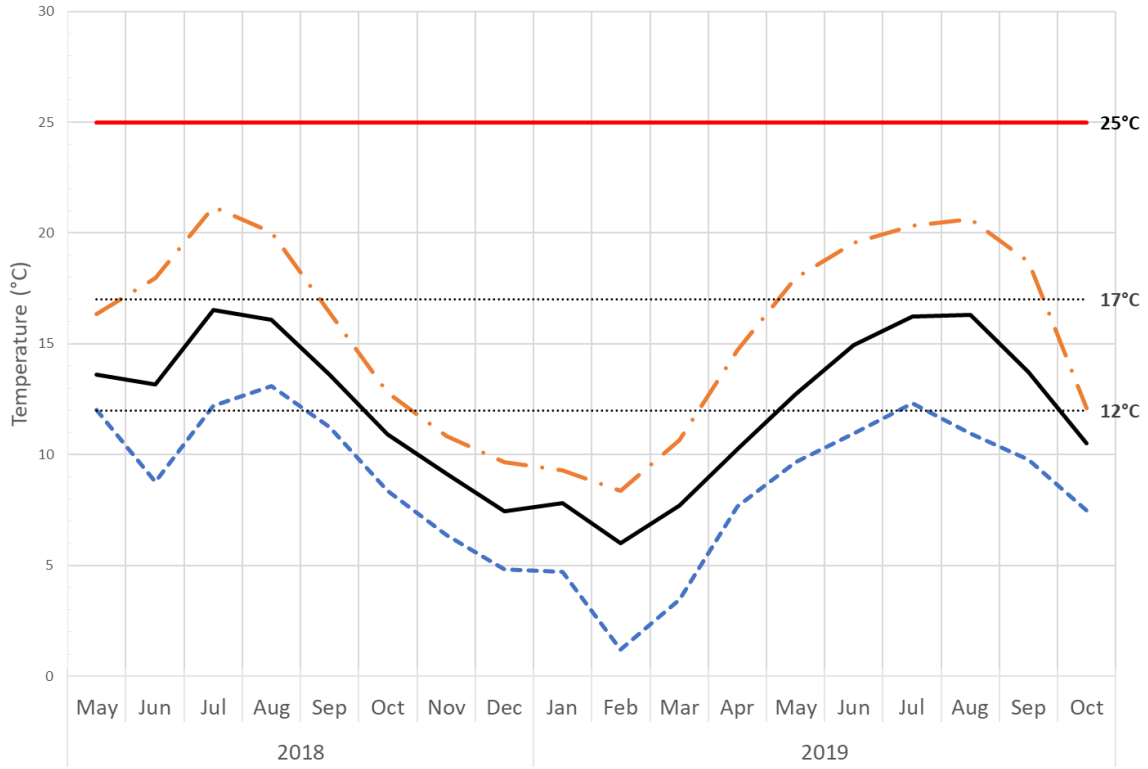
Station E (Culvert 3) Tidal Channel <50% Wetted



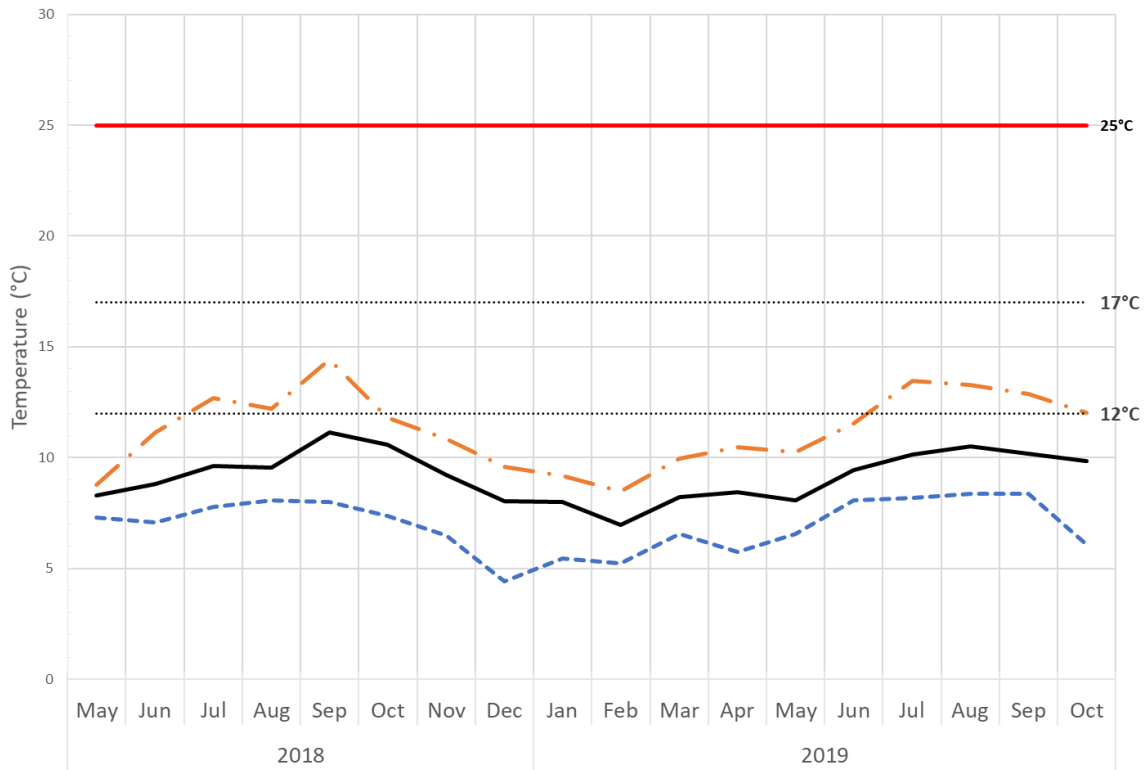
Station E (Culvert 3) Tidal Channel Wetted



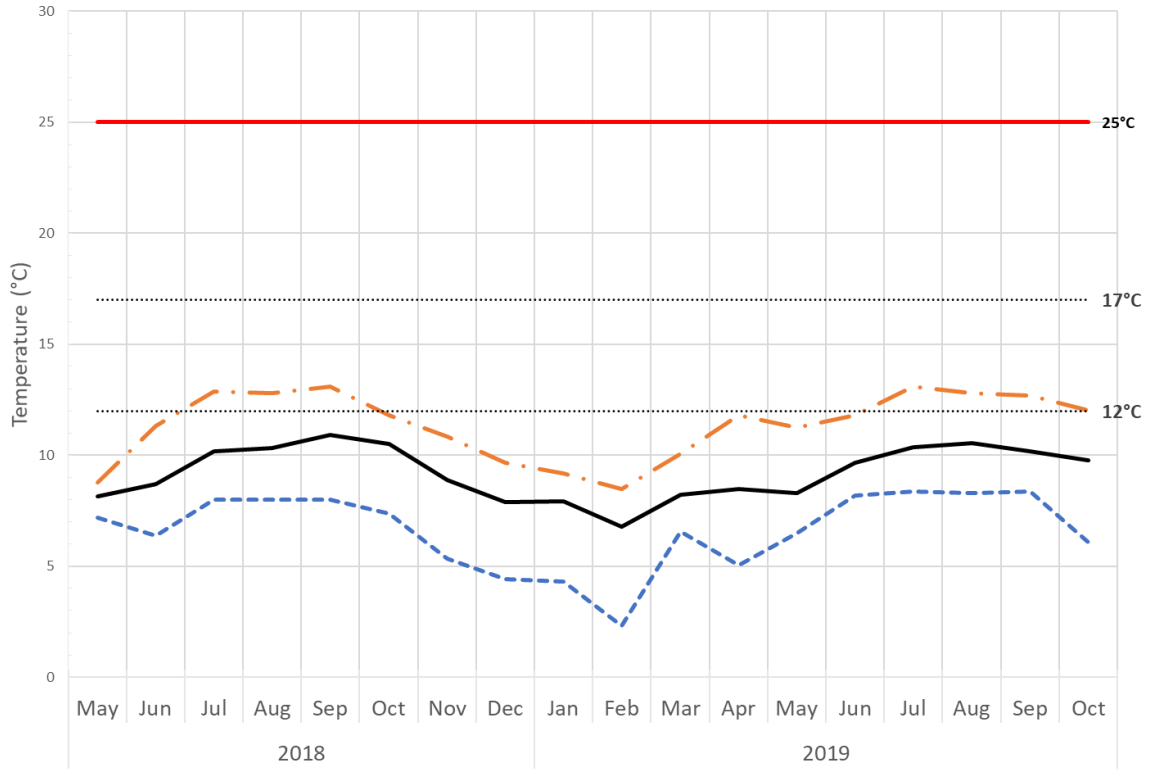
Station E (Culvert 3) Marsh Wetted



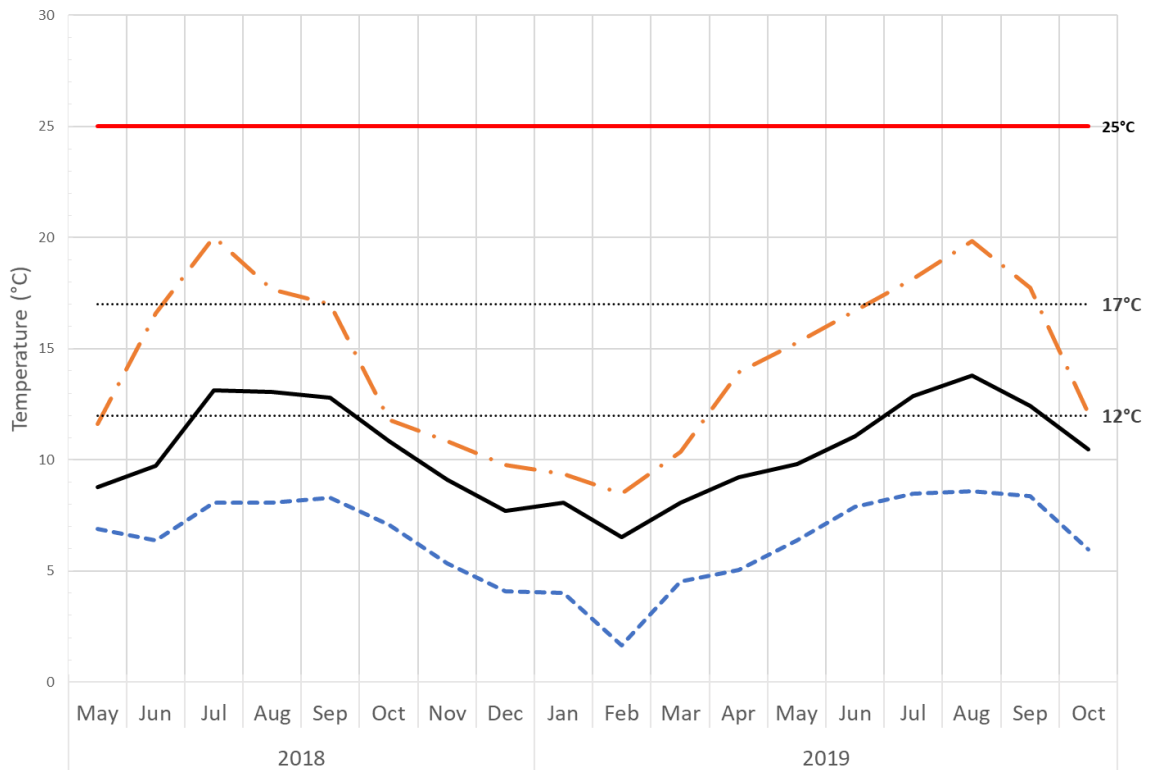
Station F (Culvert 4) Tidal Channel <50% Wetted



