A mitigation plan for salmonid spawning habitat in the Lower Seymour River, North Vancouver

by

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List of Acronyms

A.T.U.	Accumulated temperature unit
B.C.	British Columbia
D.O.	Dissolved oxygen
G.P.S.	Global positioning system
N.H.C.	Northwest Hydraulic Consultants
N.T.U.	Nephelometric Turbidity Unit
L.S.C.R.	Lower Seymour Conservation Reserve
P.N.W.	Pacific Northwest
T.W.N.	Tsleil-Waututh Nation

Executive Summary

Salmonids are a very important species to British Columbia and the Pacific Northwest. They are an icon of British Columbia's heritage and they hold many ecological, economical, recreational, and cultural values. Unfortunately, Pacific salmonid populations have been declining over the last century due many reasons including degradation of freshwater habitat used for spawning and rearing. This degradation is largely due to expanding urbanization and the installation of dams for flood control, hydropower and water supply.

The Seymour River is a mountainous river located in North Vancouver. Over the past century, this river has been subjected to many anthropogenic activities that have cumulatively altered the natural flow and sediment regime. The Seymour Falls Dam, located in the middle of the watershed, intercepts gravel transport from the upper watershed into the lower reaches. This combined with the intense channelization within the lower 4 km of the river, which has created conditions incapable of gravel deposition and retention, has led the lower reaches to become gravel deficient. This gravel deficiency has caused the degradation of traditional spawning grounds of chum (*Oncorhynchus keta*), and pink salmon (*Oncorhynchus gorbuscha*). This study aims to: 1) determine if there is a gravel deficiency for chum and pink salmon spawning in the lower 1.5 km reaches and, 2) provide recommended mitigative treatments of gravel addition to increase suitable spawning area, and therefore increase salmon productivity of the Seymour River.

A site assessment was conducted on the lower 1.5 km of the Seymour River and included sampling of the five key parameters that define spawning habitat (i.e., water depth, velocity, dissolved oxygen, water temperature and substrate). A particular focus was given on analysing the substrate as it was expected to be deficient for spawning due to the predetermined conditions in the watershed such as the dam and the channelization.

Results of the site assessment confirmed that substrate is the limiting factor for chum and pink salmon spawning in this area as the bed surface is composed of large cobbles and boulders too large for these specific species to move to dig a redd. Therefore, a

mitigation plan of gravel addition is proposed to increase spawning habitat and conserve these salmon runs.

Two gravel placement sites were selected between Mt. Seymour Parkway and Dollarton Bridge. A gravel mobility analysis determined that suitable-sized gravel will not be deposited or retained naturally on the channel bed due to the slope and water depth at high flood events. Therefore, gravel catchment structures are proposed to dissipate energy, thereby promoting deposition and reducing scouring. Each site contains a different design tailored to the specific characteristics of that reach. To retain gravel, spurs composed of the surface cobbles and boulders are proposed along with imbedded gravel pads composing of suitably sized gravel brought in from a local source. In total these two sites could provide about 1,925 m^2 of additional spawning habitat which could support 209-836 pairs of chum or 3,208 pairs of pink salmon.

Through long-term monitoring, this project in the Seymour River could provide strategies of gravel placement in large, urbanized, gravel-deficient rivers, in which current research is limited. Many rivers in North Vancouver (i.e., Capilano River, Lynn Creek, McKay Creek and Mosquito Creek) may be experiencing a gravel deficit similar to the Seymour River, and the strategies outlined in this project could be adapted to the specific conditions of those rivers. The cumulative effect of adding spawning gravel in each river within the Burrard Inlet, as well as elsewhere in the Pacific Northwest, could reduce stress in their freshwater phase and aid in rebuilding salmon populations from their precipitous decline in which they are on currently on track for.

The strategies provided will also become important as more rivers become sediment deprived due to the construction of hydropower dams in response to a change from fossil fuels to renewable energies as climate change continues. The need for more innovative habitat mitigation strategies will be necessary to keep salmon from becoming a relic of the past.

Chapter 1: Introduction

1.1 Salmonids in the Pacific Northwest

Salmonids are a very important species to British Columbia (B.C.) and the Pacific Northwest (P.N.W.). They are an icon of B.C.'s heritage and they hold many ecological, economical, recreational and cultural values.

1.1.1 Salmonid importance

Ecological importance

Salmonids are a keystone species that influence the survival of other species and therefore, have a large role in determining community structure and the function of an ecosystem (Cederholm et al. 1999). They link aquatic and terrestrial ecosystems through physical predator-prey interactions, and are a vector for nutrient transfer across ecosystems (i.e., across marine, freshwater and terrestrial environments) (Wilson and Halupka 1995, Cederholm et al. 1999). The unique life stages of anadromous salmonids also provide many opportunities for different wildlife species. For example, adult salmonids are preyed upon by carnivores such as bears, while juveniles are preyed upon by otters and birds, and eggs are preyed upon by birds and other fish species (Wilson and Halupka 1995). Furthermore, salmon carcasses are scavenged by many different species (Wilson and Halupka 1995). The loss of anadromous fish could therefore have dramatic effects on the populations of the wide variety of wildlife that rely on them as a food source (Wilson and Halupka 1995). Salmonids also provide an indirect effect on other terrestrial landscape aspects such as vegetation by influencing nutrient dynamics (Wilson and Halupka 1995). For example, salmon carcasses provide marine nutrients to sustain the productivity of riparian areas, while also providing nutrients for future generation salmon juveniles in stream (Kline et al 1990, Cederholm et al. 1999, Gresh et al. 2000).

Economic importance

Salmonids play a large part in B.C.'s economy through both recreational and commercial fisheries. The commercial fishing industry supports the economy by providing jobs and supports the livelihoods of many people. Due to the symbolic nature of salmonids for the P.N.W., people come from around the world to view and learn about them, therefore, supporting the tourism industry (P.S.F. 2011).

Cultural importance

B.C.'s First Nations have had a spiritual relationship with salmonids for thousands of years (P.S.F. 2011). Salmonids have for a long time provided subsistence as a main food source (Coupland et al. 2010) and have been a focus of many cultural traditions. The protection and conservation of salmonid stocks and quality aquatic ecosystems are also of critical importance for First Nation's fisheries and their rights to these resources (F.N.F.C. 2017).

Other people living within the P.N.W. view salmonids as a unique identifier of the region and a symbol of the remaining wilderness that is left within the highly urbanized region (Yeakley 2014). For some, the status and well-being of salmonids represents the status of the environment (e.g., they are a gauge for water quality as they require high quality environments to survive), or they hold a purely intrinsic value (Crisp 2000, Lichatowich 2017).

1.1.2 Decline in wild Pacific salmonid populations

Unfortunately, wild Pacific salmonid populations in the P.N.W. have been declining over the last century, with a sharp decline since the 1990s (Gresh et al. 2000, Noakes et al. 2000, Yeakley 2014). Historically, Pacific salmon spawning ranges existed throughout the coast of North America, from Alaska to Mexico (Yeakley 2014). These ranges have been drastically reduced, specifically with the southern portion of their extent (Yeakley 2014). For example, historical breeding ranges have been reduced by about 40% in Washington, Oregon, Idaho and California (N.R.C. 1996, T.W.S. 1993). Many populations are currently threatened, endangered or even extinct (Noakes et al. 2000). While the beginning of this decline can be attributed to poor historical logging practices and over fishing (Yeakley and Hughes 2014), the continued decline today can be attributed to poor oceanic survival (Friedland et al. 2014) and decreases in the quantity and quality of freshwater habitat (Bjornn and Reiser 1991, Slaney et al. 1996, Noakes et al. 2000). Degradation of freshwater habitat has occurred due to logging, agriculture, urbanization, and the installation of dams (N.R.C. 1996, Noakes et al. 2000). Similar to those of other P.N.W. rivers and streams, the Seymour River in North Vancouver has experienced degradation of important spawning habitat as a result from human alterations such as the installation of a dam and urbanization in the lower reaches (Slaney et al. 1996, Hryhorczuk 2011).

1.2 Overview of project

The Seymour River in North Vancouver, B.C., is a regulated river and is part of the Seymour Watershed (area of 176 km^2) (Hryhorczuk 2011). Over the past century this watershed has been subjected to many anthropogenic activities, including deforestation along the banks, urbanization within the floodplain, intense channelization in the lower reaches and impoundment from dams, all of which have had negative effects on the natural system. Of importance to this project, is the cumulative effect of these stressors on the natural gravel transport from the upper watershed downstream to the estuary at the Burrard Inlet. Flow and sediment regimes have been disrupted due to the Seymour Falls Dam located in the middle of the watershed, and the intense channelization of the lower river has created conditions inadequate for gravel deposition in the lower reaches, leaving them gravel deficient. The dam intercepts natural gravel transport by trapping gravel within the reservoir, and releases flows that entrain any smaller grain sizes, producing a surface layer of armoured cobbles and boulders (K.W.L. 2003). This gravel deficiency has caused the degradation of traditional salmon spawning grounds of chum (*Oncorhynchus keta*), and pink salmon (*Oncorhynchus gorbuscha*) in the lower reaches. While some studies have shown that this gravel deficiency is a limiting factor for spawning throughout the river for other species including steelhead (Hryhorczuk 2011), this study aims to: 1) determine if there is a gravel deficiency for chum and pink salmon spawning in the lower 1.5 km reaches and, 2) provide recommended mitigative treatments of gravel addition to increase suitable spawning area, and therefore increase salmon productivity of the Seymour River.

The rationale behind this project is the strong attachment and respect for salmonids as a part of B.C.'s heritage and the many reasons stated previously (Section 1.1.1). Wild salmonid stocks in the Seymour River are declining each year (Hryhorczuk 2011) and the conservation and restoration of freshwater habitat will aid in rebuilding salmon populations to historical numbers, as well as conserve their current populations. Taking an active approach of increasing high quality spawning habitat will directly influence the conservation of these stocks. Without intervention, these stocks will not recover.

There are several stakeholders that are involved with the management and use of the Seymour River. These include: the Seymour Salmonid Society, the District of North Vancouver, Metro Vancouver, Department of Fisheries and Oceans Canada, Allied Shipbuilders LTD, and the citizens of North Vancouver who live around the river and use it for recreational activities. The study area is located on traditional Tsleil-Waututh Nation and Squamish Nation land.

1.3 Project goals and objectives

The purpose of this project is to demonstrate if gravel in the lower 1.5 km of the Seymour River is deficient and to propose a migration plan to increase suitable spawning area for chum and pink salmon.

Goal 1: To determine if there is a gravel deficiency for chum and pink salmon spawning in the lower 1.5 km reaches

> Objective 1.1: Determine the current conditions of the five parameters that define spawning habitat (i.e., substrate, velocity, depth, temperature, dissolved oxygen), with a main focus on gravel distributions.
>
> Objective 1.2: Determine current gravel transport of the system based on bankfull depths and slopes.

Goal 2: To recommend mitigative treatments to increase spawning habitat through gravel addition

> Objective 2.1: Propose a hierarchy of restoration efforts throughout the watershed, especially upstream to sustain efforts.
>
> Objective 2.2: Propose instream structure designs to retain gravel if results from Objective 1.2 show that shear stresses are too great to allow natural gravel deposition and retention.

Chapter 2: Salmon ecology

A basic understanding of salmonid ecology is critical to any stream or river restoration project targeted at restoring salmonid habitats (rearing or spawning). Designing treatments with a focus on the ecological life history of the targeted species will provide greater success than restoring with no knowledge and hoping the species will use and benefit from it.

Pacific salmon are classified in the genus *Oncorhynchus* and are unique from other fish species in that they are diadromous (i.e., they migrate between fresh and saltwater). Only about 1% of fish have this feature (McDowell 1987). More specifically, all Pacific salmon species are anadromous (i.e., they migrate upstream in freshwater to spawn, but live the majority of their life in the ocean) and semelparous (i.e., they spawn once and die shortly afterwards) (Meehan and Bjornn 1991). It is these unique life traits that lead to requiring different habitats for each life stage; consequentially, there may be different stressors acting on the populations in the oceanic and freshwater phases.

2.1 Chum and pink life history

Chum are the second largest Pacific salmon in size after Chinook, whereas pink are the smallest (Salo 1991). Even with these size differences, chum and pink have similar life cycle stages and habitat requirements. The main difference is the timing and lifespan of the fish. Chum salmon typically live two to five years whereas pink have a two year life span (Salo 1991). Due to the short two year life span of pink salmon, their stocks have been labelled as either odd or even years based on the year that they return from the ocean (Salo 1991).

2.1.1 Initial fresh water phase

The general life cycle (Fig. 1) of a salmonid begins with an egg buried in a redd (i.e., a gravel nest) of suitably sized gravel. Once they hatch in response to environmental signals such as temperature, they stay within the intragravel spaces as alevins and rely on yolk sacs as a primary food source (Meehan and Bjornn 1991). Once the yolk sac has been absorbed, they emerge from the gravel as fry in March to May (Meehan and

Bjornn 1991). Chum and pink are different from other species of salmon in that once they emerge from the gravel, they spend little time maturing in freshwater. Within a few days to several weeks of emerging, the fry migrate downstream to the ocean (Meehan and Bjornn 1991, Björnsson et al. 2011). This early migration is likely a genetic trait as the physical conditions of the river tend to not have an influence on their residence time (Meehan and Bjornn 1991). They become classified as parr once they develop dark oval shaped parr marks along their sides for camouflage within the riverine environment (Meehan and Bjornn 1991). As they near and enter the estuary, they undergo physiological, biochemical, morphological and behavioral transformations (known as “smoltification”) to prepare for the salt water environment (N.R.C. 1996). This process is hormone driven and results in changes in their appearance such as a change in coloration from dark parr marks to a silver body color (Hoar 1988). Smoltification also increases their hypo-osmoregulatory capacity to be better adapted within the marine environment (Meehan and Bjornn 1991, Crisp 2000, Björnsson et al. 2011).

2.1.2 Oceanic phase

Once the salmonids have left the estuary of their natal stream, they live the rest of their life in the Pacific ocean feeding and growing (Meehan and Bjornn 1991). They travel north along the continental shelf and then migrate into the open ocean (N.R.C. 1996). Chum salmon travel the furthest of all Pacific salmon, traveling as far as the coasts of Japan (Bakkala 1970). A recent decline in marine salmon survival is can be attributed to predation, increased ocean temperatures, as well as sea lice and other diseases from fish farms (Friedland et al. 2014). The adult salmon leave the ocean and return to their natal stream to spawn in the fall after two to five years and 12-18 months for chum and pink, respectively (Meehan and Bjornn 1991).

2.1.3 Spawning freshwater phase

If they survive their oceanic phase, the adult salmonids then return back to their natal streams to spawn (known as natal homing). For pink salmon, this return is from July to October (Meehan and Bjornn 1991). Chum salmon have early runs, which return from July to September, and late runs, which return from October to January (Bakkala 1970). They migrate back to their natal stream using olfactory and geomagnetic cues (Hasler et al. 1978, Lohmann et al. 2008), and they migrate upstream to the spawning areas when they receive a signal of a large runoff of water in the stream (Salo 1991). Energy for migration is derived from pre-existing body fat and protein as they do not feed while in fresh water (Bakkala 1970).

Once the salmonids reach the desired spawning area that meets the required criteria (refer to Section 2.2), the female excavates a pit in the gravel using her tail (Crisp 2000). Repetitious flicking movements form a depression in the gravel, with a tail of the excavated gravel on the downstream end (Crisp 2000). Once the shape and conditions of the depression satisfies the female, she deposits eggs into the gravel at the same time that the male releases milt, fertilizing the eggs into embryos (Crisp 2000). The female then moves upstream and begins to dig another pit in which the gravel is displaced downstream covering the previous pocket of eggs (Crisp 2000). This process may be duplicated producing more than one pocket of eggs, thus producing a redd (Crisp 2000). About two weeks later, the female and male die near their redds and add essential nutrients back into the stream system (N.R.C. 1996).

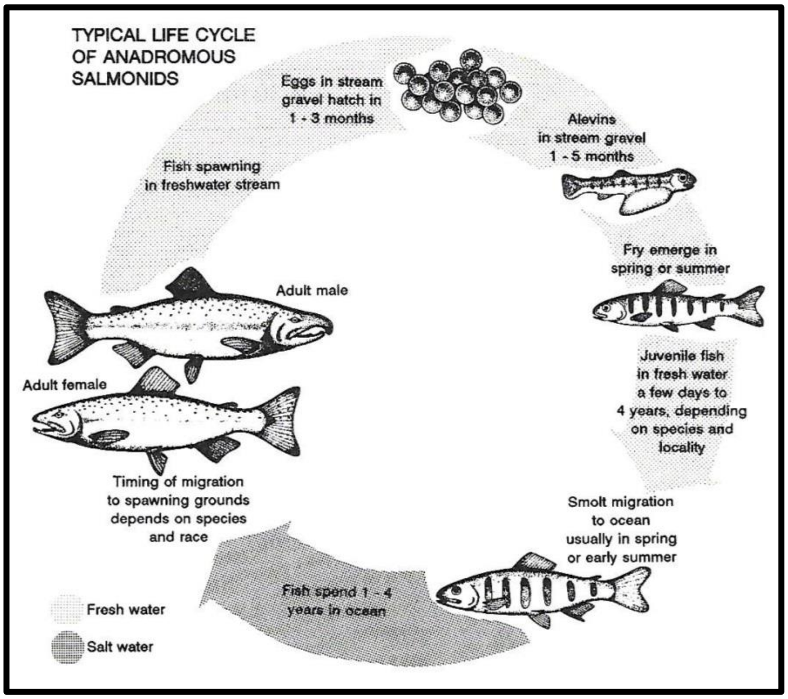

Figure 1. **The general life cycle of anadromous Pacific salmonids. Adapted from Meehan and Bjornn (1991).**

2.2 Spawning requirements

Spawning requirements vary depending on the species. Chum and pink share very similar requirements and tend to spawn in the same reaches (Salo 1991). Unlike other salmon species, chum and pink do not migrate far upstream, but rather they stay within the lower reaches of the river and can even be found to spawn within tidal zones (Meehan and Bjornn 1991). Within these lower reaches, they tend to spawn in transitional areas between turbulent riffles and the tail out of deep pools (Bakkala 1970, Tautz and Groot 1975, Salo 1991). These areas provide downwelling and optimal exchange of water across the water-gravel interface, ensuring sufficient oxygen (Keeley and Slaney 1996). There are five key parameters that define spawning habitat: temperature, dissolved oxygen, water depth, velocity, and gravel substrate (Table 1). These parameters are critical for spawning in their freshwater phase and if one does not meet requirements, population growth will be limited.

Table 1. The five main criteria that define spawning habitat for chum and pink salmon. The substrate range is a general range provided for all salmon species. The D_{50} values (i.e., median grain size) are values taken from literature and represent median grain sizes for chum and pink salmon specifically.

Species	Temperature (°C)	Dissolved oxygen (mg/L)	Water depth (m)	Velocity (m^2/s)	Substrate range diameter (mm)	Median substrate diameter, D_{50} (mm)
Chum	7.2-12.8[1]	>5[2]	0.18[3]	0.46-1.01[3]	13-102[1]	9.6-41.25[5]
Pink	7.2-12.8[1]	>5[2]	0.15[4]	0.21-1.01[4]	13-102[1]	6.5-11[6]

[1] Bell 1986
[2] Bjornn and Reiser 1991
[3] Smith 1973
[4] Thompson 1972
[5] Shirazi et al. 1981
[6] Helle 1970

2.2.1 Temperature

Water temperature is important for the survival of salmonids as they are cold-blooded (i.e., poikilothermic), and the environmental surrounding determines their body temperature (Beshcta et al. 1987). Temperature can signal upstream migration for adults but also has a strong influence on development of embryos during incubation (Bjornn and Reiser 1991). By choosing areas with appropriate temperatures, spawners increase the likelihood of survival of their eggs (Bjornn and Reiser 1991).

Rate of development from embryo to fry can be determined by the number of accumulated temperature units (A.T.U.s) (Beacham and Murray 1990). These units are the cumulative temperatures over a time period (i.e., number of days). For example, if the water is constantly 4°C for 5 days, the A.T.U.s is 20. In general, as temperature increases, the predicted A.T.U.s required for salmon to hatch from egg to fry increases and the more rapid development occurs, thereby, reducing incubation and emergence time (Bjornn and Reiser 1991, Boyd et al. 2010). At 5°C, 50% of chum and pink eggs will hatch at 498.2 and 545 A.T.U.s (i.e., 99.6 and 109 days), respectively (Billard and Jenson 1996). At a higher temperature of 10°C they will hatch at 544.5 and 629.6 A.T.U.s (i.e., 54.5 and 63.0 days) (Billard and Jenson 1996). This rate of development increases up to a temperature threshold in which it declines thereafter, and often leads to mortality (Boyd et al. 2010).

Temperature also influences the size of developing alevins and fry (Beacham and Murray 1990). Conversion of yolk into body tissue determines the size of fry, and the efficiency of this process is ultimately influenced by the temperature during embryonic development (Heming 1982).

Lastly, temperature has an inverse relationship with dissolved oxygen (i.e., as temperature increases, dissolved oxygen decreases). Dissolved oxygen is critically important for survival of adult spawners as well as for development of their eggs.

2.2.2 Dissolved oxygen

Dissolved oxygen (D.O.) around and within the redd is important for both the adult spawners and their offspring. Adequate oxygen must be available to ensure the spawners deposit their eggs and milt before dying, as well as to support developmental processes of the embryo, alevins and fry (i.e., respiratory and metabolic processes) (Alderice et al. 1958). The oxygen demand increases from the early stages of embryo development (at about 1 mg/L) towards the point of hatching (at about 7 mg/L) (Alderice et al. 1958). Low D.O. concentrations that are still above these minimum thresholds can impair embryo development during incubation, resulting in morphological abnormalities such as smaller embryos and altered hatching times (i.e., hatching is either delayed or occurs pre-maturely) (Alderdice et al. 1958).

The D.O. within the gravel of the redd is determined by: water temperature, exchange with surface waters, the velocity of flow within the redd, permeability of the substrate and the oxygen demand from organic matter within the redd (Bjornn and Reiser 1991).

2.2.3 Water depth

The required water depth for spawning is dependent on fish size (Keeley and Slaney 1996). Larger fish (e.g., chum salmon) are capable of spawning in greater depths than smaller fish (e.g., pink salmon) as deeper water is often associated with faster velocities in which larger fish are better equipped to withstand (Keeley and Slaney 1996). In general, individuals prefer enough water depth to cover their body as it can help protect against predators (Bjornn and Reiser 1991).

2.2.4 Velocity

Velocity during spawning varies depending on species' size as mentioned in Section 2.2.3. Larger fish are capable of spawning in higher velocities compared to smaller fish due to their greater ability to swim against a stronger current long enough to dig and deposit their eggs (Keeley and Slaney 1996). This ability to spawn in faster areas gives them the advantage of exploiting specific spawning sites other smaller individuals are unable to use (Keeley and Slaney 1996).

