Restoration of the upper Salmon River watershed: projected effects of diversion removal on salmonid abundance

by

Shane Byrne

Bachelor of Science, Simon Fraser University, 2015

Project Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

in the
Ecological Restoration Program

Faculty of Environment (SFU)
and
School of Construction and the Environment (BCIT)

SIMON FRASER UNIVERSITY
BRITISH COLUMBIA INSTITUTE OF TECHNOLOGY
2017

Approval

Name:	**Shane Byrne**
Degree:	**Master of Science**
Title:	**Restoration of the upper Salmon River watershed: projected effects of diversion removal on salmonid abundance**
Examining Committee:	**Chair: Dr. Leah Bendall** Faculty, SFU

Dr. Ken Ashley
Senior Supervisor
Faculty, BCIT

Dr. Scott Harrison
Internal Examiner
Faculty, BCIT

Date Defended/Approved: April 24, 2017

Abstract

The Salmon River, located within the Laich-kwil-tach First Nations' traditional territory on Vancouver Island, supports a diverse community of anadromous and resident salmonids despite having cumulative effects from historical resource development (Burt 2010a). Currently, BC Hydro's diversion dam and transfer canal on the Salmon River provides water for hydroelectric power production in Campbell River, but restricts the upstream and downstream movement of native salmonids (Anderson 2009, BC Hydro 2012). This report addresses removing the Salmon River diversion and providing coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) unrestricted access into the upper Salmon River watershed. This restoration project will mitigate projected effects of climate change on freshwater life stages of the Salmon River salmonids by addressing increasing stream temperatures and seasonal low flows. Completing this restoration project is the first step in recovering the salmonid productivity of the upper Salmon River.

Keywords: Salmon River; coho salmon; steelhead trout; ecological restoration; dam removal; salmonid productivity

Acknowledgements

I would like to extend a thank you to all the faculty members at SFU and BCIT for their constant support throughout this degree. I would like to acknowledge my supervisor, Dr. Ken Ashley and Dave Harper for their guidance and expertise during my applied research project. I would like to thank Giti Abouhamzeh for her endless support during the program. Furthermore, I would like to thank Dr. Ahmed Gelchu, Shannon Anderson, Mel Sheng, Mike McCullough, Kevin Pellett, Ian Murphy, Dr. Jonathan Abell, and Dave Burt for their consultation on the Salmon River ecosystem. Finally, I would like to acknowledge the work completed by Mike Gage on this project over many years and his efforts to protect and restore conditions on the Salmon River for the native salmonid populations.

I would like to thank Eric Balke, Sonya Oetterich, and Blair Byrne for their support during the writing process. To the inaugural ecological restoration cohort of 2017, I am proud to have undertaken this journey with everyone. Finally, I would like to thank my parents, Tony and Donna Byrne for their unwavering support throughout my university education. Achieving my academic and career goals would not have been possible without your guidance, support, and encouragement.

Table of Contents

List of Tables

List of Figures

List of Acronyms

BC	British Columbia
BCCF	British Columbia Conservation Foundation
CPSF	Critical period stream flow
DFO	Fisheries and Oceans Canada
FHAP	Fish habitat assessment procedures
FPU	Fry/100 m^2
LWD	Large woody debris
MAD	Mean annual discharge
MDN	Marine derived nutrients
MOE	Ministry of Environment
PNW	Pacific Northwest
SRD	Salmon River diversion
WSC	Water Survey of Canada
WUP	Campbell River Water Use Plan

Executive Summary

The Salmon River, located within the Laich-kwil-tach First Nations' traditional territory, is the fourth largest watershed on Vancouver Island. The river supports a diverse community of anadromous and resident salmonids despite having cumulative effects from historical resource development (Burt 2010a). First Nations and local communities support the recovery of the Salmon River salmonid populations because they are ecologically, socially, and culturally important (Watkinson 2001, Haggan et al. 2006, Heal and Schlenker 2008).

In 1958, BC Hydro constructed a diversion dam and transfer canal on the Salmon River that provides water for hydroelectric power production in Campbell River (BC Hydro 2012). Unfortunately, the infrastructure restricts the upstream and downstream movement of salmonids (Anderson 2009). BC Hydro has committed to removing the diversion and restoring the river because of a business assessment of the infrastructure and the community consultation on fish passage. This provided the opportunity to produce a restoration plan for removing the Salmon River diversion and improving fish passage into the upper Salmon River watershed.

This restoration plan establishes pre-restoration conditions for flows, stream morphology, and salmonid abundances from historical data. This information provides measurable targets for restoration goals. The main deliverables include: 1) estimates of abundance increases for coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*O. mykiss*) from the upper Salmon River watershed; 2) deigns for reconstructing the river channel post-dam removal, and 3) post-restoration monitoring protocols to evaluate if restoration goals have been achieved. Upstream of the Salmon River diversion is 26 km of mainstem spawning and rearing habitat capable of producing a conservative 4,706 adult coho salmon and 1,670 adult steelhead trout. Future restoration recommendations include increasing stream heterogeneity, continuing stream enrichment, and increasing riparian bank stabilization (Polster 2002, Pellett 2011, Roni et al. 2015). Each of these treatments can further improve salmonids productivity.

Restoration of Pacific Northwest watersheds must incorporate treatments that will mitigate the projected effects of climate change and increase salmonid resilience. Removing the Salmon River diversion will improve instream conditions for salmonids by addressing increasing stream temperatures and seasonal low flows. The removal also allows juvenile salmonids the opportunity to migrate upstream to cooler waters (Anderson 2009). Completing this restoration project is the first step in recovering the salmonid productivity of the upper Salmon River.

1.0 Introduction

The Salmon River watershed located on the east coast of Vancouver Island has supported Pacific salmonids through extensive resource development (Burt 2010a). Forestry, road construction, and hydro development have altered the Salmon River's physical, chemical, and ecological functions undermining the Salmon River's salmonid productivity (Hauer et al. 2016). These historical disturbances require an extensive list of salmonid specific restoration efforts throughout the watershed. However, the removal of BC Hydro's Salmon River diversion (SRD) to allow salmonids unrestricted access to historical headwater spawning and rearing habitats is the first priority. If the SRD is not removed, other restoration activities upstream of the diversion will have a limited effect.

The SRD and water transfer canal was completed in 1958 to divert water from the Salmon River into the Campbell River watershed for power generation at BC Hydro's Ladore and John Hart facilities (Anderson 2009). Operation of the SRD: 1) alters hydrology downstream of the diversion, 2) interrupts downstream transport of sediment and large woody debris (LWD), and 3) obstructs the upstream and downstream migration of adult and juvenile salmonids. These negative direct and indirect effects on the Salmon River salmonids have developed over the 60-year lifespan of the SRD, but the removal of the diversion can eliminate all three stressors. BC Hydro committed to removing the diversion and restoring salmonid access to the upper watershed on June 26, 2016. The purpose of this report is to provide salmonid abundance estimates for the upper watershed (i.e., reaches SR5, USR 1 – 4, and GC1 – 3) and recommendations for channel design to re-establishing unrestricted salmonid migration. This report builds off previous and ongoing work conducted on the Salmon River to forecast the changes in salmonid distribution and abundances throughout the upper watershed following dam removal.

1.1. The Effects of Dams on Watershed Ecosystems

River impoundments are a major source of watershed fragmentation across the Pacific Northwest (PNW). Human made obstructions in rivers interrupt physical and biological processes that maintain a watershed's ecological functions (Hart et al. 2002, Hauer et al. 2016). Dam construction influences the quantity and quality of spawning and rearing habitat available for salmonids upstream and downstream of the barrier (Slaney and Zaldokas 1997). Dams create deficient reaches below structures by regulating flows and impounding sediments, LWD, and nutrients (Stockner and Ashley 2003, Rosenau and Angelo 2009). For example, the Columbia River watershed has the largest number of dams in the PNW which have caused fragmentation and degradation across the watershed (Williams 2008).

Watershed fragmentation from dams negatively influence the upstream and downstream movement of salmonids. Older dams often completely block fish access to spawning and rearing habitat previously available to anadromous salmonid populations. Furthermore, salmonids trapped behind the dams are forced to shift to potamodromous life histories to survive (Winter and Crain 2008). This loss of spawning and rearing habitat decreases a stream's salmonid carrying capacity and lowers anadromous and resident salmonid productivity (Pess et al. 2008, Rosenau and Angelo 2009). Decreases in salmonid productivity have larger implications for the ecological integrity of PNW watersheds because salmonids are keystone species (Watkinson 2001). Any reduction in salmonid productivity in freshwater environments reduces the productivity of the stream and surrounding riparian forest (Johnston and Slaney 1996, Douglas 2001, Watkinson 2001, Hauer et al. 2016). Therefore, the negative effects of dams extend beyond the direct zone of influence upstream and downstream of the infrastructure.

1.2. Dam Removal in Watershed Restoration

Dam removal is becoming a more common watershed restoration technique as aging infrastructure degrades and energy technology improves. Dam removal provides the opportunity where defensible, to improve conditions for salmonid communities over large areas (Hart et al. 2002, Winter and Crain 2008, Magilligan et al. 2016). One of the major challenges with dam removal is addressing the uncertainty of the physical, chemical, and biological responses to dam removal (Hart et al. 2002). The Elwha River, located on Washington State's Olympic Peninsula, was the location of the largest dam removal in the United States to date. This dam blocked salmonid access to 90% of the watershed for over 90 years (Pess et al. 2008). Pess et al. (2008) predict that permanent self-sustaining populations of certain salmonids that are capable of accessing the available space will occur in one to five generations (i.e., 2 to 20 years). If recolonization is achieved, returning salmonid populations will contribute to the slow recovery of the watershed by supplying marine derived nutrients (MDN) to the upper Elwha River and floodplain (Hauer et al. 2016). Although the Elwha River is a success story, there are still over 75,000 dams over 2 m in height still operating in the United States and Canada (Graf 1999). Many of the larger dams are unlikely to be decommissioned due to their essential role in power production. However, many smaller dams can be targeted for removal when they become structurally unsound or economical irrelevant. This is the case with the SRD.

1.3. Restoration Rationale

Restoration of British Columbia's (BC) watersheds focuses on increasing the productivity of native salmonids because salmonids support the ecology, socioeconomics, and culture of the west coast of Canada (Watkinson 2001, Haggan et al. 2006, Heal and Schlenker 2008). The SRD affects all three components and through restoration improvements can be achieved in all areas. Together these three components form the framework for planning and implementing this ecological restoration project.

The Salmon River hosts a variety of salmonid species that are key components of the aquatic and terrestrial ecosystems. Salmonids return nutrients and energy from marine ecosystems back to freshwater environments (Watkinson 2001). The seasonal return of salmonids to the Salmon River maintains the aquatic community, cultivates the surrounding forests, and feeds various consumers (Pike et al. 2010, Field and Reynolds 2011). In the upper Salmon River watershed, these ecological benefits of salmonids have been suppressed by the SRD. This restoration project will reconnect salmonids to their historical range and slowly return the benefits of salmonids to the upper watershed.

The Salmon River salmonid populations support local recreational and commercial fisheries. A documented recreational steelhead trout (*Oncorhynchus mykiss*) fishery has been conducted on the Salmon River since 1968 and commercial fisheries for various species are conducted within Johnstone straights, BC (Burt 2010a). Over time, increases in salmonid productivity in the Salmon River will provide increased opportunities for the local communities to harvests the resources.

The removal of the SRD will eliminate a source of water used in BC Hydro's Campbell River hydropower system. This represents an economic loss associated with the project. However, the cost of repairing and upgrading the SRD and canal exceeds the cost to decommission (Z. Cecic, pers. comm. 2017). Therefore, the increased fish passage and reduced cost of decommissioning contributed to BC Hydro's decision to remove the SRD and restore the site (Dr. A. Gelchu, pers. comm. 2016).

The Salmon River is within traditional Laich-kwil-tach territory and continues to serve the local indigenous communities (Figure 1). There are four First Nation bands (i.e., Wei Wai Kum, Wei Wai Kai, K'ómoks, and Tlowitsis) located around the Campbell River and Discovery Islands region that identify the Salmon River as part of their traditional territory. The Laich-kwil-tach people lived in the village of H'Kusam located on the Salmon River estuary until approximately 1916, before migrating south to the Campbell River and Quadra Island areas (LKT 2012). Any restoration that occurs within the Salmon River watershed will have both an economic and cultural influence on these communities (Haggan et al. 2006).

2.0 Salmon River Diversion Restoration Goals

The SRD restoration goals have been developed in collaboration with First Nations, stakeholders, government agencies, and local community members. Consultation with invested groups has identified four primary goals:

Goal 1) To restore a historical flow regime to the Salmon River downstream of BC Hydro's infrastructure through the termination of water diversion into the Campbell River watershed;

Goal 2) To increase the Salmon River's longitudinal connectivity through removal of BC Hydro's diversion infrastructure and by reconstructing river morphology;

Goal 3) To increase the Salmon River's coho salmon and steelhead trout productivity; and

Goal 4) To increase the ecological resilience of the Salmon River salmonid populations to disturbance to support their long-term survival.

BC Hydro's main goal is to achieve unrestricted fish migration through the restoration reach (Dr. A. Gelchu pers. comm. Jan 19, 2017). Their goal aligns with Goal 2, which promotes the free movement of water, nutrients, energy, and biota longitudinally through the watershed. These goals aim to improve abiotic conditions on the Salmon River at the watershed scale to support salmonid populations.

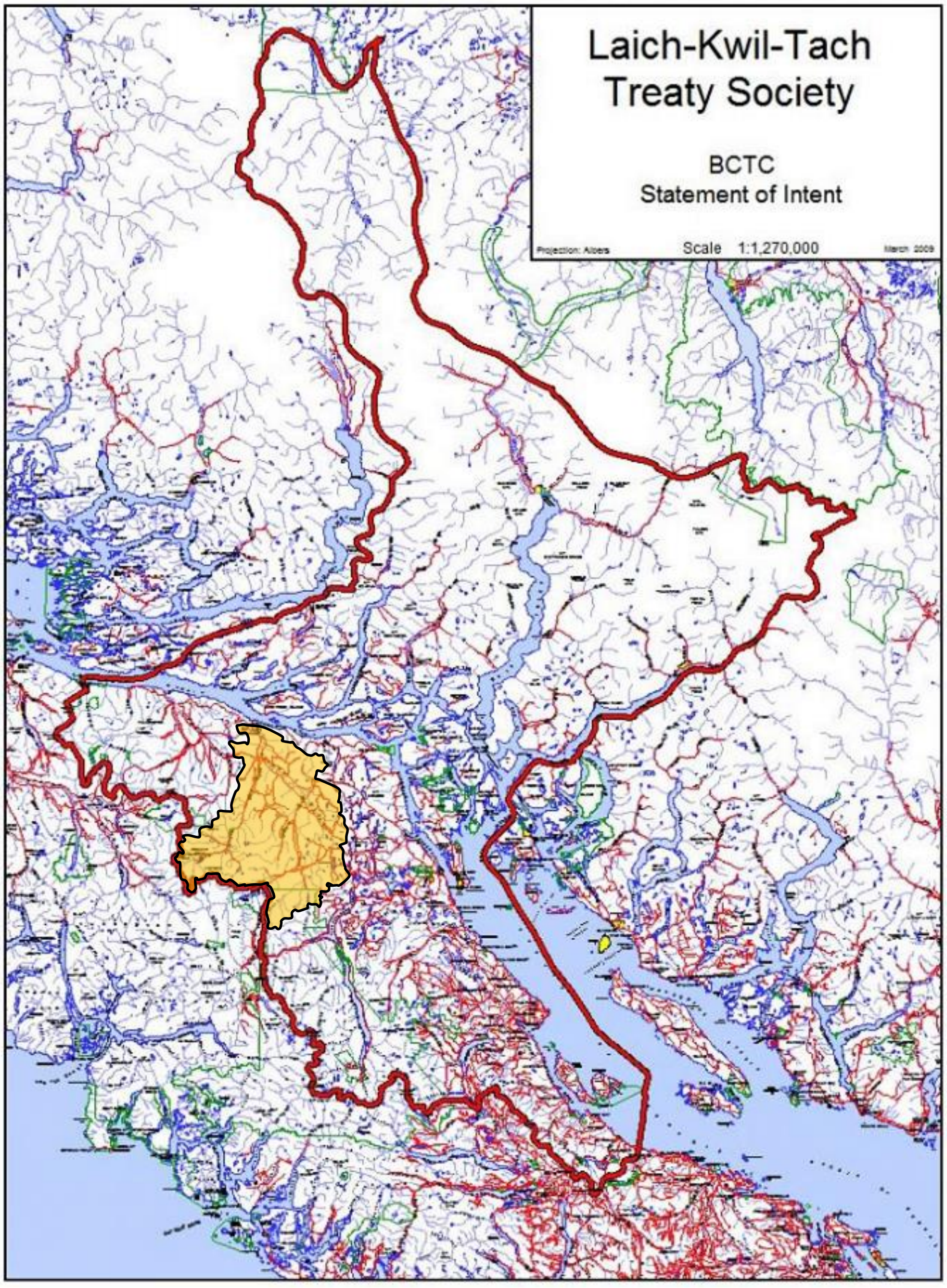

Figure 1. Laich-kwil-tach traditional territory summited to the BC Treaty Commission. The orange polygon contains the Salmon River Watershed (LKT 2012).

3.0 Salmon River Diversion Public Engagement

The Laich-kwil-tach First Nations support improving fish migration and increasing salmonid productivity in the upper watershed by decommissioning the SRD (J. Meldrum, pers. comm. December 21, 2017). Laich-kwil-tach Environmental Assessment Ltd., in partnership with Ecofish Research Ltd., is currently involved in salmonid monitoring on the Salmon River for BC Hydro's Fish and Wildlife Compensation Program. This First Nations environmental consulting company will be incorporated into restoration monitoring to continue ongoing stewardship over the project. First Nations have an extensive history of successful resource management and environmental stewardship of salmonid populations and their freshwater habitats along the west coast (Haggan et al. 2006). First Nations communities are valuable partners in achieving restoration goals by incorporating their traditional ecological knowledge into the project.

Planning and implementing the SRD restoration requires input from First Nations, multiple government agencies, stakeholders, and community groups to ensure the project addresses the goals of invested parties (Table 1). BC Hydro has been engaging with the Salmon River Diversion Fish Passage Consultative Committee since 2008 to address salmonid passage concerns (Burt 2010a). Though this committee was previously concerned with operation procedures and structural improvements to the SRD, the committee is now providing recommendations for the dam removal and channel restoration. The majority of the previous monitoring conducted on the Salmon River was undertaken by Fisheries and Oceans Canada (DFO) and British Columbia Conservation Foundation (BCCF). In recent years monitoring has been split between Ecofish Research Ltd. and Laich-kwil-tach Environmental Assessment Ltd.

Practitioners of ecological restoration aim to engage the public to promote a better understanding of the ecological, socioeconomic, and cultural implications of restoration in their community. Promoting stewardship over restoration projects with the local community will contribute to long-term monitoring and maintenance of the site. This can be accomplished by organizing fieldtrips with local schools, fish and game clubs, and environmental groups to learn about the removal of the SRD and the recovery of the local salmonid populations. Restoration work can also benefit from local volunteers contributing to riparian treatments at the SRD and throughout the upper watershed.

Table 1. List of First Nations, agencies, stakeholders, and groups involved in the SRD restoration project.

Agency or Stakeholder	Project Involvement	Contacts
Infrastructure owner		
BC Hydro	Main project proponent	Zeljko Cecic Dr. Ahmed Gelchu.
Laich-kwil-tach First Nations		
Wei Wai Kai (Cape Mudge)	Indigenous community	Mercedes Brown
Wei Wai Kum (Campbell River)	Indigenous community	Jason Price Tony Roberts Jr.
K'ómoks (Comox)	Indigenous community	
Tlowitsis (Campbell River)	Indigenous community	
Government Agencies		
Ministry of Forest, Lands, and Natural Resource Operations	Provincial regulation	Mike McCullough
Ministry of Environment	Provincial regulation	
Fisheries and Oceans Canada	Federal regulation	Shannon Anderson Mel Shang
Non-governmental Organizations		
British Columbia Conservation Foundation	NGO	Kevin Pellett Craig Wightman
Campbell River Salmon Foundation	NGO	Mike Gage
Steelhead Society of BC	NGO	
Sayward Fish and Game Club	Local community group	
Private Proponents		
Ecofish Research Ltd.	Environmental consulting	Ian Murphy Dr. Jonathan Abell
D. Burt and Associates.	Environmental consulting	David Burt
Klohn Crippen Berger	Engineering firm	Andrew Muir

4.0 The Salmon River Watershed

The Salmon River watershed is located in the north-eastern region of Vancouver Island. The drainage area is approximately 1,300 km² making it the fourth largest watershed on Vancouver Island (Figure 2) (Anderson 2009). The headwaters of the Salmon River begin in Strathcona Park where the river flows northward for 82.2 km and terminates at Kelsey Bay, Johnstone Straits (Burt 2010a). Three main tributaries (i.e., Grilse Creek, Memekay River, and White River) join the Salmon River contributing to its mean annual discharge (MAD) of 63.3 m^3/s (Burt 2010a). The Salmon River and its tributaries follow a concave river profile and reach elevations of 1,200 – 1,300 m (Silvestri and Gaboury 2008). The mainstem of the Salmon River is segregated into 10 reaches. This restoration project is concerned with the upper watershed which includes SR5, USR 1 – 4, and GC1 – 3 (Figure 3). Reaches upstream of these sections are separated by natural barriers and are not considered anadromous salmonid habitat.