Station F (Culvert 4) Tidal Channel Wetted

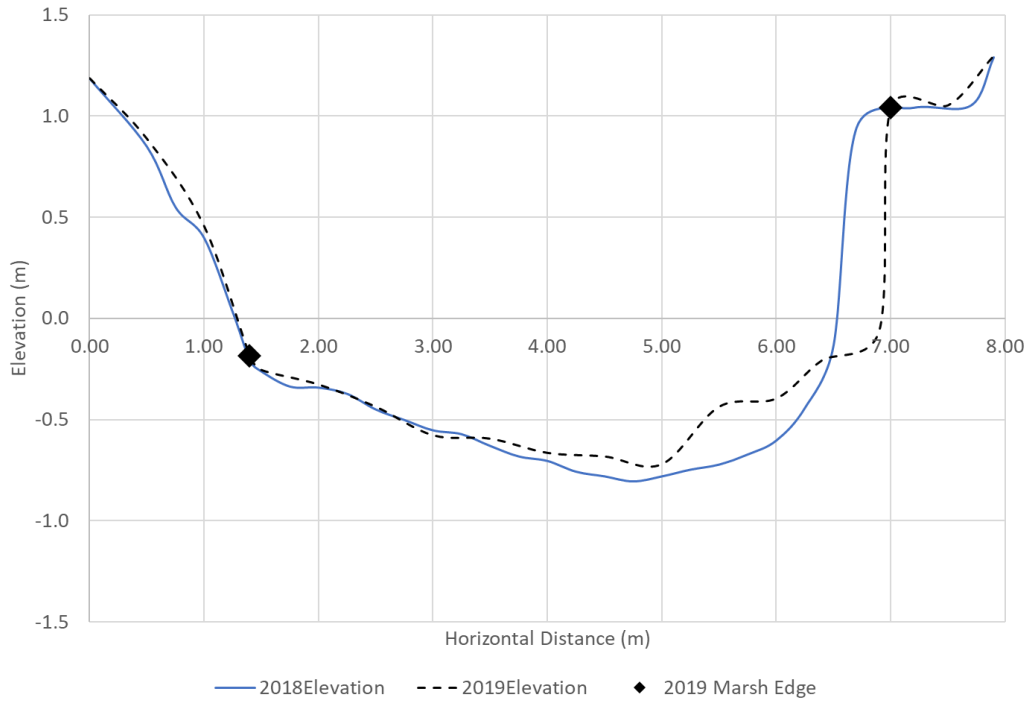


Station F (Culvert 4) Marsh Wetted

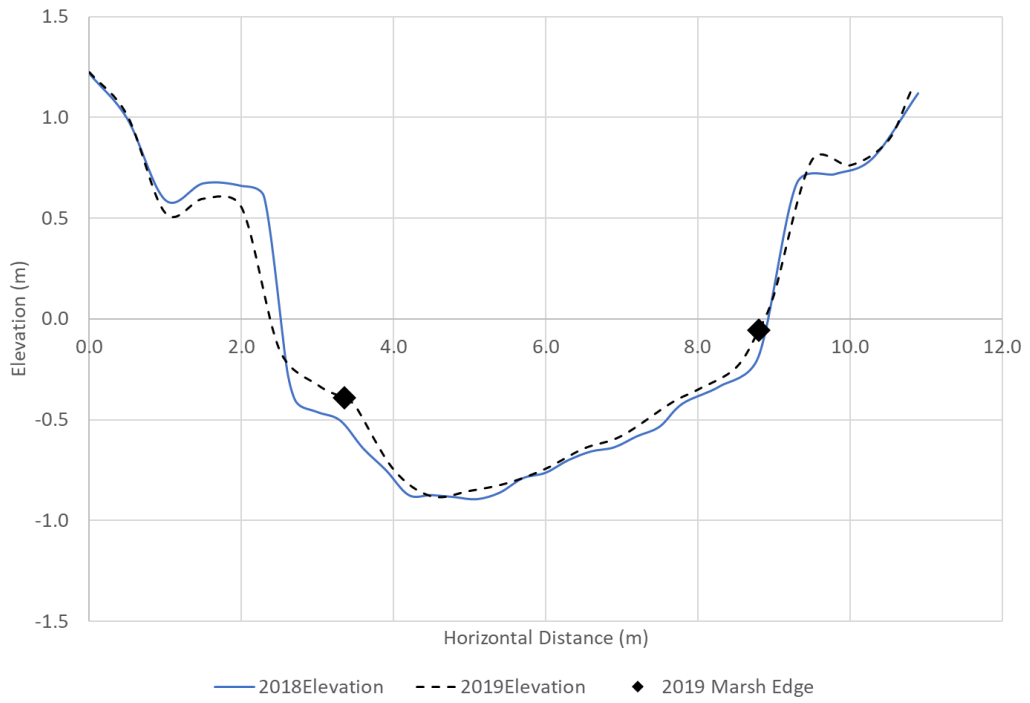


Appendix 5: Channel Cross Sections

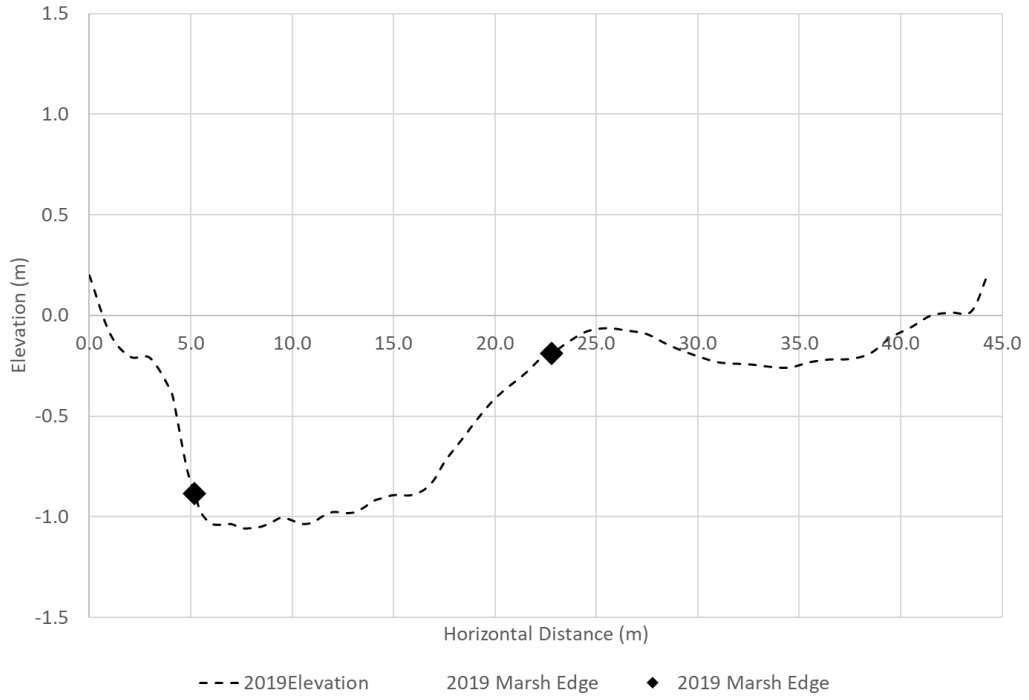
Station B: C1-CS1



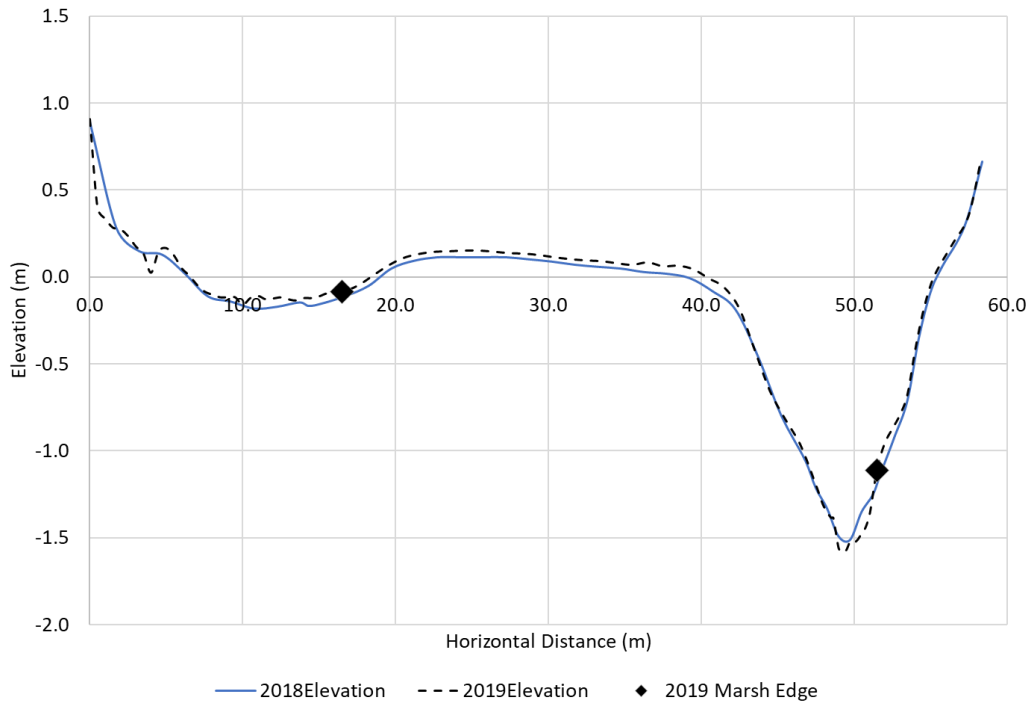
Station B: C1-CS2



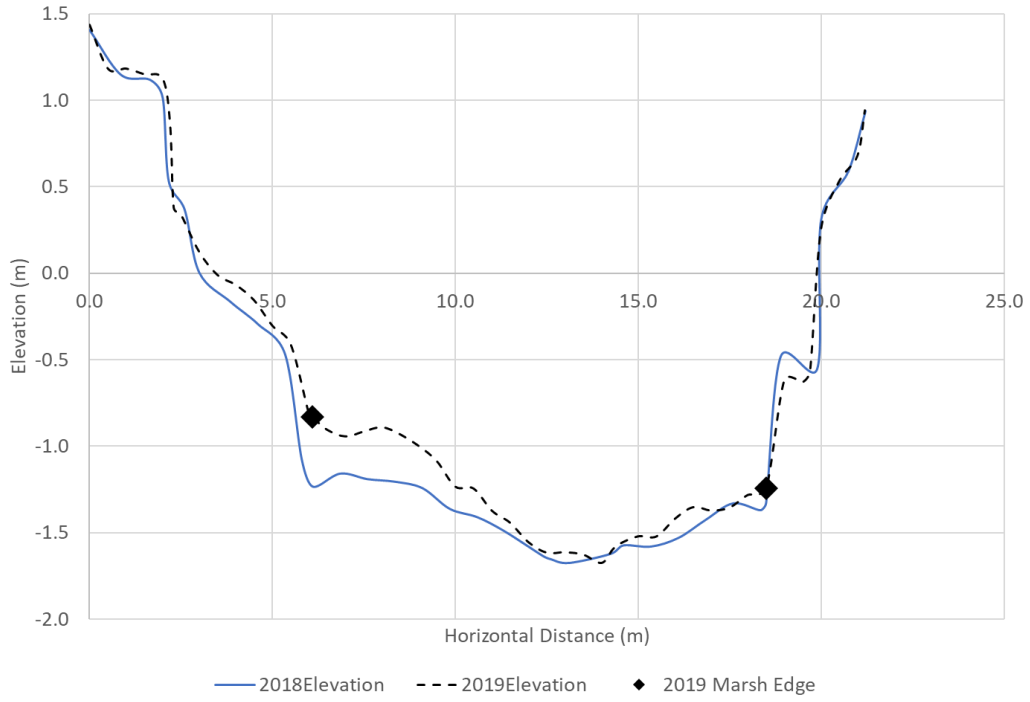
Station C: BS-CS1



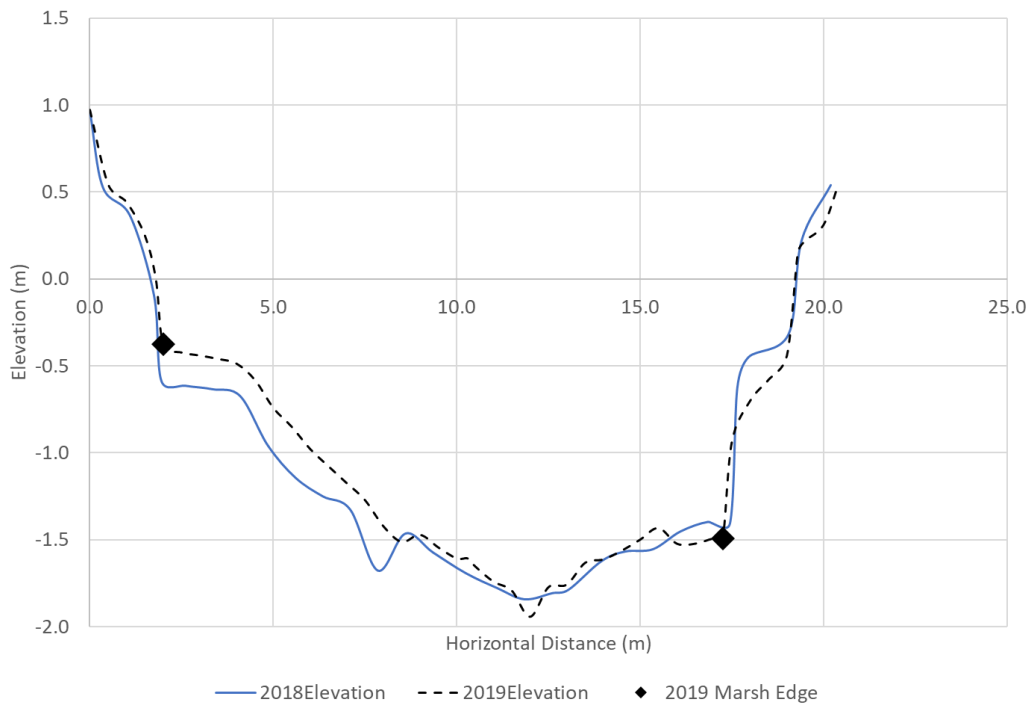
Station E: C3-CS1



Station F: C4-CS1



Station F: C4-CS2



Appendix 6: Sediment Station Data

Name	C1-SS1	C1-SS1	C1-SS2	C1-SS2
Date Surveyed	15-Aug-18	26-Aug-19	4-Jul-18	26-Aug-19
Distance	cm	cm	cm	cm
Dist Pin AC (cm)	0.00	0.00	0.00	0.00
Dist 2	10.00	10.00	9.00	6.20
Dist 3	20.00	20.00	19.00	16.20
Dist 4	30.00	30.00	29.00	26.20
Dist 5	40.00	40.00	39.00	36.20
Dist 6	50.00	50.00	49.00	46.20
Dist 7	60.00	60.00	59.00	56.20
Dist 8	70.00	70.00	69.00	66.20
Dist 9	80.00	80.00	79.00	76.20
Dist 10	90.00	90.00	89.00	86.20
Dist 11	100.00	100.00	99.00	96.20
Dist 12	110.00	110.00	109.00	106.20
Dist Pin BD (cm)	130.00		117.20	114.70
Heights	m	m	m	m
Ht Pin AC (m)	0.76	0.85	0.66	0.72
Ht 2	0.72	0.85	0.70	0.72
Ht 3	0.70	0.86	0.68	0.70
Ht 4	0.70	0.87	0.68	0.71
Ht 5	0.67	0.85	0.69	0.72
Ht 6	0.71	0.84	0.72	0.72
Ht 7	0.68	0.84	0.71	0.73
Ht 8	0.74	0.84	0.69	0.73
Ht 9	0.70	0.86	0.70	0.74
Ht 10	0.75	0.86	0.71	0.76
Ht 11	0.73	0.88	0.71	0.74
Ht 12	0.68	0.86	0.71	0.75
Ht Pin BD (cm)	0.73		0.71	0.74

Table A 5: Site B sediment station data for 2018-2019.