Velocity within the redd must be high enough to provide oxygen to the embryos and alevins, and to remove metabolic wastes (Bjornn and Reiser 1991), while not being too high that it scours the gravel and either exposes or displaces the eggs. Variation in flows is a large contributor to the mortality of eggs as high flows remove them from the redd, displacing them elsewhere, and low flows might leave the eggs dewatered causing the eggs to dry out (Bjornn and Reiser 1991).

2.2.5 Gravel substrate

The correct size and composition of the gravel substrate is very important for multiple reasons. Firstly, loose large gravel affects the survival of the eggs and embryos by supplying intragravel spaces for sufficient water flow (and therefore adequate dissolved oxygen), and the removal of metabolic wastes (Bjornn and Reiser 1991, Kondolf 2000). In general for all salmonid species, the preferred composition of spawning gravel is 80% composed of 10-50 mm gravel, 20% composed of up to 100 mm gravel and a small portion of 2-5 mm coarse sand (Whyte et al. 1997). A large proportion of fine sediment within the substrate is detrimental to egg survival if it fills these intragravel spaces and thus, suffocates the eggs and alevins (Keeley and Slaney 1996, Kondolf 2000). The fine sediment can also become a physical barrier for fry emergence and can alter the abundance of invertebrates which are a primary food source for the juvenile salmonids (Whyte et al. 1997).

Gravel size tends to increase with body size because larger fish have stronger tails and are therefore capable of moving larger grains and are able to withstand greater velocities which can aid in gravel movement (Kondolf and Wolman 1993). They also require larger intragravel spaces for their eggs, which are larger and have a greater oxygen demand (Van den Berghe and Gross 1989). The maximum grain size a salmon can move is of a median diameter equal to about 10% of their total body length (Kondolf and Wolman 1993). This size represents the upper grain size limit for suitable spawning gravels (Kondolf 2000). Larger individuals therefore have a larger range of gravels they can use, and consequently can utilize a greater area of the river bed for spawning. While larger salmon are capable of using larger grain sizes, in situations where spawning gravel is limited, they might use the gravel that is available regardless of size (Kondolf and Wolman 1993). It has also been found that salmon tend to build the most redds in relatively finer grained substrate (Riebe et al. 2014).

While a general size range for spawning gravel for all salmon species is 13-102 mm (Bell 1986), a study by Helle (1970) found D_{50} values (i.e., a size in which 50% of the gravel is finer, also known as the median grain size) for pink of 6.5-11 mm, which is smaller than the lower limit of this proposed general range (Table 1). This discrepancy could be due to the exclusion of larger grains (>100 mm), which changes the distribution and provides a smaller D_{50} value.

Due the digging nature of the redd construction, salmon require gravel depths of 0.15-0.35 m (Bjornn and Reiser 1991, Devries 1997).

2.3 Territorial space and redd specifics

The space required for spawning is dependent on four factors: the size of the fish (i.e., larger fish require more space), the quality and availability of habitat (i.e., whether it meets the proper criteria of the five parameters), the number of spawners, and the area that each spawning pair requires (i.e., the populations are density dependent) (Bjornn and Reiser 1991). Therefore, these factors determine the redd density in a stream or river. Redd size is determined by the size of the fish, with larger fish constructing larger redds (Keeley and Slaney 1996) as they deposit more eggs than smaller fish (Riebe et al. 2014). While redds are the specific nest in which eggs are buried, the total area that salmon require for spawning takes into account territorial behavior and is approximately four times the redd area (Burner 1951). This area is defended by both the female and male, especially when suitable habitat becomes limiting (Keeley and Slaney 1996). The specific dimensions of redds and territorial areas also varies with species (Table 2).

Since spawning habitat depends on the five specific parameters mentioned previously, the total area suitable for spawning is likely less than that of the area of suitable gravel alone (Bjornn and Reiser 1991). Therefore, when suitable gravel is limiting, as in the case of downstream from dams, the area for spawning is greatly reduced. In these limiting situations the number of spawners a stream can support is therefore determined by the territorial size of that species (Keeley and Slaney 1996). In these limiting situations, the gravels get saturated with spawners resulting in the superimposition of redds (Bjornn and Reiser 1991). Superimposition leads to high egg densities, which can reduce oxygen and create poor conditions for incubation (Bjornn and Reiser 1991). This density dependent relationship can therefore determine the growth of a population.

Table 2: Average areas required per spawning pair (territorial area) as well as the area and depth of the redd for both chum and pink salmon

Species	Area per spawning pair (m^2)	Average area of redd (m^2)	Redd depth (m)
Chum	9.2[1]	2.3[1]	0.15-0.35[3]
Pink	0.6[2]	0.6[2]	0.15-0.35[3]

[1] Burner 1951
[2] Hourston and MacKinnon 1957
[3] Devries 1997

Chapter 3: Seymour River background

3.1 Site location

The Seymour River is a mountainous river located in North Vancouver, B.C. It flows south from the headwaters at Loch Lomond (49°35′19″N 123°02′16″W) in the Coast Mountains, down into the Burrard Inlet (49°17′50″N 123°1′20″W) immediately east of the Ironworkers Memorial Bridge, and is about 35 km in length (Fig. 2) (K.W.L. 2003). The river is part of the Seymour Watershed which has a drainage area of 176 km^2 and is one of three watersheds (along with the Capilano and Coquitlam watersheds) managed by Metro Vancouver (K.W.L. 2003). The river is split into two sections (i.e., the Upper and Lower Seymour River) by the Seymour Falls Dam. The lower portion is about 19 km in length and water levels within this section are controlled by the dam and seasonal water demands (Hryhorczuk 2011). The Lower Seymour Conservation Reserve (L.S.C.R.) (56.68 km^2) comprises a majority of this lower section (excluding the estuary and last 20% of the river) and provides the public with many recreational activities and environmental educational opportunities (K.W.L. 2003).

The Seymour Fish Hatchery is located 300 m downstream from the dam and is managed by the Seymour Salmonid Society (C.R.M. Ltd. 2012). The Seymour Salmonid Society's main goal is mitigating the effects on salmonid species caused by the dam through managing projects such as off-channel and rearing pool creation (S.S.S. 2017).

The area of interest for this study is within the Lower Seymour River, from Grantham Place Bridge down 1.5 km to the estuary (Fig. 2)

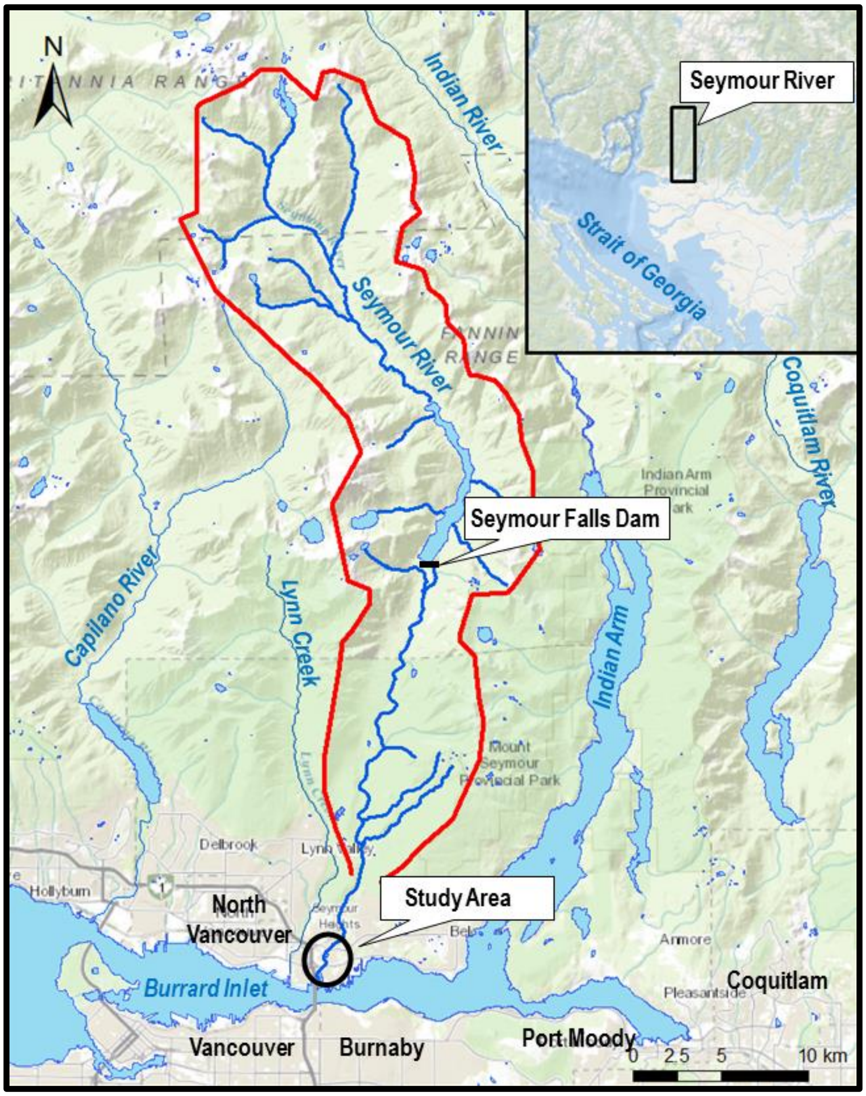

Figure 2. **The Seymour River watershed outlined in red and the study area located within the black oval in North Vancouver, B.C. The Seymour Falls Dam creates the Seymour Reservoir immediately upstream.**

3.2 Physical conditions

3.2.1 Surficial geology

Until about 11,000 years ago, the Seymour River Valley (along with most of southern B.C.) was covered by the thick Cordilleran ice sheet. This glacier eroded the landscape down into a u-shaped valley with steep slopes (Kahrer 1989). The valley fill is composed of sediments that were deposited during the glacial period and are capped by deposits from the paraglacial period that followed the retreat (Lian and Hickin 1996). The river channel itself incises through alluvial deposits which were transported downstream from the fluvial erosion of the valley fill (consisting of those glacial and paraglacial deposits) (Lian and Hickin 1996). The materials on either side of the river are floodplain and terraced sediments deposited during the natural movement of the river channel. Bedrock and colluvial deposits (i.e., deposits from mass wasting) also exist farther upstream into the canyon portion of the river (Lian and Hickin 1996, D.N.V. 2014).

3.2.2 Topography and river planform

The Seymour River is a typical mountainous river with steep channels in the upper watershed and becomes braided as it flows downstream in the valley bottom (D.F.O. 1999). The Lower Seymour River below the dam is constrained by the canyon until the lower 4 km where it experiences lower gradients as it nears the estuary (D.F.O. 1999). The lower reaches of the Seymour River exhibit a generally gentle decreasing elevation from the highest elevation of about 9 m at Grantham Place Bridge to the estuary (Fig. 3). This longitudinal profile is typical of an alluvial fan in which the sediment that built the fan was brought down from the river and deposited over a long period of time.

Due to the river being regulated by the dam, along with the mechanisms put in place to channelize the river for urbanization purposes (i.e., flood and erosion control etc.), the channel morphology of the Lower Seymour River is relatively stable (D.F.O. 1999).

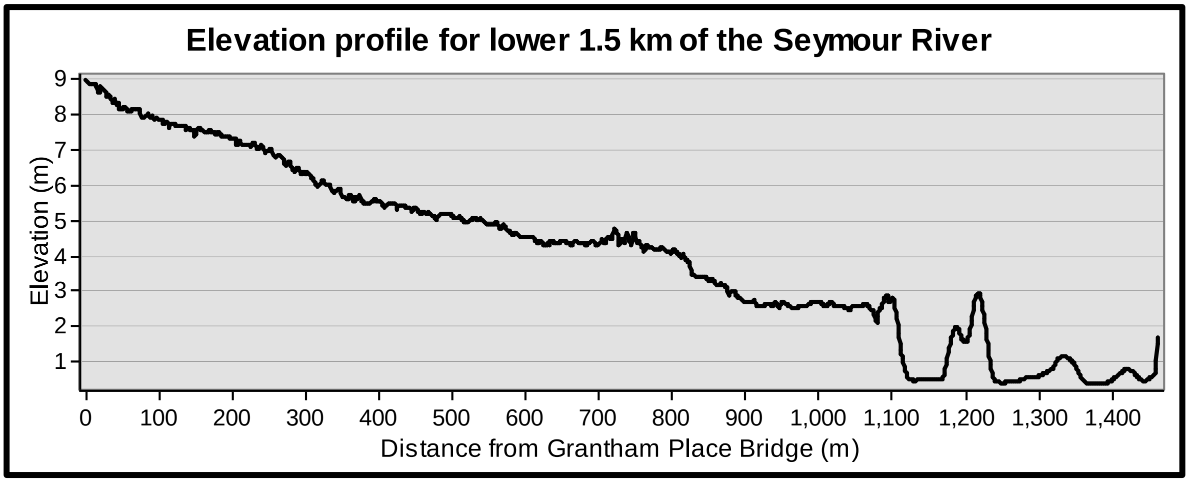

Figure 3. **The elevation profile of the lower reaches of the Seymour River starting from Grantham Place Bridge (0 m) down to the CN railroad bridge upstream from the estuary. Data extracted from LIDAR data from the District of North Vancouver.**

3.2.3 Climate

The Lower Seymour River is located within the Coastal Western Hemlock biogeoclimatic zone, while higher elevations in the upper watershed are within either Mountain Hemlock or Alpine Tundra zones (Kahrer 1989, Pojar et al. 1991). The Seymour River experiences a marine climate with wet, cool winters and dry, mild summers (Pojar et al. 1991, K.W.L. 2003). The variation in elevations across the Seymour Valley also causes a strong orographic effect, causing spatial variation in precipitation (K.W.L. 2003). The annual average rainfall and snowfall is 1805.6 mm and 24.9 cm, respectively (Government of Canada 2017). There is also temporal variation in precipitation throughout the year in which the hydrologic conditions (e.g., flow) of the river follow.

3.2.4 Hydrology

The Seymour River exhibits a mixed transitional flow regime, with large flows occurring in the fall and winter mainly from rainfall events (Fig. 4). Due to the strong influence of these precipitation patterns, peak flows occur in October to January with fall and winter storms (K.W.L. 2014). The largest event on record was on October 31, 1981, which had a discharge of 650 m^3/s (K.W.L. 2014).

The discharge is also controlled by Metro Vancouver's water demand and the operation of the Seymour Falls Dam. The dam releases water following seasonal variation in inflows, as well as in accordance with drinking water demands (C.R.M. Ltd. 2012). From the fall to spring, reservoir levels are high and often overflow through the spillway due to large inputs from precipitation events. In spring and summer, water is conserved and kept at maximum capacity but gradually drops due to low inflows and high water demand, and in late summer to early fall the reservoir gradually refills (C.R.M. Ltd. 2012).

The only tributary within the study area is Maplewood Creek (49°18′22″N 123°01′13″W); therefore, the discharge is relatively the same throughout the study area. A hydrology station located at Grantham Place Bridge (49°18′49″N 123°00′52″W) is managed by Northwest Hydraulic Consultants (N.H.C.) and is used to measure discharge and water levels.

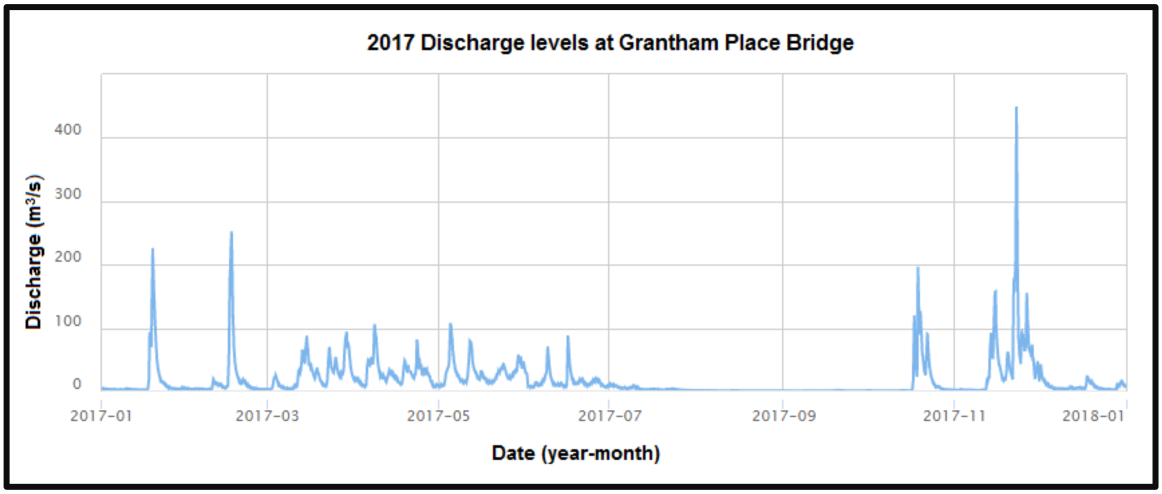

Figure 4. **The discharge levels for the Seymour River at Grantham Place Bridge in North Vacnouver, B.C. for 2017. Highest flows occur in fall and winter in correspondance to rainfall events. Adapted from N.H.C. Web Portal (2018)**

3.3 Biological conditions

3.3.1 Fish

The Seymour River and the associated tributaries provide spawning and rearing habitat for many anadromous and resident fish species. The most abundant species are: chum, pink, coho (*Oncorhynchus kisutch*), and Chinook (*Oncorhynchus tshawytscha*) salmon, steelhead (*Oncorhynchus mykiss*), rainbow (*Oncorhynchus mykiss*), and cutthroat (*Oncorhynchus clarkii*) trout, and Dolly Varden char (*Salvelinus malma*) (D.F.O. 1999). Other aquatic species such as sculpins (family Cottidae) have also been observed within the lower reaches. This study looks at spawning areas specifically for chum and pink salmon as they have been identified to spawn in areas located in the lower 4 km above Dollarton Bridge (D.F.O. 1999).

The Seymour River Hatchery supports sport fisheries and annually releases steelhead trout, coho, chum and pink (every two years) salmon (C.R.M. Ltd. 2012). Every second year, the hatchery releases about 500,000 pink and 500,000 chum smolts into the watershed (S.S.S. 2017).

Current and historical escapement numbers for chum and pink salmon (and for other species) is not well documented. Escapement records from 1976-1985 showed a maximum number of 800 and 1,000 for chum and pink, respectively, and a mean of 319 and 306 (Appendix A-1, D.F.O. 1989). Over that time period there was an oscillating trend, with some years being better than others. Based on the limited data, the numbers of chum and pink salmon in the Seymour River have been relatively stable compared to other species such as coho, and have been at a lower abundance (Fig. 5).

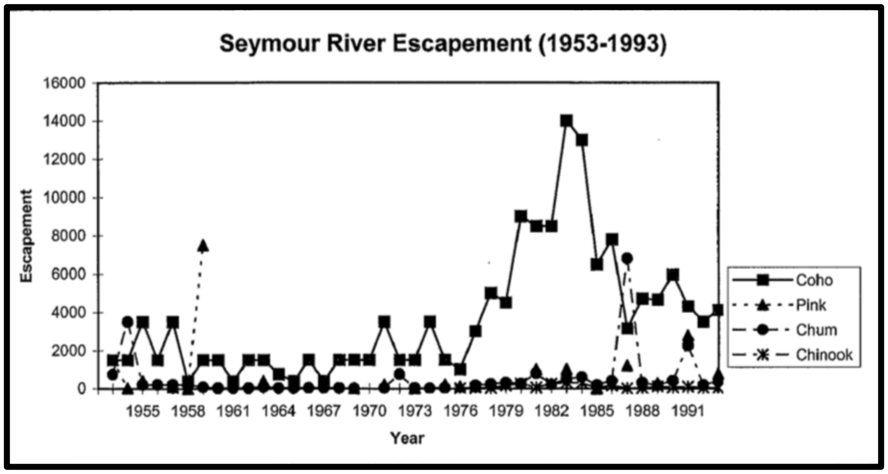

Figure 5. **Seymour River escapement numbers for the four species of salmon present in the river from 1953 to 1993. Coho has the highest abundance and has shown the greatest variability, while chum and pink have been relatively stable and have been at lower abundances. Adapted from D.F.O. (1999).**

3.3.2 Wildlife

Many species other than fish use the Seymour River for different life stages such as feeding and resting. Many birds have been observed using the waters of the river including (but not limited to): great blue herons (*Ardea herodias*), mallard ducks (*Anas platyrhynchos*), bald eagles (*Haliaeetus leucocephalus*) and seagulls (*Larus* spp.). Canada geese (*Branta canadernsis*) are often found in the estuary. Habour seals (*Phoca vitulina*) have been seen to frequent the pools upstream of the estuary as well as in the estuary itself, waiting for migrating adult chum and pink salmon as a preferred food source (Meehan and Bjornn 1991, Thomas et al. 2016). Evidence of beavers (*Castor canadensis*) has also been observed in the lower reaches.

The upper portion of the Seymour watershed (as well as within the L.S.C.R.) is less impacted by urbanization and thus provides resources for larger mammals such as bears (*Ursus* ssp.), cougars (*Puma concolor*) and elk (*Cervus canadensis*).

3.3.3 Vegetation

Riparian vegetation is reduced going down stream towards the estuary due to the large influence of industry on either bank. Many residential areas are located along the river from Mt. Seymour Parkway up to Grantham Place Bridge. Along these reaches, there is no vegetation on the banks directly beside the river as the slopes are stabilized with riprap. Shading within the channel from large trees located on the tops of the banks is still prominent. The riparian vegetation is a mix of coniferous and deciduous trees, as well as shrubs, grasses and mosses.

Invasive species observed within the riparian zone include: Himalayan blackberry (*Rubus armeniacus*), English ivy (*Hedera helix*) and Japanese knotweed (*Fallopia japonica*). Japanese knotweed is also located on vegetated bars within the river channel.

3.4 First Nations use

The Seymour River is located on traditional Squamish Nation and Tsleil-Waututh Nation territory. The land on the west side of the river is Squamish land and was designated as the Seymour Creek Indian Reserve No. 2 (O'Donnell 1988). Unfortunately, most of the original land was surrendered for industrial use (O'Donnell 1988). While the Tseil-Waututh Nation Reserve is located further east, they often travelled to different villages around the Burrard inlet (Lilley et al. 2017) and visited the Seymour River in the fall (Morin 2015).

The Seymour River is in close proximity to many different ecosystems such as marine, terrestrial and riverine environments, which all offer diverse resources. Fishing (specifically salmon and herring) was, and still continues to be, a critical component to the Coast Salish First Nations diet, religious and ceremonial activities, as well as once contributed a large part to their economy through trading (Morin 2015). For the Tseil-Waututh Nation who are the "People of the Inlet", the Burrard inlet provided intertidal and nearshore harvesting of shellfish, which was a staple in their diets, economy and cultural activities (Morin 2015). On the terrestrial landscape, there was an abundant supply of cedar for building structures and canoes (O'Donnell 1988). These canoes were used to travel the Seymour River, as well as within the Burrard Inlet, making these waterways a critical component for navigating the landscape (O'Donnell 1988, Morin 2015). Bark, fiber and wood were also utilized for other materialistic goods (Morin 2015). The terrestrial landscape also offered the hunting of mammals, and foraging of plants such as berries, nettles and crab apples (Morin 2015).