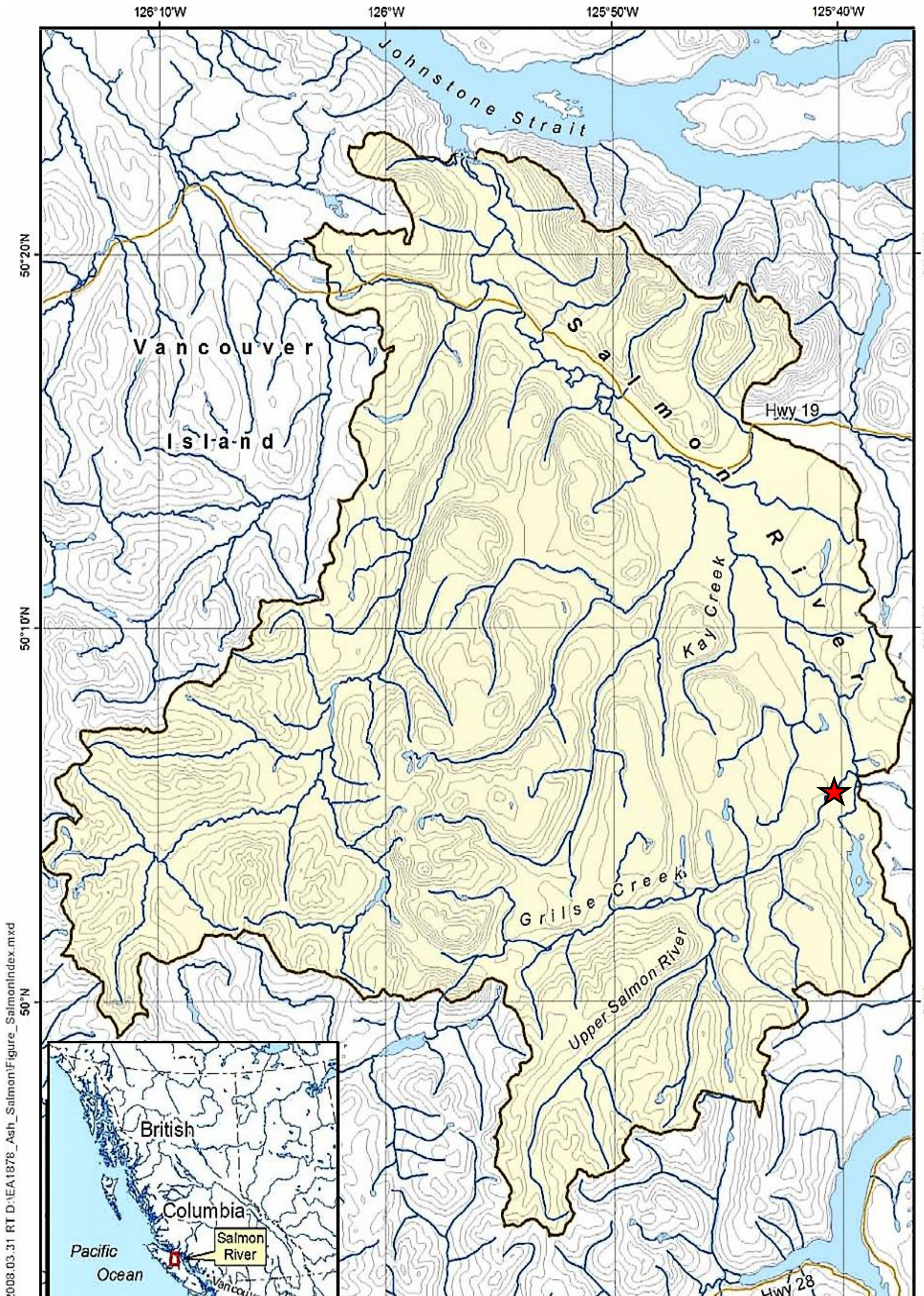

Figure 2. Map of the Salmon River watershed (i.e., yellow) located on north-eastern Vancouver Island, BC. The Salmon River Diversion is located at the red star (Silvestri and Gaboury 2008).

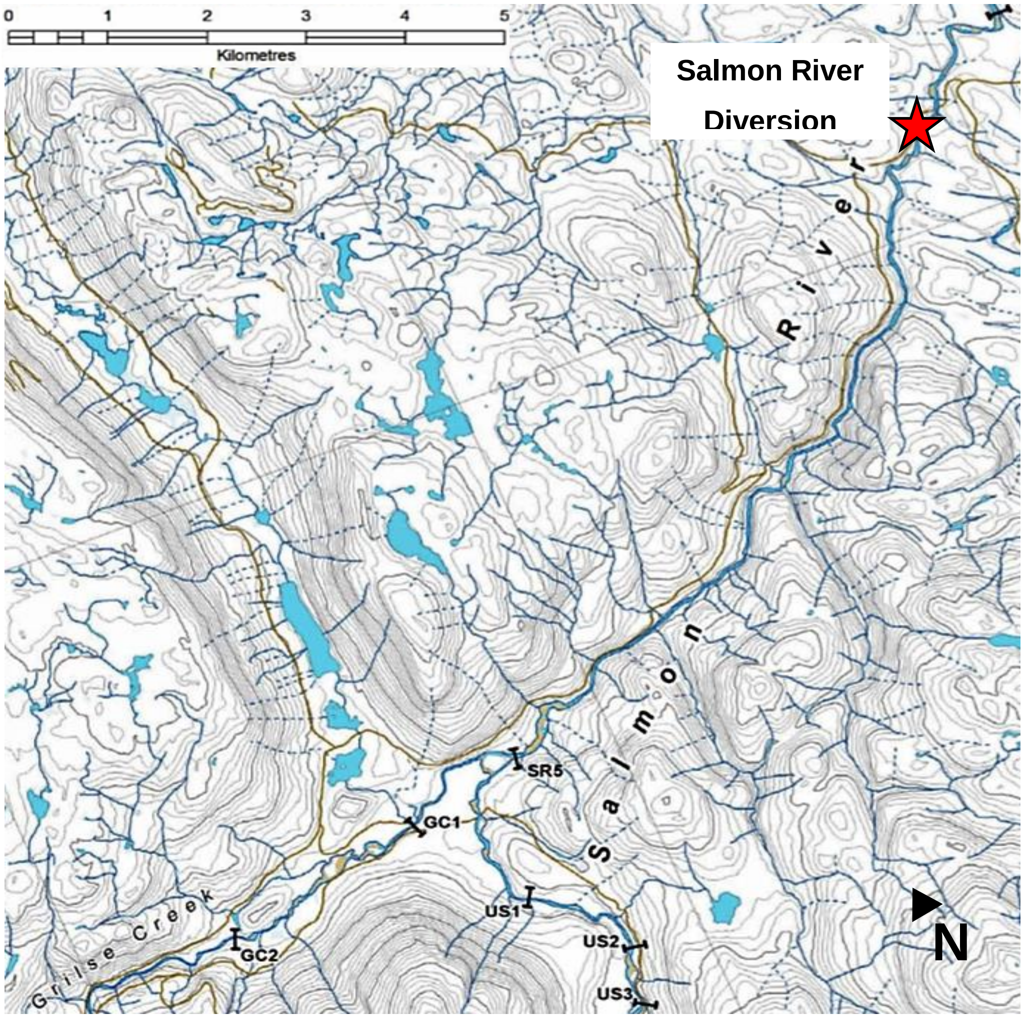

Figure 3. **The upper Salmon River watershed showing reach segmentation and the location of the Salmon River diversion (red star) (50.05.28.02 N 125.40.29.95 W) (Silvestri and Gaboury 2008).**

4.1. Salmon River Diversion

The SRD is located on the mainstem 54.2 km upstream from the river mouth (Burt 2010a). The location is 224 m above sea level resulting in an upstream catchment area of approximately 268 km^2 (Anderson 2009, BC Hydro 2014). Upstream of the SRD there is 26.2 km of mainstem river and several additional tributaries, lakes, and wetlands accessible to salmonids (Burt 2010a). The SRD is comprised of three main components: 1) the diversion dam, 2) the water diversion control tower, and 3) the diversion canal (Figures 4 and 5). The dam is approximately 70 m long and has an elevation change between the dam crest and apron of 5 m (BC Hydro 2012). The dam diverts water to the right bank where flow is partitioned. A mandatory flow of 4.0 m^3/s re-enters the Salmon River mainstem through an undersluice gate, while surplus flow is diverted down a 7.8 km concrete canal completing the interbasin transfer of water from the Salmon River to the Campbell River system (Burt 2010b). The canal was constructed to transport a maximum capacity of 42.5 m^3/s for a potential total withdrawal of 493.4 million m^3 of water annually in compliance with BC Hydro's water license (Anderson 2009, BC Hydro 2012). During times of high flows, excess water can spill over the diversion dam and trimming weir.

Figure 4. **Aerial photography of BC Hydro's Salmon River diversion. Photos taken by Allister Mclean April 24, 2007.**

The original design of the SRD was not conducive to fish passage. There have been attempts to improve fish passage on the SRD through upgrades and changes in operation. In 1986, BC Hydro and the BC Ministry of Environment (MOE) installed an experimental fish screen 500 m down the diversion canal in an attempt to prevent interbasin transfer of salmonid juveniles (Anderson 2009). However, the screen lead to complications with juvenile scale loss and operational performance issues (Anderson 2009). In 1992, BC Hydro and DFO retrofitted a fish ladder to the side of the canal to facilitate the movement of spawning adult salmonids into the upper watershed. Both of these alterations to the original SRD have proven ineffective because of poor structural and hydrologic design (Lyderson et al. 2008, Anderson 2009, McCubbing and Burroughs 2009, Pellett 2014a).

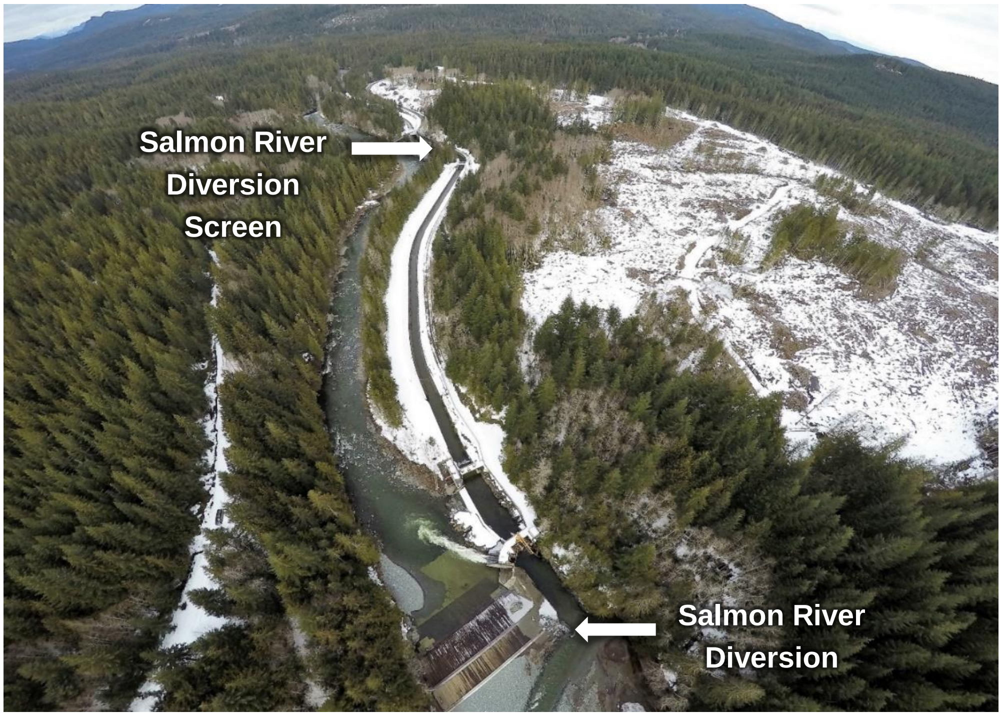

Figure 5. Aerial photography of the first 500 m of Salmon River diversion canal. Photo taken by D. Harper on February 23, 2017.

5.0 Historical and Current Watershed Conditions

Resource development has negatively influenced the physical and biological conditions of the Salmon River watershed. Data were compiled to summarize historical and current river conditions for the Salmon River salmonids during the life span of the SRD.

5.1. Forestry

Historical forestry practices in the Salmon River watershed negatively influences salmonid habitat and productivity by altering watershed drainage patterns, increasing slope instability, increasing river siltation, and decreasing stream morphological complexity (Slaney and Zaldokas 1997). Logging began in the lower Salmon River watershed in the 1890's and expanded into the upper watershed by the 1960's (Burt 2010a). Historical logging regulations resulted in clear-cutting riparian zones on the Salmon River and its tributaries decreasing the recruitment of LWD into the stream channels (Figure 6). A reduction of LWD recruitment into PNW streams decreases habitat complexity and reduces the abundance and quality of salmonid spawning and rearing habitat (Johnston and Slaney 1996, Slaney and Zaldokas 1997, Roni et al. 2015). The legacy effects of forestry on stream morphology have been documented extensively on the Salmon River (Ptolemy et al. 1977, Craig et al. 1998, Wong and Komori 1999, Silvestri and Gaboury 2008). The cumulative effects of historical logging practices will influence the watershed for approximately 100 – 200 years while riparian forests regenerate (Slaney and Zaldokas 1997). The majority of the watershed is now comprised of second growth stands at various regrowth stages (Burt 2010a). Over time regrowth of the riparian areas along the Salmon River will begin to contribute LWD to improve stream morphology for fish.

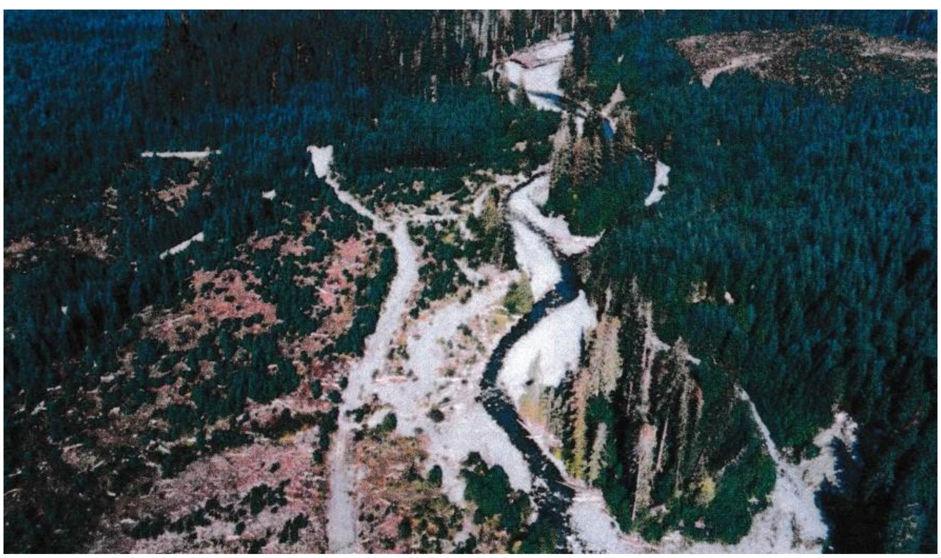

Figure 6. Aerial photography showing riparian clear-cut logging on the upper Salmon River (Wong and Komori 1999).

5.2. Hydrology

There is variability in the hydrology of the Salmon River due to seasonal precipitation trends (Hill 2011). The Salmon River is a snowmelt dominated system. Historical discharge data is available from the Water Survey of Canada (WSC) for three different locations along the mainstem of the Salmon River (Figure 7). In the context of the restoration site, the Salmon River shows fluctuating stream flows from September to May due to heavy rainfall and rain-on-snow events (Figure 8). Stream flows from June to August are dependent on the winter snowpack (Figure 8) (Hill 2011).

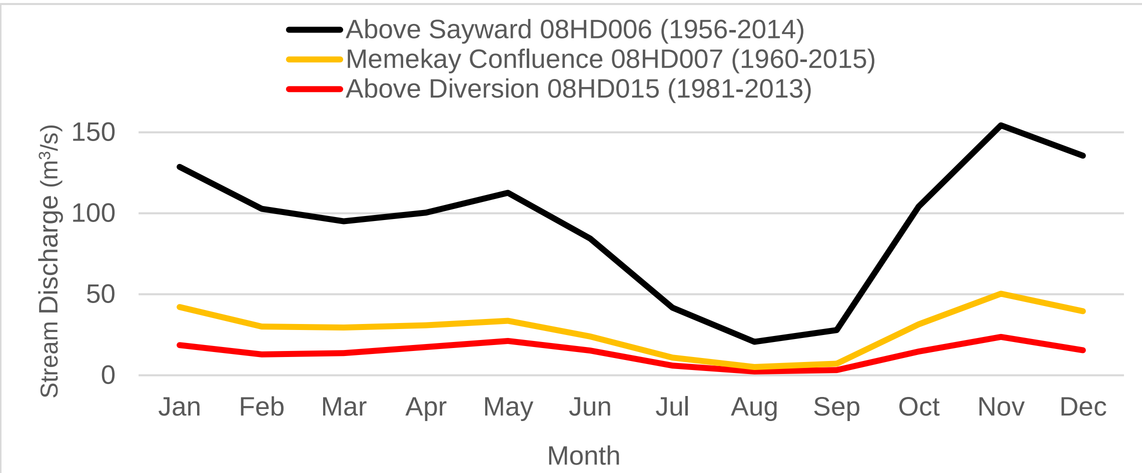

Figure 7. Mean daily stream discharge at three hydrology stations (i.e., 08HD015, 08HD007, and 08HD006) on the Salmon River (WSC 2016).

BC Hydro has withdrawn water from the Salmon River since 1958 under BC water license #C023239. Water removal is currently regulated by the Campbell River Water Use Plan (WUP) completed in 2012 (BC Hydro 2012). This updated the water use in the Campbell River system from the 1997 regulations. Before the latest update to the WUP, the critical period stream flow (CPSF) for June to August was 10.1 m^3/s at the river mouth, 1.90 m^3/s upstream of the Memekay River confluence, and 1.35 m^3/s upstream of the SRD. These discharges were deemed insufficient for various salmonid life stages and the three CPSF requirements were increased (Burt 2010b, BC Hydro 2011). The Salmon River is now required to receive a minimum flow of 4.0 m^3/s at all times below the SRD when water is available (BC Hydro 2012). The water discharge in the canal is restricted to 43.0 m^3/s from Jan 1 – Mar 31 and reduced to 15.0 m^3/s from Apr 1 – Dec 31 (BC Hydro 2012).

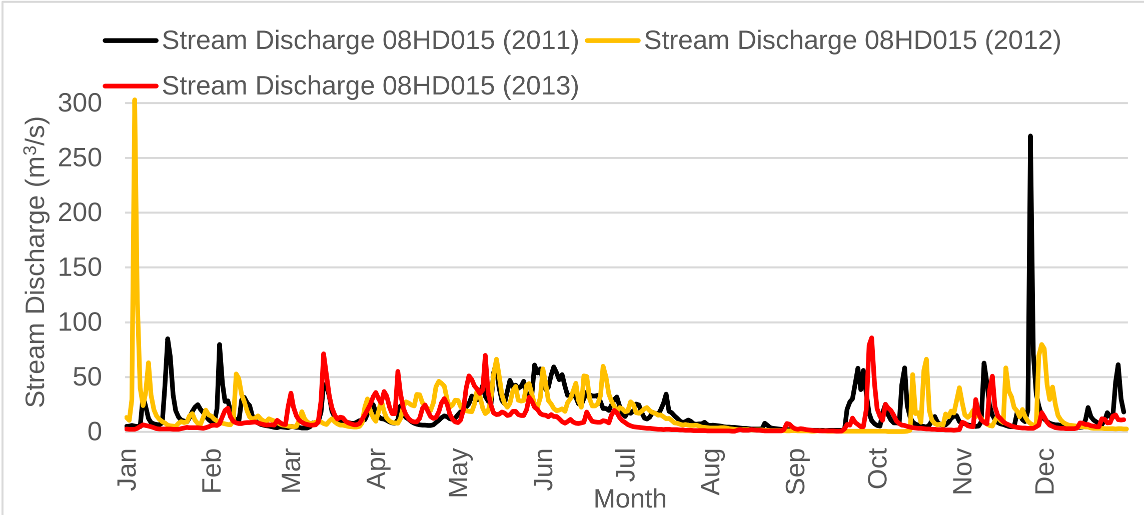

Figure 8. **An example of annual variation in stream discharge at WSC station 08HD015 on the Salmon River. Note the two large storm events reaching 270 m^3/s and 303 m^3/s during November 2011 and January 2012 respectively (WSC 2016).**

5.3. Water Temperature

Water temperature in the upper watershed affects salmonids seasonally during their fresh water life history stages. Water temperature regulates egg development and fry emergence for all salmonid species (Bjornn and Reiser 1991). Juvenile coho salmon prefer water temperatures between 11.8 – 14.6 °C, while steelhead trout target colder waters ranging from 7.3 – 14.6 °C (Beschta et al. 1987, Bjornn and Reiser 1991). Juvenile salmonid growth is controlled by a minimum threshold of 7 °C (Burt 2010a). The Salmon River water temperatures exceed this threshold for an approximate growth season of 175 days (Burt 2010a). Salmonids also experience risks at both end of the temperature ranges observed on the Salmon River. At higher temperatures, thermal induced mortality is becoming a higher risk as global temperatures warm freshwater ecosystems during summer months (Mauger et al. 2015). Salmonids experience thermal-induced mortality at 22.5 – 25.8 °C depending on species and duration of exposure (Beschta et al. 1987). Water temperatures have been collected continuously at the WSC station 08HD015 since 2005 (Figure 9) (WSC 2017). Historically, the reach directly downstream of the diversion has experienced higher temperatures due to water withdrawal (Burt 2010a). At lower temperatures, adult coho salmon and steelhead trout experience difficulties migration upstream to spawn when water temperature drops below 4.4 °C (Anderson 2009). Eliminating water transfer will contribute to lowering water temperatures downstream of the restoration site.

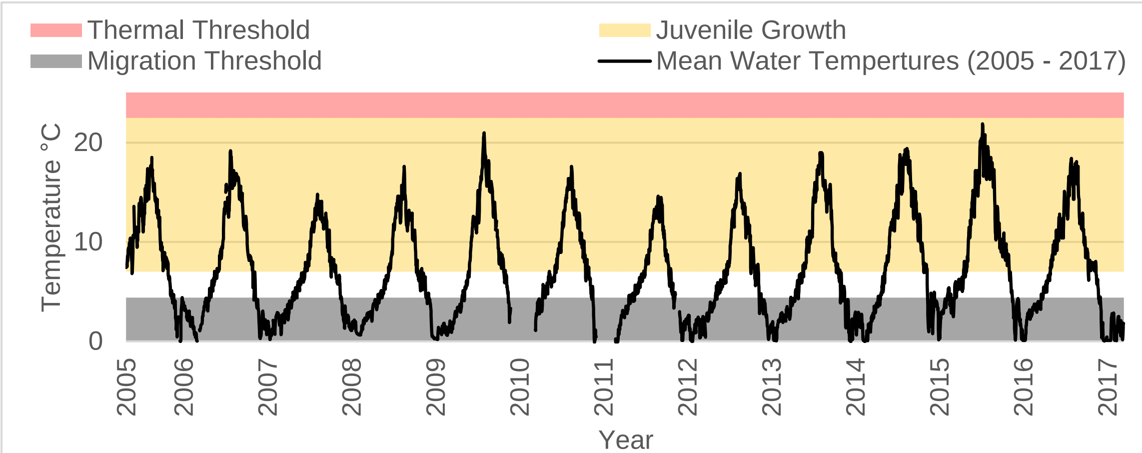

Figure 9. **Preliminary mean daily water temperatures for the WSC station 08HD015 from 2005 – 2017 (WSC 2017). Seasonal thresholds for migration (< 4.4 °C), juvenile growth (> 7.0 °C), and thermal mortality (>22.5 °C) are highlighted. Note the summers of 2009 and 2015 when temperature peaked at 21.0 and 21.9 °C representing high levels of thermal stress on juvenile salmonids.**

5.4. Water Quality

Water quality monitoring has been conducted on the Salmon River since 1989 when a stream enrichment program was implemented to increase the carrying capacity for juvenile salmonids in compensation for the SRD (Manley et al. 2005, Pellett 2011). The stream enrichment program on the Salmon River is one of the longest ongoing stream fertilization projects in BC (Figure 10) (Pellett 2011). Oligotrophic streams have low concentrations of nutrients (i.e., nitrogen and phosphorus) that limits their primary and secondary productivity (Ashley and Stockner 2003). Low abundances of periphyton and aquatic invertebrates lead to decreased food availability for juvenile salmonids. Stream fertilization increases nutrient concentrations resulting in increased productivity and energy transfer to juvenile salmonids (Stockner and Ashley 2003). Phosphorus concentrations are considered the primary limiting nutrient in the Salmon River watershed, though there is some evidence that co-limiting conditions with nitrogen do occur periodically (Pellett 2011). Over the years modifications to loading locations, rates, fertilizer quantities, and fertilizer type have been tested to refine the program (Pellett

2011). Modifications to the Salmon River stream enrichment program may be required if long-term restoration goals of the SRD removal are met.