Name	BS-SS1	BS-SS2
Date Surveyed	2019-08-26	2019-08-26
Distance	cm	cm
Dist Pin AC (cm)	0	0
Dist 2	7.5	6.5
Dist 3	17.5	16.5
Dist 4	27.5	26.5
Dist 5	37.5	36.5
Dist 6	47.5	46.5
Dist 7	57.5	56.5
Dist 8	67.5	66.5
Dist 9	77.5	76.5
Dist 10	87.5	86.5
Dist 11	97.5	96.5
Dist 12	107.5	106.5
Dist Pin BD (cm)	115.5	112.2
Heights	m	m
Ht Pin AC (cm)	-0.269	-0.280
Ht 2	-0.263	-0.283
Ht 3	-0.263	-0.285
Ht 4	-0.259	-0.290
Ht 5	-0.258	-0.295
Ht 6	-0.258	-0.295
Ht 7	-0.257	-0.302
Ht 8	-0.254	-0.305
Ht 9	-0.258	-0.303
Ht 10	-0.256	-0.302
Ht 11	-0.256	-0.308
Ht 12	-0.255	-0.305
Ht Pin BD (cm)	-0.257	-0.308

Table A 6: Site C sediment station data for 2018-2019.

Name	C3-SS1	C3-SS1	C3-SS2	C3-SS2	C3-SS3	C3-SS4
Date Measured	25-Jun-18	14-Jun-19	25-Jun-18	1-Aug-19	16-Aug-19	16-Aug-19
Distance	cm	cm	cm	cm	cm	cm
Dist Pin AC (cm)	0	0	0	0	0	0
Dist 2	9	3	10	5	4	10
Dist 3	19	13	20	15	14	20
Dist 4	29	23	30	25	24	30
Dist 5	39	33	40	35	34	40
Dist 6	49	43	50	45	44	50
Dist 7	59	53	60	55	54	60
Dist 8	69	63	70	65	64	70
Dist 9	79	73	80	75	74	80
Dist 10	89	83	90	85	84	90
Dist 11	99	93	100	95	94	100
Dist 12	109	103	112	105	104	110
Dist Pin BD (cm)	115	113		116	114	
Heights	m	m	m	m	m	m
Ht Pin AC (cm)	-0.132	-0.097	0.387	0.400	-0.677	-0.795
Ht 2	-0.131	-0.106	0.378	0.406	-0.676	-0.794
Ht 3	-0.127	-0.099	0.373	0.384	-0.675	-0.793
Ht 4	-0.130	-0.105	0.345	0.377	-0.671	-0.790
Ht 5	-0.122	-0.102	0.357	0.373	-0.673	-0.789
Ht 6	-0.129	-0.118	0.346	0.369	-0.673	-0.784
Ht 7	-0.124	-0.117	0.352	0.365	-0.671	-0.784
Ht 8	-0.122	-0.116	0.336	0.356	-0.673	-0.783
Ht 9	-0.120	-0.108	0.332	0.356	-0.668	-0.783
Ht 10	-0.112	-0.102	0.327	0.350	-0.670	-0.783
Ht 11	-0.116	-0.105	0.325	0.345	-0.675	-0.780
Ht 12	-0.117	-0.114	0.319	0.345	-0.674	-0.783
Ht Pin BD (cm)	-0.149	-0.120		0.339	-0.675	

Table A 7: : Site E sediment station data for 2018-2019.

Name	LE-SS1	LE-SS1	LE-SS2	LE-SS2	LE-SS3	LE-SS4	LE-SS5
Date Measured	15-Aug-18	1-Aug-19	15-Aug-18	2-Aug-19	2-Aug-19	2-Aug-19	15-Aug-18
Distance	cm	cm	cm	cm	cm	cm	cm
Dist Pin AC (cm)	0	0	0	0	0	0	0
Dist 2	10	7.5	10	10	10	10	10
Dist 3	20	17.5	20	20	20	20	20
Dist 4	30	27.5	30	30	30	30	30
Dist 5	40	37.5	40	40	40	40	40
Dist 6	50	48.5	50	50	50	50	50
Dist 7	60	58.5	60	60	60	60	60
Dist 8	70	68.5	70	70	70	70	70
Dist 9	80	78.5	80	80	80	80	80
Dist 10	90	88.5	90	90	90	90	90
Dist 11	100	98.5	100	100	100	100	100
Dist 12	110	108.5	105	106.1	110	109.7	109.4
Dist Pin BD (cm)	112.4	113.5			118.2		
Heights	m	m	m	m	m	m	m*
Ht Pin AC (cm)	0.697	0.725	0.609	0.642	-1.861	-2.134	0.589
Ht 2	0.700	0.718	0.597	0.629	-1.855	-2.131	0.559
Ht 3	0.722	0.743	0.577	0.620	-1.858	-2.133	0.574
Ht 4	0.704	0.726	0.572	0.609	-1.860	-2.128	0.569
Ht 5	0.701	0.719	0.565	0.603	-1.861	-2.123	0.563
Ht 6	0.680	0.706	0.553	0.590	-1.864	-2.120	0.566
Ht 7	0.686	0.709	0.555	0.591	-1.862	-2.116	0.567
Ht 8	0.692	0.714	0.552	0.591	-1.866	-2.118	0.567
Ht 9	0.700	0.722	0.553	0.587	-1.870	-2.115	0.548
Ht 10	0.707	0.732	0.554	0.588	-1.866	-2.111	0.554
Ht 11	0.708	0.743	0.547	0.587	-1.860	-2.109	0.551
Ht 12	0.686	0.739	0.545	0.583	-1.865	-2.113	0.542
Ht Pin BD (cm)	0.695	0.726			-1.868		

*LE-SS5 heights not corrected for elevation

Table A 8: Site F sediment station data for 2018-2019.

Appendix 6: Vegetation and Soils

Station	Strata	Date Sampled (Veg)	Transect ID	Transect Start	Transect End	Transect Length (m)	Total Plots	Vegetation Plots (Marsh)	Soil Plots	Veg Zones
B	S9	2019-08-10	S9.T1	10U 488193 5506935	10U 488206 5506926	67.3	5	5	1	2
B	S9	2019-08-20	S9.T2	10U 488152 5506980	10U 488118 5507005	38	3	3	1	1
B	S9	2019-08-20	S9.T3	10U 488152 5506968	10U 488152 5506968	50	3	3	3	3
B	S9	2019-09-07	S9.T4	10U 488200 5506990	10U 488206 5507050	56	3	3	3	4
E	S8	2019-09-08	S8.T1	10U 487744 5506114	10U 487800 5506078	68.9	4	4	2	5
E	S8	2019-09-08	S8.T2	10U 487707 5506078	10U 487758 5506039	69.6	4	4	3	5
E	S8	2019-09-08	S8.T3	10U 487705 5506018	10U 487798 5505960	113	8	7	3	6
E	S8	2019-09-08	S8.T4	10U 487653 5505993	10U 487775 5505921	153	13	10	3	6
F	S8	2019-09-08	S8.T5	10U 487653 5505963	10U 487553 5505803	185	0	0	0	13
G	LE	2019-08-28	LE-T1	10U 487457 5504738	10U 486983 5504745	470	0	0	0	8

Table A 9: Soil and vegetation sampling effort. Some plots combined vegetation and soils. Veg Zones refers to number of vegetation communities encountered along transect.

Station	Site Name	Sample Type	Veg Survey Date	Soil Survey Date	UTM	# of Soil Samples
B	S9.T1.P1	BOTH	10-Aug-19	20-Aug-19	10 U 488162 5506959	2
B	S9.T1.P2	VEG	10-Aug-19		10 U 488172 5506952	
B	S9.T1.P3	VEG	10-Aug-19		10 U 488181 5506943	
B	S9.T1.P4	VEG	10-Aug-19		10 U 488196 5506933	
B	S9.T1.P5	VEG	10-Aug-19		10 U 488206 5506926	
B	S9.T2.P1	BOTH	20-Aug-19	20-Aug-19	10 U 488141 5506979	2
B	S9.T2.P2	VEG	20-Aug-19		10 U 488134 5506991	
B	S9.T2.P3	VEG	20-Aug-19		10 U 488122 5507002	
B	S9.T3.P1	BOTH	20-Aug-19	22-Aug-19	10 U 488198 5506972	2
B	S9.T3.P2	BOTH	20-Aug-19	22-Aug-19	10 U 488200 5506959	2
B	S9.T3.P3	BOTH	20-Aug-19	22-Aug-19	10 U 488195 5506941	2
B	S9.T4.P1	BOTH	07-Sep-19	07-Sep-19	10 U 488201 5506999	2
B	S9.T4.P2	BOTH	07-Sep-19	07-Sep-19	10 U 488201 5507013	2
B	S9.T4.P3	BOTH	07-Sep-19	07-Sep-19	10 U 488203 5507027	2
E	S8.T1.P1	BOTH	20-Jun-19	20-Jun-19	10 U 487749 5506119	2
E	S8.T1.P2	VEG	20-Jun-19		10 U 487765 5506103	
E	S8.T1.P3	VEG	20-Jun-19		10 U 487777 5506094	
E	S8.T1.P4	BOTH	21-Jun-19	21-Jun-19	10 U 487792 5506094	2
E	S8.T2.P1	BOTH	21-Jun-19	13-Jul-19	10 U 487716 5506078	2
E	S8.T2.P2	BOTH	22-Jun-19	13-Jul-19	10 U 487724 5506070	2
E	S8.T2.P3	BOTH	21-Jun-19	13-Jul-19	10 U 487742 5506059	2
E	S8.T2.P4	VEG	21-Jun-19		10 U 487755 5506051	
E	S8.T3.P1	/	27-Jun-19		10 U 487706 5506017	
E	S8.T3.P2	BOTH	27-Jun-19	13-Jul-19	10 U 487714 5506012	1
E	S8.T3.P3	VEG	27-Jun-19		10 U 487727 5506005	
E	S8.T3.P4	BOTH	27-Jun-19	13-Jul-19	10 U 487739 5506000	2
E	S8.T3.P5	BOTH	27-Jun-19	13-Jul-19	10 U 487756 5505988	1
E	S8.T3.P6	VEG	27-Jun-19		10 U 487769 5505982	
E	S8.T3.P7	VEG	27-Jun-19		10 U 487780 5505972	
E	S8.T3.P8	VEG	27-Jun-19		10 U 487794 5505964	
E	S8.T4.P1	/	20-Jul-19		10 U 487645 5506000	
E	S8.T4.P2	BOTH	20-Jul-19	22-Jul-19	10 U 487654 5505993	1
E	S8.T4.P3	VEG	20-Jul-19		10 U 487667 5505984	
E	S8.T4.P4	VEG	20-Jul-19		10 U 487681 5505977	
E	S8.T4.P5	VEG	20-Jul-19		10 U 487693 5505970	
E	S8.T4.P6	SOIL		10-Aug-19	10 U 487696 5505966	1
E	S8.T4.P7	VEG	20-Jul-19	10-Aug-19	10 U 487708 5505962	
E	S8.T4.P8	VEG	20-Jul-19		10 U 487718 5505954	
E	S8.T4.P9	VEG	20-Jul-19		10 U 487729 5505946	
E	S8.T4.P10	SOIL		10-Aug-19	10 U 487739 5505941	1
E	S8.T4.P11	VEG	20-Jul-19		10 U 487743 5505938	
E	S8.T4.P12	VEG	20-Jul-19		10 U 487755 5505932	
E	S8.T4.P13	VEG	20-Jul-19		10 U 487767 5505922	

Table A 10: Soil and vegetation sampling Summary. Sample Type refers to vegetation (VEG) or soil (SOIL) sampling occurred, or both (BOTH).