3.5 Land use and stressors

The Seymour River has been under pressure from many anthropogenic stressors over the past century, all of which can result in damaging effects on available spawning habitat in the lower reaches.

3.5.1 Historical logging and mining

Logging began in the Seymour Watershed in 1875, as the value of timber along the river became apparent during exploration and attempts at building the Lillooet Trail into the interior (Kahrer 1989). The first sawmills opened up in 1875 and 1887 within the lower portion of what is now known as the L.S.C.R. (Kahrer 1989). During this time there was unrestricted resource use for both timber as well as mining of gold and copper (Kahrer 1989). Along with the logging came the construction of skid roads for transport of the logged timber (Kahrer 1989). Not only was the watershed recognized for its rich timber and mining resources, but it was also acknowledged as a potential water source for the growing population of Vancouver. In 1908 the Seymour Water System opened and through time, the importance of the watershed as a water source became more important than a timber source (Kahrer 1989). In 1936, logging within the catchment area was prohibited due to the concern of the effects logging would have on the water quality (Kahrer 1989). The Seymour watershed was thereafter considered a closed watershed (Kahrer 1989).

Logging within the Seymour watershed was mostly through small lumber companies and independent loggers (Kahrer 1989). There was never any large scale developments, leaving most of the watershed relatively untouched (Kahrer 1989). Unfortunately, much of the logging that has occurred was through poor practices causing slope failures and instability of the banks, and thus leaving a legacy of degraded, sediment infilled salmon rearing and spawning habitat (Hryhorczuk 2011).

While the upper portion of the watershed remains relatively untouched, the Lower Seymour was logged along the banks and floodplains to support urbanization. This logging can have many negative impacts on river and stream channels. One main impact is the alteration of hydrologic processes through the removal of riparian vegetation. Without vegetation along the banks, there is a reduction in infiltration and evapotranspiration. This results in higher runoff, and consequently higher peak flows after a storm event (Whyte et al. 1997). These higher flows may cause erosion along the banks and therefore provide an increased supply of sediment and debris which can lead to degradation of downstream spawning gravel quality. Increased flows lead to the scouring of suitable gravel and the increased supply of sediment will infill habitat, clogging the intragravel spaces required for egg and alevin survival (refer to Section 2.2.5) (Cederholm et al 1980, Whyte et al. 1997). A loss of riparian vegetation also reduces cover from predators, and shade which will become necessary to militate against rising water temperatures with climate change (see 3.5.5 Climate change).

3.5.2 Seymour Falls Dam

The Seymour River has been regulated by a dam since 1928, with the construction of the first dam known as Seymour Falls (Hryhorczuk 2011). This initial dam was only 6.7 m in height, a small fraction of the height of the present day dam called the Seymour Falls Dam (completed in 1961) at a height of 30 m. (Hryhorczuk 2011). The Seymour Falls Dam is managed by Metro Vancouver's Greater Vancouver Water District and forms the Seymour Reservoir which provides water supply for 40% of Metro Vancouver municipalities (K.W.L. 2003). The dam regulates the flow from the upper two-thirds of the Seymour watershed, altering flows and reducing connectivity of the upper and lower watershed (K.W.L. 2003).

The Seymour Falls Dam has many effects on the downstream aquatic environment. These effects include: regulated and unnatural flows (which may expose redds during the low flows, or cause scouring of the redds during high flow events), retention of gravel, sediment and organic material within the reservoir, reduced and altered water quality, and reduction of fish migration (Hryhorczuk 2011). Currently the dam releases 0.57-1.36 m^3/s as ecological baseflow for salmon and other aquatic life downstream (C.R.M. Ltd. 2012), but this baseflow has been considered to be too low, especially in the summer (Hryhorczuk 2011).

Typically dams result in peak flows of lower magnitude than pre-dam conditions, but the peaks flows of the Seymour River coincide slightly with natural peak flows (Hryhorczuk 2011). This is due to the restricted storage capacity of the reservoir which results in the dam releasing large amounts of water when reservoir water levels reach the spillway caused by these peak events (Hryhorczuk 2011). These high peak flows (which are enhanced by channelization) result in the mobilization of a range of suitably sized gravels, and the bed surface is left composed of large cobbles and boulders which are only entrained in less frequent higher flows (Hryhorczuk 2011). This process of coarsening of the bed material is termed "armouring" and the substrate is thereby too coarse for salmon spawning (Kondolf 2000). Female salmon may not be able to construct redds as they are unable to move these large grains, or they might dig shallow redds which are more vulnerable to scour (DeVries 1997). The reduction in gravel stability due to varied flows and modifications to the channel morphology, along with the reduced gravel supply from the retention in the reservoir, produces degraded substrate conditions for salmon spawning, and as a consequence may be limiting salmon populations (Meehan and Bjornn 1991).

3.5.3 Urbanization

A majority of the urbanization within the Seymour River watershed is within the lower 4 km. The river has been highly channelized (e.g., bankfull width has been reduced by 40% since the late 1950s (Fig. 6)) with residential and industrial areas on either side of the river and Squamish Nation land on the west side (K.W.L. 2003, N.H.C. 2016). Flood control management has caused major anthropogenic modification to the lower reaches of the Seymour River. Rip rap has been used as protection for most of these reaches as past floods have destabilized the banks, creating the concern of certain structures, such as bridges and properties, becoming undermined (N.H.C. 2016). A training berm also runs along the east bank of the river along a portion between Dollarton Highway and Mt. Seymour Parkway (N.H.C. 2016). More diking is proposed for future flood control with the changing climate (K.W.L. 2014). The Seymour River estuary has also been highly modified into a narrow channel constrained by industry such as shipbuilders and repairs, warehouses, and metal recycling (D.F.O. 1999). In 2014 the estuary underwent restoration to improve aquatic and terrestrial habitat as well as repair natural processes.

The channelization that has transformed the Seymour River planform over the past century has also contributed to the gravel deficiency in the lower reaches. Hardened banks with rip-rap constrain and prevent the natural meandering movement which can be seen in Figure 6. This reduces the length of river (and therefore the slope), while also increasing the depth and velocity of the water. These modifications then increase the shear stress acting on the channel bed and prevent gravel deposition and retention. These faster flows also contribute to the armouring of the bed for the same reason as mentioned previously.

Urbanization has many other negative effects on a river’s hydrology. Due to the increase in impervious surfaces (i.e., concrete), storm water is restricted from percolating into the groundwater and adding to the river’s baseflow. Instead, it enters the river though runoff and can increase the flashiness of the river’s hydrograph (i.e., higher and earlier peak flows) (Yeakley 2014).

Culverts are abundant in urbanized environments. If improperly designed, these culverts can be a physical barrier to upstream migration for adult salmonids, and downstream migration for juvenile salmonids. These culverts can produce impassable obstacles to spawning habitat, as well as to critical overwintering ponds and channels due to high velocities and low depths within the culvert (Whyte et al. 1997). Within the Lower Seymour below Grantham Place Bridge, there are no culverts.

The Seymour River and the surrounding areas are popular destinations used by the citizens of North Vancouver. Maplewood Farm and the Seymour River Heritage Park are located adjacently to the east of the river. During summer people swim in the naturally formed pools as well as lounge along the banks. There is a path that runs up along the bank of the lower river and is a popular dog walking trail. The estuary is also a popular place where people bring their dogs, or fish for salmon.

Figure 6. **The change in the Lower Seymour River planform (North Vancouver, B.C.) from just above Grantham Place Bridge down to the estuary over time from 1946 (pre-Seymour Falls Dam), 1963 (post-Seymour Falls dam) and 2017. Red arrows represent the direction of flow. In 1946, meanders are prominent and large gravel bars can be seen on either side of the channel. Historical air photos from Government of Canada, current satellite image obtained from Google Earth (2017).**

3.5.4. Rock slides

In 2014, 80,000 m^3 of rock and debris entered the Seymour River within the canyon of the L.S.C.R. (S.S.S. 2017). This rockslide had (and continues to have) negative impacts on both the hydraulics of the channel and salmonids. Initially the rocks and debris produced an impoundment that caused water depths to increase by 10 m upstream, inhibited migration upstream of salmonids, and destroyed suitable spawning and rearing habitat (S.S.S. 2017). The rockslide also acts as another barrier preventing the natural transport of gravel downstream.

Through deliberations with experts, removal of the debris was decided to occur over two to five years through rock breaking (i.e., using low velocity explosives beginning in August 2016) and drilling as a $1.2 million recovery project (S.S.S. 2017). As stewards of the river, the Seymour Salmonid Society is managing the recovery of the slide area and have aided in returning adult salmon to the upstream habitats by collecting them downstream of the slide at a floating fish fence.

3.5.5 Climate change

Climate change is likely to be a major stressor for aquatic ecosystems. It will cause alterations to four out of the five key parameters required for suitable spawning habitat (i.e., temperature, D.O., depth and velocity). Changes in depth and velocity may also affect the gravel substrate; consequently, spawning habitats could be severely degraded and further reduced.

Based on modelling of different climate scenarios, water temperatures in the P.N.W. are expected to increase (Beechie et al. 2013). This might directly affect the eggs through decreasing hatching time, or indirectly affect eggs through reducing the D.O., leading to mortality or impairment of embryonic development (refer to Section 2.2.1). The threat of temperatures leading to mortality is high for rivers where the temperatures are already near the threshold (Beechie et al. 2013).

A large impact from climate change for the Seymour River will be the change from a transitional regime to a rainfall dominated regime (Beechie et al. 2013). Summer depths will be reduced due to the lack of water storage as snowpack in the mountainous regions, and will therefore not be released slowly as summer baseflow (Beechie et al. 2013). This reduced water depth will also increase temperatures and reduce access to suitable spawning habitat (Beechie et al. 2013). Based on an analysis by Kerr Wood Leidal Consulting Engineers (2014), peak river flows will increase by 6% by the 2080s do to this regime shift along with increased precipitation. These increased peak flows could cause scouring of gravels and embryos (Beechie et al. 2013).

Chapter 4: Site assessment

4.1 Site locations

The area of interest for this study is from Grantham Place Bridge downstream to the estuary. This stretch is about 1.5 km long and is further divided into three main study areas (S.A.) labelled as: S.A. 1, S.A. 2, and S.A. 3 with lengths of about 0.75 km, 0.30 km, 0.45 km, respectively (Fig. 7). These areas were assigned based on incorporating at least one riffle-pool sequence for each (Bunte and Abt 2001). This length is also about five to seven times the bankfull width, which is a common method in designating sampling reaches (Bunte and Abt 2001).

The extended river portion of the estuary is labelled as S.A. 4, but was minimally sampled due to the greater influence from estuarine processes (i.e., tidally influenced) rather than riverine. However, it was sampled to provide an overall picture of how the gravel changes throughout the lower reaches of the Seymour River and if it coincides with the literature stating size decreases moving down the longitudinal profile (Charlton 2008).

Sampling was done systematically and randomly whenever possible to cover a greater area and to avoid bias. Sampling of instream parameters began in early August (during lowest flow) and water quality was sampled in late October towards the time of spawning. For all sampling, a buffer zone of about 20 m on either side of bridges was given to avoid any effects they may cause such as scouring and erosion of the bed and banks, which often occurs downstream from bridges (Gregory and Brookes 1983).

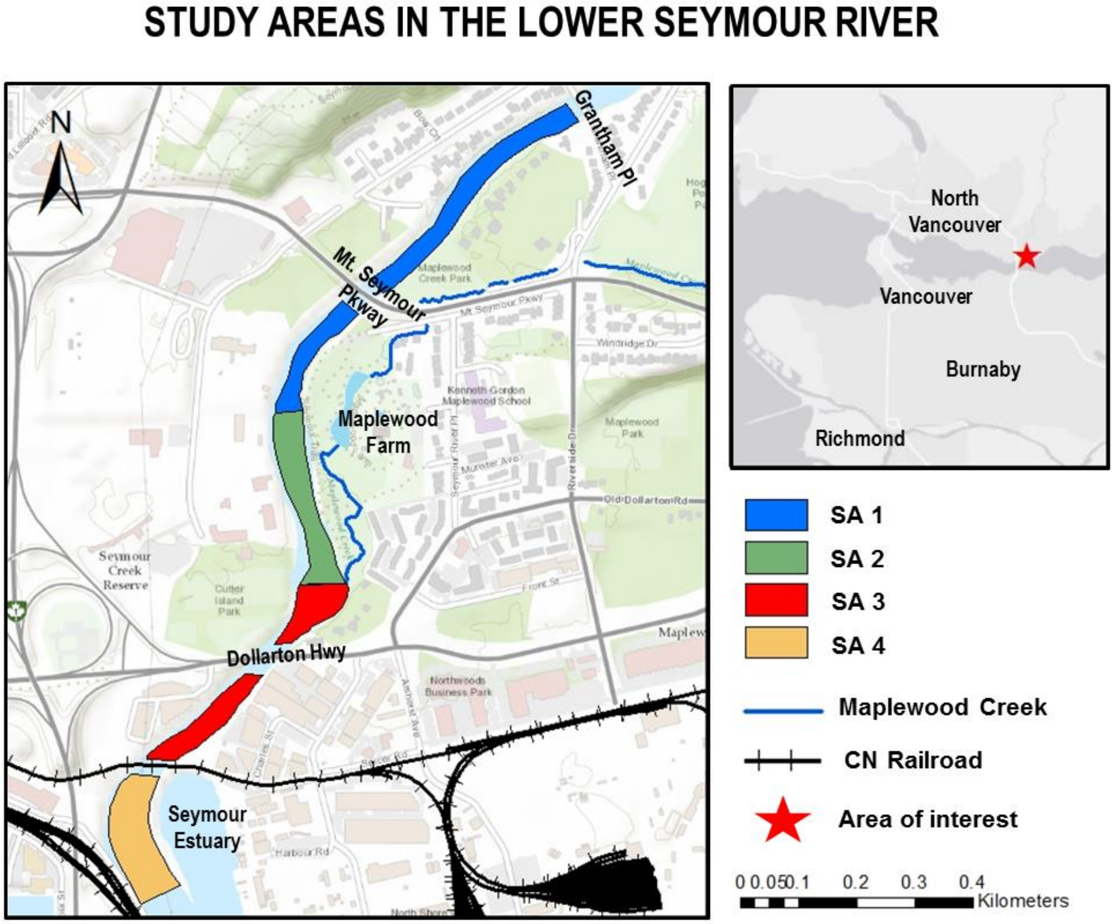

Figure 7: **The locations of the four study areas within the Lower Seymour River from Grantham Place Bridge to the estuary. Sampling of instream parameters and water quality occurred in August and October 2017, repsectively. Stream and railway data retrieved from District of Vancouver (2017).**

4.2 Methods

The assessment was divided into three areas of interest: 1) bed material sampling to determine reach averaged grain size distributions, 2) sampling of the other four parameters required for spawning (refer to Section 2.2) to ensure gravel as the only limiting factor, and 3) an analysis of gravel movement based on simple tractive force equations.

4.2.1 Grain size analysis

Two methods were used to analyze the substrate of the channel bed: surface pebble counts and bulk subsurface samples. Both methods were done at the same locations along the river in transects spaced 60 m apart in to provide a general reach averaged evaluation (Appendix B-1). This transect interval resulted in a total of 16 transects (five, transects in S.A. 1 and 2, four transects in S.A. 3 and two transects in S.A. 4). Sixty metres was chosen as an appropriate interval between transects in attempt to sample each geomorphic feature/unit (i.e., riffles, pools and glides). The length of each unit tends to be longer than 60 m and therefore no units would be overlooked and there would be a better attempt to capture the complexity of the river. Within S.A. 1 there is a reach located between Grantham Place Bridge and Mount Seymour Parkway that was observed to be quite homogeneous in its substrate and geomorphologic features. Due to this homogeneity, two transects were deemed to be adequate (Bunte and Abt 2001).

Surface pebble counts

To determine the surface grain size distribution, pebble counts were used. These counts provide a more quantifiable distribution than the visual estimates that are often done in fish studies (Kondolf and Li 1992). These visual estimates are based purely on observer judgement and if the observer is not properly trained, it can provide highly variable and biased data (Kondolf and Li 1992). The original pebble count (Wolman 1984) was done by stepping heel-to-toe and the sampler blindly picking up a stone that was touching a consistent part of their boot (Bunte and Abt 2001). The intermediate axis (i.e., the b-axis) is then measured (Wolman 1954). This can lead to issues such as surveyor's bias for picking large particles and double counting particles larger than the sampler's boot (Bunte and Abt 2001).

In this study it was decided to complete a systematic, equal interval pebble count. First, a tape measure was strung across the channel. Each transect was across a relatively homogenous gravel geomorphic unit (Kondolf and Li 1992, Bunte and Abt 2001). The interval between picking up a stone was chosen to be approximately one to two times the length of the largest particle available (i.e., D_{max}) to prevent double counting (Bunte and Abt 2001). A 1 m-interval was chosen to be consistent throughout all transects and study areas. Some areas had one or two boulders larger than 0.5 m but these were decided to be outliers as were not representative and were often boulders that had fallen from the riprap on the right bank. At every 1 m-mark on the tape, the particle that was directly under the mark was measured along the b-axis. If the particle was imbedded into the bed, the shortest visible axis was measured (Bunte and Abt 2001). In areas where the depth was too great to determine a stone that was directly under the mark, the sampler stuck their wading stick at the mark and the stone that it touched was measured. At each transect about 30-50 stones were measured depending on the width of the channel. To obtain the traditional sample size of 100 particles (Wolman 1954), the measuring tape was moved 1 m upstream and the sampler continued moving back to the bank they started on. This process was repeated until 100 stones were measured. One hundred stones was decided to be adequate for this study because the scope of the project (i.e., examining fish habitat, not determining precise sediment transportation processes) does not require a small error like that of a 400 stone sample (Rice and Church 1996, Diplas and Lohani 1997).

Analysis

Each sample of 100 stones was then categorized into size classes based on an adapted Wentworth grain size scale (Appendix B-2), and the cumulative distributions were graphed to determine the median grain size class (i.e., D_{50}). This value from the graph represents the grain size in which 50% of the sample is finer than that size and gives a good approximation for the average grain size (Bunte and Abt 2001).

Limitations

There are some limitations with this surface pebble count. Due to the nature of the sampler picking up a stone, it only measures grain sizes > 4 mm as they are more likely to pick up a substantial enough sized stone (Kondolf and Li 1992). Although measurements were taken during low flow, some transects contained waters too deep to properly bend over, pick up, and measure the stone. Therefore, the sampling was limited to the height of the sampler and their waders. In these instances, the sampler's best guess was recorded along with the depth of the water.

Subsurface bulk sampling

Due to the unique spawning characteristic that female chum and pink salmon dig their redds to a specific depth of 15-35 cm (refer to Section 2.3), surface sampling done with pebble counts alone would be insufficient. Subsurface sampling is also done to further examine the fines that are neglected in pebble counts based distributions. Therefore, subsurface samples were collected along systematically spaced transects (60 m apart, at the same transects as the pebble counts). A total of 51 samples were collected from 245 potential sampling sites across the 16 transects (S.A.1 had 10 samples, S.A. 2 had 20 samples, S.A. 3 had 14 samples and S.A. 4 had 7 samples).

To accomplish a proper grain size distribution to describe the substrate, it would require very large samples. Church et al. (1987) suggested the largest clast should not make up more than 1% of the total sample mass. Based on this criterion, and the largest clasts in the river being at least 0.5 m, it would require taking samples with masses of thousands of kilograms. This was deemed unnecessary due to the purpose of the sampling being to determine a general estimate of the subsurface substrate and whether it would be suitable for chum and pink salmon.

Instead, a fixed volume of substrate was attempted to be collected every 3 m using a 796 mL can (with height and diameter of 10 cm) along a transect (Fig. 8a). The can was driven into the substrate as far as possible, and using a shovel, the core was collected and stored in a plastic bag. Most of the area in the channel was covered by boulders with a b-axis of up to 0.5 m wide (Fig. 8b). When a cobble/boulder greater than 10 cm was at the designated sampling increment on the transect, no sample was taken and the particle's b-axis was measured. This occurred for a majority of the sampling locations. While this method did not provide sampling for every point, it further demonstrates that the substrate is too large for chum and pink spawning. Chum and pink salmon have a physical limit on the weight and size of gravel that can be moved with their tail based on their length (refer to Section 2.2.5). All the boulders recorded where a sample could not be collected, were much larger than this physical limit.

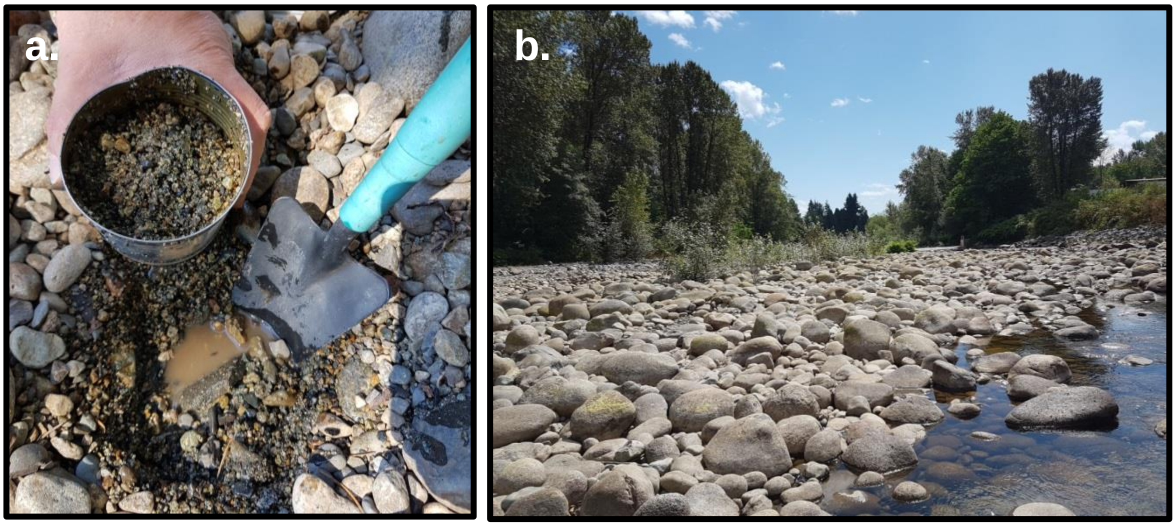

Figure 8. **Subsurface sampling using a 10 cm-diameter can (a). A representative photo of the large surface grain sizes in S.A. 2 looking downstream (b).**

Analysis

The subsurface samples were then dried, sieved and analyzed based on the field methods in Bunte and Abt (2001). A field rocker sieve was used with 8 different-sized sieves to split the samples into size classes (Appendix B-2). Each sieved grain size class was then weighed, and grain size distributions were graphed and median grain sizes (D_{50}) were determined. A visual map of all sampling locations (whether a sample was taken or not) was created using ArcMap to qualitatively assess the spatial variation in subsurface grain sizes, but ultimately to show the abundance of large surface substrate from the lack of subsurface samples collected.

Limitations

The samples taken within the flowing water results in distributions biased towards larger particles and will not contain fines and silt as these particles were quick to wash away in the water column. Due to the objective of the sampling to get larger gravel distributions (>4 mm), this was not an issue.