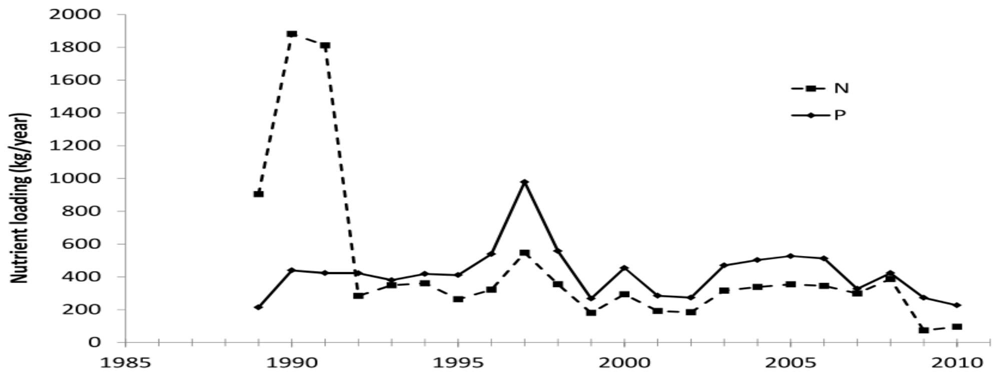

Figure 10. Summary of nitrogen and phosphorus loading on the Salmon River from 1989 – 2010 (Pellett 2011).

5.5. Stream Morphology

The Salmon River has been assessed several times in the past to record river morphology and evaluate fish habitat quality. The targeted upper portion of the Salmon River contains riffle-pool morphology used in spawning and rearing for coho salmon and steelhead trout (Ptolemy et al. 1977, Craig et al. 1998, Wong and Komori 1999, Silvestri and Gaboury 2008, Burt 2010a). Heterogeneity in gradients, channel forms, habitat units, and off channel areas provides preferred rearing spaces for both species (Table 2). During rearing and overwintering, coho fry and parr show a preference for slow moving pools and off channel areas high in LWD and overhanging riparian shade (Groot and L. Margolis (eds.) 1991, Keeley and Slaney 1996). Steelhead fry and parr prefer riffle tail outs with higher water velocities. The upper watershed contains both of these habitat conditions (Silvestri and Gaboury 2008).

Table 2. Habitat use coefficients for specific juvenile salmonid species. A value of -1 indicates total avoidance, 0 indicates equal use in all habitats, and increasing positive values indicate increasing preference. Table sourced from Slaney & Zaldokas (1997) and adapted from Bisson et al. (1982).

Habitat Unit	Coho 0+	Steelhead 0+	Steelhead 1+	Cutthroat 0+	Cutthroat 1+	Cutthroat 2+
Pool	1.46	-0.19	0.58	-0.28	0.16	0.33
Riffles	-0.90	0.60	0.29	-0.40	-0.06	-0.64
Glides	-0.91	0.34	0.86	1.42	-0.77	-0.92

The upper watershed contains a higher percentage of riffles relative to pools and glides (Figure 11) (Silvestri and Gaboury 2008). The average percentage of available pool habitat for rearing salmonids in the upper watershed is 13%. Johnston and Slaney (1996) state that high grade salmonid rearing habitat should contain pool densities greater than 40 % in streams less than 15 m at bankfull widths with gradients of 2 – 5%. The average bankfull width for the Salmon River's upper nine reaches is 30.7 m, so these standards need to be used with caution (Slaney and Zaldokas 1997). However, there was still a shortage of pool habitat along the mainstem as of 2008. Changes in stream morphology from clear-cut logging practices and associated stream bank erosion have likely occurred since this assessment. The SRD is located in the fifth reach of the Salmon River between the Patterson Creek and Grilse Creek confluences (Burt 2010a). The reach is 10.8 km long and has an average gradient of 1% (Northwest Hydraulic Consultants Ltd. 1996).

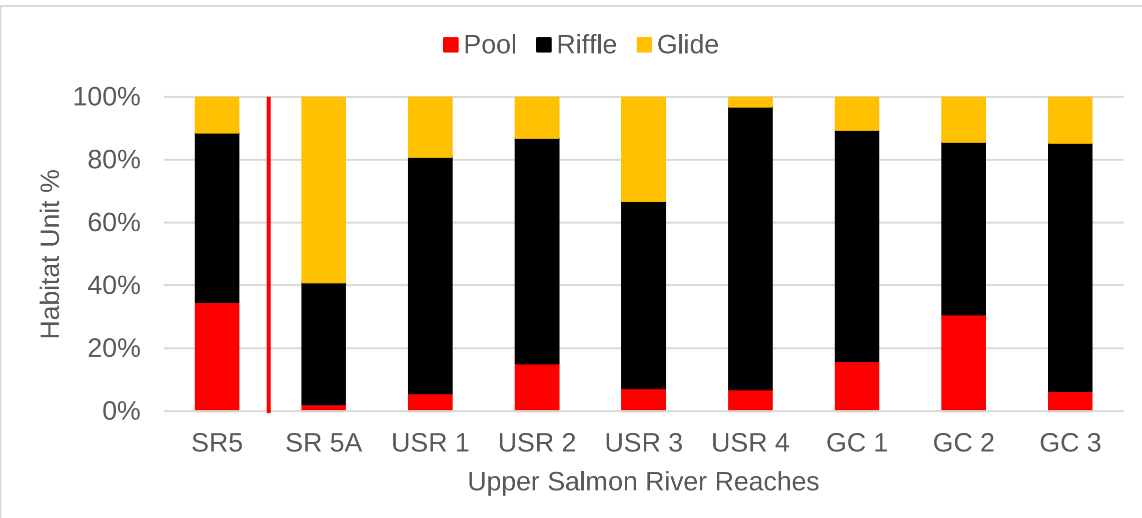

Figure 11. Relative distribution of habitat units within the surveyed lengths of the nine upper Salmon River reaches (Silvestri and Gaboury 2008). The Salmon River diversion splits reach 5.

5.6. Salmon River Salmonids

The Salmon River supports anadromous and resident salmonids including all five Pacific salmon and steelhead trout. All documented species present within the Salmon River are summarized in Table 3. Pink (*O. gorbuscha*) and chum (*O. keta*) salmon spawn within the lower reaches on the Salmon River and will not directly benefit from the

SRD restoration. Sockeye salmon (*O. nerka*) returns for the Salmon River are very low due to limited lake rearing habitat within the watershed (Burt 2010a). However, kokanee salmon (i.e., resident sockeye salmon) have been documented in the upper headwater lakes and the diversion removal could promote changes to an anadromous life history. Chinook salmon (*O. tshawytscha*) populations uses the lower and middle reaches of the Salmon River (Burt 2010a). The Chinook salmon may benefit from the SRD restoration but prefer locations in the lower watershed (Burt 2010a). Coho salmon and steelhead trout have been selected as target species for this restoration plan due to their spawning distribution and current populations trends below federal and provincial targets (Fig 12) (Burt 2010a). The timing and duration of life history stages for both of these salmonids are summarized in Table 4. Microhabitat requirements for both species are summarized in Table 5.

Table 3. Common and scientific names of fish species reported in the Salmon River (Burt 2010a).

Common Name	Scientific Name	Comments
Anadromous Salmonids		
Chinook Salmon	*Oncorhynchus tshawytscha*	
Coho Salmon	*Oncorhynchus kisutch*	Target species
Pink Salmon	*Oncorhynchus gorbuscha*	
Chum Salmon	*Oncorhynchus keta*	
Sockeye Salmon	*Oncorhynchus nerka*	
Steelhead Trout	*Oncorhynchus mykiss*	Target species
Sea-run Cutthroat Trout	*Oncorhynchus clarki*	Anadromous form of O. clarkii
Sea-run Dolly Varden Char	*Salvelinus malma*	Anadromous form of S. malma
Atlantic Salmon	*Salmon sala*	Non-native salmonid
Resident Salmonids		
Rainbow Trout	*Oncorhynchus mykiss*	Resident form of O. mykiss
Cutthroat Trout	*Oncorhynchus clarki*	Resident form of O. clarkii
Kokanee Salmon	*Oncorhynchus nerka*	Resident form of O. nerka
Dolly Varden Char	*Salvelinus malma*	Resident form of S. malma
Non- Salmonids		
Coastrange Sculpin	*Cottus aleuticus*	Resident in fresh and brackish water
Prickly Sculpin	*Cottus asper*	Inferred presence (not confirmed)
Three Spine Stickleback	*Gasterosteus aculeatus*	Resident in fresh, brackish, and marine waters
Pacific Lamprey	*Lampetra tridentata*	Anadromous

Table 4. **The Salmon River life history timing for coho salmon and steelhead trout. Red lines depict duration and orange cells indicate growth season for juveniles. Abbreviations: E = start of emergence, S = start of smolt outmigration, P = peak spawning. Table adapted from Burt (2010a).**

Species	Life Stage	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Coho Salmon	Adult Migration												
	Spawning										P P		
	Incubation												
	Rearing			E E E	E E E								
	Juvenile Migration				S								
Steelhead Trout	Adult Migration												
	Spawning			P P P	P								
	Incubation												
	Rearing												
	Juvenile Migration				S								

Table 5. **Estimates of rearing and spawning microhabitat requirements for coho salmon and steelhead trout expressed as means and ranges (Burner 1951, Briggs 1953, Orcutt et al. 1968, Taylor and Smith 1973, Crone, R.A., Bond 1976, Bovee 1982, van Den Berghe and Gross 1984, Kondolf and Wolman 1993, Keeley and Slaney 1996, Abell et al. 2016).**

Species	Water Depth (m)	Water Velocity (m/s)	Substrate Category	Territory (m^2)
Rearing				
Coho salmon	0.20 (0.10 – 0.40)	0.12 (0.01 – 0.28)	5 Gravel (4 Sand – 8 Bedrock)	0.03 – 0.08
Steelhead trout	0.42 (0.12 – 0.80)	0.17 (0.4 – 0.40)	6.5 Cobble (6 Cobble – 8 Bedrock)	0.05 – 1.0
Spawning			**Grain size (mm)**	**Redd Size(m^2)**
Coho salmon	0.22 (0.18 – 0.30)	0.40 (0.26 – 0.70)	22 (8 – 32)	3.0
Steelhead trout	0.20 (0.18 – 0.30)	0.38 (0.28 – 0.70)	24 (14 – 35)	4.0 (1.0 – 6 .0)

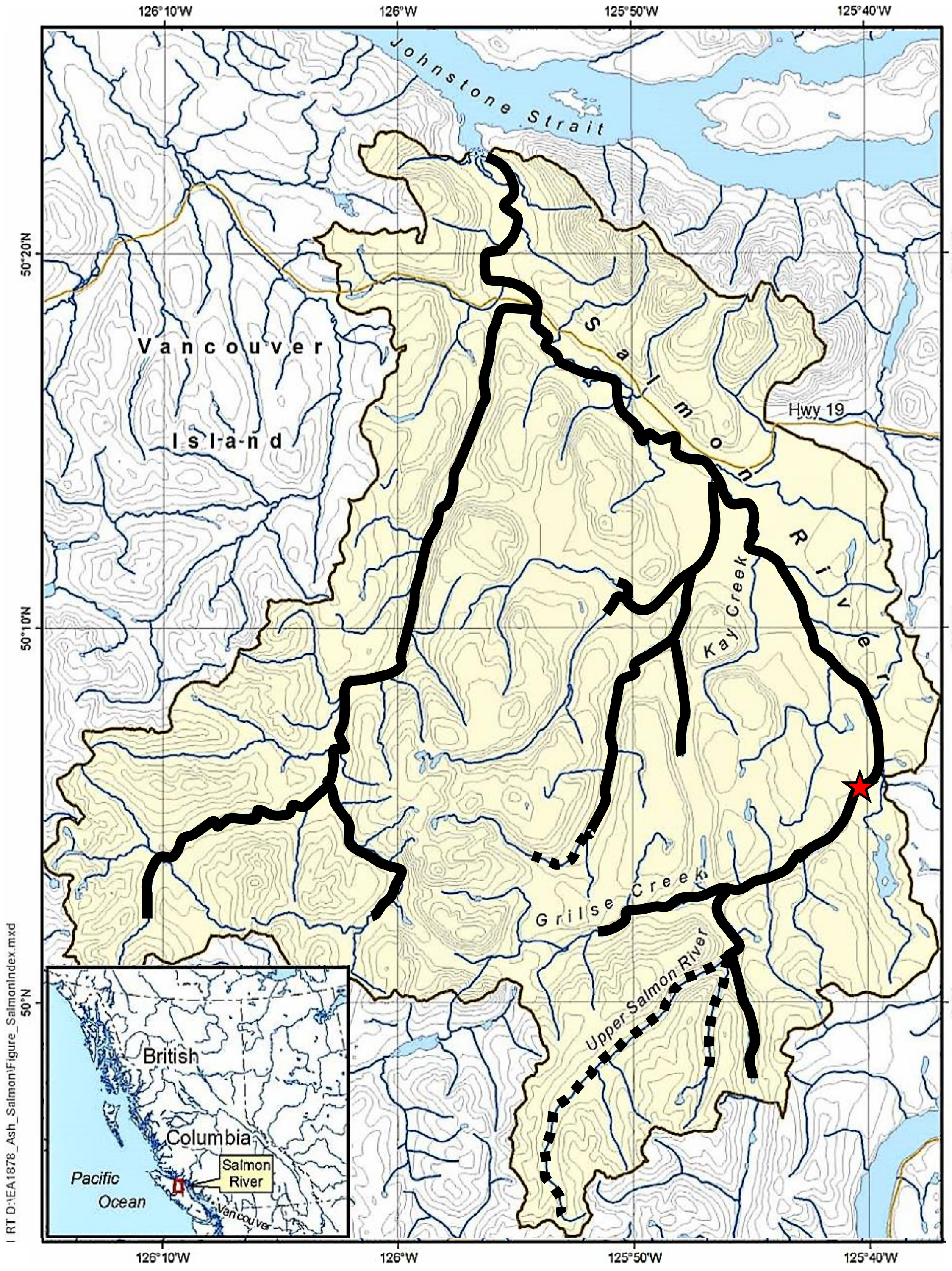

Figure 12. **Distribution of coho salmon and steelhead trout within the Salmon River and main tributaries. Dashed lines indicate unconfirmed distribution (Silvestri and Gaboury 2008, Burt 2010b). The Salmon River diversion is located at the red star.**

Two coho salmon stocks have been identified in the Salmon River watershed. A summer run uses the White River system, followed by a fall run that uses the Salmon River proper (Burt 2010a). Access to reaches upstream of the SRD will provide additional spawning and rearing areas for the fall coho salmon stock. Fall adult coho salmon arrive between September and late November and spawn between October and late December (Groot and L. Margolis (eds.) 1991, Burt 2010a). Eggs hatch between January and February, followed by alevin emerging between March and late April (Burt 2010a).

The DFO monitors adult coho salmon annually for stock assessment and fisheries management. Annual coho salmon escapement is estimated using multiple snorkel counts targeting spawning coho salmon in the lower Salmon River during mid-October. The DFO does not prioritize assessing spawning abundances upstream of the SRD. Aerial counts have been conducted when funding is available to record the distribution of coho salmon throughout the entire watershed. Coho salmon escapement data is available from 1953 – 2014 (Figure 13) (DFO 2016). This data set should be used with caution because there is temporal variation in survey methods and population estimates. A five-year moving average shows a downtrend in spawner abundance after record years in in 2006, 2007, and 2009 (DFO 2016).

Three age classes of coho juveniles are present in the Salmon River system. A small proportion of coho fry will smolt in their first year. However, the majority will rear for their first summer and overwinter before smolting the following April – June (Burt 2010a). Another small proportion will remain in the freshwater ecosystem for a second year. These age classes are determined by environmental conditions (e.g., food availability, stream temperature, and flow regimes) and competition which dictate summer juvenile growth (Quinn and Peterson 1996). Positive growth conditions produce increases in fish length and weight that improve overwintering survival and decreases freshwater residence time (Holtby et al. 1990). Coho smolts out-migrate during mid-April to mid-June transitioning to their marine life history stage. Fish will mature in the ocean for an average of 16 months before returning to spawn (Groot and L. Margolis (eds.) 1991). There can be premature and late returns adding to the variation in spawning adult age classes (Groot and L. Margolis (eds.) 1991).

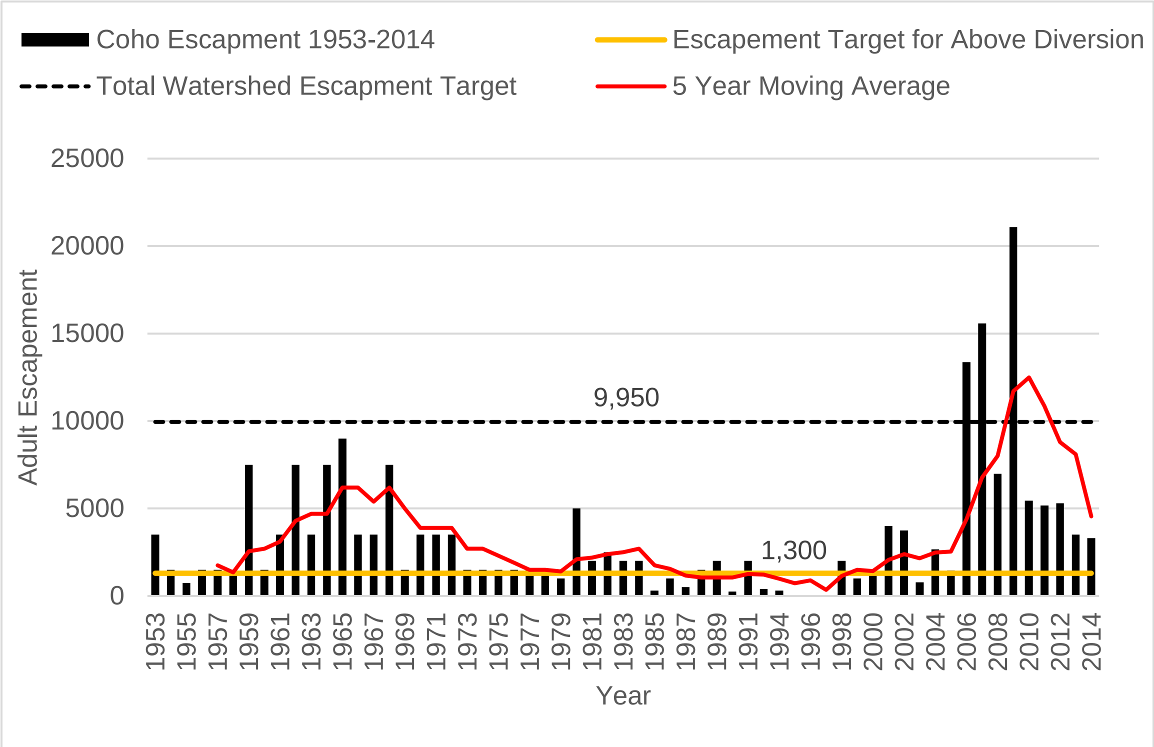

Figure 13. **Historical coho salmon escapement for the Salmon River from 1953 – 2014 (DFO 2016). Escapement from 2002 – 2014 was estimated using area under the curve calculations from multiple snorkel surveys. The estimation method for the remainder of the data set is unknown.**

Juvenile coho salmon abundances has been monitored by DFO, BCCF, and Ecofish Research Ltd. using different methods across various study sites over the years. Beach seining has occurred at six sites upstream and downstream of the SRD since 2008 (Figure 14) (DFO, unpublished data). Sites were not sampled in 2012 and 2013. However, coho salmon juvenile densities do not reach the 249 fry/100 m^2 (FPU) target for the river during years sampled (Section 8.4). This data provides a short term representation of coho densities upstream of the diversion. Coho salmon juveniles separated by the screen on the SRD canal provide supplemental information about coho densities upstream of the diversion. However, juvenile coho salmon stocking occurred from 1990 – 2003 in the upper watershed. Therefore, counts are not representative of natural densities. Data after 2008 will serve as a pre-restoration baseline to be compared with post-restoration information collected.

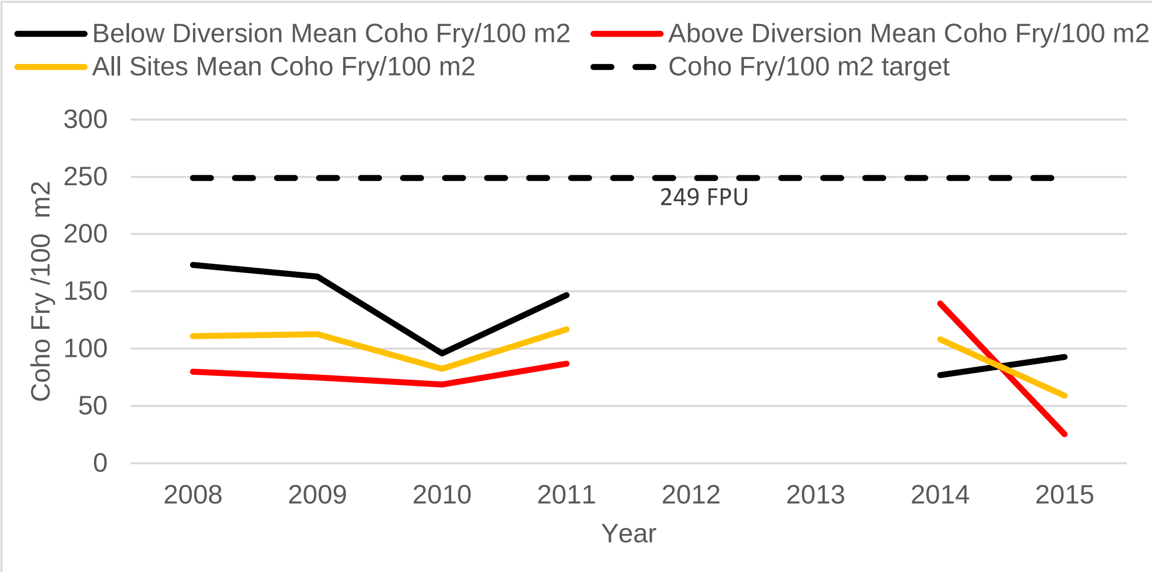

Figure 14. **Juvenile coho salmon abundances from six sampling sites upstream and downstream of the Salmon River diversion from 2008 – 2015 (DFO, unpublished data). Sampling was not conducted during 2012 and 2013. Densities of juvenile coho salmon were only higher upstream of the diversion is 2014.**

A winter-run of steelhead trout use the Salmon River proper. These salmonids return to the watershed from January to May and spawn between early March and late May (Burt 2010a). Fry emerge between mid-April and late June (Burt 2010a). Steelhead trout have a complex juvenile life history relative to other anadromous salmonids. Variation in juvenile growth can produce multiple age classes of rearing juveniles (Ward and Wightman 1989). Steelhead smolts out-migrate during mid-April to mid-June (Burt 2010a). A proportion of steelhead trout are iteroparous (i.e., spawning multiple times) and individuals from one cohort can contribute to multiple brood years, enhancing the complexity of their multi-age structure (Ward 2000).