Site Name	Sample #	Unique ID	Soil Survey Date	Time	Depth (cm)	bulk density (g/cm ³)	% Inorganic Carbon (DL = 0.01)	% Total Nitrogen (DL = 0.01)	% Total Carbon (DL = 0.01)	% LOI (DL= 0.1)	% Sand	% Silt	% Clay
S8.T1.P1	1	8.19.08	20-Jun-19	13:30	0-10	1.00	<DL	0.049	0.91	2.2	16	74	10
S8.T1.P1	2	8.19.07	20-Jun-19	13:30	10-20	0.91	0.016	0.069	1.1	2.3	11	79	10
S8.T1.P4	2	8.19.03	21-Jun-19	16:00	13-18	1.05	<DL	0.06	1.2	2.6	20	72	8.8
S8.T1.P4	1	8.19.06	21-Jun-19	16:00	3-8	1.02	<DL	0.096	1.9	3.1	9.5	80	10
S8.T2.P1	2	8.19.33	13-Jul-19	12:30	10-20	0.93	<DL	0.059	1.3	2.5	17	75	7.5
S8.T2.P1	1	8.19.02	13-Jul-19	12:30	0-10	0.99	<DL	0.082	1.4	2.9	15	77	8.8
S8.T2.P2	2	8.19.36	13-Jul-19	10:45	10-20	1.33	<DL	0.022	0.49	1.2	50	45	5
S8.T2.P2	1	8.19.01	13-Jul-19	10:45	0-10	1.23	<DL	0.041	0.78	1.6	47	48	5
S8.T2.P3	2	8.19.31	13-Jul-19	11:30	10-20	1.24	<DL	0.031	0.77	1.7	52	44	3.8
S8.T2.P3	1	8.19.32	13-Jul-19	11:30	0-10	1.02	<DL	0.063	1.2	2.5	37	59	3.8
S9.T3.P1	1	9.19.14	22-Aug-19	16:52	5-10	0.84	<DL	0.14	2.8	5.7	9.3	82	8.8
S9.T3.P1	2	9.19.28	22-Aug-19	16:52	20-25	0.64	<DL	0.2	3.1	6	4	81	15
S9.T3.P2	1	9.19.21	22-Aug-19	16:30	5-10	0.87	0.01	0.24	3.7	7.8	5.2	86	8.9
S9.T3.P2	2	9.19.25	22-Aug-19	16:30	20-25	0.91	<DL	0.11	1.6	3.4	5.5	88	6.3
S9.T4.P1	1	9.19.24	7-Sep-19	9:30	5-10	0.41	<DL	0.39	5	10	7.2	84	8.9
S9.T4.P1	2	9.19.26	7-Sep-19	9:30	20-25	0.77	<DL	0.25	3	6.5	13	82	5.1
S9.T4.P2	1	9.19.17	7-Sep-19	10:17	5-10	0.41	<DL	0.48	5.5	11	7.3	84	8.9
S9.T4.P2	2	9.19.23	7-Sep-19	10:17	20-25	1.20	<DL	0.069	1.1	2.6	16	79	5
S9.T4.P3	1	9.19.27	7-Sep-19	12:12	2-7	0.60	0.018	1.1	12	21	41	51	7.6
S9.T4.P3	2	9.19.15	7-Sep-19	12:12	9-14	1.02	<DL	0.1	1.3	2.9	40	56	3.8
S8.T3.P2	1	8.19.12	13-Jul-19	8:41	0-10	0.73							
S8.T3.P4	1	8.19.05	13-Jul-19	9:20	0-10	0.83							
S8.T3.P4	2	8.19.10	13-Jul-19	9:20	10-20	1.07							
S8.T3.P5	1	8.19.04	13-Jul-19	9:50	0-10	0.74							
S8.T4.P2	2	8.19.34	22-Jul-19	14:56	15-20	0.72							
S8.T4.P2	1	8.19.37	22-Jul-19	14:56	5-10	0.58							
S8.T4.P6	1	8.19.22	10-Aug-19	8:40	10-20	0.70							
S9.T1.P1	1	9.19.16	20-Aug-19	12:21	5-10	1.19							
S9.T1.P1	2	9.19.30	20-Aug-19	12:21	20-25	0.67							
S9.T1.P2	1	9.19.20	19-Aug-19	15:07	19-24	1.47							
S9.T2.P1	1	9.19.35	20-Aug-19	13:45	5-10	0.51							
S9.T2.P1	2	9.19.29	20-Aug-19	13:45	25-30	0.64							
S9.T3.P3	1	9.19.13	22-Aug-19	16:08	5-10	1.03							
S9.T3.P3	2	9.19.18	22-Aug-19	16:08	20-25	0.87							

Table A 1: Results of Bulk Density and Carbon/Nitrogen analysis. Area greyed did not undergo lab analysis, other than bulk density.

Appendix 7: Photopoints

Site	Photo Point #	UTM	Photo Heading	Height	Description	Date	Time
B	213-A	10 U 488153 5506966	248°	Standing	Photo is of Culvert 1 estuarine channel facing upstream to the west.	15-Sep-19	15:31
	213-B	10 U 488154 5506972	32°	Standing	Photo is of the gravel bar in the estuarine channel of Culvert 1, facing downstream to the east.	15-Sep-19	15:33
	214-A	10 U 488190 5506988	280°	Standing	Photo is of the Culvert 1 estuarine channel, facing upstream to the west. C1 logger is visible in channel.	15-Sep-19	15:36
	214-B	10 U 488190 5506988	82°	Standing	Photo is of the Culvert 1 estuarine channel, facing downstream.	15-Sep-19	15:40
D	201-A	10 U 487894 5506386	106°	Standing	Photo is of the north bank of Culvert 2 channel on the east side of Spit Road (estuarine side).	29-Aug-18	
	201-B	10 U 487894 5506386	125°	Standing	Photo is of the centre of the channel of Culvert 2 (estuarine side).	29-Aug-18	
	201-C	10 U 487894 5506386	136°	Standing	Photo is of the south bank of Culvert 2 channel (estuarine side).	29-Aug-18	
	202	10 U 487850 5506411	280°	Standing	Photo is of the Culvert 2 channels on the west side of Spit Road (river side). Culvert 2 is visible on the bottom left side of photo.	29-Aug-18	
E	203-A	10 U 487737 5506121	218°	Standing	Photo is of the estuarine channel at Culvert 3 (east side of Spit Road). Standing on a trail on the north side of Culvert 3.	15-Sep-19	13:52
	203-B	10 U 487725 5506081	180°	Crouching	Photo of the low elevations of the north/left bank of Culvert 3, with the south/right bank visible past Culvert 3.	15-Sep-19	13:59
	203-C	10 U 487725 5506081	210°	Crouching	Photo of the low elevation and riparian area of the north/left bank of Culvert 3, with the south/right bank visible past Culvert 3. Project kiosk is also visible.	15-Sep-19	14:02
	204	10 U 487712 5506087	133°	Standing	Photo is of the estuarine channel at Culvert 3 on the east side of Spit Road. Flow area of Culvert 3. Standing on top of Culvert 3.	15-Sep-19	14:08
	209	10 U 487719 5506093	106°	Standing	Photo of the low elevations of the north/left bank of the Culvert 3 estuarine channel.	15-Sep-19	14:19
	210-A	10 U 487691 5506112	302°	Standing	Photo is of the Culvert 3 channel river side with the Squamish River visible in the distance.	15-Sep-19	14:24
	210-B	11 U 487691 5506112	340°	Standing	Photo is of the northern bank of the riparian area at Culvert 3 channel river side.	15-Sep-19	14:27
	210-C	12 U 487691 5506112	254°	Standing	Photo is of the southern bank of the riparian area at Culvert 3 channel river side.	15-Sep-19	14:28
	211	10 U 487693 5506115	246°	Standing	Photo is of the northern bank of the riparian area at Culvert 3 channel river side. Facing towards the Culvert 3 channel. Squamish river visible in background.	15-Sep-19	14:30
	212	10 U 487695 5506136		Standing	Photo is of the west side of Spit Rd showing the riparian area of the northern bank of Culvert 3 channel river side. Project kiosk located on the eastern side of Spit Rd is visible in the middle of the photo.	15-Sep-19	14:40
	205-A	10 U 487657 5506112	138°	Standing	Facing towards Culvert 3 from the river channel (west side of Spit Road). Photo is taken beside the first trash rack.	15-Sep-19	14:43
	205-B	10 U 487639 5506124	224°	Standing	Photo is of the centre of the channel on the river side of Culvert 3 (west of Spit Road). Last trash rack is visible near north bank.	15-Sep-19	14:51
	F	206	10 U 0487515 5505840	184°	Standing	Photo taken of the estuarine channel of Culvert 4 (east side of Spit Road). Culvert 4 and Culvert 4 level/conductivity logger visible on the right side of the photo.	29-Aug-18
207		10 U 487506 5505847	162°	Crouching	Photo is of the culvert 4 estuarine channel. Taken above culvert 4, facing the chief.	15-Sep-19	13:31
208		10 U 487506 5505847	60°	Standing	Photo is of the north/left bank with Culvert 4 and logger visible.	15-Sep-19	13:36

Table A 2: Summary of Photopoint monitoring sites, locations and descriptions, and date established.
































Site	Photopoint # (Site)	2018	2019
B	213-A	n/a	
B	213-B	n/a	
B	214-A	n/a	
B	214-B	n/a	
D	201-A		

Table A 3: Photos associated with each photopoint location from Table A-3.

Site	Photopoint # (Site)	2018	2019
D	201-B		
D	201-C		
D	202		
E	203-A	n/a	
E	203-B	n/a	
E	203-C	n/a	

Site	Photopoint # (Site)	2018	2019
E	204		
E	209	n/a	
E	210-A	n/a	
E	210-B	n/a	
E	210-C	n/a	
E	211	n/a	

Site	Photopoint # (Site)	2018	2019
E	212	n/a	
E	205-A		
E	205-B		
F	206		
F	207	n/a	
F	208	n/a	

Squamish Training Berm Removal – Phase 2

Squamish River Watershed Society

Model Criteria and Progress Report

DRAFT

11 | 06 | 2020

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1. Introduction

1.1 Background

The Squamish River Watershed Society (SRWS) retained SNC-Lavalin to assess the impacts of the training berm removal from 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 central estuary for juvenile chinook.

Initially SNC-Lavalin conducted a preliminary wave impact study for two berm removal scenarios considering existing extreme event and water levels (Ref [1]). The bathymetry used in the wave model for the removal scenarios was estimated based on available information and previous hydrodynamic and sediment transport models for the region.

In the present study, the initial model bathymetry was updated by incorporating more recent survey data. A comprehensive hydrodynamic and sediment transport model to forecast the sedimentation process is being conducted to provide a comparative assessment between the current situation and the preferred berm removal scenario. This study will assess the impacts to navigation (current speeds), water levels and sedimentation in the region.

1.2 Scope

The scope of this assessment is to conduct a hydrodynamic and sediment transport model, coupled with wave modelling, for the present (existing) scenario and the preferred future scenario for the training berm removal. The scope is a continuation of the Phase 1 wave assessment previously completed by SNC-Lavalin. This document describes the hydrodynamic and sediment transport related modelling criteria and progress. This document is expected to be updated and revised as necessary and re-issued if or when additional information becomes available and the modelling work progresses further.

1.3 Modelling Approach

The hydrodynamic / sediment transport coupled with the wave model is being used to simulate anticipated extreme and operational hydrodynamic and metocean conditions. Model details are described in Section 3. The general approach for modelling is as follow.

- › Update model bathymetry by incorporating the following datasets.
 - Canadian Coast Guard Aid to Navigation Waterways Management for Squamish Terminal project 2017 (Ref [2]);
 - Terminal Berth and Seabed Condition Survey Ref [3] provided by Canadian Survey Inc.;
 - CCOM - Center for Coastal and Ocean Mapping 2019 Ref [4]; and
 - Squamish River Bathymetry 2007 survey: conducted and provided by BC Hydro.
- › Update wind data analysis to identify extreme value from applicable locations within the computational grid.



- › Conduct measured water level data analysis and comparison between available stations.
- › Conduct historical river discharge data analysis and associated sediment flux at the upstream boundary. Historical data and literature is being used to define sediment flux.
- › Conduct model validation and calibration using tidal stations from Environment Canada as well as Lower Estuary Station water level measurements. Currents will be validated using ADCP current data from February 16, 2017(Ref [5]).
- › Conduct a comprehensive hydrodynamic and sediment transport model coupled with wave model to forecast the sedimentation process and impacts of the proposed berm removal.

The hydrodynamic and sediment transport model will be conducted for four scenarios, with a run duration of approximately 14 days each. There are two sets of runs each for the existing and future scenarios. The future scenario includes a 1.1 km long berm removal keeping the south end of the berm. The first set of runs (1A and 1B) consists of a high river discharge and sediment influx (freshet) with operational level winds. The second set of runs (2A and 2B) considers average winter river discharge and sediment influx with extreme winds. Table 1 summarises the general run parameters.

The following describes the general aspects for the runs.

- › Operational and storm wind input is based on the updated wind data analysis, including local wind data.
- › Average winter and high river discharge are defined based on the available period of measured data discharge on Squamish River - Station 08GA022.
- › The runs representing the berm removal have the remaining south end of the existing structure
- › The range of seasonally variable combination of events that could occur (for instance a severe storm in the late spring, in combination with a late freshet or intense rainfall event in the watershed) are considered to be beyond the scope of the present investigation.
- › The expected wave effects (as a result of local wind generation) are incorporated through the coupling of the hydrodynamic and sediment model with a wave model using the non-stationary wind input (storm or operational) as defined above.
- › Sea level rise is not considered. This assignment is intended to address the near-term effects of the proposed works.



Table 1 Summary of scenario runs

Parameter	1A	1B	2A	2B
Flow and sediment discharge	Spring freshet (high flow and sediment discharge)	Spring freshet (high flow and sediment discharge)	Average winter flow and sediment discharge	Average winter flow and sediment discharge
Sea Level Rise allowance	0.0 m (current)	0.0 m (current)	0.0 m (current)	0.0 m (current)
Length of berm removal	Current	1.1 km / keeping south end of berm	Current	1.1 km / keeping south end of berm
Wind conditions	Operational wind* (AEP 1:5)	Operational wind* (AEP 1:5)	Storm wind (AEP 1:200)	Storm wind (AEP 1:200)
Deflection Berm	No deflection berm	No deflection berm	No deflection berm	No deflection berm

*to be confirmed

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2. Metrocean Environment

2.1 Water Levels

The tidal conditions are based on the water level height information for the Point Atkinson reference port (Station ID 7795). The closest water level measurements for the Squamish area was done by the SRWS at Lower Estuary (LE) Station. The period of measurements is from June, 2018 to March 2020.

Figure 1 shows the location of the two water level stations considered in this study: Point Atkinson, close to the model south boundary, and Lower Estuary, close to the Squamish training berm.