4.2.2 Water quality

The flowing water of the Seymour River ensures that the water is well mixed; therefore, water temperature and dissolved oxygen were measured using a Y.S.I. multi-parameter meter at two easily accessible locations per study area. It is important to note that temperatures were measured within the water column and this may differ from the temperature within the gravel which ultimately affects egg incubation (i.e., intragravel temperatures have been found to be warmer in winter and cooler in summer compared to surface waters, thus, buffering seasonal extremes (Shepherd et al. 1986)).

4.2.3 Hydraulic and channel characteristics

Velocity, bankfull depth and water depth were measured along transects spaced 100 m apart starting at a random number (between 0-50) from the upstream boundary of the study area (Appendix B-1). This resulted in four transects in S.A. 1, and three transects in S.A. 2 and 3. The homogeneity in the upper portion of S.A.1 (along with limited time and resources) led to the decision to only have two transects rather than three that would be equally spaced 100 m apart.

Velocity and depth

Velocity was measured at three equal interval points along the wetted width using a Swoffer flow meter. Water depth was recorded along these points as it is required for this meter to ensure the velocity is taken at a depth that is 40% of the total depth from the bed (i.e., the 0.6 method), as well as being a parameter for suitable spawning habitat.

Bankfull depth

Bankfull depth (i.e., the maximum discharge in the channel before it overtops the banks) is used to approximate the highest flood event, which could mobilize the maximum gravel grain size. True bankfull depth is difficult to measure in these lower reaches due to the intense channelization and elimination of the floodplain which would have been used to determine the top of bankfull. Two indicators were used to estimate bankfull depth: vegetation lines, and stain lines on rocks (D.F.O. 1995). Upon observation, most sites showed two flood-indication lines, a lower vegetation line, and a higher stain line on the riprap on the right bank. It was then interpreted that the lower vegetation lines were more frequent flood events, while the higher stain lines were more intense, less frequent flood events (Charlton 2008). Depths were taken at both these marks to provide a range of high floods for gravel movement.

Due to the large width of the channel and high winds (as the channel is very open with no protection from trees), it was difficult to extend a measuring tape across without it bouncing and moving in the wind. This made it hard to get an accurate depth. This is especially true in some areas where the bankfull depth is greater than 2 m and above the height of the person measuring. Instead, it was decided to use a water level to measure the bankfull depth (Fig. 9).

A basic water level was created using a 3 m-length piece of clear-0.5 inch diameter plastic tubing, a 2 L milk jug half full of water, and an expandable rod with 10 cm marks. One end of the tubing was attached to the top of the expandable rod while the other end was placed into the milk jug of water. This operation is easiest with two people, one holding the rod at the surface of the water in the river, while the other climbed to the bankfull height along the bank with the milk jug of water. Once both people were in approximate locations, water was pulled into the tube by the person holding the rod. The water level in the milk jug was then lifted to be in line with the height of the proposed bankfull height. This was at vegetation lines or stain lines as previously stated. The water in the tubing automatically levelled to that of the level in the milk jug and the rod was expanded to a height in which the water level can then be read off (Fig. 9). If the distance from the edge of the water to the bankfull height on the bank was further then the length of the tubing, two separate measurements were done and added together. This measurement is the height from the top of bankfull to the surface of the water that day. To get the entire depth, that measurement was added on to water depths that were measured using a meter stick at three equal intervals of the bankfull width.

A stage discharge curve was created based on 2017 water levels and discharges from the hydro station located at Grantham Place Bridge. The two high flood marks were also measured at the hydro station to approximate which discharges these flood events were associated with (Appendix B-3). A flood frequency curve was also produced using historical data (1929-2013) from a Government of Canada hydro station 08GA030 (49° 20' 31'' N, 123° 00' 07'' W) to approximate the reoccurrence of such events (Appendix B-4).

Slope

Slope of the bed for each study area was determined using LIDAR data acquired from the District of North Vancouver.

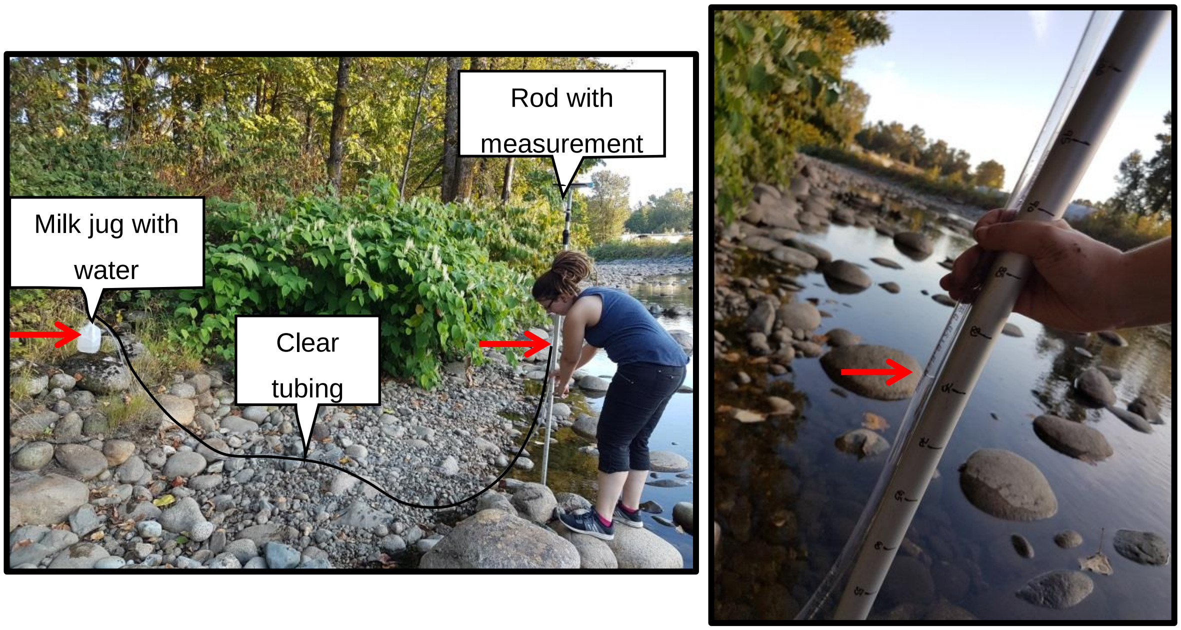

Figure 9. **The water level apparatus used for measuring bankfull depth. The apparatus consists of a water jug, clear plastic tubing and an expandable rod with 10 cm increments marked.**

4.2.4 Gravel mobility

The analysis of sediment transport over each study area was used to gain insight into the general sediment transport intensity of the system as a whole (Newson et al. 2002). Gravel mobility was determined through the two steps listed below. The first step entails determining the forces exerted on the channel bed by the flow (i.e., the shear stress) and the second step entails estimating the force required to move a specific grain size (i.e., the critical shear stress). Calculations were completed for the lower high flows (i.e., at vegetation lines), as well as for the higher flows that occur less frequently (i.e., at the stain lines).

1) Cross-sectional average shear stress acting on the bed of the channel was found using the du Boys equation (Charlton 2008):

$$\tau = \rho g R S$$

Where τ is the bed shear stress (N/m^2) acting on the channel bed, ρ is the density of water (1,000 kg/m^3 at 4 ^{o}C), g is gravity (9.81 m^2/s), R is the hydraulic radius (m), and S is the channel bed slope (m/m). Bankfull depth (d) was used in place of hydraulic radius as it is a good approximate for wide shallow channels (Charlton 2008).

2) Rearrangement of the Shields parameter for dimensionless critical shear stress equation to determine the minimum stable grain size (Charlton 2008):

$$\tau^{*} = \left(\frac{\tau}{g(\rho_s - \rho)\mathrm{D}}\right)$$

$$D = \left(\frac{\tau}{g(\rho_s - \rho)\tau^{*}}\right)$$

Where τ^{*} is the dimensionless critical shear stress (Shields parameter) (0.06), ρ_s is the density of the sediment (2,650 kg/m^3 for gravel), and D is the diameter of the minimum stable grain size (m).

The value used for Shields parameter depends on both the size of the particle (i.e., as grain size increases, greater force is required to entrain and mobilize the grain), as well as the roughness of the channel bed (Charlton 2008). The roughness of the channel bed is described as the extent that the surface grains are immersed within the laminar sublayer (i.e., a layer of water directly above the surface of the bed where flow is slowed due to the force of friction from the surface, above this layer the flow velocity increases and turbulence occurs). Hydraulically smooth surfaces, such as is characteristic of cohesive silt and clay, require greater shear stress to mobilize the grains as they are fully submerged below the laminar sublayer surface and therefore do not experience the turbulent flow required for entrainment (Ritter et al. 2011). The Shields parameter for these surfaces is greater than 0.06. Hydraulically rough bed surfaces, which are associated with loose gravel beds, exhibit surface grain sizes that are relatively large compared to the laminar sublayer and are subject to those turbulent flows that occur above the sublayer (Ritter et al. 2011). For these hydraulically rough surfaces the Shields parameter typically ranges between 0.03 and 0.06 (Ritter et al. 2011). A value of 0.06 was chosen as the Seymour River exhibits a highly rough surface due to the large surface cobbles and boulders.

4.3 Results

4.3.1 Surface pebble counts

The grain size distributions for the surface substrate resulted in median grain sizes ranging from 125-375 mm across all study areas (Fig 10, Table 3). Within each study area (except for S.A. 4) there is minimal variability in grain size distributions (i.e., each transect has relatively the same distribution), making the substrate relatively homogenous across the study area. The shape of the curves demonstrated that the substrate within each study area is uniformly graded and well sorted (i.e., there is a narrow range of large particle sizes).

Between study areas, substrate in S.A. 4 contained the greatest proportion of fines, and was the only study area that contained sand (< 2 mm). The least amount of fines was found in S.A. 3 with the smallest grains being within 17-64 mm. Similar distributions were found in S.A. 1 and 2, but S.A. 2 had a slightly higher proportion of grain sizes under 100 mm.

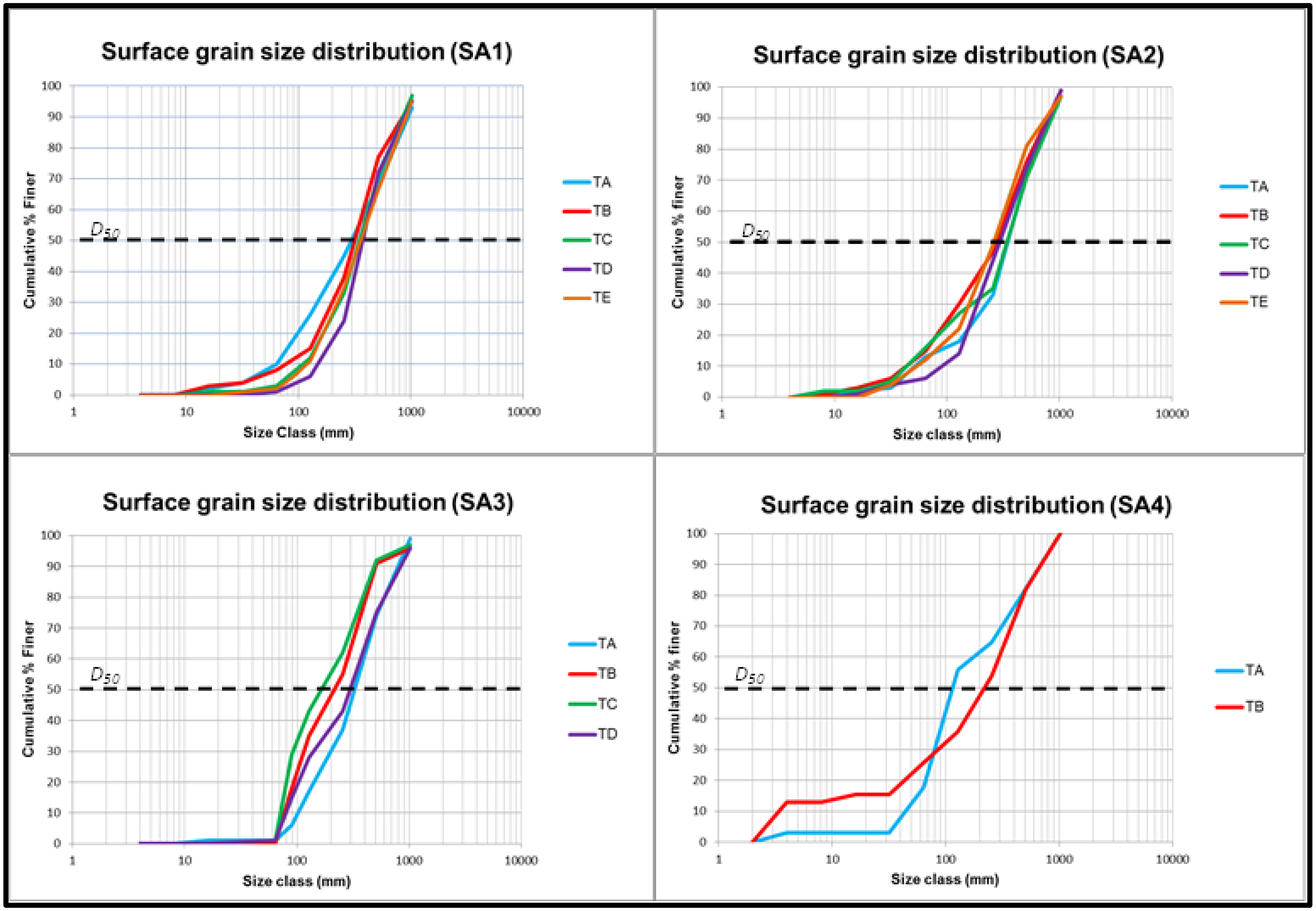

Figure 10. The surface grain size distributions produced from the pebble counts for each transect in S.A.1, 2, 3 and 4 in the Lower Seymour River, North Vancouver B.C. Samples were collected in August 2017. Each coloured line represents a different transect in that S.A. Percent finer was calculated from number of particles. D_{50} values were determined by the interception of the black dashed line.

Table 3. **Results from the data collection of the five main parameters specific for suitable spawning habitat for chum and pink salmon along with the recommended literature values. Values with an asterisk represent conditions that do not meet the required criteria from the literature.**

Study area	Transect	Velocity (m/s)	Depth (m)	Site	Temperature (°C)	D.O. (mg/L)	Transect	Surface gravel D_{50} (mm)	Subsurface gravel D_{50} (mm)
Literature		0.21-1.01	>0.15		7.2-12.8	>5		pink = 6.5-11 chum = 9.6-41.6	
SA1	**V1**	0.04*	0.54	**1a**	9.2	10.4	**TA**	275*	16.6
	V2	0.29	0.15	**1b**	9.3	10.5	**TB**	325*	15.5
	V3	0.08*	0.22				**TC**	350*	n/a
	V4	0.23	0.23				**TD**	375*	33.7
							TE	350*	11.25
SA2	**V1**	0.09*	0.30	**2a**	9.7	10.1	**TA**	350*	18
	V2	0.12*	0.45	**2b**	9.2	10.3	**TB**	250*	9
	V3	0.28	0.19				**TC**	350*	17.4
							TD	300*	16.3
							TE	250*	15.7
SA3	**V1**	0.17*	0.39	**3a**	9.0	10.5	**TA**	350*	25.5
	V2	0.07*	0.46	**3b**	10.1	9.3	**TB**	225*	25.3
	V3	0.15*	0.18				**TC**	175*	16.7
							TD	300*	53.8*
SA4	**n/a**	n/a	n/a	**4a**	8.6	11.2	**TA**	125*	38.4
	n/a	n/a	n/a	**4b**	9.2	10.3	**TB**	225*	9.5

Note: The subsurface median values were determined by averaging the samples across each transect. S.A. 1, TC did not have any samples collected due to large rocks at each sampling site.

4.3.2 Subsurface sampling

Based on mapping of the samples, a majority (about 90%) of the samples collected were located on the left side of the channel along the left bank (Fig. 11). The grain size distributions resulted in median grain sizes between 9.0-38.4 mm (Fig. 12, Table 3). The area with the greatest proportion of fines <4 mm was S.A. 2 (with the exception of one sample in S.A. 4 which was 85% sand and finer). The distributions of all samples were well graded and poorly sorted (i.e., a larger range of grain sizes is represented).

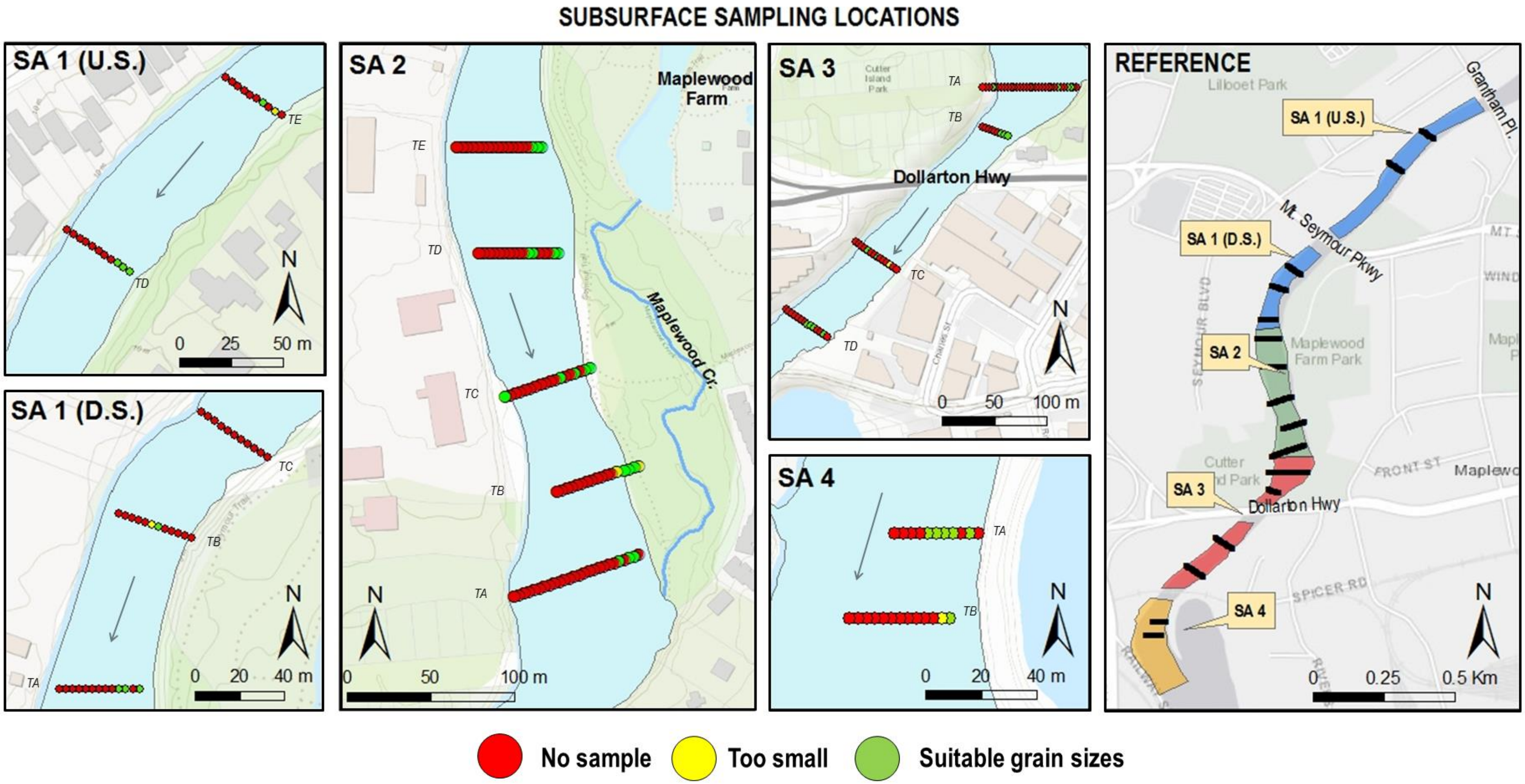

Figure 11. Locations of the subsurface samples for all study areas. Red markers represent areas where surface grains were either too large to collect a sample, or were highly armoured and prevented digging. Yellow markers represent samples that were taken, but the grain sizes were determined to be too small for spawning. Green markers represent suitable grain sizes.

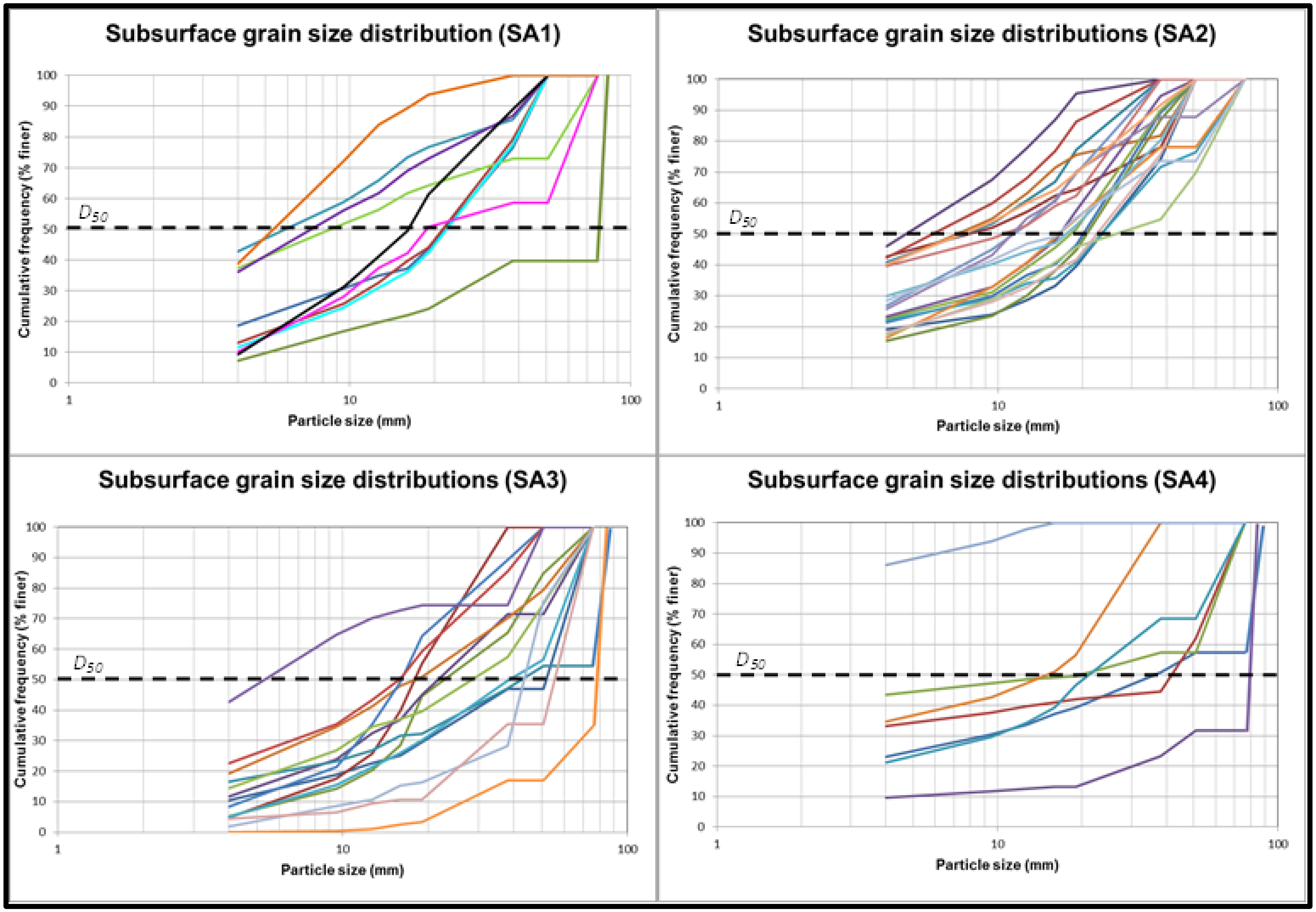

Figure 12. Subsurface grain size distributions for all 51 collected samples within the four study areas of he Lower Seymour River, North Vancouver B.C. Samples were collected in August 2017. Percent finer was calculated by weight. D_{50} values were determined by the interception of the black dashed line.