Adult steelhead trout escapement has been monitored by the MOE, BCCF, and Ecofish Research Ltd. by performing snorkel swims in three index reaches (i.e., 1 upstream and 2 downstream of the SRD) since 1982 (Figure 15) (Pellett 2014b, Abell et al. 2015, 2016). The Rock Creek index located upstream from the SRD was added in 1999. This shorter data set limits the ability to identify trends in adult steelhead abundance above the SRD. However, radio telemetry research has confirmed coho salmon and steelhead trout frequently fail to migrate past the SRD (Anderson 2009, Clarke and Mccubbing 2011, Damborg and Pellett 2011, 2012). Low abundances recorded throughout the Rock Creek index are consistent with previous fish passage assessments.

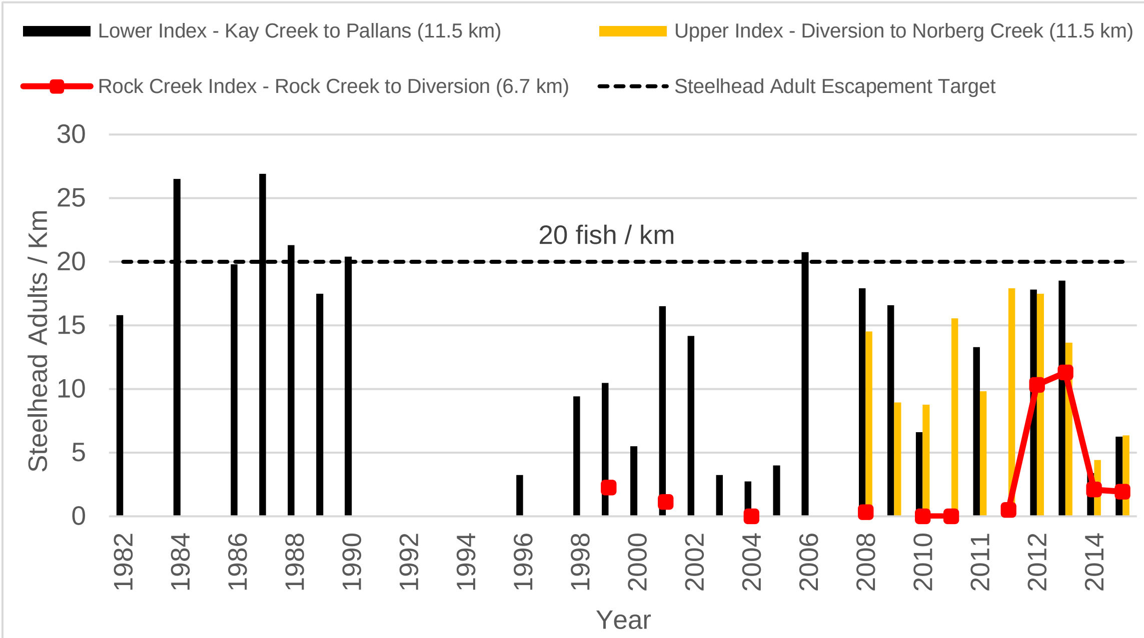

Figure 15. Adult steelhead fish/km for three snorkel swim indices on the Salmon River from 1982 – 2015 (Pellett 2014b, Abell et al. 2015, 2016). Only 11% of survey results are above the targeted 20 fish/km assigned to the Salmon River by Burt (2010b). Data gaps exist for years when swims could not be completed.

Fisheries management for the Salmon River steelhead trout have established an escapement target of 20 fish/km. This target is based on monitoring and modeling conducted on the Keogh River steelhead trout population (Ward and Slaney 1988, Ward, Bruce R; Slaney 1993, Burt 2010b). The majority of surveys for the three indices show counts below this assigned target. This is especially prevalent upstream of the diversion supporting evidence that the SRD is currently a barrier to migration.

Steelhead fry densities are monitored using electrofishing at 10 locations split upstream and downstream of the SRD (Figure 16). Collaboration by BCCF and Ecofish Research Ltd. maintained monitoring consistency across the dataset. This enhances the data's reliability as a pre-restoration baseline for juvenile steelhead trout (Pellett 2012, 2014b, Abell et al. 2015, 2016). Provincial biologists have produced a 60 FPU target for the upper Salmon River based on alkalinity modeling and average fry weights (Tautz et al. 1992, Ptolemy 1993, Lill 2002, Pellett 2014a). Since 1998, steelhead fry densities below the diversion have not met the 60 FPU target 33% of the years sampled. Average steelhead fry densities peaked at 209 FPU in 2007 and were lowest at 19 FPU in 2004. In contrast, above the diversion steelhead densities are below the target 61% of the years sampled. An average peak abundance of 155 FPU occurred in 2011 and a low of 9 FPU occurred in 2015. Pronounced density differences upstream and downstream of the SRD are greatest in 2000, 2007, 2012, and 2015.

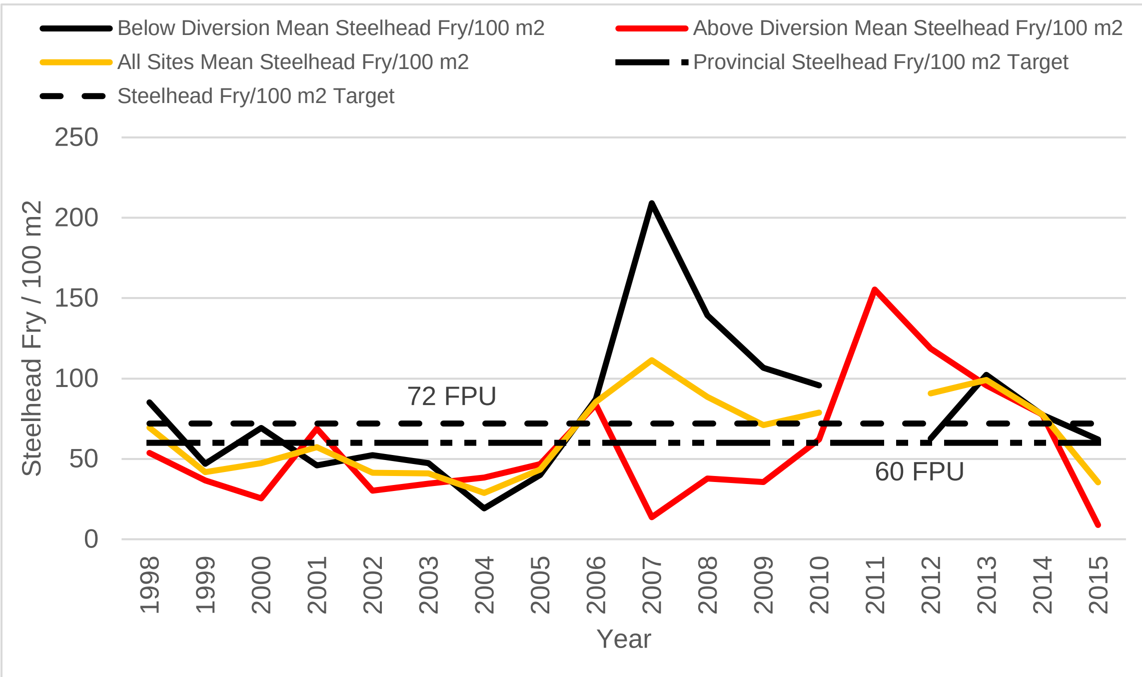

Figure 16. **Depth-velocity adjusted geometric mean steelhead fry densities for electrofishing sites upstream and downstream of the Salmon River diversion from 1998 – 2015 (Pellett 2012, 2014b, Abell et al. 2015, 2016). Fish densities are corrected for depth and velocity conditions at each electrofishing site. Sites below the SRD were not recorded during 2011.**

6.0 Salmon River Stressors

Restoration treatments must address the stressors produced by the SRD to achieve the goals of this plan. Stressors are defined as site filters that prevent a population or ecosystem from naturally recovering (D. Polster, pers. comm. 2016). Stressors affecting the coho salmon and steelhead trout can be broken down into two categories: stressors directly resulting from the SRD infrastructure and operation and stressors resulting from regional and global activities. Infrastructure and operational stressors include: 1) water removal, 2) sediment and nutrient impoundment, and 3) fish migration impediment. Regional and global stressors include: 1) historical forestry disturbance and 2) climate change. Restoration of the SRD will mitigate or address stressors from local, regional, and global scales.

6.1. Hydrologic Regulation

The diversion removes water from the Salmon River and negatively influences reaches below the dam (Burt 2010a). Alterations to a river's flow regime affects fish habitat quality and quantity by altering discharge rates and stream temperatures (Beechie et al. 2013). Burt (2010a) calculated the seasonal discharge deficit below the SRD using stream discharges recorded at three locations on the Salmon River (i.e., WSC stations 08HD015, 08HD007, and 08HD006) and stream discharge recorded within the SRD canal (i.e., WSC station 08HD020) (Figure 17). The MAD has been reduced by 54% below the SRD, 33% above the Memekay River confluence, and 10% near the river mouth relative to an unregulated flow regime (Burt 2010a). The downstream hydrological regime was first altered 60 years ago, but the magnitude of withdrawals has decreased overtime with strengthening regulations (Burt 2010a). Termination of BC Hydro's water license will restore the natural flow regime.

6.2. Sediment Impoundment

The SRD currently obstructs the downstream movement of bedload sediment and has produced an artificial elevation gradient across the diversion structure (Figure 18). Due to the 60-year lifespan of the SRD, the upstream and downstream sections have reached an alternate stable state that will be disrupted through the restoration process. A comprehensive assessment of stream morphology is needed to document the Salmon River's physical response to the restoration over time. There is uncertainty in the timeframe required for the Salmon River to re-gain a morphological equilibrium following restoration. The degree and frequency of storm events will determine the duration required for the transition to a poised stream reach.

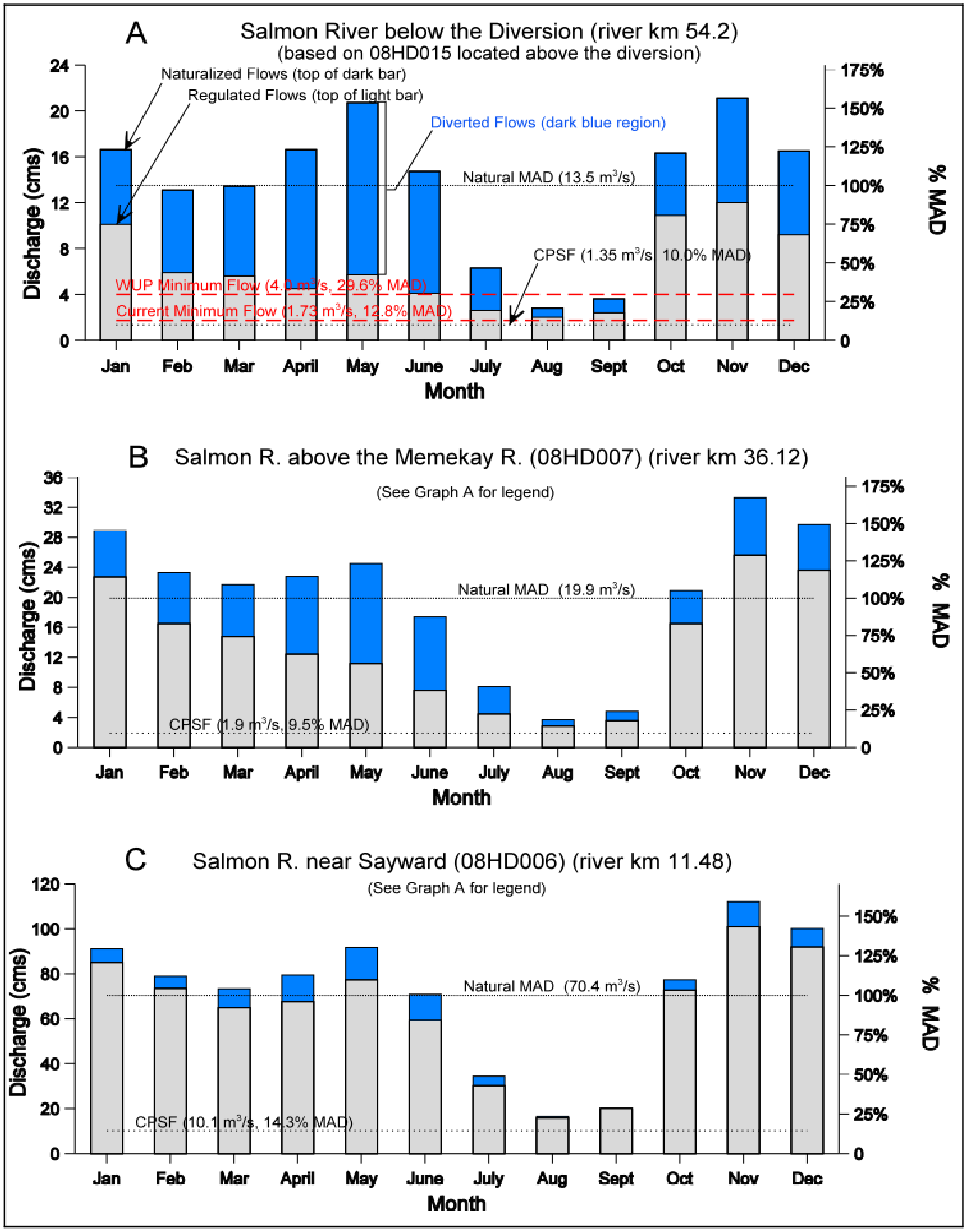

Figure 17. **Estimated natural and regulated monthly mean discharges at three Water Survey of Canada flow stations located on the Salmon River for available data up to 2008. Removal of the SRD will restore the natural flow regime. Figure sourced from Burt (2010a).**

Figure 18. Photograph showing artificial elevation gradient between the upstream and downstream sections surrounding the Salmon River diversion. Upstream gravel berm is level with top of diversion. Photo taken by S. Byrne August 29, 2017.

6.3. Fish Passage

The SRD has been a barrier for fish migration since it's construction in 1958. The structure limits upstream migration of spawning adults and downstream migration of smolts for both target species. Successful migration around the SRD is possible at the undersluice gate or via the fish ladder, but only during a small range of flow conditions (Burt 2010b). Acoustic tagging and radio telemetry have been used to document migration attempts for both species through either the undersluice gate or the fish ladder. Factors limiting the use of these pathways include water velocities >4 m/s, stream temperatures below 4.4°C, and structure blockages due to LWD debris (Figure 19) (Lyderson et al. 2008, Anderson 2009, McCubbing and Burroughs 2009, Clarke and Mccubbing 2011, Guimond and Sheng 2015). Removal of the SRD will eliminate the physical barriers to upstream and downstream fish migration.

The diversion canal also results in interbasin transfer of juvenile coho salmon and steelhead trout. The canal was fitted with a screen to divert juvenile salmonids back to the Salmon River via an outflow pipe, but design flaws compromised the screen's utility (Anderson 2009, Burt 2010b). Removal of the SRD will eliminate the issue of juvenile salmonid interbasin transfer by infilling access to the canal.

Figure 19. Photo representations of fish passage conditions for salmonids. A) The Salmon River diversion undersluice gate during diversion operation. B) Small wood debris building up within canal inhibiting salmonid migration. Photos taken by BCCF on April 6, 2006.

6.4. Historical Forestry Disturbance

Historical logging practices continue to influence salmonid communities in the Salmon River. Legacy forestry stressors are beyond the scope of this restoration plan. However, it is important to acknowledge all stressors influencing the Salmon River salmonids. There have been restoration efforts in the upper reaches of the Salmon River watershed to restore LWD densities (Gaboury and Murray 2003, Silvestri and Gaboury 2008, Atkinson and Damborg 2015). Instream LWD structures aim to improve rearing conditions for juvenile salmonids (Roni et al. 2015). Though removal of the SRD will not directly alleviate legacy forestry effects, the dam does capture LWD being transported downstream. The LWD is removed from the SRD to ensure optimal operation. Without the diversion, LWD can move downstream unobstructed and influence lower reaches.

6.5. Climate Change

Climate change is predicted to influence river ecosystems in the PNW by increasing stream temperatures and by changing the magnitude and timing of seasonal flows (Mauger et al. 2015). The aforementioned changes to stream conditions will negatively affect growth and survival rates of salmonids by causing thermal stress and elevating their energy expenditures in freshwater environments (Mauger et al. 2015, Ward et al. 2015). Juvenile life history stages are at the highest risk from the anticipated effects of climate change because of limited options to avoid the projected changes in stream temperature and seasonal high and low flows (Mauger et al. 2015). This restoration plan includes treatments that will mitigate the effects of climate change on salmonids within the Salmon River.

Water temperatures regulate growth and migration success of salmonids. Ideal temperature ranges and lethal thresholds are well documented for salmonid species across life stages (Table 6). Climate modeling throughout the PNW is used to predict the magnitude and timing of changes to stream temperature. Models for the Columbia River watershed predict a 2 – 6 °C increase in water temperature by 2070 – 2099 (Beechie et al. 2013). These temperature increases will have the largest influence on salmonid survival during summer low flow periods. Watersheds with access to their cooler headwaters are essential to allow rearing salmonids opportunities to avoid increasing stream temperatures (Anderson 2009). Opening access to the protected upper reaches in Strathcona Provincial Park will allow the Salmon River juvenile salmonids to migrate to cooler headwaters.

Water temperature regulates the upstream migration success of spawning salmonids (Salinger and Anderson 2006, Damborg and Pellett 2012). Coho salmon and steelhead trout benefit from the Salmon River's snowmelt-driven flow regime supplying cooler waters during their migration windows. However, stream temperatures in lower reaches can become limiting during migration windows due to increased solar exposure and decreases cold water inputs.

Seasonal stream flows are expected to modify in response to climate change. Climate models predict changes to the magnitude and type of precipitation, which will increase winter flows and decrease summer flows across PNW watersheds (Mauger et al. 2015). Beechie et al. (2013) predicts summer stream flows to decreases by 35 – 75% and winter high flows to increases by 10 – 60% by 2070 – 2099 in the Colombia River watershed. Stream order and elevation are key parameters that influence the degree of flow modification. Flow changes will have the largest influence on transition zones where stream flow is moderated by snowmelt and runoff (Beechie et al. 2013). Flows within the Salmon River are primarily influenced by snowmelt but lower elevations of the watershed are expected to experience shifts in precipitation type and may transition to runoff-regulated flows by 2099.

Table 6. Water temperature ranges for spawning, incubation, and juvenile rearing for anadromous salmonids in the PNW (Beschta et al. 1987, Bjornn and Reiser 1991).

Species	Upstream Migration (°C)	Spawning (°C)	Incubation (°C)	Juvenile Rearing		
				Preferred (°C)	Optimal (°C)	Upper Lethal (°C)
Chinook Salmon	10.6 – 19.4	5.6 – 13.9	5.0 – 14.4	7.3 – 14.6	12.2	25.2
Coho Salmon	7.2 – 15.6	4.4 – 9.4	4.4 – 13.3	11.8 – 14.6	-	25.8
Chum Salmon	8.3 – 15.6	7.2 – 12.8	4.4 – 13.3	11.2 – 14.6	13.5	25.8
Steelhead Trout	-	4.4 – 9.4	-	7.3 – 14.6	10.0	24.1
Cutthroat Trout	-	6.1 – 17.2	-	9.5 – 12.9	-	23.0
Brown Trout	-	7.2 – 12.8	-	3.9 – 21.3	-	24.1

It is critical that any restoration treatments will contribute to increasing the resilience of the Salmon River salmonids to climate change. The removal of the SRD mitigates climates change by restoring historical flow regimes and increasing longitudinal connectivity throughout the watershed (Beechie et al. 2013). Restoring historical flow regimes and increasing longitudinal connectivity address increasing stream temperatures, decreasing summer flows, and increases salmonid resilience (Beechie et al. 2013). This restoration plan directly improves stream conditions within the Salmon River in the face of climate change and is consistent with the highest ranking restoration treatments recommended by Beechie et al. (2013)

Canada and BC must take a proactive approach to prioritizing the protection of specific salmonid watersheds that will buffer against the projected effects of climate change. One strategy is to triage PNW watersheds into four categories (i.e., refugia, reserves, mixed-use, and urban watersheds) using physical, biological, and social parameters in order to optimize protection and restoration efforts (Ashley 2006). The Salmon River watershed can be protected as a salmonid reserve in the face of climate change based on its current conditions in the four categories (Table 7). A reserve requires a large watershed with varying levels of intact wilderness and resource development (Ashley 2006). Restoration activities are prioritized to stabilize and increase current salmonid stocks (Ashley 2006). Additional restoration efforts in areas currently unsuitable for salmonids raise the value of the watershed for conservation. A salmonid refugia requires a large area containing intact wilderness and negligible resource development (Ashley 2006). Refugia grade watersheds are currently rare because of resource extraction across BC. However, this represents a long-term restoration goal for the Salmon River. If the Salmon River was designated as a reserve or refugia, its salmonids could serve as source populations for the recolonization of surrounding watersheds strongly affected by climate change in the future (Ashley 2006).

Table 7. Salmon River watershed evaluation for designation as a salmonid reserve or refugia (Ashley 2006).