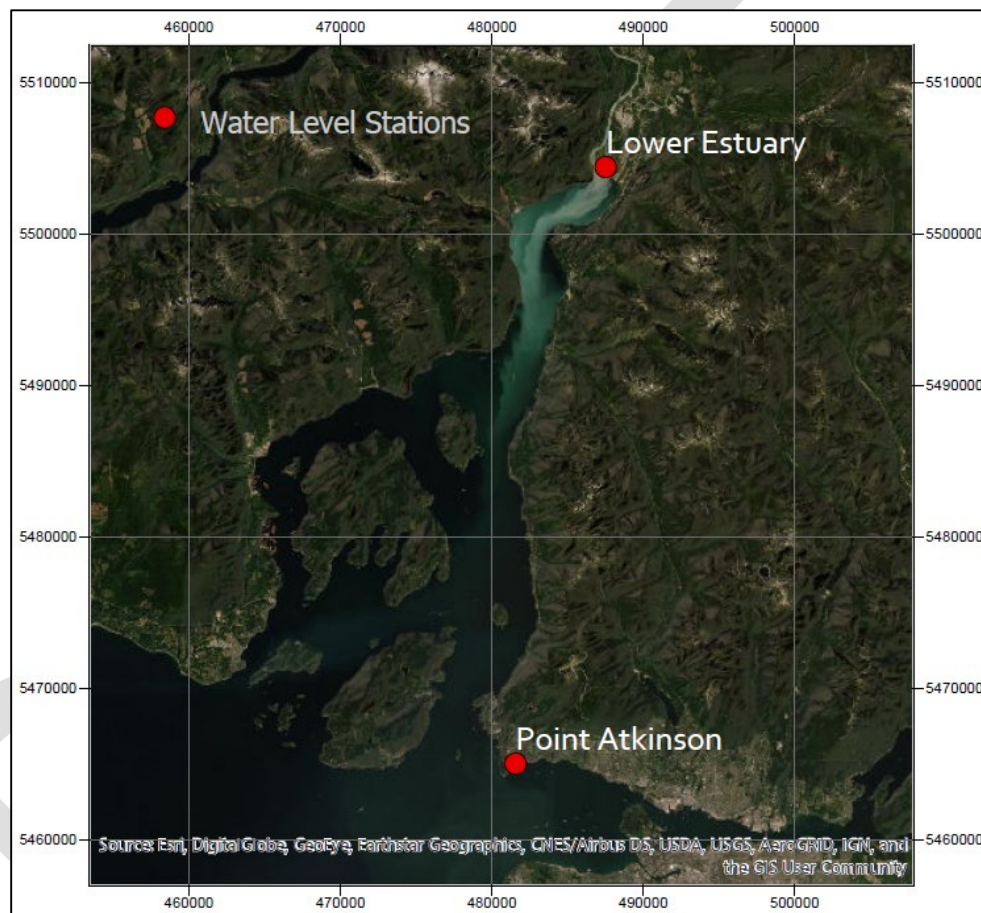


Figure 1 Water level measurements locations

2.1.1 External Storm Surge

External storm surge was input to the model based on the measured residual water level data at Point Atkinson. The water level residuals at Point Atkinson is shown in Figure 2 for a recent relatively event. The maximum water level difference water was approximately 0.7 m.

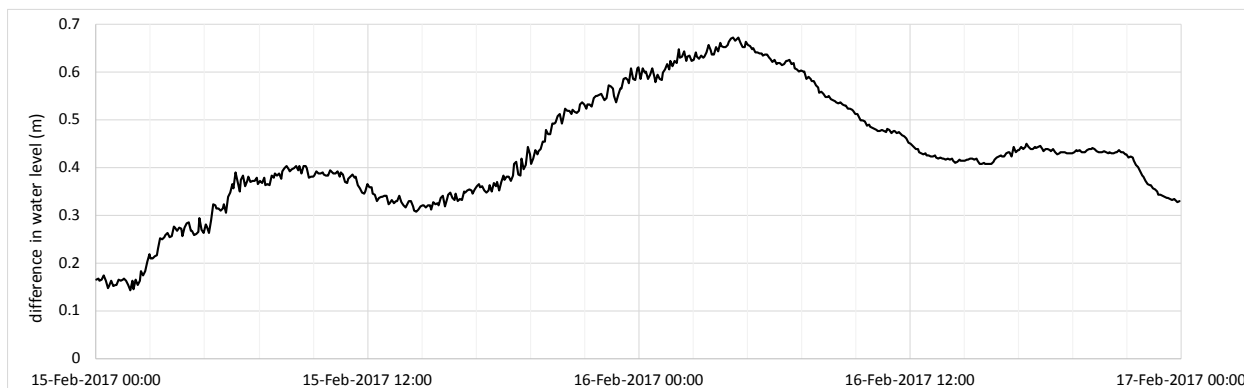


Figure 2 Water level residuals at Point Atkinson for one of the validation periods

Figure 3 shows the difference between the measured and predicted water level residual water levels for the entire year of 2019, as measured at Point Atkinson. The graph shows that large residuals are more frequent during the winter months; however, it is possible to have a significant residual (storm surge) in the the spring period also has a significant peak when a freshet can be occurring.

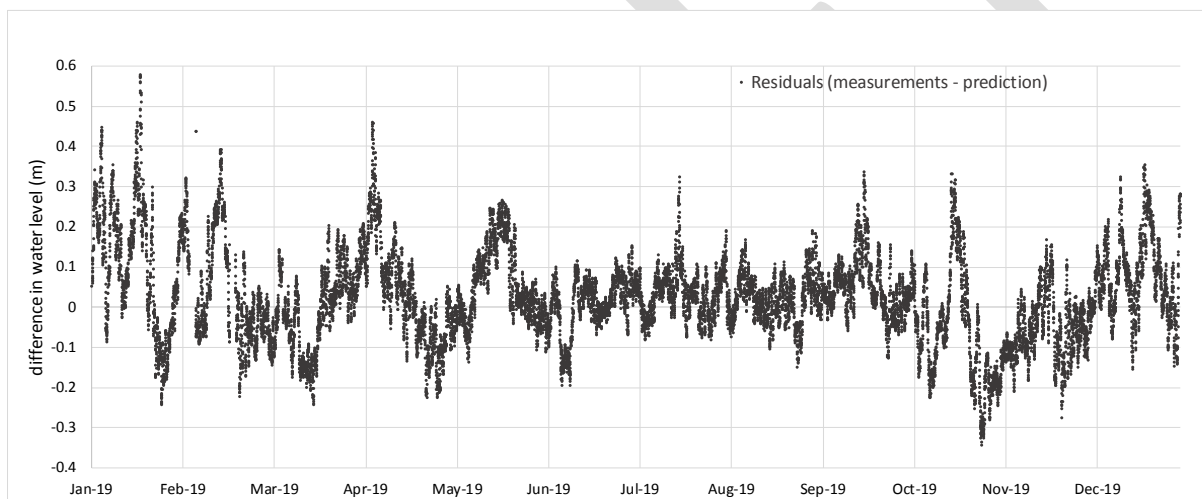


Figure 3 Difference in water level (measurements minus prediction)

2.1.2 Local Storm Surge Effects

Local storm surge effects, resulting for inflow and convergence effects in Howe Sound and Squamish Harbour, were estimated by comparison water levels measurements between the stations Lower Estuary and Point Atkinson.

Figure 4 shows the water level difference between the measurement from Point Atkinson and Lower Estuary for the maximum observed events. The maximum water level difference of the series (approximately 0.5 m) occurred in July, 2018. It should be noted that the difference is repeated (slightly lower) one and two days later, which in this instance, may be related to the effects of strong inflow winds wind conditions (during day time).

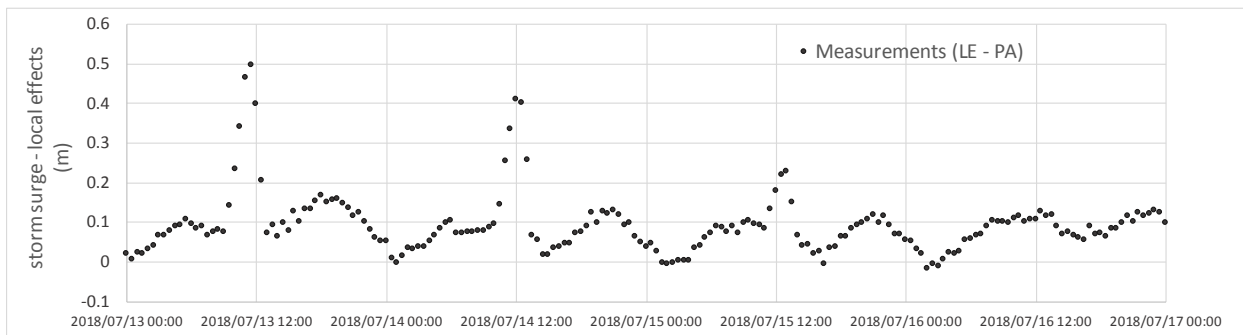


Figure 4 Water level difference between Lower Estuary and Point Atkinson for four days in 2018

2.2 Wind

The calculation of the sea state at the Squamish estuary requires a reliable estimate of the overwater winds both within Howe Sound in general but especially within the upper (north) reaches of Howe Sound.

Wind data measured from three stations were analysed: Squamish Airport, Squamish Wind Sports (SWS), and Pam Rocks. Figure 5 shows the locations where data was collected.

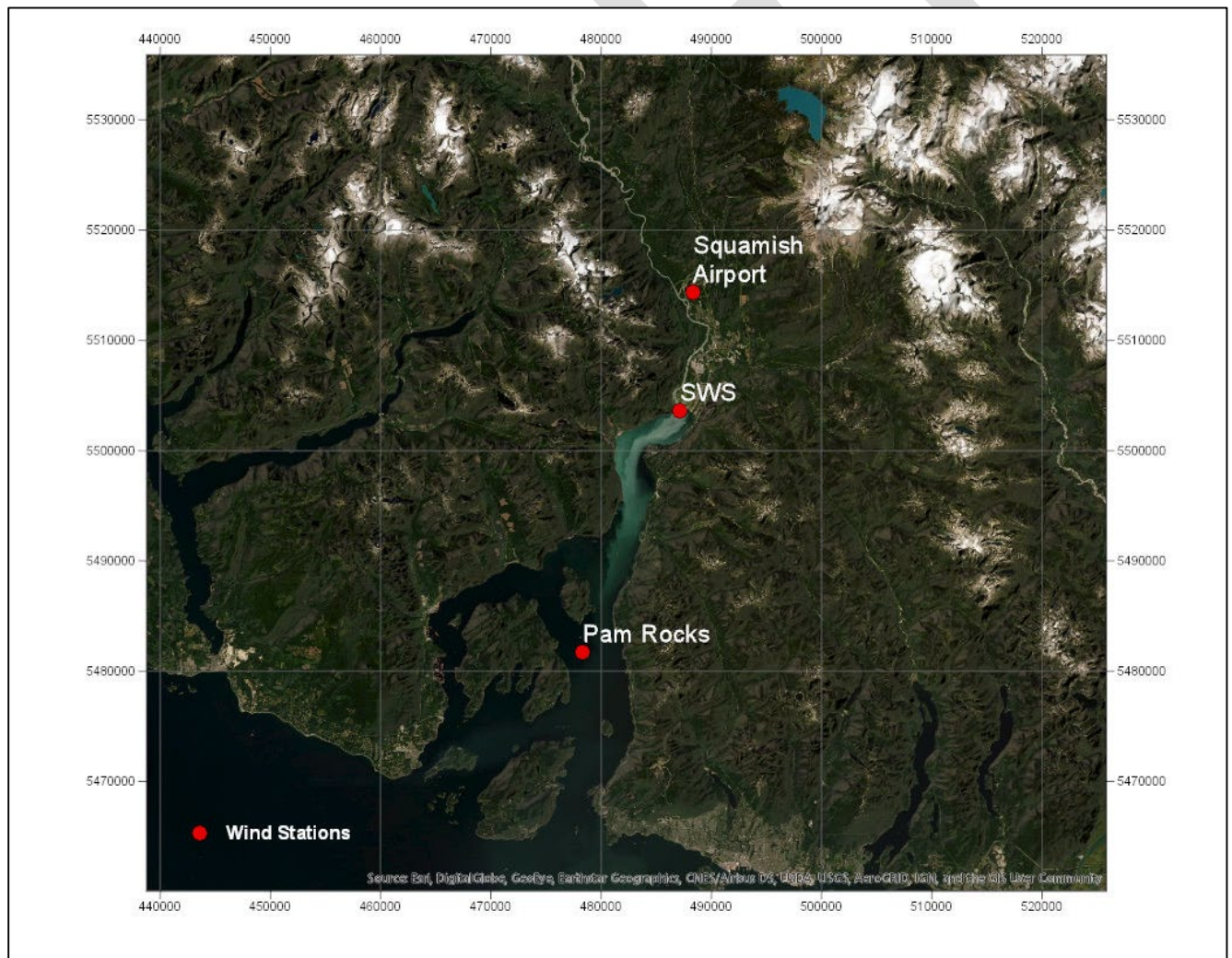


Figure 5 Location of wind stations



Table 2 shows the characteristics of each measured wind dataset. The Squamish Airport station has the longest period of measurements, followed by Pam Rocks and SWS stations. The wind comparison was focused on the last 10 years of data. Extreme wind analysis considered the entire series for each station.

Table 2 Summary of wind stations

Station Identifier	Station Name	Source	Location		Elevation (m)	Time Interval		
			Easting	Northing		Start	End	Total (years)
10476F0	Squamish Airport	EC	488341.5	5514368.5	54	1982-05-17	2020-03-31	38
-	SWS	Squamish Wind Sports Society	487145.5	5503615.2	-	2010-06-16	2020-03-30	10
10459NN	Pam Rocks	EC	478312.0	5481725.4	7.0	1994-02-01	2020-03-31	26

The wind speeds at the Squamish Airport station are consistently lower when compared to Pam Rocks or the Squamish Wind Sport (SWS) site, mainly because the station is in-land. Even though the Squamish Airport wind data is the longest measured time series, it was not considered as a reliable source for this study purpose

Based on literature review and previous study (Ref [6]), southerly winds in Howe Sound are expected to be stronger in the north Howe Sound and Squamish Harbour area than they are in the southern end of the Sound. Figure 6 and Figure 7 show the wind roses for the stations Pam Rock and SWS, respectively. The roses are for the same period of measurements from year 2010 to 2020.

The predominant wind directions at Pam Rocks are northerly and north-easterly; However, southerly winds are more significant for this study as the longer fetch will impact the wave climate at the Squamish estuary. Winds measured at SWS station are predominantly and higher from southwest, compared to Pam Rocks.