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4.3.3 Water quality

Temperature ranged from 8.6^{o}C in S.A. 4 to 10.1^{o}C in S.A. 3 and was relatively consistent across all areas (Table 3). Dissolved oxygen ranged from 9.3 mg/L in S.A. 3 to a high of 11.2 mg/L also in S.A. 3 (Table 3).

4.3.4 Hydraulic and channel characteristics

Velocity measurements ranged between 0.04-0.29 m/s across the entire 1.5 km area (Table 3). Both the fastest velocity and slowest velocity measured were found in S.A. 1.

Water depths ranged between 0.15-0.54 m across the entire 1.5 km area (Table 3). The S.A. with the greatest depth was S.A.1, but this area also had the lowest depth.

Bankfull depths for the lower and the higher flood events were found to be associated with flows of about 70 m^3/s and 290 m^3/s, respectively. The reoccurrence intervals for these events are approximately 0.6 and 8.5 years, respectively.

4.3.5 Gravel mobility

The gravel mobility results showed that with the current bankfull depths and slopes, each study area contained high grain size mobility. The three areas with the greatest grain size mobility were the upstream portion of S.A.1 (closer to Grantham Place Bridge), upstream portion of S.A. 2, and the upstream portion of S.A.3 (immediately before the Dollarton Bridge). At the lower estimated bankfull flows the shear stress ranges from 8.85 to 93.10 N/m^2 over then entire lower 1.5 km of the river (Table 4). This is sufficient to move particles of 9.12 to 95.96 mm in diameter. At the higher estimated flows, the shear stress ranges from 12.25 to 200.27 N/m^2 (Table 5). This is sufficient to move particles 12.6 to 206.42 mm in diameter.

Table 4. **Minimum stable grain size diameters for the Lower Seymour River, North Vancouver B.C. Diameters were calculated through tractive force equations for the lower bankfull estimate associated with 70 m^3/s flows. Measurements for depths were measured in August 2017.**

Transect	Low flood depth (m)	Bed surface slope	Bed shear stress τ (N/m^2)	D (cm)	D (mm)
SA1V1	1.60	0.0036	56.57	5.83	58.30
SA1V2	0.93	0.0036	32.81	3.38	33.82
SA1V3	1.17	0.0078	89.43	9.23	92.18
SA1V4	1.20	0.0078	91.98	9.48	94.81
SA2V1	0.82	0.007	56.25	5.80	57.98
SA2V2	1.22	0.007	83.69	8.63	86.26
SA2V3	1.29	0.007	88.30	9.10	91.01
SA3V1	1.90	0.005	93.10	9.60	95.96
SA3V2	1.92	0.0005	9.41	0.97	9.70
SA3V3	1.81	0.0005	8.85	0.91	9.12

Table 5. **Minimum stable grain size diameters for the Lower Seymour River, North Vancouver B.C. Diameters were calculated through tractive force equations for the higher flood estimate associated with 290 m^3/s flows. Measurements for depths were measured in August 2017.**

Transect	High flood depth (m)	Bed surface slope	Bed shear stress τ (N/m^2)	D (cm)	D (mm)
SA1V1	2.80	0.0036	98.78	10.18	101.81
SA1V2	2.36	0.0036	83.26	8.58	85.82
SA1V3	2.62	0.0078	200.27	20.64	206.42
SA1V4	2.02	0.0078	154.41	15.92	159.15
SA2V1	n/a	0.007	n/a	n/a	n/a
SA2V2	2.14	0.007	146.51	15.10	151.01
SA2V3	2.37	0.007	162.39	16.74	167.37
SA3V1	2.60	0.005	127.40	13.13	131.31
SA3V2	2.62	0.0005	12.84	1.32	13.2
SA3V3	2.50	0.0005	12.25	1.26	12.6

Note: No higher flood estimate was measured for SA2V1 as the river was very wide, and there was no visible rip rap to measure stain lines on.

4.4 Discussion

4.4.1 Spawning habitat requirements

Temperature, D.O., and depth were found to meet requirements found in the literature (Table 3). Velocity measurements for most of the areas were slower than recommended preferences by chum and pink (Table 3). These measurements were taken in August during low flow and during the time that salmon began spawning (October-November), the flow increased due to increased precipitation and release from the dam; therefore, velocity would have increased as well to meet velocity requirements. Substrate did not meet the literature values, and therefore was the sole limiting factor in the study area.

4.4.2 Gravel grain size, location and patch size

Grain size of the substrate (both surface and subsurface) is unsuitable for chum and pink salmon spawning in the lower 1.5 km of the Seymour River. Surface median grain sizes were larger than values recommended from the literature of 9.6-41.2 mm and 6.5-11 mm for chum (Shirazi et al. 1981) and pink (Helle 1970), respectively (Table 3). The medians were also well above the general reference range of sizes stated in the literature of 13-102 mm (refer to Section 2.2.5) (Table 3).The surface of the channel bed in the lower 1.5 km of the Seymour River is relatively homogeneous and is composed of large cobbles and boulders which are too large for salmon to move. Consequently, this can restrict salmon from constructing redds throughout the channel.

The average length of an adult female Pacific chum salmon is about 576 mm (Beacham and Murray 1985), and based on the estimate of females being able to move median grain sizes up to 10% of their body length (Kondolf and Wolman 1993), the maximum grain size they can move is an 57.6 mm gravel particle. For pink salmon, it is a 38.3 mm gravel particle (based on a length of 383 cm) (Beacham and Murray 1985). The results of the surface pebble counts demonstrate that the surface of the bed is composed of large cobbles to small boulders (i.e., 125-350 mm), much larger than either species would be able to move to dig a redd.

Finding an area with small enough surface cobbles to move is one obstacle a female will encounter before spawning. The subsurface grain sizes are irrelevant if they cannot first move these surface grains. The areas where subsurface samples were taken tended to occur along the left side of the channel (Fig. 11) where the water was shallower, and had lower energy, allowing for the deposition and retention of finer grain sizes. The thalweg is located closer to the right bank in which depth and velocity are greatest, therefore larger grain sizes will be prominent in those locations as any finer gravel is easily washed away. From these results, treatments should be recommended along the margin of the left bank as the shear stress is lower, aiding in the prevention of mobilizing the placed gravel.

From the subsurface grain size analysis, most of the samples had median grain sizes that met literature values for chum salmon, but are too large for pink salmon (Table 3, Fig. 12). With regards to the general range of 13-102 mm, some samples had median grain sizes smaller than this range, which contrasts to the surface layer of large cobbles and boulders. The subsurface substrate is much finer than the armoured surface layer due to the winnowing away of fines on the surface from frequent low flows, thus leaving behind large particles that are incapable of being entrained (Kondolf 2000, Charlton 2008). This armoured layer of large particles covers and protects the fine sediment below from any high flows, resulting in a larger proportion of fines (Charlton 2008).

A report published by Hryhorczuk (2011) evaluated spawning habitat along the entire Seymour River in 2008 and demonstrated that within S.A. 1 there were nine patches of suitable gravel, but they were on the order of 2 m^2 each (with one exception of 6 m^2). In S.A. 2 into S.A. 3 (within and in proximity to the bend upstream from Dollarton Bridge), there were three larger cohesive patches of areas 6, 25 and 30 m^2 (Hryhorczuk 2011). This presented a total of 61 m^2 of suitable gravel within the entire area of study for this project, but only 31 m^2 of this gravel met all five spawning characteristics including water depth at the time of assessment (Hryhorczuk 2011). This lack of cohesive and homogeneous areas of gravel was also observed in the field. Often the smaller-sized gravel was located in small pockets downstream from large boulders due to the sheltering effect from the higher flows which would normally scour them away (Fig. 13). Salmon are then forced to find available small pockets of suitable gravel to dig their redds and redd superimposition is likely to occur.

4.4.3 Gravel mobility

Suitable gravel sizes for spawning (within the range of 5-40 mm for chum and pink salmon) will not remain stable in the Lower Seymour River, even at the lower flood events measured. These flood events, which have a 60% chance of occurring any given year, will mobilize grain sizes up to 95 mm in diameter in some areas. Therefore, instream structures will need to be constructed to stabilize gravel long enough for spawners to use it.

Most of the calculated values from the tractive force equations support the field pebble counts (i.e., median values found in the field were larger than the calculated minimum stable grain sizes). Minimum stable grain sizes calculated for S.A. 3 were much smaller than what was found in the field. This is likely due to the strong tidal influence in this area in which the calculations do not incorporate.

The tractive force equations used to estimate minimum stable grain size for each study area are highly simplified, and were based on well sorted material of a single size and shape (Charlton 2008). There are many limitations to using these equations on coarse bedded rivers, such as excluding the effects of a heterogeneous mixture of grain sizes and the arrangement of the grains on the bed surface (Charlton 2008). The arrangement of grains on a bed surface can be highly influential to the mobility of the grains. This is because the amount of flow (and therefore shear stress) a grain size is exposed to is determined by the sizes of surrounding grains. Larger grains may shelter or hide smaller grains, therefore, requiring a higher shear stress to entrain the smaller particles (Charlton 2008). The opposite can also occur where large grains surrounded by smaller grains will be exposed to greater shear stress, and thus it would require less shear stress than calculated by the Shields equations (Ritter et al. 2011). These two scenarios suggest that the grain size of the particle in question is not actually what dictates the movement, but rather movement is due to the surrounding grain sizes.

The bed of the Seymour River exhibits some of these sheltering effects. The highly armoured bed surface composing of large cobbles and boulders protects finer grain sizes within the subsurface, as well as shelters smaller grains on the surface (Fig. 13) (Charlton 2008). This observation of sheltering effects provides insight into gravel catchment designs that will be required to retain gravel.

Figure 13. **Large boulders sheltering smaller grain sizes from the flow, therefore, requiring greater shear stress to mobilize. Photo taken in the Lower Seymour River, North Vancouver B.C. in August 2017.**

Chapter 5: Proposed mitigation treatments

5.1 Watershed scale recommendations

Before any instream works are completed, it is necessary that any issues upstream in the watershed are addressed. This will ensure the longevity and success of the project downstream in the lower reaches.

5.1.1 Rockslide removal

The rockslide that occurred in 2014 should continue to be removed and should be completed before commencing these proposed mitigation treatments. If not properly removed before starting the instream work, larger pieces may be transported downstream and destroy or alter the work that is done. Smaller pieces of the rock slide that are transported downstream might provide temporary spawning gravel for chum and pink salmon but will be removed from the system eventually through the same processes as previous gravel.

5.1.2 Bank and hillslope stabilization

To maintain good quality spawning habitat, it is essential that all upstream slopes, stream banks and roads are stabilized. This will prevent the infilling of the newly created spawning habitat with fines that can have detrimental effects on the survival of eggs and alevins.

5.1.3 Change in water releases from dam

Due to the unlikelihood of removing the dam, Metro Vancouver should release enough water in attempt to mimic the natural flow regime. For example, releasing water more frequently will reduce the short duration peak flows that currently exist (Hryhorczuk 2011). These large peak flows entrain any fine sediment from the banks and the sediment is transported downstream in a large flush of sediment saturated water. These flows occur within October and November at the time when the salmon begin spawning, and can be detrimental to eggs that were just buried by either scouring them away or by infilling and suffocating them.

Water flows should also be monitored to ensure releases from the dam are meeting agreed levels required for ecological life downstream. The current ecological baseflow releases are relatively low and should be re-evaluated (Hryhorczuk 2011).

Changes in the flow regime by the dam operation may also cause adverse effects to the project after completion. Large releases may cause scouring of the installed structures, thereby, damaging the structural integrity. Reduced releases may cause dewatering of the area, causing depth to become a limiting factor, making the area unusable by spawners. Therefore, it is important that Metro Vancouver is involved in the planning phase of the project in order to incorporate any changes in flows.

5.1.4 Water quality testing

Water quality testing within the Lower Seymour River and the Seymour Estuary were not completed in this study but should be performed before implementing the project. The tests should examine levels of heavy metals such as copper, as the Seymour River is within an urban area and runoff from the roads is likely. Another possible source of pollution to be investigated is Maplewood Farm which is directly adjacent to Maplewood Creek, a tributary of the Seymour River. This creek has experienced several fish kills in the past due to low D.O. and high ammonia concentrations from the runoff from the farm and a nearby equestrian centre (D.F.O. 1999). It should be investigated whether this issue was resolved or whether it is still adding pollutants to the creek.

As heavy metals at lethal levels can be detrimental to salmonids, it is important that these tests are done before implementation. If problems with water quality are apparent, water quality could become another stressor limiting salmon populations. Increasing suitable spawning habitat would therefore not be worthwhile if the eggs and fry do not survive. If there are issues regarding water quality, a popular solution in North Vancouver are rain gardens and infiltration galleries. Green infrastructure such as these could be placed along the Seymour River.

5.2 Desired conditions

The desired condition for the Lower Seymour River includes large areas of suitable spawning habitat for both chum and pink salmon. These areas are defined based on meeting the requirements of the five parameters mentioned in Table 1. Specific attention is given to providing enough area and volume of suitable sized gravel to encourage more spawning, as the current gravel distributions are inadequate.

Increasing high-quality spawning habitat has the potential to reduce stress on the Seymour chum and pink stocks during their freshwater phase, thereby, assisting in conserving these populations (Murphy and Meehan 1991, C.R.M. Ltd. 2012). Increasing the quality of spawning gravel increases egg survival and thus leads to higher productivity (Keeley et al. 1996). Increasing the quantity of gravel increases the stream's capacity to support spawners, allowing for a greater abundance of fish to spawn (Bunte 2004). Restoring spawning habitat through gavel addition has been found to increase chum and pink productivity up to 8.5 times the pre-restoration state (Keeley et al. 1996). While historical data of chum and pink escapement data is limited, and current data is unknown (i.e., the pre-project values), the deficiency of suitable sized gravel (as demonstrated in Section 4.3.1) infers that there is a constraint on the number that can spawn and likely on the survival of the eggs due to superimposition. Therefore, any additional gravel will have beneficial effects on the population. The number of pairs predicted to use the proposed spawning sites can be determined by dividing the area of placed spawning gravel by the redd area for each species.

Due to the many human activities that have affected the Seymour River over the past century, the system has been greatly altered from the natural state. Using the pre-disturbance state as a benchmark to restore the system back too is unrealistic. Therefore, this project focuses on creating spawning habitat in the new equilibrium state of the river. Rivers are complex, dynamic systems in which none are the same; therefore, reference sites are difficult to find.

5.3 Mitigation goals and objectives

Goal 1: To increase continuous suitable spawning habitat for chum and pink salmon in the lower 1.5 km of the Seymour River

> *Objective 1.1:* Install gravel catchment structures to stabilize and retain placed gravel.
>
> *Objective 1.2:* Place suitable-sized gravel within the structures due to a lack of natural gravel input from the river.

Goal 2: To Monitor the sites long term to determine the success of the treatments in a high energy environment and contribute to research in gravel augmentation studies

> *Objective 2.1:* Monitor the physical structural integrity of the gravel catchment structures after first large flood event as well as for 5-10 years after.
>
> *Objective 2.*2: Monitor the usage of the gravel pads by chum and pink salmon and compare to baseline (i.e., pre-project) numbers for 5-10 years after implementation.

Goal 3: To increase opportunity for community engagement and education on the importance of salmonids and the conservation of their spawning grounds

> *Objective 3.1:* Involvement of First Nations through all phases of the project.
>
> *Objective 3.2:* Installation of informational signage while implementation is occurring explaining the process as well as final signage with what the proposed treatments aim to accomplish.
>
> *Objective 3.3:* Engagement of volunteers from Seymour Salmonid Society through post-implementation monitoring.

5.4 Literature review on gravel augmentation

Gravel augmentation (i.e., the artificial addition of specific sized gravel to a stream reach) can be a successful strategy in restoring salmonid spawning habitat (Bunte 2004, Wheaton et al. 2004). This is especially true for areas that lack a natural source of gravel (i.e., downstream of dams such as the Lower Seymour), has a low input of fines from bank erosion and hillslopes upstream, and displays the appropriate hydraulic characteristics for gravel retention (Whyte et al. 1997). Gravel placement has become popular in the Western United States as more rivers are becoming regulated by dams, thus, degrading downstream spawning habitat (Kondolf and Minear 2004).

5.4.1 Methods of gravel augmentation

There are three main strategies of gravel placement: 1) placing stockpiles of gravel and allowing the natural flows to distribute the particles (i.e., passive augmentation), 2) creating gravel platforms (or gravel pads) in which the gravel is placed directly in the stream channel at the areas where spawning is desired (e.g., on riffles), and 3) constructing gravel catchment structures for areas where tractive forces are too great to retain the gravel naturally.

Passive gravel augmentation relies on the entrainment, transport and deposition of gravel placed in piles either within the channel or along the bank by the regulated flows (Bunte 2004). With this method it is assumed that gravel will deposit on downstream bars, riffles and tail out of pools to increase spawning habitat (Bunte 2004). It is a less-costly option as gravel can be placed in a convenient location upstream and can reduce damage to riparian vegetation and slope destabilization as it may not require machines in the channel itself (Bunte 2004). A disadvantage of this method is the high uncertainty surrounding whether flows will be adequate to move the gravel when expected. Flows may be too low and are incapable of redistributing the gravel, or they could be too large that the gravel is washed out completely.

Adding gravel directly to the area chosen for the desired spawning habitat and building pads of suitable gravel can create habitat that is ready to use immediately. It can have immediate success as the pads are created based on the specific species requirements such as depth and grain sizes. This strategy also allows for the experimentation with different designs as they are built based on the design specifications rather than allowing the flow to distribute the gravel in an unpredictable manner (Bunte 2004).

Gravel catchment structures can be a strategy for increasing spawning habitat when tractive forces are too large to retain the gravel on the bed naturally. The structures can physically catch gravel moving downstream as well as produce an area of lower velocity, thereby, dissipating energy and aiding in deposition of smaller particles both upstream and downstream from the structure (Whyte et al. 1997). Structures include full channel spanning weirs and sills, as well as partial spanning deflectors and groynes (Whyte et al. 1997). These structures can be constructed out of large wood, boulders or a combination of both. Thick wired gabions filled with angular rocks have also been used to construct weirs (Anderson and Cameron 1980) but are subject to breaking if not properly constructed. While instream structures specifically created for gravel catchment and retention are not well documented, modified instream structures used for bank erosion prevention can be used.

Any structures that are built extending into the channel will cause deposition and scour of sediment because they alter the flow of water, making it slower in some areas and faster in others. These processes can alter the geomorphology of the channel and can vary in intensity based on the hydraulic conditions, making it difficult to predict the outcomes of the structure (Bunte 2004). Due to these uncertainties it is important to consult an engineer for hydraulic modelling of the conditions to ensure appropriate placement and construction.

5.4.2 Challenges with gravel augmentation

Challenges often associated with gravel placement occur during the first year (Anderson and Cameron 1980). With the first high flows, it can be difficult to stabilize gravel due to the lack of finer particles which can help secure gravel in place (Anderson and Cameron 1980), and the gravel has not undergone fluvial sorting processes which make them more stable (Albertson et al. 2011). Response time of spawners using the gravel may also vary. Some projects show that gravel placement can have an immediate response as spawners use it right after construction (Anderson and Cameron 1980). It has also been noted that spawners tend to avoid the newly placed gravel within the first year (Anderson and Cameron 1980), and therefore there may be a lag in response time. Instream structures are subject to a variety of hydraulic forces and may fail, causing the release of any placed gravel. Failure of deflectors is likely if they are set too high in the water column or at incorrect angles which deflect the flow into the opposite bank (Whyte et al. 1997).

It is important to recognize that gravel placement is not a sustainable strategy for rehabilitating spawning habitat (Ock et al. 2013), especially in areas that have inadequate natural gravel sources. It is a mitigative measure that supplies temporary habitat which can maintain or increase salmon populations while the main stressors are still occurring (i.e., the dam is still in place and the planform is still highly channelized). Constant maintenance will be required to provide the desired conditions over time as the system cannot supply and retain gravel on its own. However, adding catchment structures will likely reduce the frequency of gravel additions (Reeves et al. 1991).

5.4.3 Examples of gravel augmentation

There are many examples of gravel augmentation in rivers to increase spawning habitat for salmonids (Table 6). Many of these projects lack post-implementation monitoring and therefore determination of whether the project met its goals and is considered a “success” is unknown. Many projects have provided some additional spawning habitat immediately after implementation but have required multiple additions years later, clearly indicating that augmentation is not sustainable on its own. This is especially true for the examples that directly placed a gravel platform or pad in channel without any type of retention structure, such as was completed for the Campbell River. Projects that have failed are often due to a lack of understanding of geomorphic processes (Iversen et al. 1993). The project at Merced River in California is an example where simple tractive force equations (i.e., the ones used in Section 4.3.5) could have predicted the scouring and erosion of the placed gavel, which was of the wrong size for the flow conditions (Kondolf et al. 1996).