Category	Condition	Ranking
Salmonid Diversity	▪ 5 pacific salmon species present ▪ Resident and anadromous rainbow and cutthroat trout ▪ Varying population status across species	Refugia
Watershed Condition	▪ Glacial fed headwaters in Strathcona provincial park ▪ Snowmelt driven system ▪ Watershed is primarily composed of second growth forests from historical logging ▪ Salmon River has 170 ha of its estuary protected (Appendix I) ▪ Minimal urban development throughout the watershed	Reserve
Hydroelectric Development	▪ No hydroelectric infrastructure after removal of SRD ▪ Prohibit further hydroelectric development	Reserve
Fisheries	▪ Current commercial, recreational, and First Nation fisheries at both oceanic and terminal location	Reserve
Hatchery Activity	▪ Termination of coho salmon stocking in 2005 (DFO 2009) ▪ Termination of steelhead trout stocking in 1998 (Burt 2010a) ▪ Prohibit future hatchery activity to protect genetic integrity of stocks	Refugia

7.0 Salmon River Ecological Trajectory

Recolonization of salmonids in the upper Salmon River can contribute to the long-term successional trajectory of the watershed toward an old growth coastal ecosystem (Pike et al. 2010). Historical coastal watersheds contained old growth riparian temperate rainforests which existed in a positive feedback loop with Pacific anadromous salmonids (Pike et al. 2010). Long-term increases in salmonid productivity throughout the upper watershed will provide higher concentrations of MDN to support the surrounding terrestrial ecosystem (Stockner and Ashley 2003, Ashley 2006). Stable isotope research in old growth riparian forests on Chichagof Island in southeastern Alaska showed that approximately 22 – 24% of their foliar nitrogen is derived from marine sources (Helfield and Naiman 2001).This nutrient source increases growth of riparian forests which in turn contribute LWD into salmonid streams via tree death, stream bank erosion, or windfall (Lienkaemper and Swanson 1987, Roni et al. 2015). Continuous LWD inputs maintains stream complexity for rearing juveniles and increases spawning gravel retention, thus completing the loop. The positive feedback loop between riparian forests and anadromous salmonids has been disrupted in harvested watersheds like the Salmon River.

Salmonid distribution and abundance responses post-restoration have been hypothesized using behavioral ecology of anadromous salmonids (Tables 8). Previous research identifies that adult salmonids return to natal spawning locations based on olfactory imprinting developed during parr-smolt transformations in freshwater environments (Cram et al. 2012, Keefer and Caudill 2014). However, deviations from homing behavior leads to adults straying from natal locations causing increases in gene flow and population distributions (Keefer and Caudill 2014). There is a large variation in straying rates and distances among salmonid from different stocks and species (Keefer and Caudill 2014). The recolonization of the upper Salmon River watershed post-restoration will primarily rely on straying rates for returning adult coho salmon and steelhead trout. Spawning females that migrate beyond their own natal spawning locations will have a high probability of selecting spawning location upstream of the diversion because of the abundant spawning gravel (Silvestri and Gaboury 2008). Over generations, continuous rates of straying will recolonize the upper watershed. Juvenile migration can also contribute to the recolonization of upstream rearing habitat. Coho fry have been documented to migrate up to 6.3 km away from spawning sites increasing colonization of available rearing habitat (Anderson et al. 2013). Additionally, juvenile distributions are expected to modify over time through density dependent competition (Grant & Kramer 1990). Territory size increases exponentially with increasing fish length and leads to juveniles seeking out lower density areas (Cramer & Ackerman 2009).

The hypothesized responses of coho salmon and steelhead trout assumes successful navigation through the restoration reach to spawn. Five hypotheses cover a range of negative, no effect, and positive responses post-restoration (Table 8). Scenario 3 represents a short-term (i.e., 4 – 10 year) response with low straying rates for coho salmon and steelhead trout populations (Table 8). Alternatively, scenario 4 assumes higher levels of straying increasing coho salmon and steelhead trout distribution throughout the upper watershed (Table 8). This will decrease density-dependent competition and increasing juvenile survival (Grant and Kramer 1990). These responses assume that environmental conditions and stochastic events do not compromise salmonid responses to the removal of the SRD. Scenario 5 represents a long-term response for salmonid distribution and productivity post-restoration. This scenario predicts salmonid population increasing over time until available habitat is saturated at different life stages for both species (Pess et al. 2008, Winter and Crain 2008). This assumes all other conditions influencing salmonid survival and reproduction are favorable. This scenario will contribute positively to aiding the Salmon River watershed progressing along the desired ecological trajectory towards an old growth coastal watershed (Hauer et al. 2016). Climate change is a key stressor that may negatively offset positive responses to the SRD restoration.

Risk management procedures were applied to the five scenarios to hypothesize scenario probabilities and ecological outcome from a salmonid perspective (Table 9). Many documented dam removals to date are significantly larger than the SRD and have larger environmental footprints. Post-restoration monitoring is necessary to assess response scenarios and evaluate the success of the SRD removal and channel restoration for salmonids.

Table 8. Hypotheses for coho salmon and steelhead trout responses to the Salmon River diversion restoration at different life stages.

Scenario	Adult Coho and Steelhead Responses	Juvenile Coho and Steelhead Responses
Scenario 1 Short-Term No change in salmonid productivity.	▪ Spawning adults do not stray upstream ▪ Majority of spawning still occurs in reach 4 and 5 below restoration site ▪ Restoration Goal 3 is not achieved	▪ Majority of fry and parr continue to compete for territories in middle reaches ▪ No net increases in fitness or survival of juvenile life history stages from decreased competition ▪ Restoration Goal 3 is not achieved
Scenario 2 Short-Term Lower salmonid productivity in both the upper and middle reaches.	▪ Restoration of channel is not navigable for spawning coho salmon and steelhead trout ▪ Removal of the diversion mobilizes sediments that deteriorate spawning habitat upstream and downstream ▪ Lower levels of successful spawning occur in both regions ▪ Restoration is considered a failure	▪ Negative effects on spawning success and offspring survival leading to population decreases for juveniles ▪ Restoration considered a failure
Scenario 3 Short-Term Small increases in salmonid productivity due to low straying rates into upper reaches.	▪ Restored channel allows for unrestricted migration of adult coho salmon and steelhead trout ▪ Small proportion of both coho and steelhead adults migrate past restoration site to spawn	▪ Juveniles use upstream rearing habitat because of spawning location affinity ▪ Slow recolonization of upstream rearing habitat
Scenario 4 Short-Term Evenly distributed salmonid productivity between upper and middle reaches due to higher straying rates.	▪ Restored channel allows for unrestricted migration of adult coho salmon and steelhead trout ▪ Higher straying rates produce a more even distribution of adults upstream and downstream of the restoration site	▪ Decreased juvenile densities leads to decreased competition for resources ▪ More juveniles survive freshwater life history stages ▪ Increases in smolt-spawner recruitment
Scenario 5 Long-Term Increases in salmonid productivity in upper and middle reaches.	▪ Restored channel allows for unrestricted migration of adult coho salmon and steelhead trout ▪ Increases in salmonid populations begin to saturate available spawning habitat in upper and middle reaches ▪ Restoration Goal 3 achieved	▪ Juveniles begin to saturate available rearing habitat in upper and middle reaches ▪ Competition begins to become more prevalent ▪ Restoration Goal 3 achieved

Table 9. Risk assessment of predicted outcomes of Salmon River diversion restoration on coho salmon and steelhead trout distribution and productivity.

Scenarios	Probability	Direction	Magnitude	Restoration Outcome
Scenario 1	Low	Neutral	Medium	▪ No recorded response ▪ Additional restoration efforts required
Scenario 2	Very Low	Negative	High	▪ Removal of SRD has a negative effect on the coho salmon and steelhead trout populations. ▪ Restoration considered a failure
Scenario 3	Medium	Positive	Medium	▪ Removal of the SRD causes a small redistribution of salmonids into upper reaches
Scenario 4	Medium	Positive	High	▪ Restoration of the SRD leads to a more even distribution of adult salmonids ▪ Use of available rearing habitat increases juvenile fitness and survival ▪ Observe increase in population over the short-term
Scenario 5 Delayed response	Medium /High	Positive	High	▪ Long-term use of available upper and middle reaches increases population size to carrying capacity

8.0 Metrics of Success

The success of this restoration project will be evaluated using restoration goals described in section 2.0. Restoration treatments target water removal, stream connectivity, and fish passage stressors produced by the SRD. Removing the SRD will immediately address the three targeted stressors. However, time will be required to monitor the abiotic and biotic responses to the removal and restoration. The continuation of ongoing monitoring protocols will capture post-restoration responses from the removal of the SRD and allow for evaluation of restoration success.

8.1. Hydrologic Regime

Removal of the SRD will terminate water withdrawal from the Salmon River. This will be an immediate outcome of the restoration. Discharge rates at the three CWS stations (i.e., 08HD015, 08HD007, 08HD006) on the Salmon River will be reviewed annually to assess if natural seasonal flows throughout the watershed have been re-established. Continued monitoring of changes in seasonal flows should be evaluated to assess predicted changes in flow magnitudes and timing in response to climate change. If the watershed shifts from a snowmelt-dominated to a rainfall-dominated system, this will have negative implications for salmonid life histories which have evolved to synchronize with river hydrographs (Beechie et al. 2013, Ward et al. 2015).

8.2. Stream Morphology

The removal of the SRD will allow the transportation of sediments and LWD downstream. There is uncertainty in the magnitude and timing of sediment transportation downstream post-restoration (Hart et al. 2002). This will alter habitat units (i.e., riffle, pool, glide) upstream and downstream. It is important that the reconstructed channel has a high degree of permanence to allow for unimpeded fish passage. Therefore, yearly FHAP assessment and thalweg transects upstream and downstream of restoration site will be used to monitor changes in stream morphology (Johnston and Slaney 1996). FHAP assessments record erosion and deposition patterns, gradients, and water velocities. The removal of the SRD provides the opportunity to measure a zone of influence associated with modification upstream and downstream. This information can be used to inform future dam removal projects. There are no specific targets associated with changes in stream morphology as long as passage is possible.

8.3. Fish Migration

Achieving unrestricted fish passage for coho salmon and steelhead trout is the most important requirement of this restoration project. Successful fish passage is regulated by stream gradient, travel distance, stream discharge, and water temperatures during migration windows. For successful upstream migration, adult coho salmon and steelhead trout require a minimum of 0.18 m of water and progress begins to be restricted when water velocities exceed 2.4 m/s (Bovee 1982). Adult coho salmon and steelhead trout migration windows are September 1 – November 30 and January 1 – May 15, respectively (Burt 2010a, Hill 2011). Swimming and jumping capabilities vary amongst species of salmonids (Table 10). Water velocities will be recorded to ensure passable conditions are produced by channel design during coho salmon and steelhead trout migration windows. Passage velocities through the restoration reach will be collected for a minimum of 3 years post-restoration. Abundance monitoring of adult and juveniles upstream of the restoration will serve as an indication of fish passage.

Table 10. Swimming and jumping capabilities of some salmonids sourced from Slaney & Zaldokas (1997) and adapted from Dane (1978).

Species and Life Stages		Maximum Swimming Speed ($m*s^{-1}$)			Maximum Jump Height (m)
		Sustained	Prolonged	Burst	
Coho/Chinook	Adults	2.7	3.2	6.6	2.4
	Juveniles (120 mm)		0.6		0.5
	Juveniles (50 mm)		0.4		0.3
Sockeye	Adults	1.0	3.1	6.3	2.1
	Juveniles (130 mm)	0.5	0.7		
	Juveniles (50 mm)	0.2	0.4	0.6	
Chum/Pink	Adults	1.0	2.3	4.6	1.5
Steelhead	Adults	1.4	4.2	8.1	3.4
Cutthroat/ Rainbow	Adults	0.9	1.8	4.3	1.5
	(125 mm)	0.4	0.7	1.1	0.6
	Juveniles (50 mm)	0.1	0.3	0.4	0.3

8.4. Coho Salmon and Steelhead Trout Productivity

Restoration of the SRD aims to increase salmonid productivity in the upper Salmon River watershed by re-establishing unrestricted access to upstream spawning and rearing habitat for coho salmon and steelhead trout. Removing the barrier will open up approximately 0.37 km^2 of rearing area in the upper Salmon River and Grilse Creek (Silvestri & M. Gaboury 2008). Adult coho salmon escapement targets have been set at 50 fish/km using biostandards derived from Marshall and Britton's coho salmon carrying capacity work (1990). Adult steelhead trout escapement targets have been set at 20 fish/km based on smolt-to-adult modeling produced from monitoring on the Keogh River

(Ward et al. 1989). Juvenile biostandard estimates were developed using Ptolemy's alkalinity model (Ptolemy 1993, 2008).

$$\text{Theoretical maximum biomass} = 35 \times ALK^{0.663} = g/100\ m^2$$

The model was developed using a multiple regression on fish densities, mean weights, and water alkalinity measurements (i.e., $CaCO_3$) during CPSF (July – Sept) on data from multiple synoptic surveys of streams throughout BC to determine a theoretical maximum biomass for trout, char, and chinook salmon (Ptolemy 1993, 2008). The theoretical biomass of coho salmon for appropriate rearing habitat is approximately double the trout estimates (Ptolemy 1993, Burt 2010a). The maximum alkalinity on the Salmon River prior to stream enrichment was 16.5 mg/L (Burt 2010a). Maximum alkalinity in 2014 and 2015 were 23.9 and 23.5 mg/L (Abell et al. 2015). Biostandards were calculated using the conservative 16.5 mg/L based on pre-fertilization conditions. Dividing theoretical biomass estimates by mean weights of coho and steelhead fry determines capacity densities. The mean coho fry weight from beach seining surveys in the Salmon River from 2008 – 2011 is 1.8 g (range 0.93 – 3.18 g) (S. Anderson pers. comm. March 10, 2017). The mean weight of steelhead fry from electrofishing surveys from 1998 – 2015 is 3.13 g (range 1.3 – 5.2 g) (Pellett 2014b, Abell et al. 2015, 2016). These weights provide fry densities of 249 and 72 FPU for coho salmon and steelhead trout. These biostandard calculations were used to calculate theoretical capacity targets for juvenile abundances that can be used to evaluate salmonid productivity post-restoration.

Ptolemy's alkalinity model uses a water chemistry indicator that does not have a direct link to fish productivity. It is one of several models available to estimate salmonids productivity in BC streams (Lewis and Ganshorn 2007). This restoration project provides an opportunity to test this model against other models that use variables influencing salmonids directly, such as stream flows, stream length, stream area, and nutrient concentrations (e.g., phosphorus and nitrogen) (Lewis and Ganshorn 2007). A sensitivity analysis of available models could be completed in the future using the SRD removal as a case study. These estimations can be evaluated with post restoration monitoring data for coho salmon and steelhead trout.

Biostandards have been used in combination with the latest FHAP data to estimate adult and juvenile coho salmon and steelhead trout capacities within the upper Salmon River watershed. Estimated smolt production from the upper watershed assumes the rearing habitat is saturated. Coho and steelhead smolt production for the upper nine reaches is estimated at 36,201 and 12,847 respectively (Table 11). Adults required to produce these estimates are under adult escapement targets for both species (Table 12). These are conservative estimates as small tributaries and off channel rearing areas were not included in calculations. Furthermore, these estimates do not account for temporal environmental variability that influences survival rates of freshwater life history stages. Ocean survival rates of 4 and 13% were used to estimate adults returns from theoretical juvenile production. Positive ocean growth conditions (i.e., 13% survival) estimate 4,706 coho salmon and 1,670 steelhead trout can be produced from the upper Salmon River mainstem (Table 11) (Burt 2010a). Complete biostandard calculations are presented in Table 12.

There are several additional estimates of smolt production from the upper watershed for comparison. Ptolemy (1980) estimated 15,000 coho smolts and 5,000 – 7,000 steelhead smolts could be produced in the area upstream from the SRD; Slaney (1980) estimated 30,000 coho smolts and 10,000 steelhead smolts. Current alkalinity based estimations are greater than Ptolemy's and Slaney's estimations.

Table 11. Estimated adult returns for coho salmon and steelhead trout using smolt production from the upper nine reaches of the Salmon River and Grilse Creek. Ocean survival rates estimate returns based on variable ocean conditions (Burt 2010a; Dr. K. Ashley pers. comm. 2017).

Species	Estimated Smolt Production	Ocean Survival (Poor)	Estimated Adult Returns	Ocean Survival (Favorable)	Estimated Adult Returns
Coho Salmon	36,201	4%	1,448	13%	4,706
Steelhead Trout	12,847	4%	514	13%	1,670

Table 12. Salmonid biostandard calculations for coho salmon and steelhead trout for the upper Salmon River adapted from Burt (2010b).

River Section	Accessible Length (km)	Spawning Area (m^2)	Rearing Area (m^2)	Adult Escapement Biostandard	Adult Escapement Targets	Fry Biostandard	Fry Saturation Estimate	Adults Require to Seed Area	Estimated Smolt Production
Coho Salmon									
Salmon River (SR 5, USR 1 – 4)	18.0	91,883.1	263,731.8	50 fish/km	900	249 fry/100 m^2	190,885	938	28,633
Grilse Creek (1 – 3)	8.2	36,777.6	109,675.9	50 fish/km	408	249 fry/100 m^2	50,452	248	7,568
Total	**26.2**	**128,660.7**	**373,407.7**		**1,307**		**241,337**	**1,186**	**36,201**
Steelhead Trout									
Salmon River (SR 5, USR 1 - 4)	18.0	91,883.1	263,731.8	20 fish/km	360	72 fry/100 m^2	65,891	329	8,296
Grilse Creek (1 – 3)	8.2	36,777.6	109,675.9	20 fish/km	162	72 fry/100 m^2	36,150	181	4,551
Total	**26.2**	**128,660.7**	**373,407.7**		**522**		**102,041**	**510**	**12,847**

Notes

A) Habitat Data
Silvestri & Gaboury 2008

B) Capacity of Spawning Habitat:

Coho: Assumed 10.0 m2 required per spawning pair (spawning biostandard from Burt 2004, Campbell River Restoration Plan)

Steelhead: Assumed 15.2 m2 required per spawning pair (spawning biostandard from Burt 2004, Campbell River Restoration Plan)

C) Quantification of Rearing Habitat:

Coho fry: Assumed to be 80% of pool habitat + 60% of glide habitat (conservative estimate based on S. Anderson's coho sample sites)

Steelhead fry: Assumed to be 70% of available riffle habitat

D) Rearing Capacity Estimates: Based on R. Ptolemy's alkalinity model using an alkalinity of 16.5 mg/L
Coho fry
Theoretical maximum biomass = double steelhead amount = 449 g/100 m2 ÷ 1.8 g = 249 fry/100 m2
Steelhead fry
Theoretical maximum biomass = 35 x $ALK^{0.663}$ = 224.5 g/100 m2
Theoretical maximum abundance = Theoretical maximum biomass ÷ mean weight of fry = 224.5 g/100 m2 ÷ 3.13 g = 72 fry/100 m2

Ocean Survival: Dr. K. Ashley pers. comm. 2017; Burt 2010a

E) Fecundity / Survival Rate Data for "Adults Required to Seed Fry/Parr Habitat"

	Fecundity	Egg-to-Fry	Fry-to-Smolt	Egg-to-Smolt	Smolt-to-Adult Survival (Low)	Smolt-to-Adult Survival (High)
Steelhead	4,600	8.7%	12.6%	1.1%	4.0%	13.0%
Coho	4,070	10.0%	15.0%	1.5%	4.0%	13.0%

Coho Fecundity: median for Salmon R. coho egg takes by Sayward Fish and Game Club (range: 3640-4500 eggs/female);
Coho Survival: upper range of DFO SEP data, Mel Sheng, pers. comm.
Steelhead Fecundity: M. McCulloch, pers. comm.;
Steelhead Survival rates: Egg-to-Smolt based on Englishman R. studies (M. McCulloch, pers. comm.);
Fry-to-Smolt from Ward and Slaney (1993) based on 1976-1982 data from Keogh R.;
Egg-to-Fry calculated from the other survival rates

F) Adults Seeding Estimates: (Fry saturation estimate / (Fecundity * Egg-Fry Ratio)) * Sex Ratio

9.0 Heber Dam Restoration

The Heber River diversion, located approximately 16 km east of Gold River, was removed in 2012 after a collaboration of First Nations, BC Hydro, stakeholders, and agencies (Figure 20). The Heber River diversion was one of three diversions that diverted water into the Campbell River watershed (BC Hydro 2011, 2012). The Heber River is one of the most productive steelhead rivers on the west coast of Vancouver Island; this was a large motivation for removing the diversion (BC Hydro 2011). The Heber Dam restoration is a reference for the restoration work planned for the SRD.

Figure 20. Progression of restoration efforts on BC Hydro's Heber River diversion 2012. Restoration involved dam and penstock removal, channel reconstruction, and riparian treatment (BC Hydro 2012).

10.0 Regulations and Permits

Restoration projects within BC require compliance with federal, provincial, and municipal legislation to minimize negative effects to aquatic ecosystems (Table 13). Professional practitioners must implement due diligence to ensure full compliance with legislation across all levels of government. The Fisheries Act (R.S.C., 1985, c. F-14) and the Water Sustainability Act (S.B.C., 2014, c. 15) will principally regulate the removal and restoration process. It is important to use the most recent version of legislation to ensure restoration activities are fully complying with current regulations. The removal of a dam and altering a stream course activates DFO's review process and requires an approval under the Fisheries Act (R.S.C., 1985, c. F-14). Under the Water Sustainability Act (S.B.C., 2014, c. 15) a restoration effort of this magnitude will require an approval under Section 10 for changes in and amongst a stream pertaining to Section 11. This restoration will also result in the termination of a water license held by BC Hydro under Section 9. Restoration projects must also comply with the Species at Risk Act (S.C. 2002, c. 29) to ensure construction does not harm endangered or threatened species and habitat. Waste removed from site must comply with the Environmental Management Act (S.B.C, 2003, c. 53). Due to the diversion dam being constructed with creosote timber, this contaminated material must be removed and transported to a designated disposal site.

Working around riparian areas requires compliance with the varies acts and regulations pertaining to the protection of vegetation and wildlife around streams (Table 13). During construction, the goal is to minimize damaging riparian areas and increasing the riparian area on the right bank post-restoration. The protection of birds and their nests within a riparian area could be of concern during restoration work. Although restoration will commence outside of nesting season so problems are likely minimal.

Working on or around dams immediately triggers public safety concerns. The Dam Safety Regulations under the Water Sustainability Act (S.B.C., 2014, c. 15) provided strict requirements for conducting any work on dam infrastructure in BC. The removal, decommissioning, deactivating, or operational termination of a dam requires a 120-day notification to a dam safety officer prior to a restrictive activity. A plan must also be submitted for works proposed 90 days prior to activities.

Table 13. Legislation and regulations pertaining to the Salmon River Diversion removal and restoration.