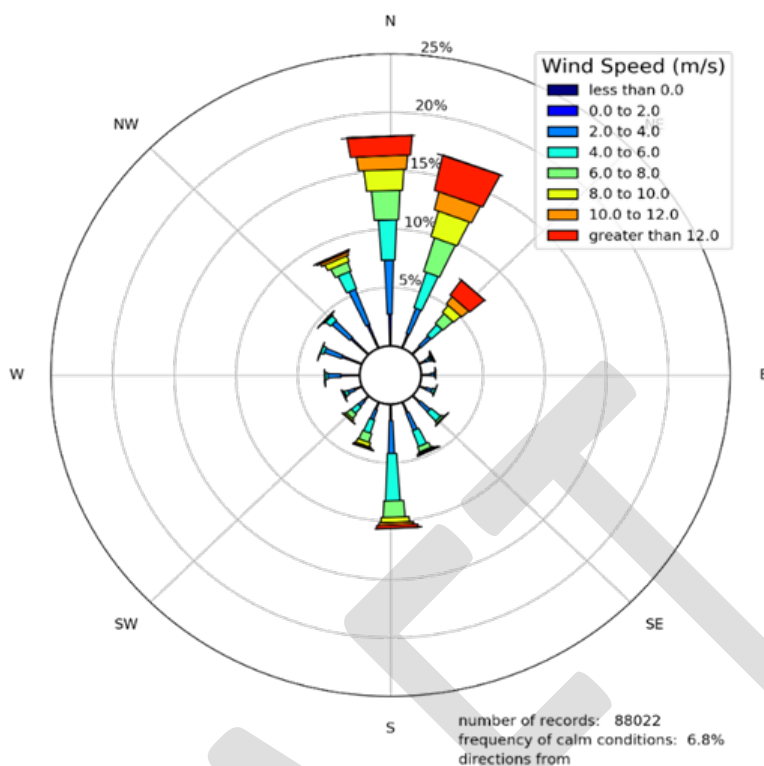


Figure 6 Pam Rocks wind rose (Date from 2010-2020)

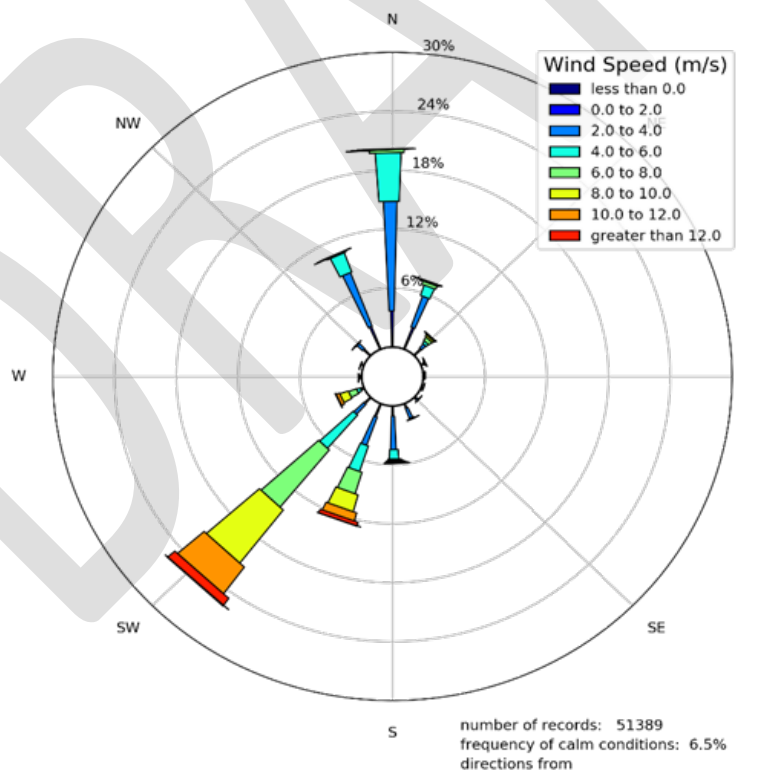


Figure 7 Squamish Wind Sport wind rose (Date from 2010-2020)

During summer, there is a consistent higher occurrence of local strong wind events measured at SWS. These high winds are formed within the upper reaches of Howe Sound, and are not registered at the Pam Rocks station. These winds intensify as they funnel towards the Squamish estuary. Figure 8 shows the



wind roses from 2010 to 2019 in a summer month (July). It is noted that the wind speeds at Pam Rock are more directionally distributed and pronominally from the south and north while at the SWS station, they are more frequent and higher from the SW direction. This difference supports the extreme popularity of Squamish Harbour as a wind surfing destination.

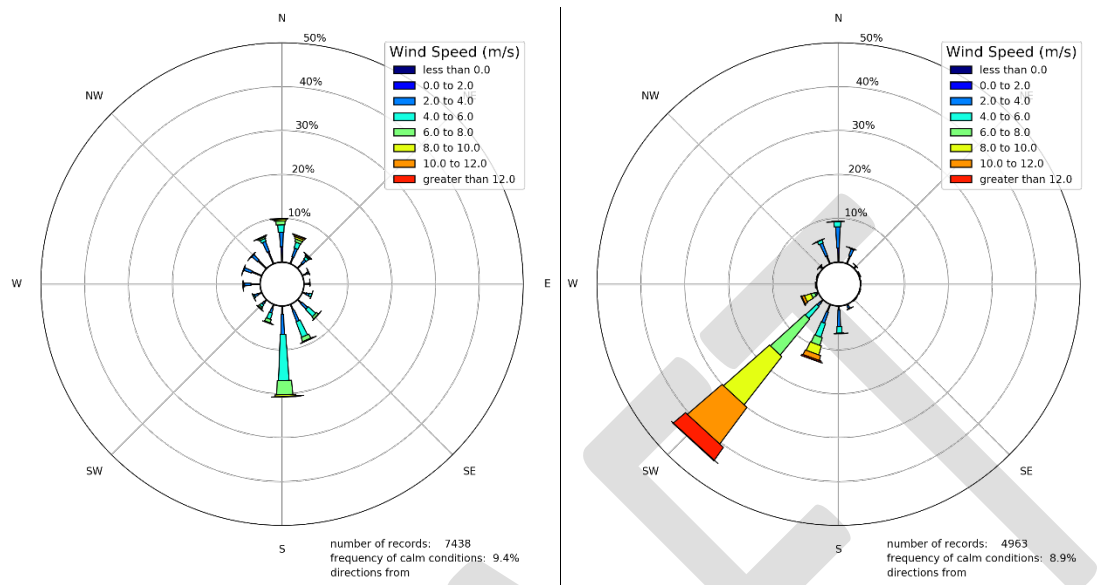


Figure 8: July wind rose 2010-2019 at Pam Rocks (left) and Lower Estuary (right)

During winter, there is high occurrence of storm events registered at the Pam Rocks station, these winds inflow into Squamish Harbour and are slightly lower than at Pam Rocks. These storm systems are controlled by the characteristics of the large-scale synoptic systems and associated fronts and are not influenced by the thermal conditions in the estuary area that define the summer characteristics.

Table 3 and Table 4 show the highest winter wind events during the recorded period at Pam Rocks and SWS, respectively. Only southern events longer than three hours were considered.

Table 3 Top wind events measured at Pam Rocks (1994-2019)

Pam Rocks			
Start Date & Time (UTC)	Duration (hours)	Wind Speed (m/s)	Direction
2010-01-18 11:00	3	24.2	150
1995-11-18 4:00	5	23.1	160
1999-01-29 6:00	11	23.1	160
2006-11-15 19:00	7	22.8	140
1997-03-31 0:00	9	22.8	150
2009-11-09 14:00	4	22.8	150
1997-01-01 10:00	7	22.2	150
2001-11-20 5:00	6	21.7	140
1998-11-25 5:00	4	21.7	180
2007-11-11 23:00	13	21.1	130
2016-10-14 22:00	3	20.6	160



Table 4 Top wind events measured at SWS (2010-2019)

Squamish Wind Sports			
Start Date & Time (UTC)	Duration (hours)	Wind Speed (m/s)	Direction (from deg T)
2015-11-17 20:00	3	21.1	182
2015-10-10 20:00	8	19.5	204
2016-03-10 16:00	7	19	211
2012-03-15 19:00	8	18.5	208
2018-01-18 12:00	4	18.5	225
2011-02-13 1:00	6	18	186
2014-01-11 15:00	6	18	182
2011-02-15 3:00	8	17.5	195
2012-01-04 23:00	9	17.5	213
2013-09-29 0:00	3	17.5	211
2017-10-17 13:00	6	17.5	203

2.2.1 Wind Fields

A time-varying wind field considering winds measured at the Pam Rocks and SWS was prepared. For the coarse grid (100 x 100 m) at Howe Sound, Pam Rocks wind field is provided as an input to the model to consider the longer fetch to define the wave climate. For the nested models (20 x 20 and 5 x 5 m), SWS time-varying wind field was provided to the model as it is more representative of local wind effects.

2.3 Extreme Wind Events

An Annual Exceedance Probability (AEP) of 1:200, or a 0.5% chance of exceedance in a given year, is the design basis conditions for wind event. The sample of wind speed storms followed a Generalized Extreme Value (GEV) distribution and the fitting parameters was estimated with maximum likelihood methods. For operational wind and AEP of 1:5 was used. The results of the extreme value analysis are summarized in Table 5 for both SWS and Pam Rocks stations.

Because the duration of the two stations are considerably different it is reasonable to consider that there is no (statistically significant) difference between these results.

Table 5 Extreme Value Analysis of wind speeds for Pam Rocks and SWS Stations

AEP	Wind Speed Pam Rocks Station (m/s)	Wind Speed SWS Station (m/s)
1/5	22	19
1/10	23	20
1/25	24	21
1/100	26	24*
1/200	27*	25*
1/500	28*	26*

*less reliable prediction due to limited measured data

2.4 Currents

According to Hughes Clarke 2016 (Ref [12]), submarine sediment-laden flows - turbidity currents - transport the majority of terrestrially derived sediments into ocean basins and can build enormous significant channel networks on the ocean floor. The author examined several surge-like turbidity currents within the Squamish delta front channel. In particular, ADCP measurements were conducted over a period of six days in June 2013. During that period, the river discharge varied between approximately 450–550 m³/s.



Based on previous field programs, the turbidity currents were most common within an hour of lower low water (LLW) when the out estuary river currents peak. The experiment was specifically designed to cover the period tides evolved from neap to spring conditions and thus the LLW level decreased daily. Seven discrete events were studied, and results showed that the current speed vary between 0.5 to 3.0 m/s.

Current speed measurements were provided by the Squamish Terminals. The data was used by the Terminals in a study Ref [5] to investigate the flow pattern in the navigational corridor in the vicinity of Berth 2 and to prioritize dredging requirements. The data consists of transects of current velocities and directions measured throughout the water column using an ADCP. The transect measurement occurred during an ebb tide period on February 16th, 2017 between 14:25 and 15:00 h. Figure 9 shows the locations of measurements.

Figure 10 shows the time series of the ADCP transect mean and maximum current speeds. The mean current throughout the depth and the mean surface velocity vary between near zero at some locations to 0.5 m/s. The currents are stronger at the central part of the transect, reaching 1.4 m/s. The maximum currents close to Squamish Terminals varies between 0.5 m/s to 0.8 m/s.



Figure 9 Vessel track for ADCP current measurement on February 16th 2017

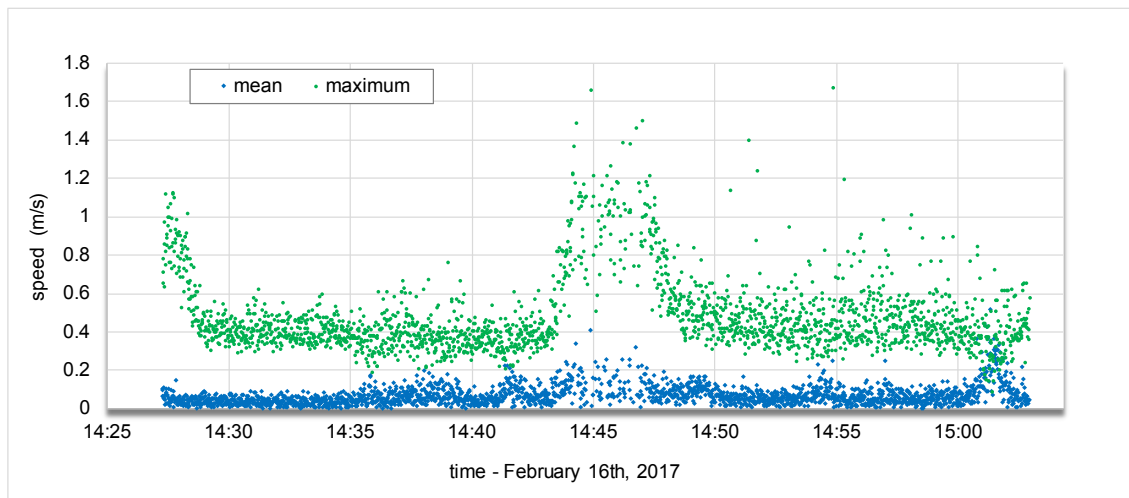


Figure 10 Time series from the transect Start Point A to the End Point B on February 16th 2017

2.5 Sediment Transport

According to Vendettuoli et al. 2019 (Ref [7]), turbidity currents are powerful flows of sediment that pose a hazard to critical seafloor infrastructure and can transport important amounts of sediment to the sea floor.

The monitoring conducted by the authors shows that more than 100 turbidity currents may occur during the spring and summer freshet each year in Squamish estuary, when seasonal meltwater increases the Squamish River discharge from roughly 100m³/s in the winter to more than 500 m³/s, with peaks of up to 1000m³/s. The high frequency turbidity current activity has formed three submarine channels which includes “northern”, “central” and “southern” channels in Squamish delta (Figure 7). These channels are partially sub-aerially exposed at low tides very close to the delta-lip.