Table 6. **A review of previous gravel addition projects, high-lighting the methods used and their results on whether they met their proposed goals (e.g., if salmon spawned).**

Site	River characteristics	Cause for lack of gravel	Reason for gravel addition	Methods	Results	Source
Coos Bay District, Oregon (1970-1980)	-low gradient, meandering	-deforestation, roads and other anthropogenic causes	-increase salmon habitat (structural complexity, creation of pools)	**-gabions** –series of V-shaped, full spanning structures -allow deposition of gravel	- 90% remain in place -gravel was caught behind each gabion -salmon observed to use for spawning	Anderson and Cameron 1980
Trinity River, California (1972-2000)	-Peak discharge: 42-311 m^3/s	- Lewiston and Trinity dams -reduced flow and sediment	- salmon spawning -restore natural gravel bar formation processes	**-high-flow stockpile and high-flow direct injection** -gravel of size 25-102 mm	-replenishment required[2] -unpredicted gravel transport to blocking some access to rearing sites[2]	Ock et al. 2013
Merced River, California (1990)	-tributary of San Joaquin River -watershed of 35,000 km^2	- New Exchequer dam and 3 other smaller dams -cut off gravel supply -coarsening of bed material	-increase Chinook spawning and production	-**replaced** existing gravel with proper sized -excavated down to 0.6 m depth - 6 full spanning lines of boulders placed perpendicular to flow -flat beds	-scoured -did not take into account natural geomorphology and mobile grain sizes and shear stress equations -assumed boulder lines would hold gravel in place at high flows -predicted 120 redds/year but actually got <56	Kondolf et al. 1996
Mokelumne River, CA (1999, 2000, 2001)	--watershed ~1624km^2 -slopes ~0.10 -riffle-runs	-Camanche Dam	-provide immediate spawning habitat for Chinook and steelhead	**-direct placement** -berm, riffle, and staggered bars 3 sites in 3 years: A=1659 m^3, B=1200 m^3, C=794 m^3 - 25-150 mm gravel from floodplain quarry -boulders (0.6-1.2m) and LWD placed throughout	-spawning use was variable each year -lost 11-24% of placed gravel with controlled flows -Site A lost 50% over 4 years -up to 20% loss in all sites first year	Merz et al. 2006

Nunome River, Japan (2004)	-high discharge controlled by dam with peak magnitude of ~80 m^3/s -occurs 1-2x per year with short duration (2-4 hours)	-Nunome Dam	-protect riverbed degradation -detach algae	**-high flow stockpile**: sediment deposited on right bank, 300 m below dam to be distributed with 81 m^3/s flow -used sediment from reservoir -80-500 m^3 -gravel of sizes 0.075-19 mm	-unknown, no published post-project monitoring	Ock et al. 2013
American River, CA (2008, 2009, 2010)	-4921 km^2 watershed -confined by levees -large woody debris and boulders are rare -some side channels and mid-islands	-Nimbus dam	-spawning habitat for Chinook and Steelhead	**-direct placement** 2008: 6350 metric tons, -6-102mm 2009:9525 metric tons -7-112mm 2010: 9707 metric tons -8-178mm	- increased utilization by Chinook and steelhead	Zeug et al. 2013
Campbell River, B.C. -Site 9 (2012), Site 7-III (2013)	- 1,461 m^2 watershed[1] -low meander pattern with riffle and pools[1] -Slopes=0.1-0.7% [1] -river width=~120 m with island in middle	- John Hart Dam -lack of gravel -armoured beds	-Chinook spawning habitat	-in channel **gravel platform** -areas of 1825 m^2 and ~2,100 m^2 -180 and 210 pairs predicted -boulders for complexity, undulated surface -0.7-1.0 m thick -stable up to 225m^3/s	-2012: ~100 Chinook and 200 chum used platform for spawning -350 Chinook, 150 coho and 60 chum - got scoured, required replacements -fish use 2 months after construction	N.H.C. 2013

[1] Burt 2004

[2] Schrock et al. 2014

5.5 Design

Due to rivers being complex and dynamic systems, there are multiple design strategies that could work in resolving the gravel deficiency problem in the Lower Seymour River (Wheaton et al. 2004). To maximize success and learning opportunity, implementation of two different designs tailored to two specific locations are recommended below.

Two spawning pads are proposed to be constructed within the reach between Mt. Seymour Parkway Bridge and Dollarton Bridge. Each pad will contain a partial spanning gravel catchment structure to dissipate energy and to promote gravel retention. Partial spanning structures were chosen due to the presence of migrating species such as coho, which might be restricted by full spanning structures.

5.5.1 Site locations

The area between Mt. Seymour Parkway Bridge and Dollarton Bridge was chosen for the placement of the spawning pads. This area has preferred channel characteristics (i.e., lowest slopes, widest widths, shallowest depths, and therefore overall less shear stress), the best access for machine entry, as well as being located far enough upstream to not be influenced by salt water from the estuary.

The spawning pads will be constructed along the left bank margin and extend into a quarter to a third of the channel width. This side possesses a lower gradient and shallower water depth than the right bank margin. Observations during the 2017 spawning season also showed chum and pink salmon using any available gravel right up to the water's edge on this bank.

Site 1

Site 1 is located approximately 150 m downstream from Mt. Seymour Parkway bridge and is on the left side of the channel, within the inside of a bend (Fig. 14). This location is within the tail out of the first pool downstream from the bridge and is immediately upstream from the main vegetated bar located by Maplewood Farm. The strategic placement on the inside of a bend will aid in promoting deposition of gravel from upstream, as it is naturally an area of lower energy.

Site 2

Site 2 is located approximately 170 m upstream from Dollarton Bridge, and is along the left bank, immediately upstream from an outer bend (Fig. 14). It is along the tail out of a large pool, and upstream from a steep riffle. Smaller-sized substrate is seen to accumulate along this area, specifically in the area immediately upstream. There is a gravel bar composed of finer grains on the left bank of the deep pool in which people use as a beach during summer. During the 2017 spawning season, this site was observed to have the highest density of spawners. Maplewood Creek also enters the river downstream from this gravel pad, providing extra nutrients, sediment, and water.

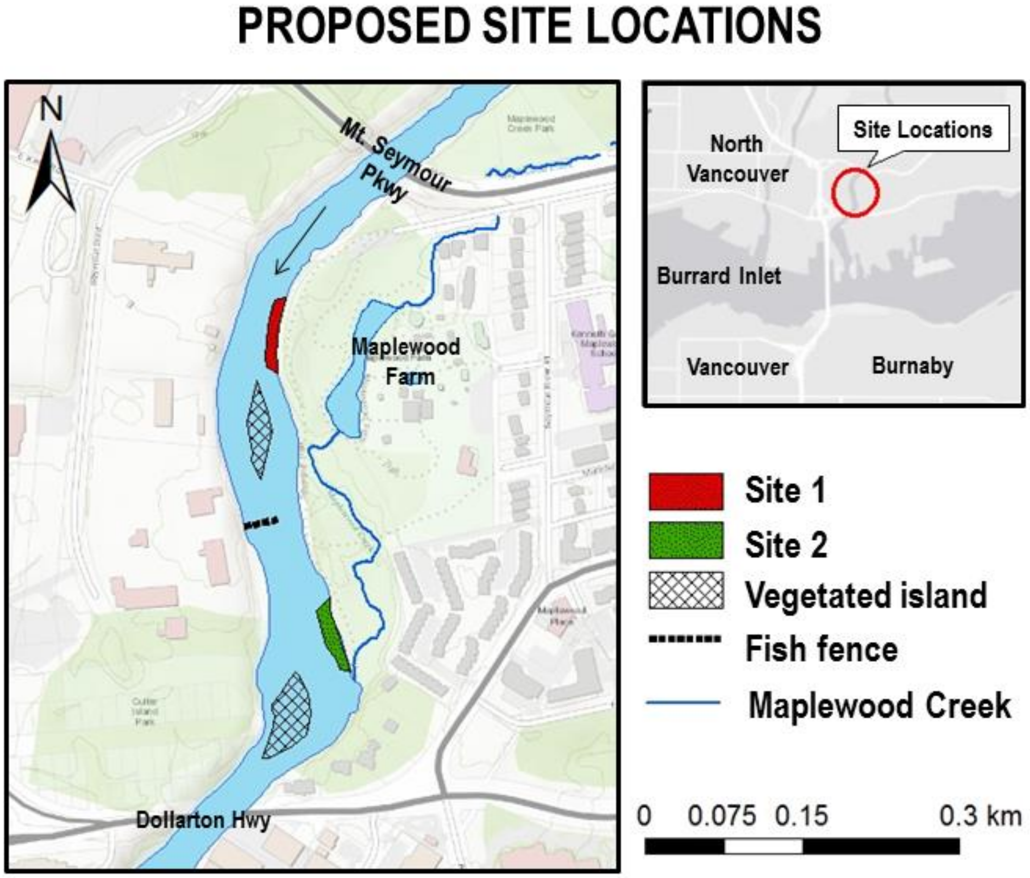


Figure 14. **Locations of proposed spawning gravel pads for Site 1 and Site 2 between Mt. Seymour Parkway and Dollarton Bridge on the Seyrmour River, North Vancouver B.C. Stream and lake data retrieved from District of North Vancouver (2017).**

5.5.2 Site-specific designs

Site 1

Site 1 will consist of a gravel pad with a maximum length of about 70 m, a width of about 15 m (Fig. 15), and will be composed of a 0.5 m thick layer of 5-40 mm sized clean gravel. The majority of the gravel (80%) will be of size 5-20 mm while the remaining 20% will be grain sizes 21-40 mm along with a small portion of 2-5 mm coarse sand. The gravel sizes are chosen to benefit both chum and pink salmon, and will allow equal opportunity to use. The gravel pad will be imbedded into the river bed and will therefore be at a slightly lower elevation than the rest of the channel bed to reduce tractive forces and to reduce the chance of dewatering during time of spawning. The surface of the placed gravel will be undulated and irregular rather than flat to increase exchange of surface and intragravel waters (Vaux 1968). Site 1 will provide approximately 1,050 m^2 of continuous spawning habitat. This could support 456 chum redds or 1,750 pink redds based on redd areas of 2.3 m^2 and 0.6 m^2 for chum and pink, respectively. If the site becomes saturated in which superimposition occurs, a conservative estimate of 114 pairs of chum is based on territorial area (9.2 m^2) along with the same redd estimate of 1,750 pairs of pink salmon. Based on average fecundity for chum and pink of 3,228 and 1,777 eggs per female (Beacham and Murray 1993), respectively, this site could potentially result in about 25,420-101,682 chum smolts and about 217,682 pink smolts migrating to the ocean.

The gravel catchment structure for Site 1 will be composed of three spurs, each of an approximate length of 15 m, and they will extend into the channel at a 90^o angle from the bank (Fig. 15). They will have a maximum height of about 0.5 m above the bed at the instream end and remain at that constant height up to the bank in to provide a flatter and consistent gradient within the gravel pad. Spacing between the spurs will be about 30 m (i.e., two times the effective length of the structure (Babakaiff et al. 1997)) to ensure their hydraulic effect shelters the gravel placed between them. Based on tractive force equations for this specific site (Table 7), the minimum stable grain size for the higher flood level is 84.85 mm. Results of the surface pebble count showed that a high proportion of the current armoured surface layer is composed of particles this size or larger, and will therefore remain stable at the higher flows of 290 m^3/s. Therefore, the spurs will be constructed reusing these large cobbles and boulders (preferably at least twice the size of the minimum grain size as a buffer) that compose the current armoured surface within the proposed area, as well as reusing any large boulders in proximity of the site.

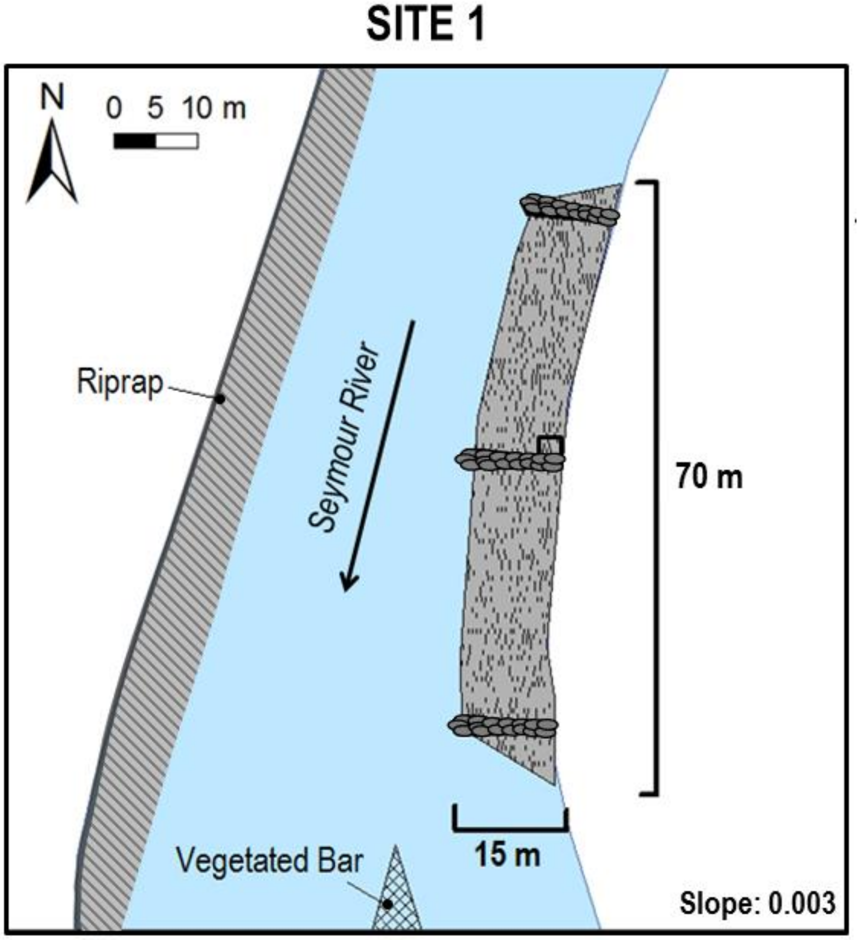


Figure 15. **Site 1 gravel pad design located downstream from Mt. Seymour Parkway bridge in the Lower Seymour River, North Vancouver B.C. The three linear features represent the three spurs created from the large surface cobbles and boulders.**

Table 7. **Specific shear stress values for Site 1 with calculated minimum stable grain size and the discharges associated with the depths used. Site 1 is located downstream from Mt. Seymour Parkway bridge in the Seymour River, North Vancouver B.C.**

Depth (m)	Slope (m)	Bed shear stress (N/m^2)	D (cm)	D (mm)	Stable discharges (m^3/s)
1.60	0.003	47.04	4.85	48.48	70
2.80	0.003	82.32	8.49	84.85	290

Site 2

Site 2 will consist of a gravel pad with a maximum length of about 70 m, and a width of about 15 m at the upstream end and 10 m at the downstream end (Fig. 16). Similar to Site 1, it will also be a 0.5 m thick layer of 5-40 mm clean gravel with the same composition, and will be imbedded into the river. The surface of the placed gravel will also be undulated. Site 2 will provide approximately 875 m^2 of continuous spawning habitat which could support 380 chum redds or 1,458 pink redds. Conservatively, based on territorial area, it could support 95 pairs of chum salmon, and the same 1,458 pairs of pink salmon. This site could potentially result in about 21,183-84,735 chum smolts and about 181,402 pink smolts migrating to the ocean.

The gravel catchment structure for Site 2 is composed of two spurs of length 30 m (Fig. 16). Both will be angled into the upstream flow at 20-30^o from the bank. Due to the location of Site 2 being immediately upstream from the outside of the bend (i.e., the section of river with the highest energy flow), the angled spurs will aid in diverting the flow away from the left bank towards to the center of the channel (Johnson et al. 2002), producing quiescent conditions next to the bank (Rosgen 2001). The spurs will be spaced 30 m apart and will be 0.5 m in height. The downstream spur at this site will also have a hook on the end to prevent lateral escapement of gravel. The spurs will be constructed from the large cobbles and boulders which make up the current armoured surface as is done for Site 1. Based on tractive force equations for this specific site (Table 8), the minimum stable grain size at the higher flood level is 64.85 mm, and the current surface grain sizes are this size or are larger and will therefore remain stable at the higher flows of 290 m^3/s.

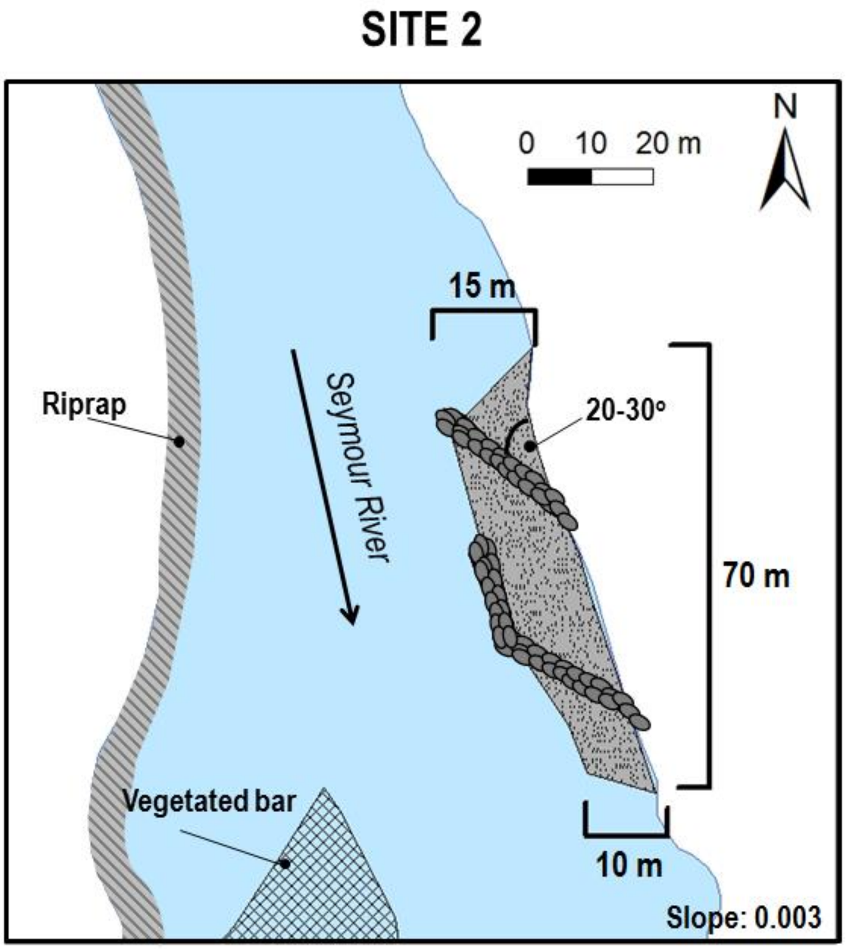


Figure 16. Site 2 gravel pad design located upstream from Dollarton Highway bridge in the Lower Seymour River, North Vancouver B.C. The two linear features represent the three spurs created from the large surface cobbles and boulders.

Table 8. Specific shear stress values for Site 2 with minimum stable grain sizes and the discharges associated with the depths used. Site 2 is located upstream from Dollarton Highway bridge in the Seymour River, North Vancouver B.C.

Bankfull depth (m)	Slope (m)	Bed shear stress (N/m^2)	D (cm)	D (mm)	Stable discharges (m^3/s)
1.22	0.003	35.89	3.70	36.97	70
2.14	0.003	62.92	6.49	64.85	290

Note: No bankfull measurements were taken directly at Site 2, therefore the values provided are the depths measured at the transect upstream from the site (SA2V2)

5.6 Gravel sources

Due to the absence of a natural gravel source for the Lower Seymour River, manual replenishment will be required when necessary based on the monitoring of the structures of whether they remain stable and retain the gravel. Therefore, it would be the most practical if local gravel sources are utilized.

A potential local source of gravel for this project is the dredgeate removed from the Seymour estuary by Allied Shipbuilders Ltd. for navigational purposes. This material will need to be analysed to determine its size distribution (i.e., whether it is all fines or contains gravels) and whether it is clean from any industrial toxins as the estuary is heavily industrialized. The material that is being dredged is naturally from the Seymour River and rather than removing the material and disposing it in the Strait of Georgia as they are currently doing, it could be a practical source for this project.

Another potential local gravel source is the lower reaches of Lynn Creek where bed load gravel is being removed (Chilibeck, N.H.C., pers. comm., 2018). It could then be transported a short distance (about 2.5 km) to the site where it would be cleaned and sieved to the desired sizes. This gravel will need to be cleaned thoroughly to ensure the prevention of any cross contamination of diseases from Lynn Creek that could have detrimental effects to aquatic life in the Seymour River.

Lastly, if neither of these local gravel sources are considered appropriate (e.g., too many fines, not correct size distributions, toxic, etc.), clean and sorted gravel can be bought. This option is the least practical as it is more costly for both the gravel itself, and for transport.

5.7 Climate change

A major impact from climate change which this project will likely be affected by is the changes in water depths. Higher peak flows may test the integrity of the structures thereby causing scouring of the retained gravel. Low flows during summer and into fall may cause the gravel pads to become dewatered, leaving them unusable by spawners. Increased water temperatures may also have a large impact as it would cause the built gravel pads to become unusable.

This project is intended to create spawning habitat for the present conditions to reduce pressure created by the shortage of spawning habitat for chum and pink salmon during their freshwater phase in the Lower Seymour River. These specific gravel pad designs are not meant to be maintained in perpetuity, as they are designed for the current conditions. Continuous monitoring of the changes to the hydrologic regime of the Seymour River over time will be necessary to gauge whether these structures will remain intact in future conditions. These structures can easily be adjusted for larger peak flows, but if the other four spawning habitat characteristics (i.e., temperature, D.O., depth and velocity) are not within suitable range, this gravel augmentation project would not be worthwhile.

5.8 Limitations to treatments

The proposed mitigative treatments are based on theoretical calculations and an understanding of geomorphic processes. Due to the complexity of the natural river system, the outcomes of such treatments may not be as predicted. Unexpected high flows may cause degradation of the structures, and gravel may be subjected to the same forces that caused scouring pre-project. Bankfull depth measurements, in which these calculations are based on, have inherent error due to the difficulty in determining the bankfull depths of a channelized river channel absent of floodplains. For optimal success, detailed hydraulic modeling should be done by engineers (Bunte 2004). Engineers should also determine the optimal angles, heights and lengths of the structures to ensure a higher probability of maintained stability as the designs outlined in Section 5.5.2 are only a general prototype.

Chapter 6: Implementation

6.1 Planning

The planning phase will take place one to two years in advance of actual construction. This phase is the most important to get stakeholder support, acquire required permits and to prepare the initial construction budget.

6.1.1 First Nations engagement

Both the Tsleil-Waututh Nation and Squamish Nation should be involved in the project throughout all phases. From the beginning, they should be informed about the goals of the project and their own goals and ideas should be integrated. Constant consultation and collaboration will strengthen this project through the use of both Traditional Ecological Knowledge and western ecological restoration practices of aquatic ecosystems. Traditional knowledge from these nations on historical salmon runs can provide a historical benchmark that would be helpful in adjusting resulting goals or desired outcomes.

The Tsleil-Waututh Nation supports many projects that promote restoring the Burrard Inlet and have been involved with both the Seymour Estuary restoration project as well as the rockslide project (Ogston, T.W.N, pers. comm., 2018). The Tsleil-Waututh Nation and the Squamish Nation both possess the traditional obligation to be proper stewards of the land, water and air of the Burrard Inlet, along with the rich resources that the inlet provides (Lilley et al. 2017). This includes protecting, defending and restoring habitats that are of cultural, economic, and spiritual importance (Lilley et al. 2017).

6.1.2 Stakeholder engagement

Other stakeholders involved in this project on the Lower Seymour River include: the Seymour Salmonid Society, the District of North Vancouver, Metro Vancouver, Allied Shipbuilders L.T.D., Department of Fisheries and Oceans Canada and the citizens of North Vancouver.

All stakeholders should be informed of the project and their input should be incorporated throughout. Meetings should be held in which each party can express their ideas, perspectives and concerns. These meetings early on in the planning phase can provide excellent learning opportunities and a transfer of knowledge that will only strengthen the resulting project. Plans can then be adjusted based on these gatherings.