Legislation / Regulation	Governance Level	Objective	Approval
Fisheries Act	Federal	The Fisheries Act (R.S.C., 1985, c. F-14) protects and preserve fisheries as a public resource in Canada.	Yes
Species at Risk Act	Federal	The Species at Risk Act (S.C. 2002, c. 29) aims to prevent species which are at risk of become extirpated or extinct by promote their recover through protection of populations and their critical habitat.	Compliance
Navigable Protection Act	Federal	The Navigable Protection Act (R.S.C., 1985, c. N-22) pertains to any activity in, around, under, and over navigable waters within Canada regulated by either the coast guard or DFO.	Yes
Water Sustainability Act	Provincial	The Water Sustainability Act (S.B.C., 2014, c. 15) protects BC water resources and stream networks	Yes
Forest Range Practices Act	Provincial	Forest Range Practices Act (S.B.C., 2002, c. 69) regulates forestry practices in BC.	Compliance
Riparian Areas Protection Act	Provincial	The riparian regulations exist under the Riparian Protection Act (S.B.C, 1997, c. 21) and are in place to protect riparian areas from development.	Compliance
Wildlife Act	Provincial	The Wildlife Act (R.S.B.C., 1996, c. 488) protects both wildlife and their habitat within BC.	Compliance
Environmental Management Act	Provincial	The Environmental Management Act (S.B.C., 2003, c. 53) protects BC's air, land, and water from contamination from hazardous materials.	Yes
Dam Safety Regulations	Provincial	The Dam Safety Regulations are a part of the Water Sustainability Act (S.B.C., 2014, c. 15) and regulate dam construction, repair, removal, and operation.	Yes
Local Government Acts	Municipal	Local acts allows municipalities to enforce their own bylaws on environmental issues like erosion control, waterway protections, and tree retention (Ministry of Environment 2004).	Compliance

11.0 Restoration Budget

BC Hydro estimates the cost of decommission the SRD to range from $12.1 to $21.3 million with an expected value of $14.2 million (Z. Ceric pers. comm. 2017). This is a high level estimate that is currently being refined during the planning process. Budgeting for the decommissioning of the SRD is beyond the scope of this restoration plan. However, a budget has been presented for the cost of including LWD and boulder complexity in the SRD restoration design (Table 14). The inclusion of these techniques adds ecological value. Capitalizing on the heavy machinery being onsite for the decommissioning reduces the cost of including these restoration treatments.

Instream restoration work completed in the Keogh River watershed cost $30,000/km in 1996 (Slaney and Zaldokas 1997). The cost is approximately $44,000/km when adjusted for inflation. This included a majority of boulder placement compared to LWD installation (Slaney and Zaldokas 1997) Costs can be reduced by 50% with well-trained machinery operators and cabling crews (i.e., $15,000/km) (Dr. K. Ashley pers. comm. 2017).

Table 14. Costs of installing 30 logs during the Salmon River diversion restoration. Log number was determined using the equation N = (80m^3/Va)*(L/100) (Slaney and Zaldokas 1997). This assumes an average log volume 3.85 m^3 (i.e., length 10 m and diameter 0.7 m) and an estimate stream length of 150 m (Slaney and Zaldokas 1997). Cost of logs will be dependant on dimensions available. Cost were determined for installing one log with 4 ballast rocs and two cables.

Stream Channel LWD Complexing						
#	**Item**	**Detail**	**Unit**	**Quantity**	**Rate**	**Cost**
1	Construction	200 series Excavator	/hr	30	$ 140.00	$ 4,200.00
2	Logs	Supply and Transport (Douglas Fir-X)	/log	30	$ 150.00	$ 4,500.00
3	Rocks	Supply and Transport	/log	30	$ 100.00	$ 3,000.00
4	Cabling	Cable	/log	30	$ 25.00	$ 750.00
		Epoxy	/log	30	$ 55.00	$ 1,650.00
		Drill bits	/log	30	$ 20.00	$ 600.00
		Misc. (grease, plunders, brush, baster, fuel, etc.)	/log	30	$ 5.00	$ 150.00
5	Rental	Rock drills, wood auger, generator, cable cutters, cords etc.	/log	30	$ 15.00	$ 450.00
6	Labour	Supervisor (2 hrs/log)	/log	30	$ 120.00	$ 3,600.00
		Field crew (2 hrs/log)	/log	30	$ 180.00	$ 5,400.00
7	Administration	10% of total cost				$ 1,100.00
					Subtotal	**$ 25,400.00**
					Gst	5%
					Total	**$ 26,670.00**

12.0 Restoration Logistics

Decommissioning the SRD requires in-stream work that may have short-term negative effects on the downstream aquatic environment. Construction will occur during the summer in-stream work window to minimize negative effects. Due to the time required to implement the restoration, BC Hydro has requested an extension of the required work window from July 1 – September 30. Table 15 outlines specific goals and objectives for decommissioning the SRD and the stream channel reconstruction.

Table 15. Implementation goals and objectives for removal of the SRD.

Goals and Objectives	Description	Completion Schedule (2017)
Goal 1.0	Remove BC Hydro Salmon River Diversion dam and restore channel to allow for salmonid migration.	Sept 30
Objective 1.1	Terminate water diversion down the Salmon River diversion canal.	June 30
Objective 1.2	Construct staging area for restoration work.	June 3 – 8
Objective 1.3	Install erosion control measures (silt screens) within construction areas.	July 10 – 14
Objective 1.4	Install fish screens upstream and downstream of the SRD and conduct fish salvage procedures.	July 10 – 14
Objective 1.5	Install water filtration system for contaminates.	July 10 – 14
Objective 1.6	Divert water along right bank to allow for left bank access.	July 14
Objective 1.7	Deconstruct diversion dam infrastructure and remove contaminated material off site.	July 17 – 28
Objective 1.8	Stabilize left stream bank with rock stabilization techniques	July 24 – 28
Objective 1.9	Divert water along left bank to provide right bank access.	July 28
Objective 1.10	Deconstruct water control tower, trimming weir, canal entrance, and fish ladder.	July 31 – Aug 11
Objective 1.11	Regrade 100 – 300 m of river channel over restoration site to a 2 – 4% slope.	Aug 14 – 25
Objective 1.12	Reconstruct river thalweg along right bank.	Aug 21 – Sep 1
Objective 1.13	Reconstruct 10 – 50 m of the right stream bank using integrated bank stabilization techniques.	Aug 28 – Sep 8
Goal 2.0	Restore riparian area on banks within the restoration site to prevent soil erosion and restore riparian shading.	Sept 15
Objective 2.1	Decompact soil within right and left riparian construction areas.	Sept 4 – 8
Objective 2.2	Add coarse woody debris at a density of 100 m^3/ha.	Sept 4 – 8
Objective 2.3	Live stake and seed upper stream bank	Sept 11 – 15

Mobilizing machinery to the restoration site will have minimal effects on adjacent riparian areas due to adequate site access from both banks. Right bank access is available using BC Hydro's service road for the diversion. Access to the left bank is approximately 2 km farther up the Salmon River road after crossing a bridge located at the diversion screen. A turn off leads down to the riverbed where machinery can back track to the diversion infrastructure along the gravel berm. A remnant clearing along BC Hydro's service road will serve as the main staging area for the restoration project. In-stream restoration activities need to minimize the transport of sediments downstream. Under section 46 (1) of British Columbia's Water Sustainability Act (S.B.C., 2014, c. 15) it is prohibited for any individual to introduce sediment into a stream, stream channel, or adjacent area without proper authorization. Therefore, silt fences and soil coverings are needed to mitigate in-stream works.

12.1. Fish Salvage

Federal and provincial regulations require fish salvage procedures be completed prior to in-stream deconstruction. The purpose is to minimize fish mortality by removing any fish within the construction area using non-lethal methods (Ministry of Agriculture 2005). Permits through DFO and MFLNRO allow for salvaging saltwater and freshwater fish. A combination of beach seining and electrofishing is suggested to remove all individuals from the enclosed area. Beach seining can be used initially, followed by electrofishing. A minimum of three seine passes, followed by two electrofishing passes is recommended per targeted section (Ministry of Agriculture 2005). Holding containers and water pumps are required to minimize fish stress during transportation to lower reaches of the river before release. Exclusion nets will be in place on the river during the duration of the in-stream construction.

12.2. Diversion Deconstruction

Deconstruction of diversion infrastructure will be conducted in two phases to minimize in-stream effects and to control flows. The first phase is to remove the diversion dam, followed by the stabilization of the left bank. The removal of the diversion dam is of special concern due to the creosote treated wood used in the structure. Debris and sediments removed from this area are contaminated materials and need to be transported to an off-site disposal site in accordance with BC's Environmental Management Act (S.B.C., 2003, c. 53) (Zapf-Gilje et al. 2001). Water treatment during decommissioning will remove mobilized residual contaminants. After the diversion has been removed, flows will be diverted to the left portion of the river channel to facilitate removing the water control tower, the trimming weir, and the fish ladder. The canal will be capped to ensure the canal does not receive flows from the Salmon River. Regrading the restoration site, reconstructing the river channel, and reconstructing the right bank will be conducted post-decommissioning.

12.3. Channel Grading and Reconstruction

The SRD has created an artificial 5 m elevation difference across the site. Reach 5 on the Salmon River has an average gradient of 1%, however it is not feasible to achieve this gradient at the restoration site (Silvestri and Gaboury 2008). The channel will be regraded to a slope that is logistically possible, but ecological suitable (i.e., < 4%) for fish passage (Slaney and Zaldokas 1997). If channel gradient cannot be reconstructed to a more gradual slope, channel design should incorporate baffling structures to allow for rest areas for migrating salmonids. The combination of gradient and flow velocities during migration windows will determine the success rate of upstream migration. The Salmon River will continue to regrade the restoration reach potentially improving fish passage condition (East et al. 2015).

Channel reconstruction will occur over 200 m to obtain gradient targets. The thalweg will be constructed towards the right bank in accordance with the natural meander of the river. Reach 5 is dominated by a riffle-pool stream morphology that will be used to guide channel reconstruction. Reach 5 has a mean bankfull width of 38.7 m which produces a meander wavelength of 310 m with a 89 m radius of curvature (Slaney and Zaldokas 1997, Silvestri and Gaboury 2008). Channel geology and canyon geography may constrain channel design. The Salmon River will naturally create an erosional zone along the right bank and a depositional zone along the left bank in the location of the diversion dam post- restoration. Therefore, reconstruction of the river channel will conform to projected flow path and create a logical habitat unit progression. Figure 21 and 22 provides a before-and-after plan view of the restoration site.

Figure 21. Aerial photograph showing a plan view of the Salmon River diversion on February 23, 2017. Photo taken by D. Harper on February 23, 2017.

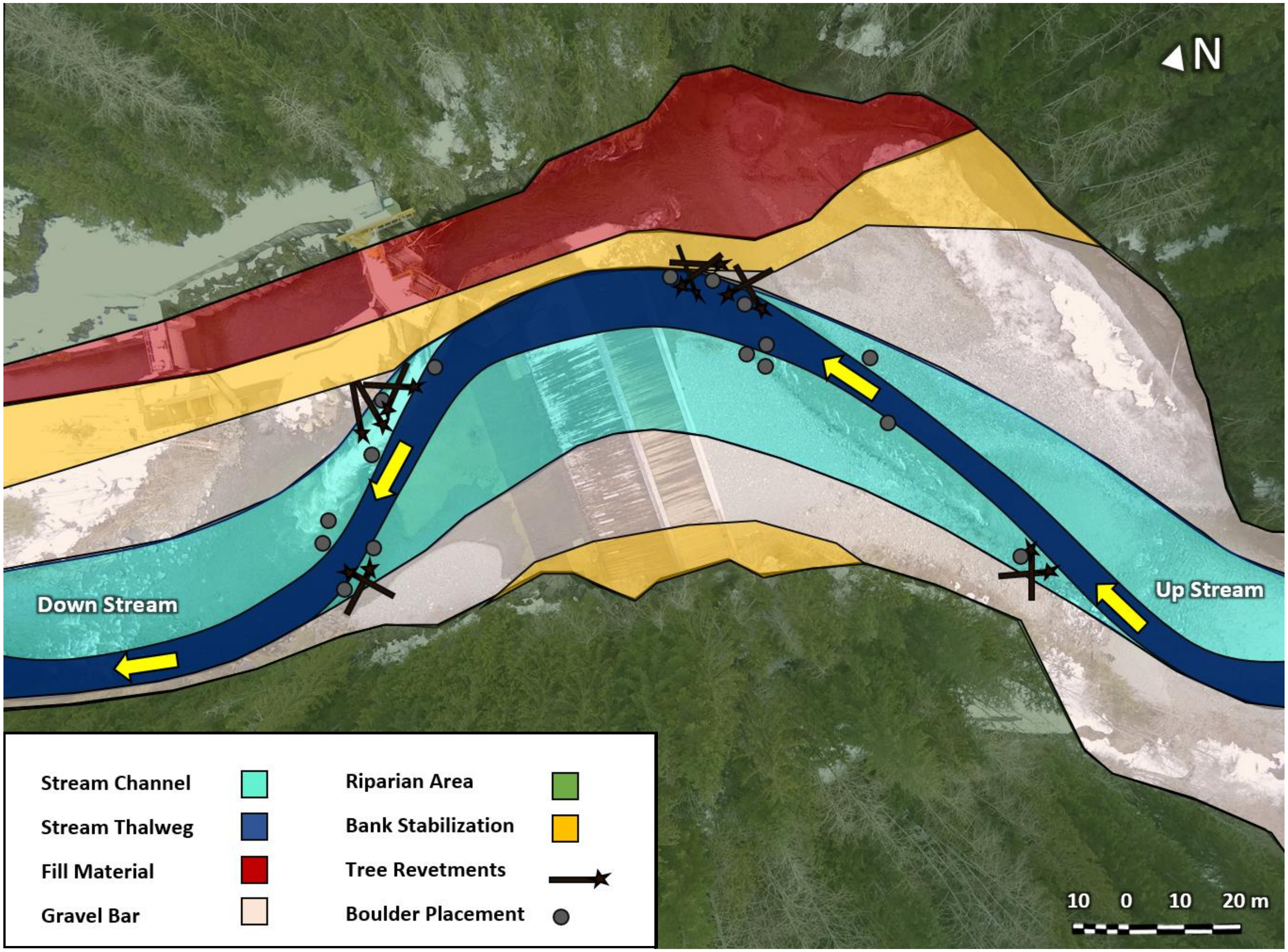

Figure 22. **Conceptual stream channel design after the Salmon River diversion has been removed. Photo taken by D. Harper on February 23, 2017.**

12.4. Bank Stabilization and Channel Complexing

The right bank of the site will be at risk of hydraulic scouring as water energy is redistributed post-restoration. Several restoration treatments are available to provide bank stability and improved stream complexity. A combination of rock stabilization and LWD revetments have been selected to maximize bank stability and provide cover, hydraulic variability, and morphological complexity (Slaney and Zaldokas 1997). The majority of the right stream bank will require rock placement to protect against erosion forces. The stream banks will be constructed to withstand a 100-year flood event for the 268 km^2 catchment above the restoration site (A. Muir pers. comm. Jan 31, 2017). The estimated discharge of a 100-year flood event is 550 - 580 m^3/s (Figure 23) (Hill 2011). This estimate has a high degree of uncertainty due to a small data set and projected increases in peak flows with climate change.

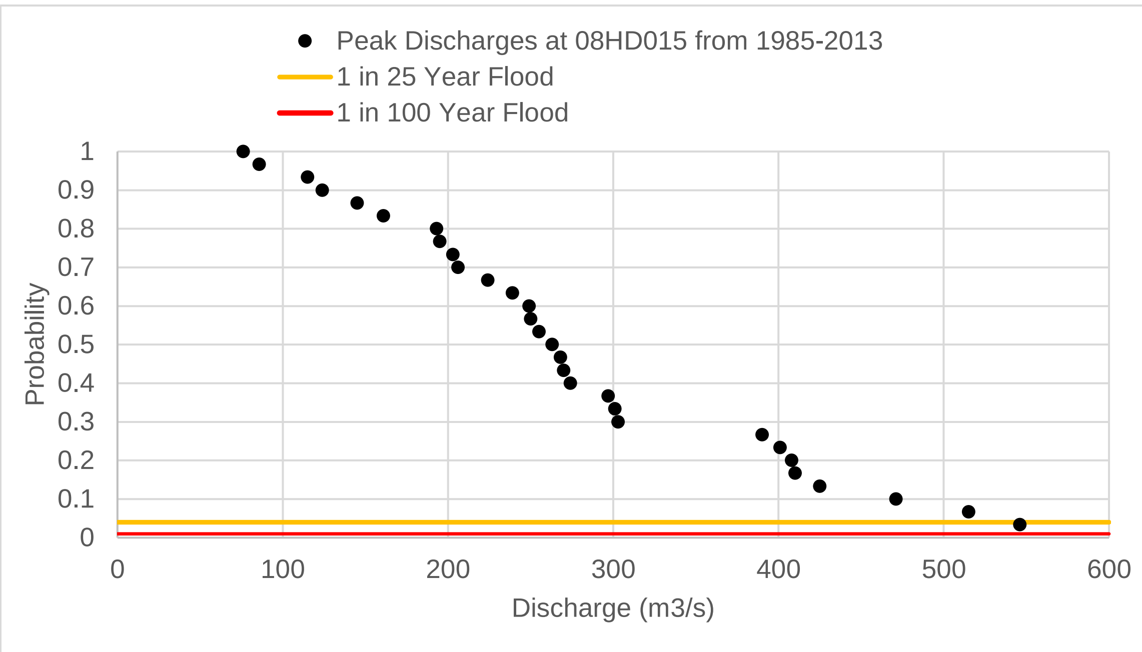

Figure 23. Estimated discharges for flood events on the Salmon River located at the restoration site. Peak flows were used from WSC station 08HD015 to determine probability curve. These estimates should be used with caution as data only exists from 1985 – 2013 (n = 30).

The LWD revetments will be installed adjacent to the outside curve along the right bank to avoid the high energy zone. This restoration technique requires conifer trees (e.g., Douglas fir) to be imbedded in the bank and ballasted with boulders to ensure permanence against drift and buoyancy forces (Figure 24). Complexing with LWD structures produce an upstream deposition zone and downstream scour pool (Slaney and Zaldokas 1997).

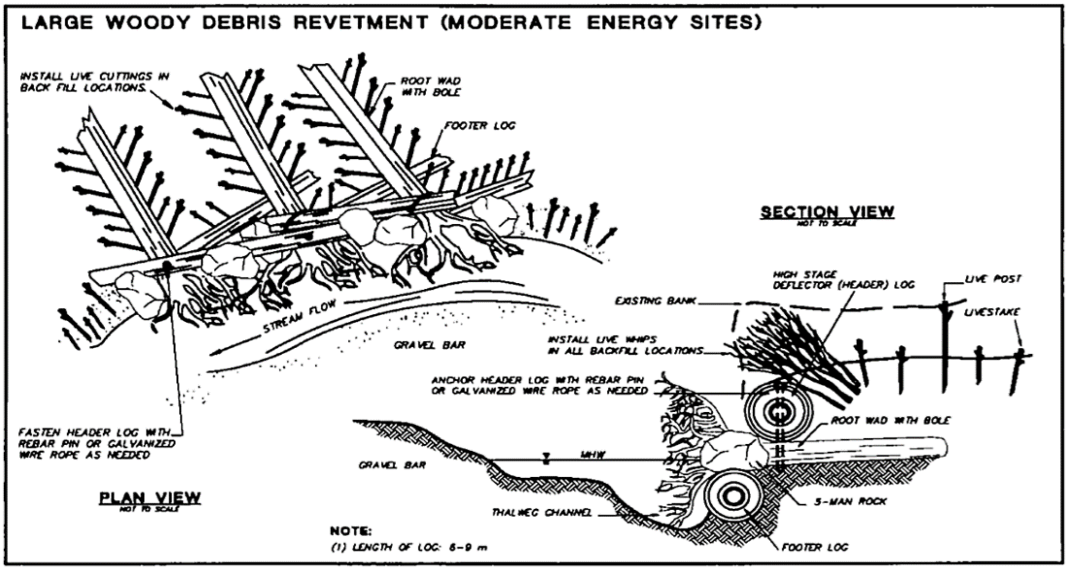

Figure 24. Conceptual design of tree revetments in moderate energy site (Slaney and Zaldokas 1997). Revetments will be installed upstream and downstream of the reconstructed outside bend.

12.5. Riparian Restoration

Riparian restoration will be required along the right bank after in-stream work is complete. The re-establishment of riparian vegetation will decrease soil erosion and provide channel shading for salmonids. Soil and fill material requires decompaction by an excavator to promote water and plant root infiltration (Polster 2002). Pioneering species (e.g., willow (*Salix spp.*), Red alder (*Alnus rubra*), and Balsam poplar (*Populus balsamifera*)) will establish naturally on disturbed riparian area (Polster 2002, Muller et al. 2016). Live staking willow or Balsam poplar and spreading red alder seeds are accelerate revegetation options. Invasive species are always a concern when restoring disturbed sites. However, the remote location of the SRD decreases the probability of invasive species establishing on site. The greater probability is invasive seeds are brought on site by machinery. Therefore, machinery must be thoroughly cleaned and contain aquatic friendly hydraulic oil before arriving on site as per the contracted agreement. Course woody debris will be spread over the riparian area at a density of 100 m^3/ha (D. Polster, pers. comm. 2016). There will be ongoing consultation regarding the future status of the SRD canal. Decommission of additional structures and road access is desirable, but will be determined at a later date.

13.0 Restoration Schedule

It is required that instream work is conducted within the designated work window (e.g., July 15- Aug 15) for salmonids to minimize negative effects. BC Hydro has requested for an extended work window of July 1 – September 30, 2017 due to the estimated time required to complete this restoration project. Additional time must be allocated for travel regarding transportation of material and labor due to the remote location. A preliminary project schedule describing objectives, durations, and timing is available in Table 16. A comprehensive schedule will be developed in partnership with BC Hydro and the construction company hired to undertake the restoration work. It is important to add in time contingencies to accommodate complications with construction.

14.0 Salmon River Diversion Restoration Monitoring

The continuation of current monitoring programs as a component of the SRD restoration aims to: 1) compile site data to assess the success of the restoration and 2) contribute to a database of case studies available to the restoration ecology community to inform future projects (Rieger et al. 2014). Monitoring for this restoration plan will produce data that contributes to these categories for the three identified stressors (i.e., water removal, sediment impoundment, and impediment to fish passage). Consistent monitoring methods are critical to allow for robust data analysis and evaluation of project success.

It is recommended to compile pre- and post-restoration data into a geographic information systems database with spatial and temporal references to track changes in salmonid populations and watershed conditions. This can be developed into a comprehensive tool to inform management of salmonid populations and to identify additional restoration needs in the Salmon River watershed. If successful, this database could be expanded to include additional watershed producing a localized repository of BC salmonid populations, restoration efforts, and changing climatic conditions.