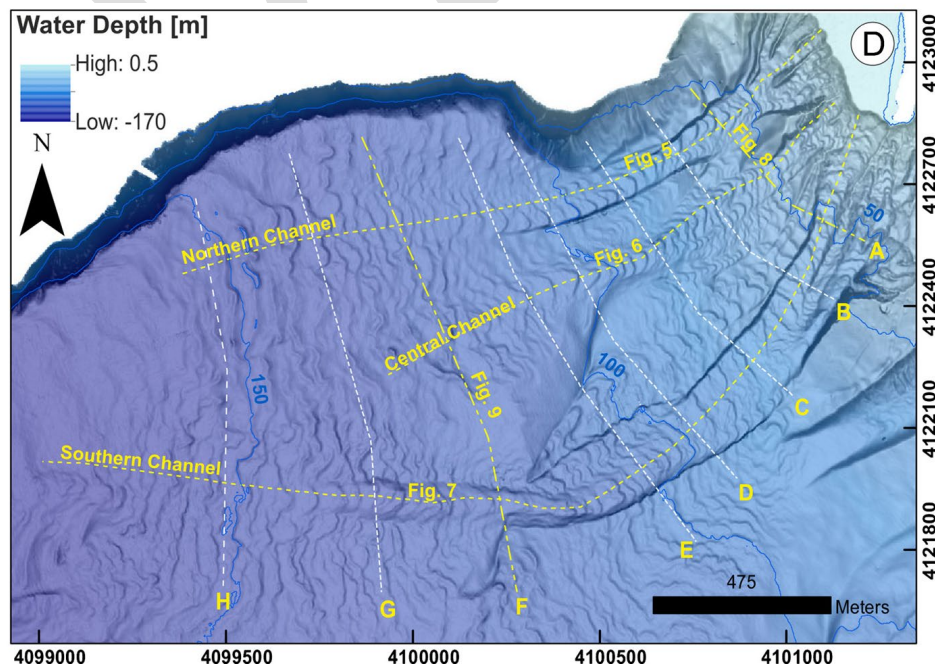


Figure 11 Submarine channels in Squamish Delta (Ref. 7)



Several other studies have also reviewed the sedimentation pattern in the Squamish estuary and the Squamish River. WSP conducted a geotechnical study (Ref [8]) to provide engineering design and construction inspection services of the proposed Squamish River Spit Road Bridge. The bridge is located at approximate dyke chainage of 2+660 on the Squamish River training berm. According to WSP (Ref [11]) the proposed bridge site is located in floodplain sediments consisting of sand and silt and underlain in many places by a gravel layer of 1 to 3 m thick; occurring as flat surfaces close to river level with a high probability of flooding. Organics may also be encountered in these deposits.

The sediment characteristics were taken from geotechnical drilling program comprised of two (2) sonic boreholes at approximately 18 m depth from the existing ground surface. The sediment size and characteristics input to the model were based on sieve size analysis report and borehole log information (Ref [11])

Amec Foster Wheeler (Ref [7]) conducted soil sampling and logging of the soil along the Spit Road (Dike Road) in 2016. A total of five boreholes were advanced along the Dike Road at three separate locations. The soil type at the boreholes consist of fine sand and silt layers.

Tetra Tech (Ref [5]) used the Syvitski and MacDonald 1982 (Ref [10]) study for sediment characteristics. Syvitski and MacDonald (1982) studied particles size of bottom sediment at Squamish Harbour and Howe Sound by collecting over 200 samples in various parts. The sediment at the tidal flats in Squamish Harbour was characterized as ‘muddy sand’ with particle size ranging from 11 Φ to -1 Φ (or 1 micron - 2,000 micron) with a large proportion between 4 Φ (65 micron) and 2 Φ (260 microns), and a smaller, but still significant proportion at 7 Φ (8 microns).

KWL, 2018 (Ref [11]) concluded that the Squamish River itself is the primary source of sediment in this area, including Berth 2, and that Crescent Slough, in it’s present configuration, is a less important or even negligible, source of sediment; for the existing condition.

2.6 River Discharge and Sediment Influx

River discharge data at Squamish River (08GA022) is available from 1922 to 2018 from measurements by the river gauge maintained by the Water Survey of Canada. The summary of Squamish River station information is presented in Table 6. The data was analysed during the period of measurement to define the maximum flow discharge (freshet) event and the average winter flow. Winter average is considered based on average of measurement record from October to February. Summer freshet is considered during May, June and July.

Table 6 Squamish River Station (08GA022) information

Parameter	Value
Lat	49° 47' 42" N
Lon	123° 12' 11" W
Period of Record	1922-2018 (71 years)
Vertical Reference	Chart Datum

Figure 12 presents the average and maximum monthly flow discharge rate for the last 10 years of record. In general, monthly average and maximum flows are highest from May to August.

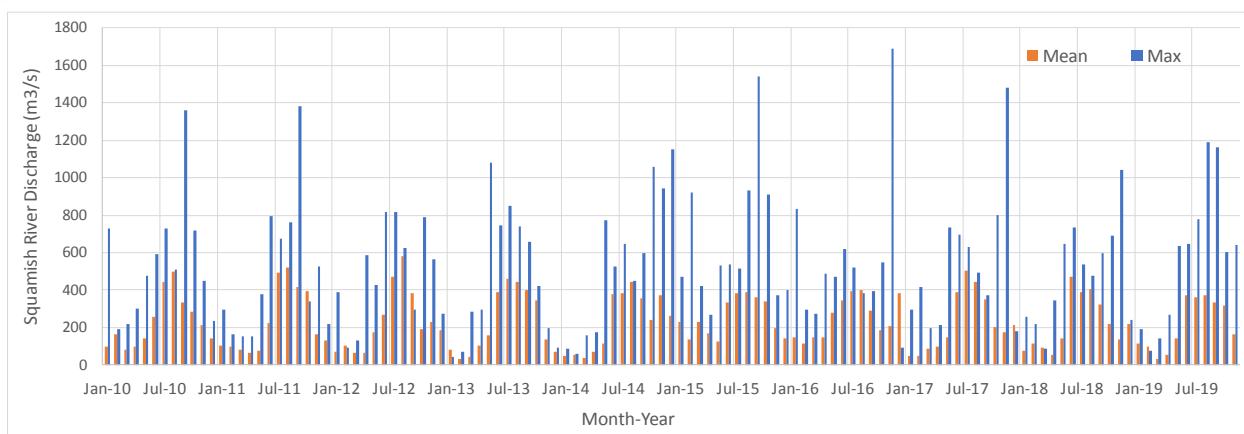


Figure 12 Average and maximum monthly flow discharge from 2010 to 2020

Table 7 shows the highest river discharges for the period of record (1922-2020). Six of the ten events occurred during the months of October and November. The events varied from 1,700 to 2,630 m³/s

Table 7 Highest Squamish River discharges for the period of record (1922-2020)

Event Rank	Year	Month	Q (m3/s)
1	2003	October	2,630
2	1957	September	2,230
3	1984	October	2,150
4	1991	August	2,120
5	1981	November	2,110
6	1980	December	2,020
7	1984	October	1,950
8	1975	November	1,800
9	1990	November	1,720
10	1968	June	1,700

Clarke, 2016 (Ref [12]) stated that the Squamish river carries more than 10 million m³ of sediment into the delta annually, and much of that sediment is transported down the submarine pro-delta slope by turbidity currents.

Hickin, 1989 (Ref [13]) delineated the rating curve that describes the relationship between the flow rate of the Squamish River and the suspended-sediment concentration. A brief literature review on Squamish river influx indicated that this study is the most reliable one based on long-term (1956 - 1986) flow analysis and sediment-load characteristics of Squamish River.

This study used digitized bathymetric surfaces based on the Canadian Hydrographic Services surveys of 1930, 1973, and 1984 at the head of Howe Sound to obtain a long-term sedimentation rate for Squamish River delta. The data indicated that the modal discharge-effectiveness class is in the range of 600-700 m³/s, moving 13% of the annual suspended-sediment load. Discharges up to 1400 m³/s composed of 99.8% of all flows and are responsible for transporting 81.5 % of the annual load. A very significant 18.5 % of the load is moved by large-magnitude floods (less than 1,400 m³/s), which occur less than 0.2 % of the time.



Figure 13 shows daily mean suspended-sediment concentration versus daily mean discharge, a relationship for which the second-order polynomial least-squares rating curve statistically explains 60 % of the variance in concentration. The unexplained 40 % variance is mostly attributed to discharges less than about 200 m³/s, a domain in which suspended-sediment concentration becomes independent of discharge but very dependent on the occurrence of sediment-supplying events such as storms.

The sediment transport discharge concentration input to the model utilized this rating curve for the sedimentation study depending on the discharge rate.

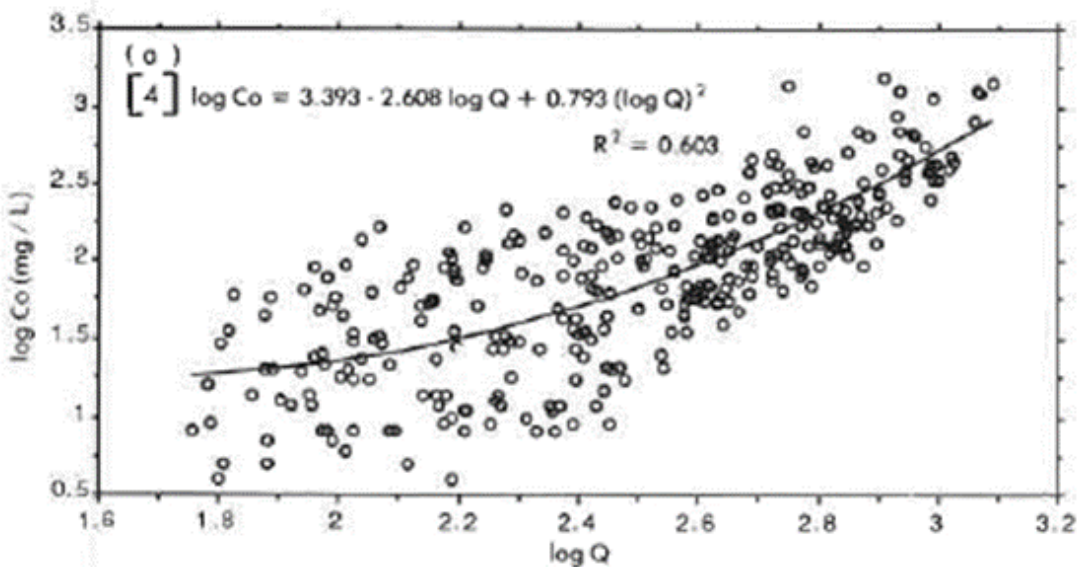


Figure 13 Suspended-sediment rating curve for the Squamish River

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3. Numerical Modelling

The modelling for this study used the open source Delft 3D-Flow numerical model. Delft3D-Flow is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid. Source and sink terms are included to model discharges and withdrawals. For the present application, the simulations were conducted in 2D model (depth-averaged) using Cartesian grid coordinates.

Delft3D-Flow supports several kinds of boundary conditions such as astronomical constituents, water levels, velocities, combinations of water levels and velocities and discharges.

The Delft3D-Flow program has the following standard features:

- › Tidal forcing
- › The effect of the Earth's rotation (Coriolis force)
- › Density driven flows (pressure gradient terms in the momentum equations)
- › Advection-diffusion solver included to compute density gradients with an optional facility to treat very sharp gradients in the vertical
- › Space and time varying wind and atmospheric pressure
- › Advanced turbulence models that account for vertical turbulent viscosity and diffusivity based on the eddy viscosity concept. Four options are provided: $k \epsilon$, $k L$, algebraic and constant model
- › Time varying sources and sinks (e.g. river discharges)
- › Simulation of thermal discharge, effluent discharge and the intake of cooling water at any location and any depth
- › Drogue tracks
- › Robust simulation of drying and flooding of inter-tidal flats.

To investigate the morphologic changes of the Squamish estuary system due to physical processes and sediment exchange between Squamish River and the open coast, a coupled Delft3D Flow and SWAN wave numerical model was developed. Delft3D-Flow forms the core of the model system; simulating water motion due to tidal and meteorological forcing by solving the unsteady shallow-water equations in two (depth-averaged). The wave model SWAN was applied in a non-stationary computational mode to propagate waves from the offshore boundaries of the model to the estuary, and also to generate wind-induced waves within Howe Sound. SWAN models the effects of wind-wave generation, refraction, shoaling, dissipation by bottom friction, white capping, nonlinear wave-wave interactions, and ambient currents on the wave properties.

3.1 Reference system

The horizontal coordinates and vertical reference datum used in this analysis are given in Table 8. 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. Horizontal reference is UTM Zone 10N (NAD 1983).



Table 8 Horizontal and vertical references specifications

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

At Squamish, Chart Datum (CD) is 3.08 m below CGVD 28. This is the same difference considered for the Designated Flood Level Studies –Ref [6] and Ref [14]). In Howe Sound and the approaches to the Squamish Estuary, CD is 3.1 m below the 0 m (CGVD) contour. For computational purposes, depths are positive referencing Chart Datum as the vertical datum.

3.2 Bathymetry

The bathymetry data is a compilation of surveys shown in Table 2 and the previous model bathymetry used by SNC-Lavalin in Ref [6].

Table 9 Summary of bathymetric datasets

Source	Original Reference System	Comments
CCOM - Center for Coastal and Ocean Mapping (2019)	WGS84 / CD	Provided by John Hughes Clark
Terminal Berth and Seabed Condition Survey (2018)	NAD83 (UTM Zone 10) / CD	Contour intervals 5 m CRA Canada Survey Inc. provided by Squamish Terminals
Canadian Coast Guard (2017)	NAD83 (UTM Zone 10) / CD	-
SNC-Lavalin IFHMP Bathymetry (2015)	NAD83 (UTM Zone 10) / CD	Compilation of datasets – See Ref [6]
Squamish River (2007)	NAD83 (UTM Zone 10) / CD	Survey was conducted and provided by BC Hydro.