6.1.3 Public outreach

Education is a critical component in any restoration or mitigation project. It can help inform people who may be opposed to the project on benefits it will produce. It can also provide information to engage people in learning more about the importance of salmonids and the issues they are currently facing in the Pacific Northwest.

Public outreach will be conducted through events such as the annual World Rivers Day, as well as through signage that will be posted within the vicinity of the gravel pads. These signs will be an integral part in providing information to park visitors and will not only provide background information on salmonid importance and their decline, but the project's goals and what the structures are meant to accomplish.

6.1.4 Regulations and permits

Appropriate permits must be obtained well in advance (i.e., at least six months in advance) of beginning any work. This includes:

- Change Approval under the Water Sustainability Act regarding Section 11 (changes in and about a stream)
    - An application will be submitted outlining the details of the project including the location, the proposed treatments (including engineering drawings), timeframe of the project, the people involved, and mitigative measures that will be completed to ensure minimizing harm to aquatic life (Slaney and Martin 1997).

Regulations and best practices that must be followed include:

- Water Sustainability Act (Provincial)
- Fish Protection Act (Provincial)
- Riparian Area Regulations (Provincial)

- Navigable Waters Protection Act (N.W.P.A.) (Federal)
- Fisheries Act (Federal)
- Canadian Environmental Assessment Act (C.E.A.A.)(Federal)
- Canadian Environmental Protection Act (C.E.P.A.)(Federal)

It is very important that a qualified environmental professional (e.g., environmental consultants, fisheries or aquatic biologists etc.) is hired to ensure all the appropriate permits have been acquired, all regulations are being met, as well as to provide guidance on avoiding and reducing harmful impacts to aquatic life and habitats prior to starting any work.

Other permissions that might be required include the use of Maplewood Farm’s parking lot and the small parking lot near Seymour River Heritage Park for staging areas. Permission may also be required from the District of North Vancouver regarding entering the park with the excavator to access Site 1.

6.2 Implementation

Implementation will occur between mid-July to mid-August. This is within the work window for Pacific salmon in the Lower Mainland (i.e., mid-July to mid-September) (Ministry of Environment 2006) and is the lowest flow of the year.

6.2.1 Site access

Site 1 will be accessed through Heritage Park Lane and along Seymour Trail (Fig. 17). The staging area for this site is located at the end of Heritage Park Lane in the cul-de-sac. Access to this site will require the excavator to move through some of the riparian area and therefore will require replanting after implementation to restore the riparian vegetation.

Site 2 will be accessed through the Maplewood Farm parking lot along the Maplewood Farm Trail (Fig. 17). The staging area for this site is located at the south end of the parking lot.

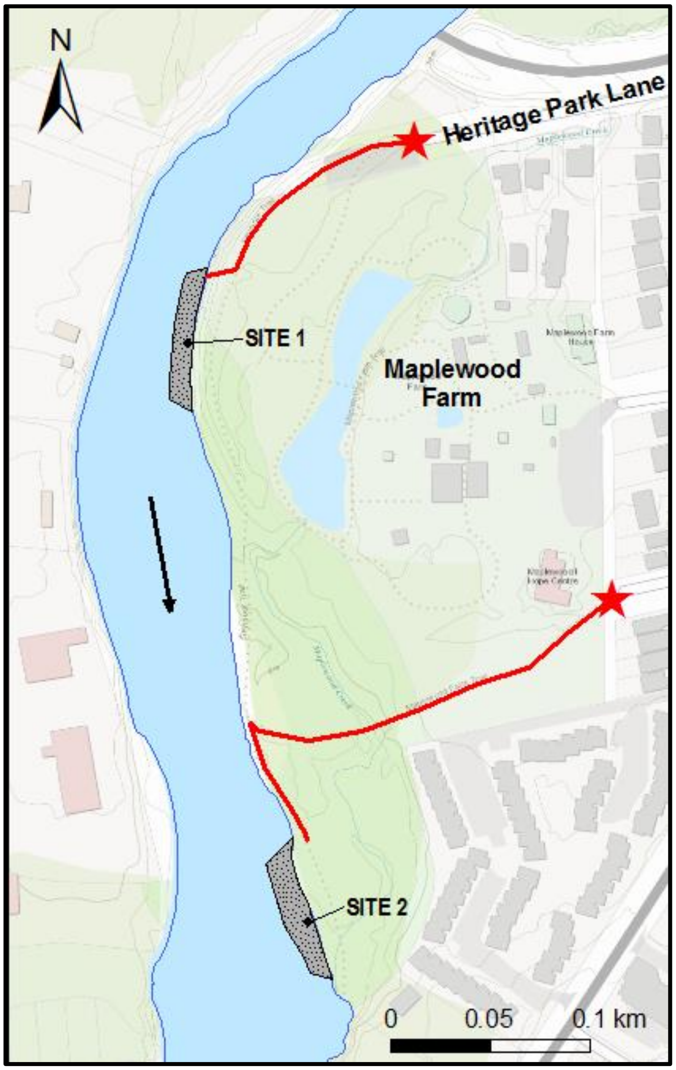


Figure 17. **Access routes outlined in red for both Site 1 and Site 2 in the Lower Seymour River, North Vancouver B.C. Red stars represent the staging areas, with Site 1's staging area at the cul-de-sac at the end of Heritage Park Lane, and Site 2 at the south end of Maplewood Farm's parking lot.**

6.2.2 Site construction logistics

In advance of the designated implementation days, signage will be installed with the dates of construction to inform the public. The implementation phase for each gravel pad will be about 2 days each, for a total project implementation of 4-5 days. Site 1 will be completed first as construction could cause effects downstream to Site 2. There are three phases of implementation: site preparation, construction, and post-construction (Figure 18).

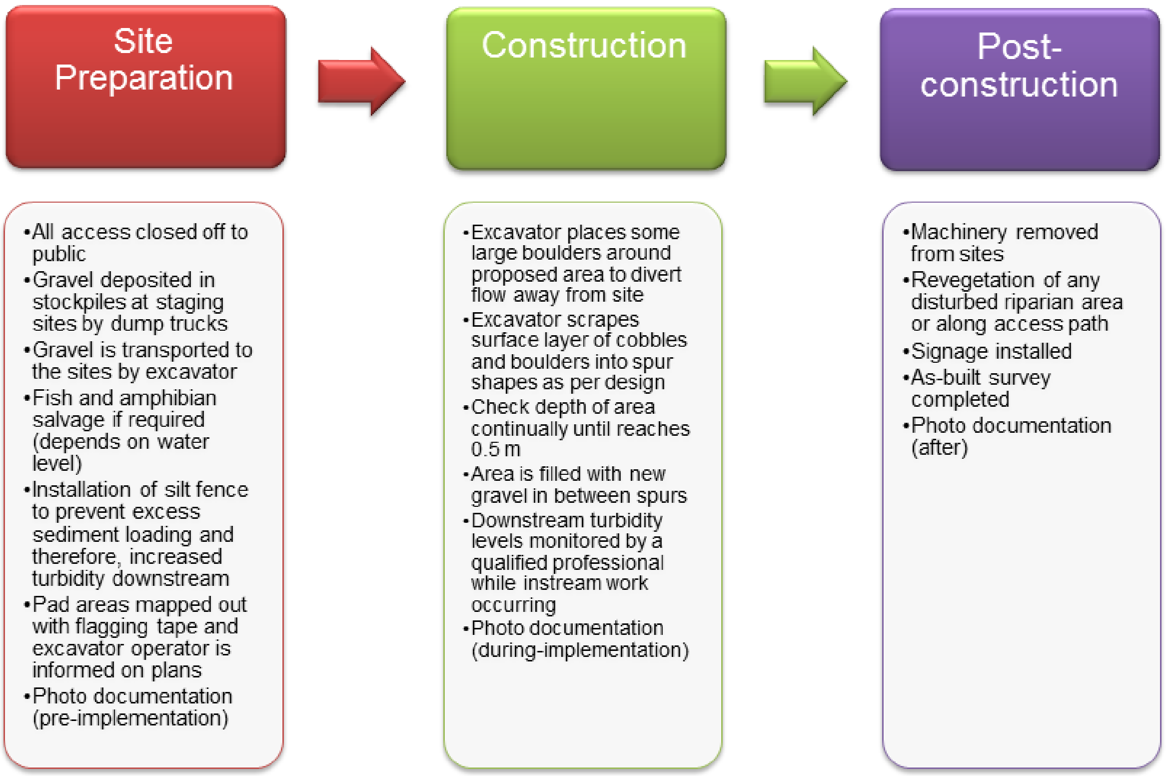
There are two general stages to the construction of each site: the construction of the spurs, and the placement of gravel. For the first phase, an excavator will remove the surface layer (i.e., the depth of the diameter of D_{max}) of cobbles and boulders starting at the upstream boundary of the marked area and will build up the first upstream spur with the surface material. The sequential spurs downstream will be constructed in the same process. For the second phase, gravel will be moved to the specific sites by the excavator from the staging areas. The excavator will then place the gravel in the bed in between the spurs as per the design.

A walking mobile excavator (also known as a spider excavator) is chosen for this project as they are an optimal option for sensitive environments, such as streams, due to their walking motion and have a smaller footprint than a traditional excavator. They will also be beneficial for Site 1 in getting down the steeper bank to the channel while disturbing minimal vegetation.

Best management practices for works instreams provided by the Ministry of Environment (2004) should be followed which includes doing as much work from the banks rather than instream to prevent harm to aquatic life. A silt fence will be installed around the proposed area in attempt to prevent fines from going downstream. During construction, turbidity levels downstream will be monitored by a qualified professional to ensure the levels do not exceed levels harmful to aquatic life (maximum 25 N.T.U. downstream) (W.L.A.P. 2004).

An ‘as built’ report will be written as construction occurs to document all changes in the planned design, as conditions in the field may be different than what is planned. Documentation of all actions and the resulting report is essential for transferring techniques to other restoration projects in other rivers and can therefore be easily replicated. This report will also contain pre-project photos, photos during construction as well as post-project photos.

Signage will be installed on the trail in front of each site and will describe the goals of the project, and the importance of salmonid conservation and restoration. They will also mention that each site is ecologically sensitive during the spawning season and should not be walked on or disturbed. Due to this section of the river being a popular recreational destination with a lot of human interaction, these signs will hopefully prevent vandalism such as moving boulders and ultimately affecting the success of the project. This is especially important for Site 2 which is a popular swimming and beach spot in the summer.



Site Preparation

- All access closed off to public
- Gravel deposited in stockpiles at staging sites by dump trucks
- Gravel is transported to the sites by excavator
- Fish and amphibian salvage if required (depends on water level)
- Installation of silt fence to prevent excess sediment loading and therefore, increased turbidity downstream
- Pad areas mapped out with flagging tape and excavator operator is informed on plans
- Photo documentation (pre-implementation)

Construction

- Excavator places some large boulders around proposed area to divert flow away from site
- Excavator scrapes surface layer of cobbles and boulders into spur shapes as per design
- Check depth of area continually until reaches 0.5 m
- Area is filled with new gravel in between spurs
- Downstream turbidity levels monitored by a qualified professional while instream work occurring
- Photo documentation (during-implementation)

Post-construction

- Machinery removed from sites
- Revegetation of any disturbed riparian area or along access path
- Signage installed
- As-built survey completed
- Photo documentation (after)

Figure 18. **General implementation sequencing for both sites. Includes three phases: site preparation, construction and post-construction**

6.2.3 Budget

The cost of the project depends on the source of gravel. The most opportunistic and convenient choice would be the free gravel from the estuary, but if it is considered to be unsuitable, new clean gravel can be bought. An estimated Class C budget resulted in the project total of $53,695 if gravel is reused and $110,205 if gravel is bought (Table 9). A full breakdown of the implementation budget for each site is provided in Appendix C.

Table 9. **Summary of the Class C construction budget for reusing gravel or buying new gravel.**

Category	Site 1	Site 2
Reuse Gravel		
Materials ($)	2,794	1,794
Equipment ($)	9,750	9,750
Labour ($)	8,800	8,800
Contingency (15%)	3,202	3,052

Tax (12%)	2,946	2,807
Site total ($)	27,492	26,203
Project total ($)	**53,695**	
New Gravel		
Materials ($)	26,419	22,044
Equipment ($)	9,750	9,750
Labour ($)	8,800	8,800
Contingency (15%)	6,745	6,089
Tax (12%)	6,206	5,602
Site total ($)	57,920	52,285
Project total ($)	**110,205**	

Chapter 7: Monitoring

7.1 Metrics of success

There are two metrics to be evaluated at one year, three years and five years post implementation: gravel depth within the gravel pads, and redd density (Table 10).

The physical metric of gravel depth determines the effectiveness of the gravel catchment structures to stabilize placed gravel. Since the structures are most vulnerable to degradation during the first year (see Section 5.4.2), this year will be the most critical to project success. If gravel depth does not meet the metric for the first year, and it has undergone greater scour than expected, more gravel may need to be added and the structures may need to be re-evaluated.

The ultimate factor that will consider these spawning pads a success is that both chum and pink must be using the sites, and their usage should ideally meet the biostandard densities. The biological metric for chum and pink usage will be redd density. The expected capacity for redds on Site 1 and Site 2 are at least 114 redds per 1,050 m^2 and at least 95 redds per 875 m^2, respectively. It is important to note that these values are based on chum territorial areas which are larger than pink territorial areas and therefore provide a lowest expected density. If pink spawn on the pads at the same time, there will be more than these estimates. This metric increases with time as salmon response and usage may not be apparent for a few years post-implementation. The gravel pads may not be attractive to the spawners until it has settled within the system and the aquatic food sources have been established (Kondolf and Micheli 1995).

Table 10. **Metrics of success for one year, three years and five years post-implementation of gravel pads. These metrics include a physical metric of gravel depth as well as a biological metric for fish response.**

Metric	1 year	3 years	5 years
Gravel depth	6% gravel loss (0.03 m)	18% total gravel loss (0.09 m)	30% total gravel loss (0.15 m)
Redd density	Redd density of at least 50% of expected capacity	Redd density of at least 75% of expected capacity	Redd density of at least 90% of expected capacity

7.2 Pre-implementation baseline data collection

Baseline data collection is critically important as it provides the opportunity to compare pre-project conditions to post-project conditions. For the data to be useful for that purpose, it is important that the same methods and sampling locations used for the baseline data is used for post-implementation monitoring. Therefore, G.P.S. locations of transects along with the transect bearings should be recorded.

7.2.1 Fish and redd counts

Fish and redd counts in the area between Mt. Seymour Parkway and Dollarton Bridge should be completed for at least two spawning seasons proceeding project implementation. For chum that is at least two years in advance and for pink at least three to four years, depending on whether the implementation year is a year of pink return (odd years). More years of data would be more useful to incorporate annual variation and should be done if funding allows for it. This data will be important for determining whether goals of increasing salmon productivity have been met.

7.2.2 Spawning habitat parameters

Sampling of all five parameters critical for salmon spawning habitat should occur on the proposed sites to provide specific conditions which may alter designs since the parameters measured in this study were for the river as a whole. Velocity, water depth, temperature and D.O should be measured along transects across the proposed area. Surface pebble counts and subsurface sampling should be conducted in the proposed locations using the same methods outlined in Section 4.2.1 and are essential for comparison for later effectiveness monitoring of the gravel pads and determining whether the distributions have changed.

A survey of the current suitable gravel (i.e., the size of patches and the G.P.S. locations) that also meet the other four spawning habitat parameters should also be completed and should be compared to the study completed in 2008 by Hryhorczuk.

7.3 Post-implementation monitoring

Monitoring the project after implementation is essential. Many augmentation projects do not include baseline data and post-implementation monitoring. This limits the usage for other projects and determining whether these projects work in increasing salmonid productivity from the pre-restoration state (Kondolf and Micheli 1995, Kondolf et al. 2007). Post-implementation monitoring should be long term (i.e., five to ten years) to account for processes that occur on a longer time scale such as sediment transport and fish response. Often the absence of monitoring is due to a lack of funding, and therefore it should be included in the overall project budget. Volunteers from the Seymour Salmonid Society provide a cost-efficient option for long term monitoring.

Due to the inherent maintenance associated with gravel augmentation projects (including this project), monitoring will be essential in determining the frequency of maintenance as well as possible adjustments to the structures. Monitoring will therefore occur over the entire lifetime of the project. If the project is at some point cancelled, monitoring of the areas should be continued for at least five years post cancellation to observe how the channel responds geomorphically and biologically. It is recommended that fish records are continued past this five years regardless in order to monitor their populations. Post-implementation monitoring is divided into two main goals: 1) monitoring physical parameters such as the structural condition of the gravel catchment structures (including the gravel pad), spawning habitat parameters, and channel geomorphology, and 2) monitoring the use of the gravel pads by chum and pink salmon for spawning.

7.3.1 Physical condition of structures and gravel pads

The first goal is based on monitoring the structural durability of the structures to high flows. While the tractive force equations provide boulder sizes that will remain stable during specified flows, river flow regimes can be highly variable. Higher flows may occur in which the structures are not expected to withstand. Therefore it is important to monitor whether the boulders composing the structures have been displaced from the original position. The displacement of one boulder could have detrimental effects on the structural integrity of the catchment structures, causing failure of the structure and the movement of the held spawning gravel downstream. The physical monitoring should also include monitoring gravel conditions, the other spawning habitat characteristics and geomorphic changes to the channel (Table 11).

The structures should be checked immediately after the first high flow event (>70 m^3/s) which will likely occur in October (Fig. 4). This initial high flow will have the greatest effect on the newly placed gravel. Monitoring after this event should continue after every high flow, otherwise every month if there are no large events. For months in which high flows are not an issue (i.e., summer) monitoring is necessary to check for vandalism of the structures.

Spawning habitat parameters should be measured immediately before spawning (i.e., late September) to ensure conditions are still suitable for spawning. Methods for measuring these parameters will be the same as for the baseline data collection to be consistent (Section 7.2). Photo monitoring is also essential to qualitatively evaluate the structures and channel morphology changes through time (refer to Section 7.3.3).

Table 11. **Physical parameters to be monitored post- implementation, along with the methods recommended to be used and the frequency of monitoring of the proposed gravel addition sites in the Lower Seymour River, North Vancouver B.C. This includes the structural condition of gravel catchment structures (including the gravel pad), spawning habitat parameters and changes to the geomorphic features of the channel.**

Parameter	Description	Methods	Frequency
Structural condition of spurs:			
	Determination of displacement or complete absences of cobbles and boulders composing the spurs Determination of whether tractive force equations were correct	-Observations of changes in shape of spurs -Comparing photos to immediately after implementation photos and details on as built report	-Immediately after first high flow >70 m^3/s -After every high flow event, otherwise once every month
Gravel conditions:			
Surface grain sizes	Determination of whether the pads contain the same distributions as when placed and are suitable for spawning	-Pebble counts on pads (determination of D_{50})	-Immediately after first high flow event >70 m^3/s -After each following high flow event, otherwise every other month
Gravel depth	Determination if scouring, or deposition have occurred and if depth is suitable for	-Total station surveys will be completed to determine elevation pre project and post	-Immediately after first high flow event >70 m^3/s

	spawning	project at the same spots (using G.P.S.)	-after every high flow event, otherwise every other month -Prior to each spawning season
Quality of placed spawning gravel	-Determination of accumulation of fines (% fines) which are not washed out through intragravel flows	-Subsurface sampling with McNeil sampler and determine size distributions -Use of fine sediment traps	-Immediately after first high flow event >70 m^3/s -Every other month
Other spawning habitat characteristics:			
Velocity	Determination if still suitable for spawning	-Swoffer flow meter along transects across gravel pads	-Prior to each spawning period
Water Depth	Determination if still suitable for spawning	-Measured at same locations as velocity	-Prior to each spawning period
Temperature and D.O.	Determination if still suitable for spawning	-Multimeter measurements along transects across gravel pads	-Prior to each spawning period
Geomorphic changes to channel:	Determination if there are unexpected changes to geomorphology of channel	-Observation of newly formed scour pools and bars within the reach -Monitor estuary for deposition -Compare photos pre and post implementation and mapped features	-Immediately after first high flow event >70 m^3/s -After every high flow event, otherwise every other month

7.3.2 Biological monitoring

The second goal is determining the effectiveness of the gravel pads for chum and pink salmon spawning. This will be completed by measuring redd density and spawner usage (Table 12). Their response may show if they are attracted to one structural design or site over the other. Evaluation should be completed during and immediately after the spawning period. If completed during, attention should be given to not disrupting the buried eggs, and should only be visually examined.

Snorkel surveys are useful in determining whether the salmon are using the constructed spawning pads, but observations from walking along the bank are also sufficient in viewing newly formed redds and movements of spawners during spawning.

It is important to note that it is difficult to determine an appropriate metric to infer increases in salmon due to their unique life history. Being anadromous makes them vulnerable to many off-site factors which may influence their numbers. This includes weather, quality and quantity of flows, food and shelter availability, survival as smolts in the estuary, and oceanic survival, all of which will affect the returning spawner numbers (Mesick 2001). The different locations of the two sites might also affect the number of redds found. Currently spawners have been observed to use the area that Site 2 is located, but not as much where Site 1 is located. Therefore, they may initially choose Site 2 over Site 1 because of its close proximity to their original spawning sites.

Table 12. Biological parameters to be measured and monitored post-implementation to determine whether chum and pink salmon are using the sites for spawning.

Parameter	Description	Method	Frequency
Redd density	Number of redds present compared to full capacity of gravel pad (redds per specified area)	-Presence, number -Snorkel surveys -Mapping redds with G.P.S. and spatial analysis -Size of redds to estimate species	-At end of spawning period
Spawner usage	Determination of whether species are using one site more than the other	-Observational counts of adult spawners -Estimate numbers	-During each spawning period

7.3.3 Photo monitoring

Photo monitoring is a valuable monitoring tool. It should be completed throughout the entire project process starting from the pre-implementation baseline data collection. Photos should be taken from the same vantage point to easily show changes in the structures, and channel. Consistent photos taken every month can qualitatively show how the structures look in the different seasons, as well as at different flows.

7.4 Maintenance

As previously mentioned, gravel augmentation projects are unsustainable without constant human involvement because it is not repairing or restoring the natural processes that can aid in natural recovery. Maintenance of the structures and the gravel pad must be acknowledged and accepted and will need to be accounted for in the overall long term budget.

The results from the monitoring of the structural integrity of the structures, as well as the condition of the placed spawning gravel, will determine whether gravel will need to be added and the frequency of such additions. If the structures remain stable but it is noted that the spawning gravel has been diminished, an option could be to place gravel on the bank in an upstream reach and at higher flows the gravel will naturally distribute and be caught by the structures (i.e., passive gravel augmentation). Therefore rebuilding will not be necessary and the maintenance costs and effort will be reduced.

If the structures do not remain stable (i.e., the tractive force calculations did not account for certain factors and are incorrect), they may have to be rebuilt or adjusted using larger boulders.