Table 16. **Gantt chart of in-stream restoration procedures to be conducted between July 1 – September 30, 2017.**

Objective	Description	Duration (Days)	July 3 – 8	July 10 – 14	July 17 – 21	July 24 – 28	July/Aug 31 – 4	Aug 7 – 11	Aug 14 – 18	Aug 21 – 25	Aug/Sept 28 – 1	Sept 4 – 8	Sep 11 – 15
1.1	Terminate water diversion down the Salmon River diversion canal	1	—										
1.2	Construct staging area for restoration work	3 – 5	—										
1.3	Install erosion control throughout construction area	1		—									
1.4	Conduct fish salvage procedures	1		—									
1.5	Install water filtration system for contaminates	3 – 5		—									
1.6	Divert water along right bank to allow for left bank access	1		—									
1.7	Deconstruct diversion dam infrastructure and remove contaminated material off site	12 – 14			—	—							
1.8	Stabilize left stream bank with rock techniques	3 – 5				—							
1.9	Divert water along left bank to provide right bank access.	1				—							
1.10	Deconstruct water control tower, trimming weir, canal entrance, and fish ladder	12 – 14					—	—					
1.11	Regrade 200 m of river channel over restoration site to a 2-4% slope.	12 – 14							—	—			
1.12	Reconstruct river thalweg along right bank curve	12 – 14								—	—		
1.13	Reconstruct right stream bank using rock and LWD complexing	12 – 14									—	—	
2.1	Decompact soil on right and left riparian areas	1 – 2										—	
2.2	Add course woody debris at a density of 100 m3/ha	1 – 2										—	
2.3	Stake and seed stream bank	3 – 5											—

14.1. Stream Flow Monitoring

Monitoring of stream discharge will be used to gauge the success of this project at restoring historical flow regimes downstream of the SRD (Goal 1, Section 2.0). Current CWS water gauge stations on the Salmon River provide continuous stream discharge data (i.e., 08HD015, 08HD007, and 08HD006) along the Salmon River (WSC 2016). Ongoing monitoring of stream flow by WSC will capture changes in the flow regime post-restoration. Annual analysis of hydrographs for a minimum of five years post-restoration is recommended to track the Salmon River's shift back to a natural flow regime. Long-term monitoring of discharge and temperature is recommended to track hydrologic responses to climate change. Supplemental water velocity data from future FHAP and salmonid monitoring can be integrated into the Salmon River restoration database.

14.2. Stream Morphology

Monitoring stream morphology will be used to track sediment transport through the restoration site (Goal 2, Section 2.0). There is uncertainty around the zone of influence upstream and downstream of the SRD post-removal. Fish habit assessment procedures (Level 1) will be paired with channel thalweg profiles distributed upstream and downstream of the restoration to track erosion and deposition changes (Johnston and Slaney 1996, Lewis et al. 2004, 2012, Hatfield et al. 2007).

The FHAP survey and channel profile transects will be conducted over 5 km split evenly upstream and downstream of the SRD (Lewis et al. 2012). The FHAP surveys will be conducted by a minimum of two individuals during seasonal low-flow conditions on the Salmon River (i.e., July – August) in year 1, 2, and 5 post-restoration. A complete watershed FHAP has not been completed on the Salmon River since 1977 (Ptolemy et al. 1977). A comprehensive survey of the mainstem is recommended to identify areas for future restoration activities.

Using thalweg profiles allows for tracking changes in stream bed elevation over time. Pre-restoration thalweg elevations benchmarked to stable bank location at each transect need to be recorded prior to restoration. The frequency of measurements should be higher directly after restoration procedures to capture the initial morphological response to restoration (Lewis et al. 2012). Additionally, measurements should be taken after large storm events and spring freshets which have the largest power to cause large changes in stream morphology (Pohl 2004). Sampling frequencies can be adjusted according to preliminary finding. The long term duration of sampling can be adjusted based on the degree of changes observed after May, 2018.

14.3. Salmonid Monitoring

Post-restoration monitoring of coho salmon and steelhead trout will assess salmonid recolonization and changes in abundances (Goal 2 and 3, Section 2.0). Sampling of a minimum of 3 generations (10 – 12 years) is required to observe initial restoration responses. After this time, spawner-recruitment relationships can be examined to compare to pre-restoration abundance estimates (Ward 2000).

Snorkel surveys are currently conducted on the Salmon River in October and late March to estimate adult coho salmon and steelhead trout abundances. Swims are conducted in the down stream direction with particularly steep or treacherous sections omitted for safety. Swim length and observation time are recorded to determine effort. Surveyors must record the number, length, and condition of targeted species along with additional variables (Table 17). Sources of error include visibility during swims, surveyor experience, and swim difficulty

Table 17. Variables and data requirements for snorkel surveys conducted on the Salmon River. Table adapted from Abell et al. (2016).

Variable	Data Requirement
Weather	Observation
Water temperature	°C
Effective visibility	Measured or estimated in meters
Fish size class	Fry, parr, adult: 150 – 250 mm, 251 – 350 mm, 351 – 450 mm, >450 mm
Fish species	Coho (CO) / steelhead (ST) / cutthroat (CT) / rainbow (RT)
Fish condition	Bright / moderately coloured / mid spawn / post spawn / undetermined
Redd observations	Location / size / number / species

Fisheries and Oceans Canada conduct multiple snorkel surveys in the lower Salmon River to produce an annual coho salmon stock assessment. These surveys do not provide data regarding upper watershed spawning distributions. I recommend that two additional snorkel swims are conducted during the adult coho salmon migrations to assess distribution and abundances of spawning coho salmon in the upper watershed post-restoration. Additional snorkel surveys will be conducted on the current Rock Creek and lower diversion snorkel swim indices upstream and downstream of the restoration site (Figure 25). These snorkel surveys must be completed by two trained fisheries technicians during the third week in October.

Adult steelhead trout snorkel surveys are conducted on three index reaches upstream and downstream of the SRD for steelhead stock assessment. It is recommended snorkel assessments continue post-restoration. Surveys of the lower reach are traditionally scheduled for the second week of March followed by assessments of the upper reaches in early April. Swims will be conducted by a pair of experienced fisheries technicians in compliance with historical methods to ensure data comparability. Ecofish Research and Laich-Kwil-Tach Environmental Assessment Ltd. are currently contracted to conduct snorkel surveys. Observed changes in steelhead adult distribution and abundances will be paired with annual stock assessments to assess long-term trends.

Sampling for coho and steelhead fry has been conducted by different methods and organizations prior to the SRD restoration. Different methods are selected for sampling respective rearing conditions. Each method requires a similar set of variables to be recorded with additional parameters specific to beach seining or electrofishing (Table 18). Beach seining is used to assess juvenile coho salmon. Initial surveys were conducted by DFO. Laich-Kwil-Tach Environmental Assessment Ltd completed surveys for 2014 – 2016. Continuing this monitoring post-restoration is recommended. The six locations upstream and downstream of the SRD were selected as representative coho rearing habitat (i.e., pools) (Figure 25) (Abell et al. 2016). Modification of sampling location may be needed due to morphological changes post-restoration. Sampling will be conducted between late September and early October on an annual basis. Detailed beach seining methods and data collection requirements are summarized in Abell et al. (2016).

Table 18. **Variables and data collection requirements for beach seining and electrofishing sampling for both coho salmon and steelhead trout on the Salmon River. Table adapted from Abell et al. (2016).**

Variable	Data Requirements
Weather	Observation
Morphology	Cover type, substrate, habitat unit, stream gradient, compaction
Site area	Length (m), full wetted width (m) and width at 0.1 m depths
Water depth	Max pool depth and 0.1 m depth perimeter
Water velocity	Recoded at multiple locations across site (m/s)
Water temperature	°C
Water chemistry	Conductivity (µS/cm)
Scale sampling	Sub sample within size classes to determine fish age
Fish counts	Number of fish caught
Fish species	Coho (CO) / steelhead (ST) / cutthroat (CT) / rainbow (RT)
Fish length	Fish fork length (mm)
Fish mass	Mass (g)
Beach Seining	
Sampling effort	Number of passes, typically 2 – 4 for observed decline in catch
Electrofishing	
Sampling effort	Shocking time (sec), number of passes required to observe declines in catch

Electrofishing is used to assess juvenile steelhead abundances upstream and downstream of the SRD. It is recommended that electrofishing sampling post-restoration continues to monitor steelhead juvenile abundance and distributions. Juvenile steelhead sampling will be conducted at ten sites during mid-September (Figure 25). These locations were selected as representative steelhead fry habitat within the upper Salmon River. Five parameters are considered before the selection of an electrofishing site (Table 19). Electrofishing is only effective when conductivity is greater than 30 µS/cm and water temperatures are above 4 °C (Lewis et al. 2012). Modification of sampling location may be needed due to morphological changes post-restoration. Electrofishing methods and data collection requirements are summarized in Abell et al. (2016).

Table 19. **Electrofishing site selection criteria for sampling juvenile steelhead trout in the upper Salmon River watershed. Table adapted from Abell et al. (2016).**

Parameter	Requirement
Water depth	Maximum 1 m, typical 0.1 – 0.4 m
Water velocity	Maximum 1.0 m/s, typical 0.1 – 0.5 m/s
Cover and substrate	Non- embedded boulder, cobble, and / or gravel
Area	100 m^2 target
Proximity	A close as possible to previous sampling sites

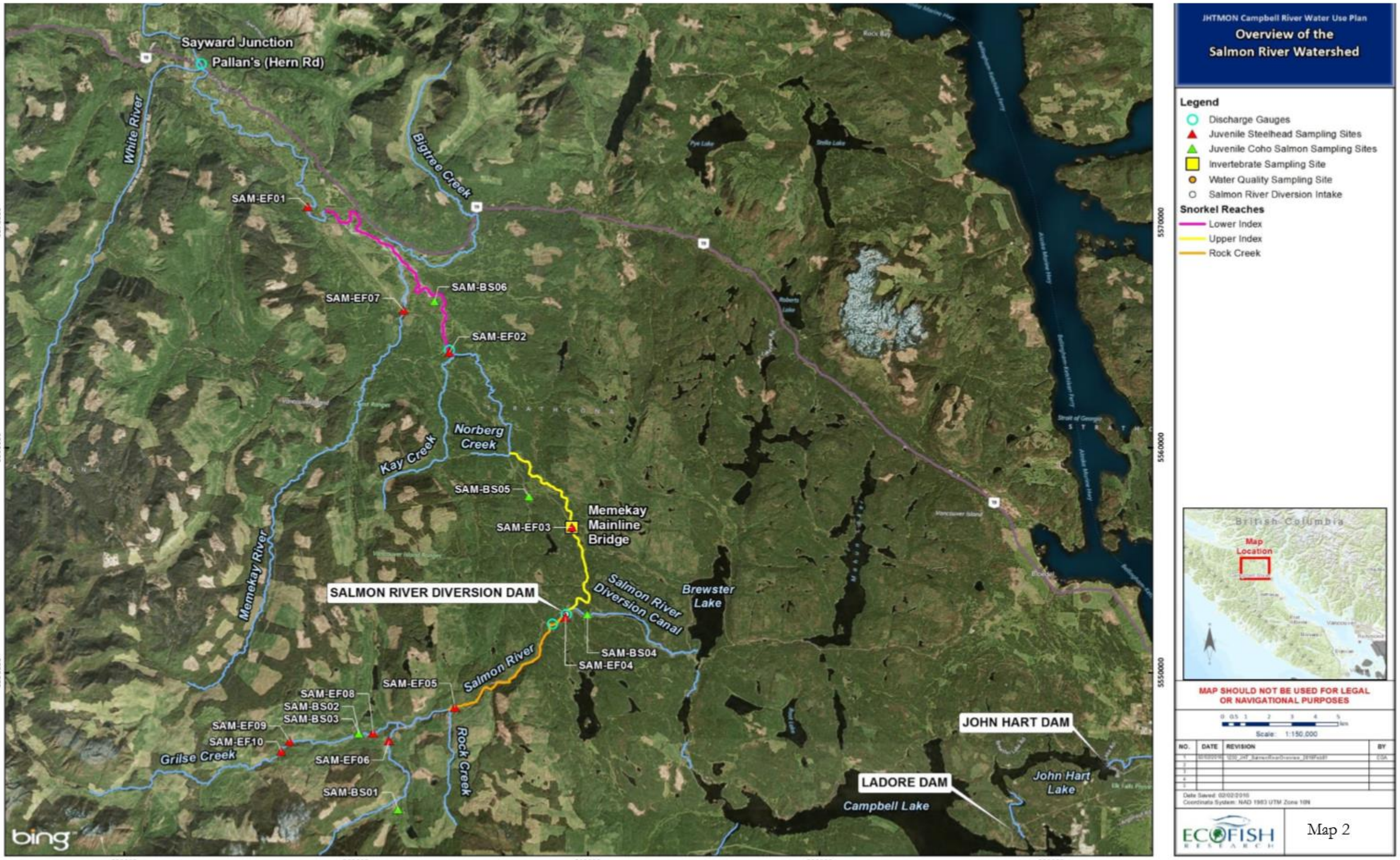

Figure 25. **Salmon River coho salmon and steelhead trout juvenile and spawner abundance assessment locations within the upper Salmon River. Sampling sites are consistent with historical sampling conducted by DFO and BCCF. Figure sourced from Abell et al. (2016).**

15.0 Restoration Maintence

Maintaining fish passage throughout the restoration reach may require additional restoration activities; annual FHAP assessment will identify areas of concern. Future spring freshets may cause significant changes to stream morphology that could compromise the navigability of the restoration reach. Additional LWD structures or boulders may be prescribed to increase heterogeneity if adult salmonids experience poor navigation success through the restoration reach (Slaney and Zaldokas 1997).

16.0 Ocean Survival

Ecological restoration is limited to influencing salmonid growth and survival in freshwater and brackish environments. Research has shown that increases in smolt length and weight prior to outmigration increase coho salmon and steelhead trout marine survival (Ward and Slaney 1988, Ward et al. 1989, Holtby et al. 1990). Once salmonids transition into salt water, populations move beyond the range of restoration influence until adults return back to their native streams to spawn. Improvements in coho salmon and steelhead trout production from the upper Salmon River will be controlled by ocean survival. Ocean survival rates are influenced by multiple environmental and ecological conditions including ocean temperature oscillations, ocean currents, food availability, predation, disease, and parasitic induced mortality (Mueter et al. 2002, Price et al. 2010). Mechanisms influencing salmonid ocean survival can be partitioned into three phases: 1) early ocean mortality, 2) oceanic residence mortality, and 3) return migration mortality.

Understanding the causes of early ocean mortality is a priority for fisheries science because high mortality rates in the early ocean life stage compromises freshwater restoration and enhancement efforts (Melnychuk et al. 2014). High predation pressures from avian and pinniped species (i.e., seals and sea lions) is a concern as smolts transition from freshwater to marine environments. Many studies have documented the high predation pressure piscivorous birds put on juvenile salmonids during their estuary residence time (Collis et al. 2002, Iese et al. 2008). Evans et al.

(2016) estimated a predation probability of 6 – 28% on Columbia River steelhead smolts from piscivorous bird populations throughout the lower reaches. Additionally, high predations pressures by harbor seals (*Phoca vitulina*) on out-migrating salmonid smolts has prompted experimental treatments to suppress feeding at the Puntledge River on Vancouver Island (Yurk and Trites 2000). Estuary predation is significant factor as salmonid smolts enter the marine environment at high densities causing a congregation of predators (Melnychuk et al. 2014).

Another major stressor for wild salmonids during their early ocean migration is parasite induced mortality (Krkošek et al. 2007). Sea lice (*Lepeophtheirus salmonis*) are a native parasitic copepod that target pacific salmonids as their host (Price et al. 2010). These parasites occur in high concentrations within salmon aquaculture pens positioned along the migration route of the Salmon River salmonids (e.g., Johnstone Straits and the Broughton Archipelago) (Price et al. 2010). High levels of exposure increase the probability that migrating juvenile salmonids are infected by these parasites (Krkosek et al. 2011). The removal of these pens from BC's coastal waters was identified as an essential step to protect the Fraser River sockeye against the high levels of parasitic and viral exposure from cultivated salmonids held in open-pen aquaculture farms (Cohen 2012). The scientific evidence and risk assessment of open-pen salmonid aquaculture combine to warrant a precautionary response from the Canadian and BC governments legislating the transition of salmonid aquaculture to land-based systems to protect wild salmonids populations migrating along the coast (Morton and Routledge 2016). This issue will influence marine survival for coho salmon and steelhead trout from the Salmon River and must be acknowledged as a stressor capable of undermining restoration benefits.

Shifting spatial and temporal climatic conditions of the Pacific Ocean influence ocean productivity and food availability for Pacific anadromous salmonid species (Friedland et al. 2014). Changes in seas surface temperature and ocean currents on short term (i.e., El Nino and La Nina oscillations) and long term (i.e., Pacific decadal oscillation) scales influence phytoplankton and zooplankton productivity across the Pacific Ocean (Batten and Welch 2004, Haeseker et al. 2012). The upwelling of cold, nutrient-rich water along BC's coast is positively correlated with increased salmonid survival (Holtby et al. 1990, Ryding and Skalski 1999). Chittenden et al. (2010)

documented that a 1.5 – 3 fold increasing in smolt-to-adult survival for Seymour River coho salmon during 2007 – 2009 when smolt migration timing matched with oceanic planktonic blooms. It is projected that phytoplankton and zooplankton productivity will be influenced by climate change by shifting the location, timing, and species assemblages of blooms in the Pacific Ocean (Mackas et al. 2007). These projected changes in combination with other marine environmental and ecological mechanism will influence the survival ratio of salmonids during their marine residence.

Salmonids that survive their oceanic residence experience increasing predation pressures during their return migration. Due to protection measure implemented for marine mammals, populations of harbor seals, California sea lions (*Zalophus californianus*), and Steller's Sea lions (*Eumetopias jubatus*) are recovering resulting in increased predation on adult salmonids throughout the PNW (Wright et al. 2007, Adams et al. 2016). Additionally, salmonids (i.e., predominantly Chinook salmon followed by coho salmon) make up approximately 98% the diet of the endangered southern resident killer whale (*Orcinus orca*) population (Ford et al. 2016). These predation pressures are expected to influence returns to the Salmon River for both salmonids species.

Harvesting efforts from humans represent a large proportion of salmonid mortality during their return migration. Salmonids are targeted by various commercial, recreational, and aboriginal fisheries along their coastal migrations routes. Historical overfishing in the PNW has suppressed salmonid populations and reduced the benefits they provide to their freshwater watersheds (Pike et al. 2010). A fisheries management recommendation is to transition to terminal fisheries to target specific stocks capable of sustaining the harvest effort (Ashley 2006, Cohen 2012). This restoration project aims to increase the productivity of the system and provide future opportunities for managed harvesting for local communities, but improper management of stocks could compromise the restoration benefits.

17.0 Future Restoration Recommendations

The removal of the SRD is the first priority for restoring the upper Salmon River. Additional restoration treatments can be implemented upstream of the SRD to further improve salmonid productivity. These restoration treats included: 1) installing LWD structures to increase stream complexity, 2) continuing the Salmon River stream enrichment program, and 3) implementing gravel bar staking for riparian succession and channel stabilization.

Increasing the density of LWD/km along the mainstem of the upper Salmon River and Grilse Creek will increases pool density, increase salmonid cover, increase hydrologic variability, and capture spawning gravel and nutrients moving downstream (Slaney and Zaldokas 1997). Restoration efforts can build off LWD structures that were previously installed on Grilse Creek (Gaboury and Murray 2003). The upper Salmon River and Grilse Creak stream order and slope (1 – 4%) are conducive to LWD installations (Slaney and Zaldokas 1997). Research has shown LWD installation increases juvenile survival rates and subsequently can increase adult coho and steelhead abundances by 1.8 and 2.3 times respectively (Slaney and Zaldokas 1997). Formation of additional pool habitat should be prioritized based on current densities identified in last FHAP assessment of the upper watershed (Silvestri and Gaboury 2008).

The continuation of the stream enrichment program on the Salmon River is a second option. The stream enrichment program spans 1989 – 2015 with variations in fertilization loading and locations (Pellett 2011). Nitrogen is considered a limiting nutrient in stream systems when dissolved inorganic nitrogen concentrations are < 20 µg/L, while phosphorus is considered limiting when concentrations of soluble reactive phosphorus are < 1 µ/L (Ashley and Stockner 2003). After 12 years of treatment, the mean increase in fry growth was 104% between controlled and treated locations (Pellett 2011). Increases in fry size decrease overwintering mortality and promote smolting at younger ages (Ward et al. 1989). This improves the smolt-recruitment per spawner (Ward et al. 1989, Holtby et al. 1990). The enrichment program was halted for a three-year period (2011-2013) and monitored to better understand background productivity in the upper Salmon River (Pellett 2014a). Unfortunately, the program was never fully reinstated after 2013 and is currently scheduled for termination in 2018 (K. Pellet pers. comm. March 22, 2017). The continuation of the program will increase the recolonization rate of the upper Salmon River by increasing juvenile growth and survival (Pellett 2011).

Live staking the upper Salmon River gravel bars to accelerate riparian succession and stabilize stream channels will benefit in-stream conditions for salmonids (Charron et al. 2011, Ryan et al. 2013). Insufficient LWD recruitment into streams produces broader and shallower channels over time (Roni et al. 2015). Channel broadening is intensified when sedimentation rates into streams are high (Slaney and Zaldokas 1997). Live staking gravel bars promotes the natural succession of gravel bar riparian vegetation (Polster 2002). This restoration treatment requires the use of an excavator to bury live willow and Balsam poplar stakes in a downstream direction systematically over a prescribed area (Polster 2002). Stakes should be a minimum of 1 m in length and only protrude approximated 20 cm (Polster 2002). Local cuttings with larger diameters increases the success rate of staking treatments (Polster 2002). This restoration treatment will only be applicable for broader flood plain sections of the upper watershed. Wong and Komori (1999) identified several barren gravel bar sections along the upper Salmon River and Grilse Creek in need of revegetation. An assessment of riparian conditions upstream of the SRD will identify priority area for live staking that have not progressed through succession since harvesting.

18.0 Conclusions

The removal of the SRD is the first priority for restoring river processes and improving salmonid productivity on the Salmon River. The diversion dam represents a connectivity bottleneck that can be removed with a targeted restoration opening up 26 km of additional mainstem spawning and rearing habitat for coho salmon and steelhead trout (Burt 2010a). The effects of this bottleneck have developing over the 60-year lifespan of the infrastructure decreasing the productive capacity of the watershed (Anderson 2009). This restoration plan targets the three identified stressors by: 1) restoring a historical flow regime back to the downstream portion of the Salmon River; 2) restoring the longitudinal connectivity of water, sediment, and nutrients, and 3) restoring unrestricted upstream and downstream migration of adult and juvenile salmonids. By addressing these stressors this restoration plan can increase coho and steelhead abundances, thus increasing the ecological benefits salmonids provide to their freshwater environments (Watkinson 2001).