An initial review of the recent bathymetry datasets indicated that differences between the 2015 SNC-Lavalin and the more recent surveys were mostly around Squamish Terminals, south of the training berm, and within the Squamish River delta. They are typically related to dredging or the results of foreslope instabilities and are likely to continue to occur in the future in an episodic manner.

Figure 14 shows a representation of the bathymetry used for the finest grid model (5 x 5 m). The following changes were considered for the model bathymetry.

- › The bathymetric data upstream of the Squamish River (survey provided by BC hydro 2007) was added to the datasets.
- › Bathymetry at the south and west of the Squamish spit were updated using CCOM 2019, as there was a discrepancy (at some locations more than 10 m) between 2015 SNC-Lavalin and CCOM 2019 bathymetric data.
- › CCOM 2019 bathymetry also provided more detailed information at the downstream part of Squamish River and further to the south of the Squamish estuary.



- › The bathymetric data at Squamish terminal was updated with Terminal Berth and Seabed Condition Survey (2018) and Canadian Coast Guard (2017), both provided by the Squamish Terminals. The information was more recent and has higher resolution comparing to SNC-Lavalin 2015 data.

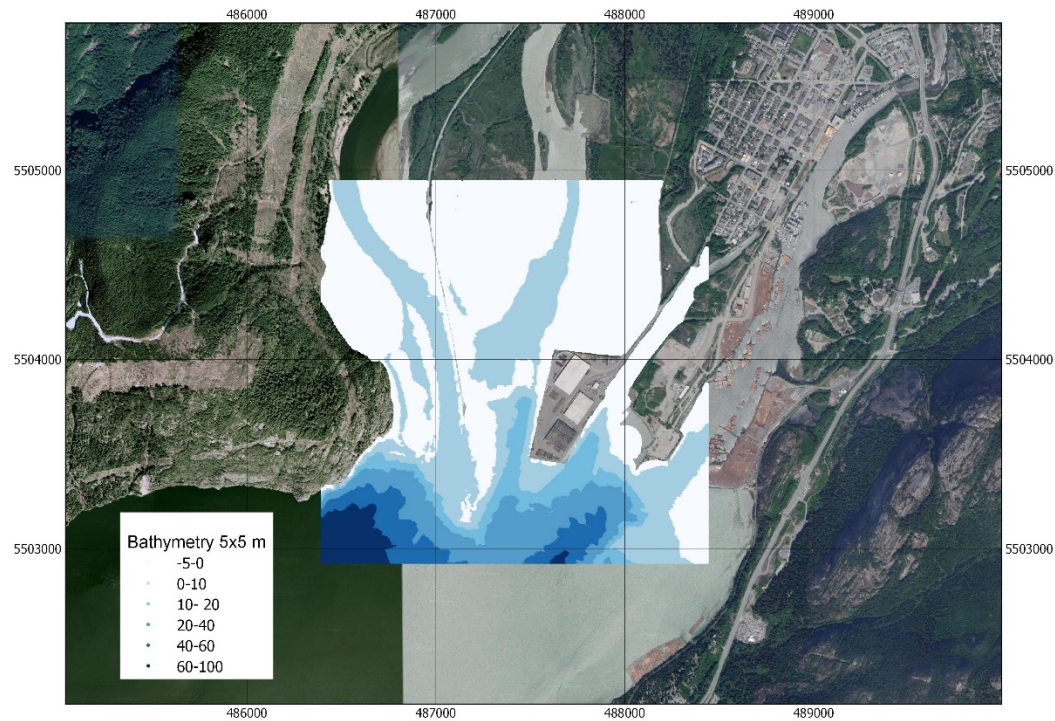


Figure 14 Simplified nested grid (5 x 5 m) bathymetry

3.3 Grids

The model grids were developed using the bathymetric dataset presented in Table 9. Three grids were generated to account for the complexity of the study. Figure 15 shows the limits of each grid.

- › Coarse Grid (100 x 100 m)
- › Nested1 Grid (20 x 20 m)
- › Nested2 Grid (5 x 5 m)

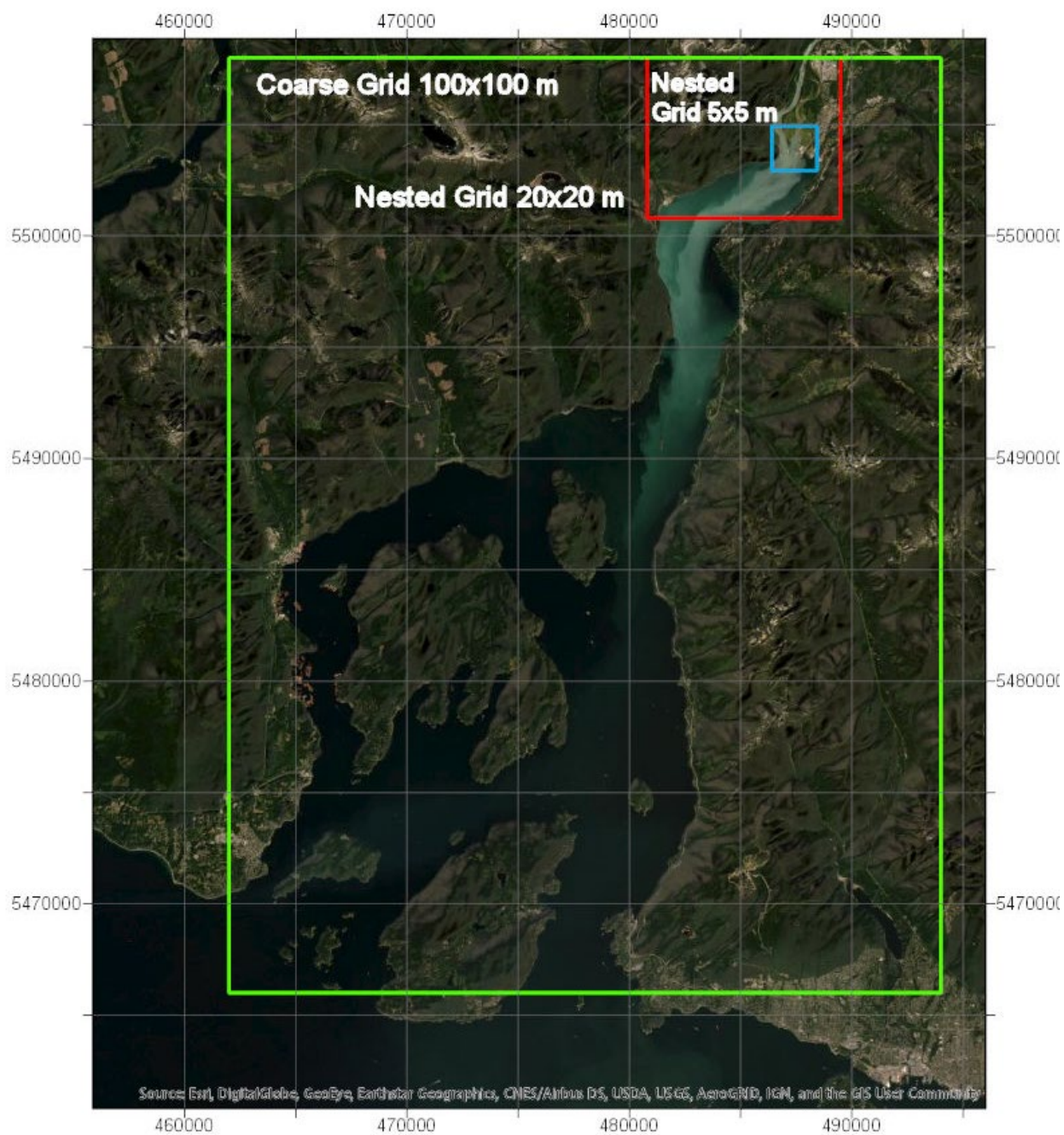


Figure 15 Model grids boundaries

3.4 Validation / Calibration

The model was validated by comparing the water level at the Lower Estuary Station and results from Nested2 (5 x 5 m) grid. The comparison for three days in 2019 is shown in Figure 16.

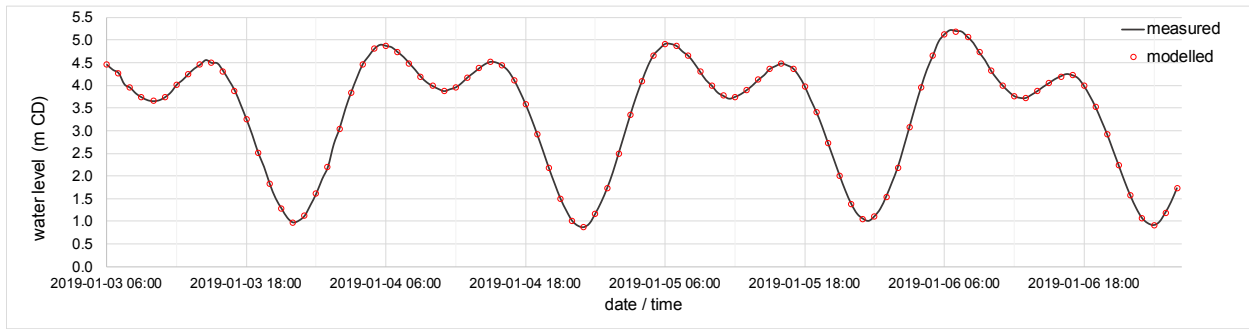


Figure 16 Validation of the circulation model

The model was calibrated using the current speed measurements described in Section 2.4. The model input consisted of measured water levels from Point Atkinson, river discharge from Squamish River, wind speeds from Pam Rocks and local winds from SWS.

The average and maximum river flow discharge at Squamish River on February 16th, 2017 is summarized in Table 10 below.

Table 10 Mean and Maximum Flow Discharge at Squamish River at February 16th, 2017

Squamish River	River Discharge (m3/s)
Mean Flow	86.7
Maximum Flow	418

Figure 17 shows the final comparison between the current speed measurements and model prediction. The limitations for calibration are that the wind and water level inputs are hourly, discharge is daily, and currents were measured for less than one hour. It is concluded that the project circulation model provides a reasonable description of currents at the site.

Currents speeds below 0.1 m/s are below the model resolution and were not target for calibration.

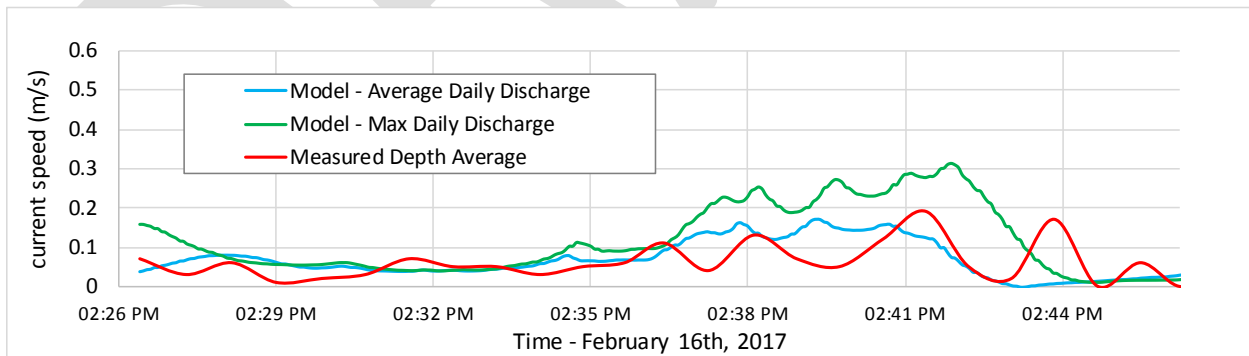


Figure 17 Final comparison between currents measured and predicted by the model



4. Next Steps

Based on the validated model, SNC-Lavalin will run four different scenarios, with durations of approximately 14 days each. These runs combine the following parameters to include full range of possible conditions to predict the fate of sedimentation pattern at the Squamish estuary.

- › Winds: operational and storm wind events will be considered. The selected run period will be within the local measurements (2010-2020), since local winds can differ from the long time series of measurements from Pam Rocks. Wind time series will be defined with the SRWS.
- › River discharge: average winter flow discharge as well as high flow discharge (freshet) from Squamish River will be considered during the available period of measurements.
- › Training Berm: two scenarios will be considered for comparison, existing berm length and 1.1 km removal.
- › The seasonal variability of the events is considered to combine the environmental parameters (i.e. wind, river discharge and spring tide) for each run. For example, if selected wind event happened in June the equivalent highest river discharge (freshet) in summer will be selected.
- › The wave climate effects (wind generated waves) is incorporated by coupling the hydrodynamic and sediment model with wave model using the non-stationary wind input



5. References

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Ref [4] “

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

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Ref [8] “Squamish River Spit Road Bridge Geotechnical Report”, WSP, March 2019.

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Ref [10] Syvitski, J.P.M and R.D. MacDonald. 1982. Sediment character and provenance in a complex Fjord; Howe.

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Ref [12] “First wide-angle view of channelized turbidity currents links migrating cyclic steps to flow characteristics.” Clarke, J.E.H., 2016., Nature communications, 7(1), pp.1-13.

Ref [13] Hickin, E.J. 1989. Contemporary Squamish River sediment flux to Howe Sound, British Columbia. Can. J. Earth

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6. Revision Index and Signatures

Issue Code	Rev. No	Date (yyyy-mm-dd)	Description of Changes	Initials
RR	PA	2020-06-09	Issued for Internal Review	GMJ
RR	PB	2020-06-11	Issued for Review and Comments	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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