Chapter 8: Conclusion

The Lower Seymour River is a highly degraded system that is gravel deficient due to a combination of factors including the Seymour Falls Dam located in the middle of the watershed and intense channelization in the lower reaches due to a growing urban environment. This gravel deficiency was found to be the limiting factor for chum and pink spawning in this area as the other four key parameters required for spawning (i.e., temperature, D.O., water depth and velocity) met suitable spawning requirements. The proposed mitigative treatments outlined in this report would provide suitable spawning habitat for a total of 209-836 pairs of chum or 3,208 pairs of pink salmon. While the limited historic escapement records demonstrate chum and pink populations being quite stable through the 1980's, the restoration of limiting freshwater spawning habitat will help conserve these populations and reduce bottlenecks in their freshwater life history phase. This will allow them to be better equipped to meet increasing pressures occurring in other life history stages such as in their oceanic phase (e.g., sea lice and disease, and ocean surface temperatures rising). The additional salmon carcasses will also provide increased nutrients for the estuary located immediately downstream.

8.1 Implications for ecological restoration

The study of gravel augmentation for salmon spawning habitat is limited. This is especially true for large, urbanized, and highly energetic rivers in which determining gravel retention can be complex and difficult. This project suggests possible gravel pad designs and strategies which are designed reusing bed material that is already determined to be stable in the channel and is supported by simple tractive force calculations. While these calculations do not incorporate all variables and complexities of the natural system, they can provide a foundation for gravel retention in larger rivers. By testing these designs in a preliminary trial in an environment such as the Lower Seymour River, alterations can be made later on to further increase their success. The location of the lower reaches in the Seymour River makes it an opportune area to test such structures as the gravel does not have a far distance until it reaches the estuary where it can be dredged and reused. If failure occurs, gravel is therefore not depositing into unwanted bars, or causing unexpected erosion, which causes changes in the overall geomorphology of the system.

Gravel augmentation is a mitigative method and does not fit under the definition of restoration, but rather it is on a continuum alongside it. It does not recover the natural processes, which allows the system to recover naturally as restoration aims to do, but it creates habitat in the current disturbed situation. Mitigative gravel augmentation projects are often discredited as solutions due to the commitment of maintenance required in the long term. But, for scenarios where anthropogenic requirements override ecological and environmental boundaries, something should be done within those conditions to provide adequate habitat, especially when salmonid habitat is being reduced on a large scale.

The best restorative solution to these issues would be remove the dam, remove the dikes and rip rap along the banks, and allow the river to naturally meander in the floodplains. Removing the dam would restore the natural flow and sediment transport regimes (Wheaton et al. 2004), while the removal of dikes will return conditions back to being able to retain gravel naturally. In many cases these are unrealistic solutions as the dam provides some benefit to society such as water, electricity and flood control, and the river is surrounded by residential areas, urban centers, and industry which would be destroyed with flood events and the natural erosive meandering. Therefore, in these highly disturbed, urban environments, mitigation measures such as gravel placement or construction of instream structures is the best option to provide additional quality spawning habitat.

Ecological restoration is multi-disciplinary, and it takes knowledge in different areas in order for it to be successful. This study focuses on the ecology of salmon as the backbone for the mitigation treatments. A full understanding of the life history of targeted species (specifically the freshwater phase) determines what parameters are sampled, as well as aids in the design of the structures. Another key for gravel augmentation projects is the understanding of fluvial geomorphology. Understanding the current state of the river through its planform determines the causes for the gravel deficiency, and determines how the treatments should be placed for best results. Basic tractive force calculations can support field data, and also be used to determine how to retain the gravel.

8.2 Applicability

The strategies of this study can be useful in other urban rivers that are found to be deficient in natural spawning gravel sources either because of steepened slopes, armoured banks or dammed headwaters. Many rivers in North Vancouver that discharge into the Burrard Inlet (i.e., Capilano River, Lynn Creek, McKay Creek and Mosquito Creek) are experiencing gravel deficits similar to the Seymour River. Depending on the results from testing these structures in the Seymour River, the methods used to design them can then be applied to these other rivers, resulting in structures adapted to those specific sites and conditions (i.e., channel characteristics). The cumulative effect of adding spawning gravel in each river within the Burrard Inlet, as well as elsewhere in the Pacific Northwest, could reduce stress in their freshwater phase and might aid in rebuilding salmon populations from their precipitous decline in which they are on currently on track for.

Sediment starved rivers formed by the construction of dams will become more likely in the future. With climate change continuing into the future, a change from a fossil fuel centered society towards one of more renewable energy is likely. This includes hydropower as an attractive solution, and therefore more dams will be built. The need for more innovative habitat mitigation strategies will be necessary in order to keep salmon from becoming a relic of the past.

8.3 Future considerations

Some future considerations to be examined include:

1) Increasing salmonid population monitoring and records. There is currently a lack of data on fish escapement for many North Shore rivers, specifically for chum and pink salmon in the Seymour River. Not only will these records benefit the monitoring of this project, but also with the threat of climate change, these fish numbers should be monitored closely to determine future declines.

2) A sediment budget analysis for the Seymour River. A professional geomorphologist should determine the sediment budget and transport of the river to provide greater detail on the frequency of maintenance of the proposed structures. These budgets demonstrate the amount of erosion occurring in the system (which is important to determine scouring) and the sediment yield being discharged from the system (i.e., if any sediment will be caught by the structures thereby increasing the gravel depth).

3) Evaluating other areas within the Seymour River system as possible gravel augmentation sites. This includes tributaries upstream which may be deprived (Hryhorczuk 2011). By adding gravel to this upstream reaches, it may also provide gravel to the lower reaches over time.

4) Metro Vancouver trying to mimic a more natural flow regime with water releases. Hryhorczuk (2011) recommended having a professional hydrologist to determine if different flow releases from the dam could alter how sediment is transported throughout the river and how it alters the bed composition.

5) Ensuring full water quality testing in the Seymour River (as well as the other North Shore rivers) and appropriate restorative actions are executed to ensure the water is clean and clear of toxic substances that can be detrimental to aquatic, and terrestrial ecosystems, as well as to humans.

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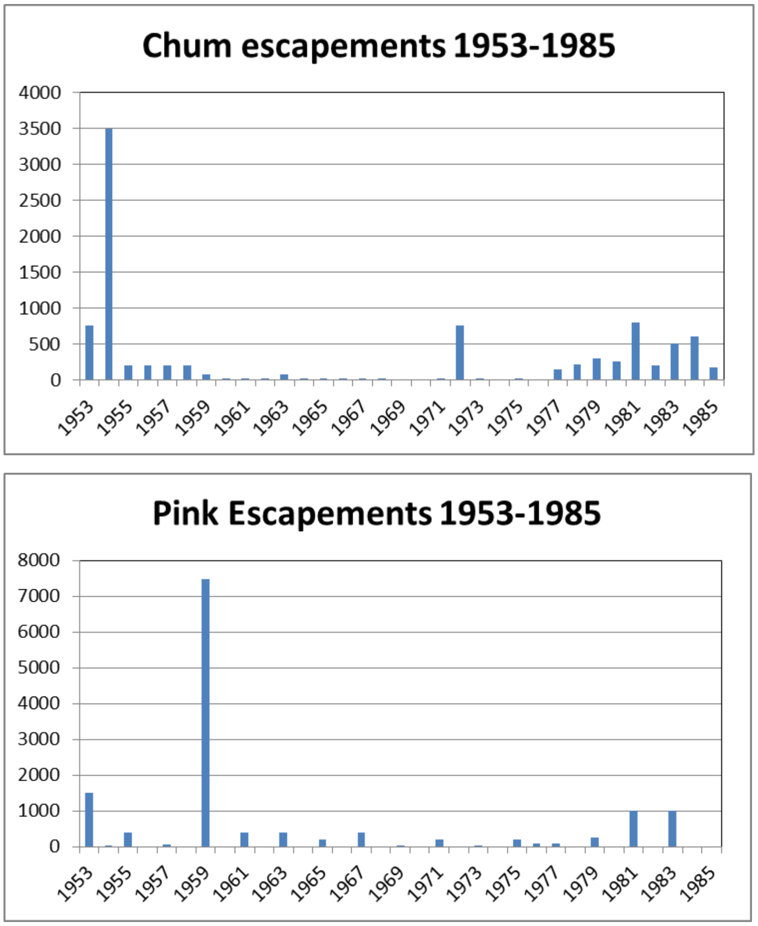
Appendices

Appendix A- Salmonid escapement records

Table A-1 and Figure A-1. Chum and pink salmon escapement numbers for the Seymour River, North Vancouver B.C. for 1953 to 1986. N/O is no fish observed, UNK is either the stream was no inspected, or species present but no estimate (D.F.O. 1989).

Year	Chum	Pink
1953	750	1500
1954	3500	25
1955	200	400
1956	200	0
1957	200	75
1958	200	n/o
1959	75	7500
1960	25	0
1961	25	400
1962	25	0
1963	75	400
1964	25	0
1965	25	200
1966	25	0
1967	25	400
1968	25	0
1969	N/o	25
1970	0	0
1971	25	200
1972	750	0
1973	25	25
1974	n/o	UNK
1975	25	200
1976	0	100
1977	150	100
1978	220	UNK
1979	300	250
1980	250	UNK
1981	800	1000
1982	200	0
1983	500	1000
1984	600	0
1985	170	NO



Appendix B- Sampling methods

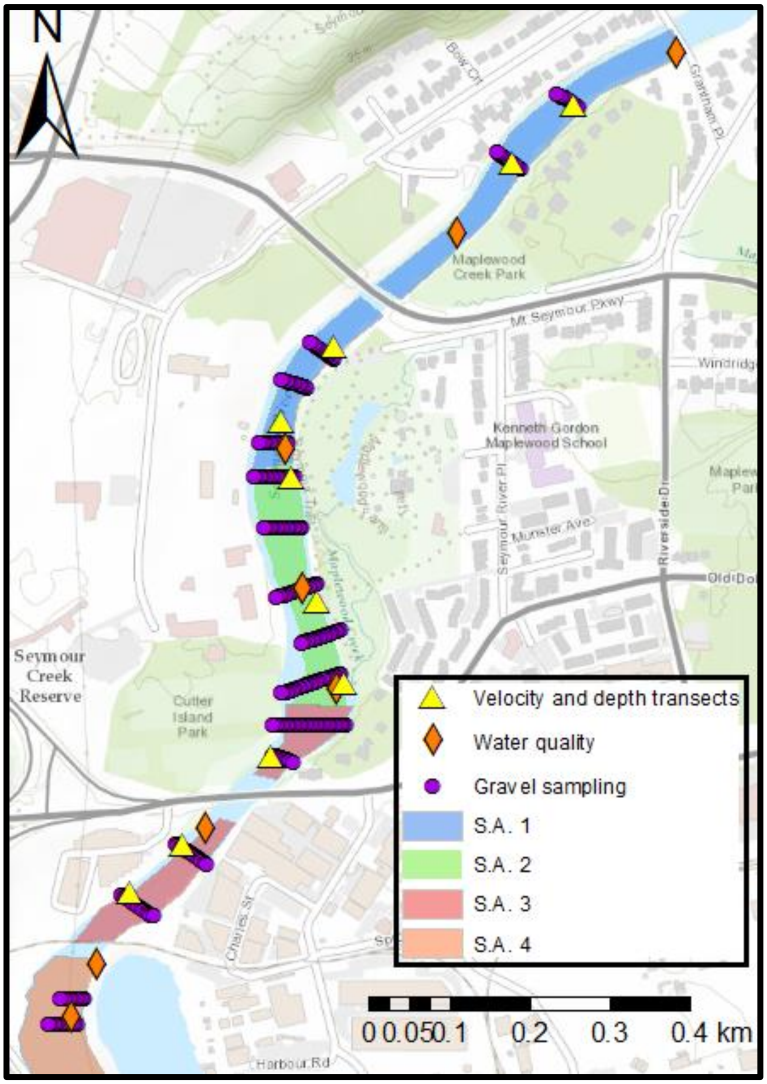


Figure B-1. **Sampling locations for velocity and depth transects, water quality sites and gravel sampling transects (for both subsurface sampling and pebble counts) in the Lower Seymour River, North Vancouver B.C. Instream parameters and water quality were measured/sampled in August and October 2017, respectively.**

Table B-2: **Size classes used for pebble count analysis (A) adapted from Pontyondy and Bunte (2002), and size classes (size of sieves) used for surface grain size analysis (B).**

A

Category	Size class (mm)
large boulder	>1024
medium boulder	513-1024
small boulder	257-512
large cobble	129-256
small cobble	65-128
very coarse gravel	33-64
coarse gravel	17-32
medium gravel	9-6
fine gravel	5-8
very fine gravel	2-4
sand	<2

B

Size class (mm)
<4
4
9.51
12.7
16
19.05
38.1
50.8
76.1

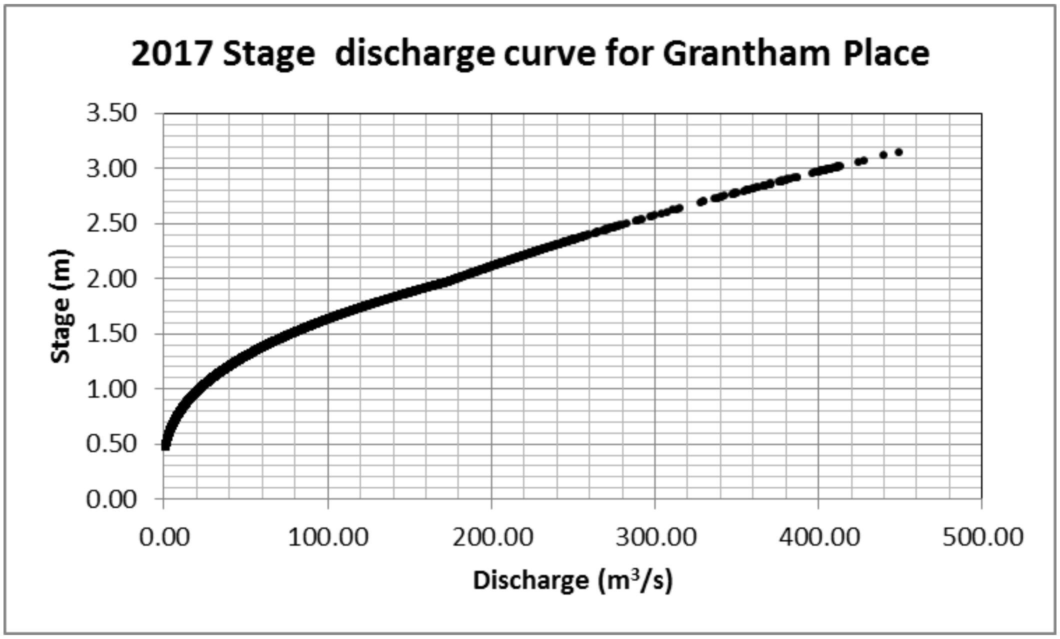


Figure B-3. **2017 Stage discharge curve for hydro station at Grantham Place Bridge in the Seymour River, North Vancouver B.C. Data retrieved from N.H.C Web Portal v2017. 2.85.**

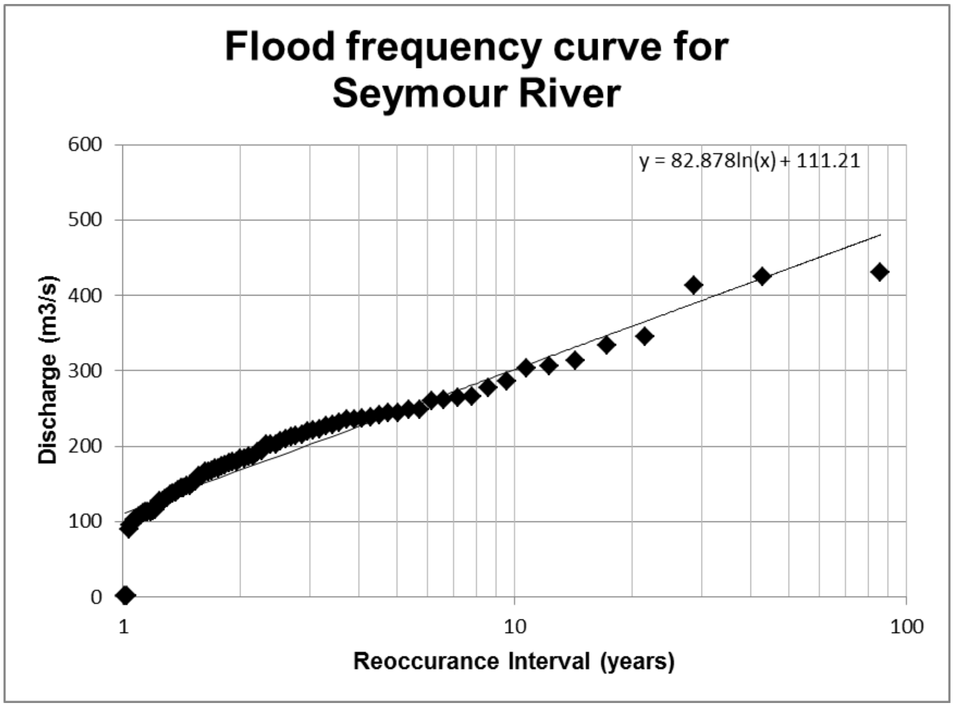


Figure B-4. The flood frquency curve for the Seymour River, North Vancouver B.C. Historical data (1929-2013) retrieved from Government of Canada hydrostation 03GA030 (2018).

Appendix C- Budget

SITE 1

Materials

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Spawning gravel	Screened/washed	525	m3	45	23625	0
Trees and plants	Revegetate riparian and access route	1	lump sum	2000	2000	2000
Safety fencing	Closure of trail and access for public, (4x100' orange)	2	each	41	82	82
Fence posts	Hold fencing up	4	each	13	52	52
Signage (during construction)	Safety and inform trail closure (30x20"plastic)	2	each	30	60	60
Signage (post-project)	Inform community and prevention of vandalism, (30x20" wooden)	2	each	200	400	400
Silt fence	To prevent fines from going downstream and increasing turbity (4' x 100' roll)	4	each	50	200	200

Equipment

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Walking mobile excavator	Spur construction and spread gravel	20	hours	225	4500	4500
Hydraulic excavator travel	Time and expenses to get equipment to site	2	each way	750	1500	1500
Hydraulic oil conversion	Conversion of environmentally friendly lubricant (EFL)	2	lump sum	1000	2000	2000
Highway truck	Deliver gravel to staging area	5	hours	150	750	750
Tool rentals	Shovels, rakes, radios, etc	1	lump sum	1000	1000	1000

Labour

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Project Supervisor	As built survey, safety	2	days	500	1000	1000
Engineer	Specific design details and drawings	2	days	900	1800	1800
Registered Professional Biologist	Ensure best work window, species identification and salvage, monitoring	2	days	700	1400	1400
Planting crew	Planting of distrubed riparian vegetation and access routes (2-3 people)	1	days	500	500	500
Security	Ensure public does not enter sites during contruction, reroute trail users (2 people)	20	hours	30	600	600
Travel expenses	Per diem (vehicles, accomodation, food) x ~7-8 people	5	days	700	3500	3500

	Total cost ($)	
	Buy gravel	Reuse gravel
Subtotal 1:	44,969.00	21,344.00
Contingency 15%:	6,745.35	3,201.60
Subtotal 2:	51,714.35	24,545.60
PST/GST tax 12%:	6,205.72	2,945.47
Total:	57,920.07	27,491.07

Note: Gravel being reused will need to sieved and an approximate cost is not provided in this budget

SITE 2

Materials

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Spawning gravel	Screened/washed	450	m3	45	20250	0
Trees and plants	Revegetate riparian and access route	1	lump sum	1000	1000	1000
Safety fencing	Closure of trail and access for public, (4x100' orange)	2	each	41	82	82
Fence posts	Hold fencing up	4	each	13	52	52
Signage (during construction)	Safety and inform trail closure (30x20"plastic)	2	each	30	60	60
Signage (post-project)	Inform community and prevention of vandalism, (30x20" wooden)	2	each	200	400	400
Silt fence	To prevent fines from going downstream and increasing turbity (4' x 100' roll)	4	each	50	200	200

Equipment

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Walking mobile excavator	Spur construction and spread gravel	20	hours	225	4500	4500
Hydraulic excavator travel	Time and expenses to get equipment to site	2	each way	750	1500	1500
Hydraulic oil conversion	Conversion of environmentally friendly lubricant (EFL)	2	lump sum	1000	2000	2000
Highway truck	Deliver gravel to staging area	5	hours	150	750	750
Tool rentals	Shovels, rakes, radios, etc	1	lump sum	1000	1000	1000

Labour

					Total cost ($)	
Item	Description	Quantity	Units	Unit Cost ($)	Buy gravel	Reuse gravel
Project Supervisor	As built survey, safety	2	days	500	1000	1000
Engineer	Specific design details and drawings	2	days	900	1800	1800
Registered Professional Biologist	Ensure best work window, species identification and salvage, monitoring	2	days	700	1400	1400
Planting crew	Planting of distrubed riparian vegetation and access routes (2-3 people)	1	days	500	500	500
Security	Ensure public does not enter sites during contruction, reroute trail users (2 people)	20	hours	30	600	600
Travel expenses	Per diem (vehicles, accomodation, food) x ~7-8 people	5	days	700	3500	3500

	Total cost ($)	
	Buy gravel	Reuse gravel
Subtotal:	40,594.00	20,344.00
Contingency 15%:	6,089.10	3,051.60
Subtotal 2:	46,683.10	23,395.60
PST/GST tax 12%:	5,601.97	2,807.47
Total:	52,285.07	26,203.07

Component	Reference
General, wages, etc.	Northwest Hydraulic Consultants [N.H.C.]. 2008. Campbell River Chinook Spawning Gravel Platform Design. Draft Report. Nanaimo, B.C. No. 07.CBR.01
Gravel price	Norgate Sand and Gravel 2018. , Pers. Comm. 2018
Signs	Signs.com. 2018. Custom rigid signs.-: https://www.signs.com/rigid-plastic/ (accessed 10 February 2018)
Security	Thumbtack. 2018. Average cost for a Security Guard ranges from $20 - $30 /hr- https://www.thumbtack.com/p/security-guards-cost (accessed 10 February 2018).
Silt fence	Lowes. 2018. -https://www.lowes.com/pd/2-x-100-Silt-Fence-Roll/1112447 (accessed 10 February 2018)
Safety fence	Uline.ca. 2018. Safety Fence - Standard, 4 x 100', Orange. -https://www.uline.ca/Product/Detail/S-14713O/Traffic-Safety/Safety-Fence-Standard-4-x-100-Orange?pricode=YF365&gadtype=pla&id=S-14713O&gclid=Cj0KCQjw-uzVBRDkARIsALkZAdlBz4bIvYQ19Rim6GIbBGJGC0PLZQcN0dNvapWLqkOTSkPjGOEIp8caAopMEALw_wcB&gclsrc=aw.ds (accessed 10 February 2018).
Excavator transport	Dig It Contracting. 2018. Dig It Civil-Plant and Equipment Prices 2018. -http://www.digitcontracting.com.au/library/document/dig-it-plant-hire-rates.pdf (accessed 10 February 2018)
Gravel transport	Lehigh Materials. 2018. Pers. Comm. 2018 Sharecoast Rentals and Sales. 2018. Hourly Trucking Rentals. -http://sharecost.ca/truck-driver-rentals.html (accessed 10 February 2018)