Removing the SRD will mitigate against the projected effects of climate change and increases salmonid resilience. Climate modeling for the PNW is projecting increases in temperatures and changes in stream flow that will affect freshwater salmonids life stages (Beechie et al. 2013). Pacific salmonid have evolved to synchronize with seasonal abiotic patterns is coastal watershed (Groot and L. Margolis (eds.) 1991). However, these stream conditions (i.e., temperature and seasonal flow) may shift at rates that are beyond the adaptive capabilities of PNW salmonids (Mauger et al. 2015). Therefore, it is critical that restoration projects within the PNW include prescriptions that plan for future conditions.

The salmonids of the Salmon River are of high ecological, social, and cultural importance to the region and the community has worked diligently for over ten years to reach the outcome that was approved last June. This restoration plan has put forth recommendation for decommissioning, channel reconstruction, post-restoration monitoring, and future restoration considerations. It is also recommended that the community engages in an active stewardship role that will maintain this project and work towards furthering the recovery of the Salmon River ecosystem.

19.0 References

Abell, J., P. Dinn, H. Wright, J. Ellenor, and T. Hatfield. 2016. JHTMON-8: Salmon River and Quinsam River Smolt and Spawner Abundance Assessments Year 2 Annual Monitoring Report. Laich-Kwil-Tech Environmental Assessment Ltd. Partnership, Ecofish Research Ltd, Courtenay, BC.

Abell, J., T. Jensma, H. Wright, J. Ellenor, and T. Hatfield. 2015. JHTMON-8: Salmon River and Quinsam River Smolt and Spawner Abundance Assessments Year 1 Annual Monitoring Report. Laich-Kwil-Tech Environmental Assessment Ltd. Partnership, Ecofish Research Ltd, Courtnay, BC.

Adams, J., I. C. Kaplan, B. Chasco, K. N. Marshall, A. Acevedo-Gutirrez, and E. J. Ward. 2016. A century of Chinook salmon consumption by marine mammal predators in the Northeast Pacific Ocean. Ecological Informatics 34:44–51.

Anderson, S. 2009. Salmon River Adult Fish Passage Assessment Study Project #07.CBR.04. Fisheries and Oceans Canada, Burnaby, BC.

Ashley, K. I. 2006. Wild salmon in the 21st Century: Energy, Triage, and Choices. Pages 71–98. Salmon 2100: The Future of Wild Pacific Salmon (ed by Lackey, R.L. et al.).

Ashley, K. I., and J. G. Stockner. 2003. Protocol for Applying Limiting Nutrients to Inland Waters. Pages 245–260. J.G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Symposium 34, Bethesda, Maryland. American Fisheries Society Symposium.

Atkinson, J., and J. Damborg. 2015. Grilse Creek Large Woody Debris Rehabilitation 2014 FWCP Project # 14.CBR.01:1–27.

Batten, S. D., and D. W. Welch. 2004. Changes in oceanic zooplankton populations in the north-east Pacific associated with the possible climatic regime shift of 1998/1999. Deep-Sea Research Part II: Topical Studies in Oceanography 51:863–873.

BC Hydro. 2011. Campbell River Watershed Salmonid Action Plan. BC Hydro, Campbell River.

BC Hydro. 2012. Campbell River System Water Use Plan. BC Hydro, Campbell River, BC.

BC Hydro. 2012. Time Lapse – Heber River Diversion Decommissioning retrieved from: https://www.bchydro.com/news/unplug_this_blog/2012/heber-dam-decommissioned.html

BC Hydro. 2014. JHTWORKS-6 Salmon River Diversion Juvenile Fish Screen Upgrade. BC Hydro, Campbell River.

Beechie, T., H. Imaki, J. Greene, A. Wade, H. Wu, G. Pess, P. Roni, J. Kimball, J. Stanford, P. Kiffney, and N. Mantua. 2013. Restoring salmon habitat for a changing climate. River Research and Applications 29:939–960.

van Den Berghe, E. P., and M. R. Gross. 1984. Female Size and Nest Depth in Coho Salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 41:204–206.

Beschta, R., R. Bilby, G. Brown, L. Holtby, and T. Hofstra. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. Pages 191–232. Streamside management: forestry and fishery interactions.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat Requirments of Salmonids in Streams. Pages 83–138. Influences of Forest and Rangeland Managment on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publication.

Bovee, K. D. 1982. A Guide to Stream Habitat Analysis Using the Instream Incremental Flow Methodology. Page Instream Flow Information Paper. United States Fish and Wildlife Service. FWS/OBS-82/26.

Briggs, J. C. 1953. The Behavior and Reproduction of Salmonid Fishes in a Small Coastal Stream. Fish Bulletin:1–66.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. U.S. Fish and Wildlife Service Fishery Bulletin 52:94–110.

Burt, D. W. 2010a. Fisheries and Aquatic Resources of the Salmon River, Vancouver Island. D. Burt and Associates, Nanaimo, BC.

Burt, D. W. 2010b. Salmon River Upstream Fish Passage Step 3 – Environmental Feasibility Assessment. D. Burt and Associates, Nanimo, BC.

Charron, I., E. A. Johnson, and Y. E. Martin. 2011. Tree Establishment on Bars in Low-order Gravel-bed Mountain Streams. Earth Surface Processes and Landforms 36:1522–1533.

Chittenden, C. M., J. L. A. Jensen, D. Ewart, S. Anderson, S. Balfry, E. Downey, A. Eaves, S. Saksida, B. Smith, S. Vincent, D. Welch, and R. S. Mckinley. 2010. Recent salmon declines: A result of lost feeding opportunities due to bad timing? PLoS ONE 5.

Clarke, M., and D. Mccubbing. 2011. Radio telemetery observations of adult Steelhead trout (Oncorhynchus mykiss) migration behaviour and movements at the BC Hydro Diversion and fishway on the Salmon River, Spring 2011. Instream Fisheries Research Inc., North Vancouver, BC.

Cohen, B. I. 2012. The Uncertain Future of Fraser River Sockeye. Volume 1: The Sockeye Fishery. Minister of Public Works and Government Services Canada, Ottawa, ON.

Collis, K., D. D. Roby, D. P. Craig, S. Adamany, J. Y. Adkins, and D. E. Lyons. 2002. Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation. Transactions of the American Fisheries Society 131:537–550.

Craig, J., R. Ferguson, M. McCulloch, and H. Wright. 1998. A Synoptic Survey of Potential Rearing Habitat for Coho Salmon in the Upper Salmon River Watershed, Vancouver Island. BC Conservation Foundation, Nanaimo, BC.

Cram, J. M., C. E. Torgersen, R. S. Klett, G. R. Pess, D. May, T. N. Pearsons, and A. H. Dittman. 2012. Tradeoffs between homing and habitat quality for spawning site selection by hatchery-origin Chinook salmon. Environmental Biology of Fishes 96:109–122.

Crone, R.A., Bond, C. E. 1976. Life history of coho salmon, Oncorhynchus kisutch, in Sashin Creek, Southeastern Alaska. Fisheries Bulletin 74:897–923.

Damborg, J., and K. Pellett. 2011. Salmon River Diversion Bypass Fishway Design and Evaluation 2010/11 Project #10.CBR.03. BC Conservation Foundation, Lantzville, B.C.

Damborg, J., and K. Pellett. 2012. Salmon River Diversion Steelhead and Coho Passage Evaluation 2011/2012 Project #11.CBR.06. BC Conservation Foundation, Nanaimo, BC.

Dane, B. G. 1978. A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia. Department of Fisheries and Environment, Pacific Region, Fisheries and Marine Services, Vancouver, BC.

DFO. 2009. Salmon River Hatchery Release 1978 -2008. Fisheries and Oceans Canada, Salmonid Enchanment Program, Nanaimo, BC.

DFO. 2016. NuSEDS: New Salmon Escapement Database System. Fisheries and Oceans Canada. Accessed on Nov 24, 2016.

Douglas, T. 2001. Ecological Restoration Guidelines For British Columbia. Ministry of Water, Land, and Air Protection, Biodiversity Branch.

East, A. E., G. R. Pess, J. A. Bountry, C. S. Magirl, A. C. Ritchie, J. B. Logan, T. J. Randle, M. C. Mastin, J. T. Minear, J. J. Duda, M. C. Liermann, M. L. McHenry, T. J. Beechie, and P. B. Shafroth. 2015. Large-scale dam removal on the Elwha River, Washington, USA: River channel and floodplain geomorphic change. Geomorphology 246:687–708.

Environmental Managment Act (S.B.C., 2003, c. 53). British Columbia, Canada.

Evans, A. F., Q. Payton, A. Turecek, B. Cramer, K. Collis, D. D. Roby, P. J. Loschl, L. Sullivan, J. Skalski, M. Weiland, and C. Dotson. 2016. Avian Predation on Juvenile Salmonids: Spatial and Temporal Analysis Based on Acoustic and Passive Integrated Transponder Tags. Transactions of the American Fisheries Society 145:860–877.

Field, R. D., and J. D. Reynolds. 2011. Sea to sky: impacts of residual salmon-derived nutrients on estuarine breeding bird communities. Proceedings. Biological sciences / The Royal Society 278:3081–3088.

Fisheries Act (R.S.C., 1985, c. F-14). Canada.

Ford, M. J., J. Hempelmann, M. B. Hanson, K. L. Ayres, R. W. Baird, C. K. Emmons, J. I. Lundin, G. S. Schorr, K. Wasser, and L. K. Park. 2016. Estimation of a Killer Whale (Orcinus orca) Population's Diet Using Sequencing Analysis of DNA from Feces. PLoS ONE 11:1–14.

Forest and Range Practices Act (S.B.C., 2002, c. 69). British Columbia, Canada.

Friedland, K. D., B. R. Ward, D. W. Welch, and S. A. Hayes. 2014. Postsmolt Growth and Thermal Regime Define the Marine Survival of Steelhead from the Keogh River, British Columbia. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 6:1–11.

Gaboury, M., and R. B. Murray. 2003. Integrated Level 1 and 2 Fish Habitat Field Assessment of Selected Reaches in Grilse Creek and Marilou Creek. LGL Limited Environmental Research Associates, Sidney, BC.

Graf, W. L. 1999. Dam nation: A geographic census of american dams and their large-scale hydrologic impacts. Water Resources Research 35:1305–1311.

Grant, J. W. a, and D. L. Kramer. 1990. Territory Size as a Predictor of the Upper Limit to Population Density of Juvenile Salmonids in Streams. Canadian Journal of Fisheries and Aquatic Sciences 47:1724–1737.

Groot, C., and L. Margolis (eds.) 1991. Pacific Salmon Life Histories. Page UBC Press, Vancouver, B.C. Vancouver, BC.

Guimond, E., and M. Sheng. 2015. Assessment of the Distribution of 2014 Brood Coho Adult Migration Below and Above the Salmon River Diversion Dam Project 14.CBR.04. Fisheries and Oceans Canada, Nanaimo, BC.

Haeseker, S. L., J. A. McCann, J. Tuomikoski, and B. Chockley. 2012. Assessing freshwater and marine environmental influences on life-stage-specific survival rates of Snake River spring–summer Chinook salmon and steelhead. Transactions of the American Fisheries Society 141:121–138.

Haggan, N., N. Turner, J. Carpenter, J. T. Jones, Q. Mackie, and C. Menzies. 2006. 12,000+ Years of Change: Linking traditional and modern ecosystem science in the Pacific Northwest. Working Paper Series:30.

Hart, D. D., T. E. Johnson, K. L. Bushaw-Newton, J. Horwitz, Richard, A. T. Bednarek, D. F. Charles, D. A. Kreeger, and J. Velinsky, David. 2002. Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration. BioScience 52:669–682.

Hatfield, T., A. Lewis, and S. Babakaiff. 2007. Guidelines for the collection and analysis of fish and fish habitat data for the purpose of assessing impacts from small hydropower projects in British Columbia. Solander Ecological Research Ltd., Ecofish Research Ltd., and BC Ministry of Environment, Victoria, BC. Courtenay, BC. Surrey, BC.

Hauer, F. R., H. Locke, V. J. Dreitz, M. Hebblewhite, W. H. Lowe, C. C. Muhlfeld, C. R. Nelson, M. F. Proctor, and S. B. Rood. 2016. Gravel-bed river floodplains are the ecological nexus of glaciated mountain landscapes. Science Advances 2:1–14.

Heal, G., and W. Schlenker. 2008. Economics: Sustainable fisheries. Nature 455:1044–1045.

Helfield, J. M., and R. J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for steam productivity. Ecology 82:2403–2409.

Hill, G. 2011. Salmon River Diversion Upstream Adult Fish Passage Study. Northwest Hydraulic Consultants. Ltd., North Vancouver, BC.

Holtby, L. B., B. C. Andersen, and R. K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (Oncorhynchus kisutch). Canadian Journal of Fisheries and Aquatic Sciences 47:2181–2194.

Iese, F. R. K. W., J. U. K. P. Arrish, and C. H. W. T. Hompson. 2008. Ecosystem-Based Management of Predator – Prey Relationships : Piscivorous Birds and Salmonids. Ecological Applications 18:681–700.

Johnston, N. T., and P. a. Slaney. 1996. Fish Habitat Assessment Procedures: Watershed Restoration Technical Circular No. 8. Ministry of Environment, Lands and Parks and Ministry of Forests.

Keefer, M. L., and C. C. Caudill. 2014. Homing and straying by anadromous salmonids: A review of mechanisms and rates. Reviews in Fish Biology and Fisheries 24:333–368.

Keeley, E. R., and P. A. Slaney. 1996. Quantitative Measures of Rearing and Spawning Habitat Characteristics for Stream-Dwelling Salmonids: Guidelines For Habitat Restoration. Watershed Restoration Project No. 4, Ministry of Environment, Lands and Parks, Vancouver, Canada:32 p.

Kondolf, G. M., and M. G. Wolman. 1993. The sizes of salmonid spawning gravels. Water Resources Research 29:2275–2285.

Krkosek, M., B. M. Connors, A. Morton, M. a Lewis, L. M. Dill, and R. Hilborn. 2011. Effects of parasites from salmon farms on productivity of wild salmon. Proceedings of the National Academy of Sciences of the United States of America 108:14700–14704.

Krkošek, M., J. S. Ford, A. Morton, S. Lele, A. Ransom, and M. A. Lewis. 2007. Declining Wild Salmon Populations in Relation to Parasites from Farm Salmon. American Association for the Advancement of Science 318:1772–1775.

Laich-kwil-tach Treaty Society. 2012. Laich-Kwil-Tach Territory and Flood Story. Retrieved from https://www.youtube.com/watch?v=_Odyng8DmjU

Lewis, A., and K. Ganshorn. 2007. Literature Review of Habitat Productivity Models for Pacific Salmon Species. Ecofish Research Ltd., Vancouver, BC.

Lewis, A., T. Hatfield, B. Chilibeck, and C. Roberts. 2004. Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia:103.

Lewis, F. A., A. J. Harwood, G. Zyla, K. D. Ganshorn, and T. Hatfield. 2012. Long term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric projects. Page Canadian Science Advisory Secretariate.

Lienkaemper, G. W., and F. Swanson. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Fisheries and Aquatic Sciences 17:150–156.

Lill, A. F. 2002. The Greater Georgia Basin Steelhead Recovery Action Plan. AF Lill Associates Ltd., North Vancouver, BC.

Lyderson, H., S. Williams, A. Porter, M. Jacobs, Y. k. Muirhead, and D. W. Welch. 2008. Salmon River Fishway Assessment Study. Kinatama Research, Nanaimo, BC.

Mackas, D. L., S. Batten, and M. Trudel. 2007. Effects on zooplankton of a warmer ocean: Recent evidence from the Northeast Pacific. Progress in Oceanography 75:223–252.

Magilligan, F. J., B. E. Graber, K. H. Nislow, J. W. Chipman, C. S. Sneddon, and C. A. Fox. 2016. River restoration by dam removal: enhancing connectivity at watershed scales. Elementa: Science of the Anthropocene 4:108.

Manley, D., L. Hansen, and H. Wright. 2005. Salmon River Nutrient Enrichment for Fish Habitat Restoration 2005. BRitish Columbia Conservation Foundation, Nanaimo, BC.

Marshall, D. E., and E. W. Britton. 1990. Carrying Capacity of Coho Salmon Streams. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2058:32.

Mauger, G. S., J. H. Casola, H. A. Morgan, R. L. Strauch, B. Jones, B. Curry, T. M. B. Isaksen, L. W. Binder, M. B. Krosby, and A. K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Climate Impacts Group, University of Washington, Seattle, Washington.

McCubbing, D. J. F., and L. Burroughs. 2009. Salmon River (BC Hydro) Diversion Coho Salmon Fishway Passage Study 2008: Resistivity Counter Evaluation. InStream Fisheries Research Inc., North Vancouver.

Melnychuk, M. C., J. Korman, S. Hausch, D. W. Welch, D. J. F. McCubbing, C. J. Walters, and J. Grant. 2014. Marine survival difference between wild and hatchery-reared steelhead trout determined during early downstream migration. Canadian Journal of Fisheries and Aquatic Sciences 71:831–846.

Ministry of Agriculture. 2005. Drainage Management Factsheet: Fish Salvage. Ministry of Agriculture, Food, and Fisheries, Victoria, BC.

Ministry of Environment. 2004. Standards and Best Practices for Instream Works. WLAP BMP Series, BC Ministry of Water, Land and Air Protection, Ecosystem Standards and Planning. Victoria, B.C. Ministry of Water, Land, and Air Protection, Ecosystem Standards and Planning, Biodiversity Branch, Victoria, BC.

Morton, A., and R. Routledge. 2016. Risk and precaution: Salmon farming. Marine Policy 74:205–212.

Mueter, F. J., R. M. Peterman, and B. J. Pyper. 2002. Opposite effects of ocean temperature on survival rates of 120 stocks of Pacific salmon (Oncorhynchus spp.) in northern and southern areas. Canadian Journal of Fisheries and Aquatic Sciences 59:456–463.

Muller, I., M. Delisle, M. Ollitrault, and I. Bernez. 2016. Responses of riparian plant communities and water quality after 8 years of passive ecological restoration using a BACI design. Hydrobiologia 781:67–79.

Nature Trust of British Columbia. 2017. Salmon River Estuary Conservation Area. Retrieved from: http://www.naturetrust.bc.ca/wp-content/uploads/2015/04/Salmon-River-map.jpg

Navigation Protection Act (R.S.C., 1985, c. N-22). Canada.

Northwest Hydraulic Consultants Ltd. 1996. Salmon River Watershed Restoration Program. Northwest Hydraulic Consultants. Ltd., North Vancouver, BC.

Orcutt, D. R., B. R. Pulliam, and A. Arp. 1968. Characteristics of Steelhead Trout Redds in Idaho Streams. Transactions of the American Fisheries Society 97:42–45.

Pellett, K. 2011. A Review of Twenty Years of Nutrient Enrichment in the Salmon River Watershed, Vancouver Island (1989-2010). British Columbia Conservation Foundation, Nanaimo, BC.

Pellett, K. 2012. Steelhead Stock Production Monitoring in the Salmon River Watershed 2012. British Columbia Conservation Foundation, Nanaimo, BC.

Pellett, K. 2014a. Salmon River Stream Productivity Monitoring 2011-2013. British Columbia Conservation Foundation, Lantzville, B.C.

Pellett, K. 2014b. Steelhead Stock Production Monitoring in the Salmon River Watershed 2013. British Columbia Conservation Foundation, Nanaimo, BC.

Pess, G. R., M. L. McHenry, T. J. Beechie, and J. Davies. 2008. Biological Impacts of the Elwha River Dams and Potential Salmonid Responses to Dam Removal. Northwest Science 82:72–90.

Pike, R. G., T. E. Redding, D. Moore, and R. D. Winkler. 2010. Compendium of Forest Hydrology and Geomorphology in British Columbia Volume 2 of 2. Page Ministry of Forests and Range Forest Science Program.

Pohl, M. 2004. Channel Bed Mobility Downstream from the Elwha Dams, Washington. The Professional Geographer 56:422–431.

Polster, D. F. 2002. Soil Bioengineering Techniques for Riparian Restoration. Pages 230–239Proceedings of the 26th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC. Polster Enviornmental Services Ltd., Ottawa, Ontario.

Price, M. H. H., a. Morton, and J. D. Reynolds. 2010. Evidence of farm-induced parasite infestations on wild juvenile salmon in multiple regions of coastal British Columbia, Canada. Canadian Journal of Fisheries and Aquatic Sciences 67:1925–1932.

Ptolemy, R. A. 1980. Salmon River (Vancouver Island Enhancement: Anticipated smolt yield from the stream above the John Hart Diversion). Memorandum to Bob Hooton. BC Ministry of Recreation and Conservation, Fish and Wildlife Branch, Nanaimo, BC.

Ptolemy, R. A. 1993. Maximum salmonid densities in fluvial habitats in British Columbia. Pages 223–250Proceedings of the 1992 Coho Salmon Workshop, Nanaimo, BC. Nanaimo, BC.

Ptolemy, R. A. 2008. Biomass benchmarks for coastal cutthroat trout Oncorhynchus clarkii clarkii: can ecoregions be used as a place-based standard for abundance? Pages 89–91. The 2005 coastal cutthroat trout symposium: status, management, biology, and conservation. Fort Worden State Park, Port Townsend, Washington.

Ptolemy, R. A., J. C. Wightman, and C. D. Tredger. 1977. A Fisheries Reconnaissance Assessment of the Salmon River Drainage, Vancouver Island, Relative to Enchanement Oppertunities. Fish Habitat Improvement Section Fish and Wildlife Branch Ministry of recreation and Conservation, Victoria, BC.

Quinn, T. P., and N. P. Peterson. 1996. The influence of habitat complexity and fish size on over-winter survival and growth of individually marked juvenile coho salmon (Oncorhynchus kisutch) in Big Beef Creek, Washington. Canadian Journal of Fisheries and Aquatic Sciences 53:1555–1564.

Rieger, J., J. Stanley, and R. A. Y. Traynor. 2014. Project Planning and Management for Ecological Restoration. Island Press, Washington.

Riparian Areas Protection Act (S.B.C, 1997, c. 21). British Columbia, Canada.

Roni, P., T. Beechie, G. Pess, and K. Hanson. 2015. Wood Placement in River Restoration: Fact , Fiction , and Future Direction. Canadian Journal of Fisheries and Aquatic Science 72:466–478.

Rosenau, M. L., and M. Angelo. 2009. Landscape-Level Impacts to Salmon and Steelhead Stream Habitats in British Columbia. Pacific Fisheries Resource Conservation Council, Vancouver, BC.

Ryan, D. K., J. M. Yearsley, and M. Kelly-Quinn. 2013. Quantifying the effect of semi-natural riparian cover on stream temperatures: Implications for salmonid habitat management. Fisheries Management and Ecology 20:494–507.

Ryding, K. E., and J. R. Skalski. 1999. Multivariate regression relationships between ocean conditions and early marine survival of coho salmon (*Oncorhynchus kisutch*). Canadian Journal of Fisheries and Aquatic Sciences 56:2374–2384.

Salinger, D. H., and J. J. Anderson. 2006. Effects of Water Temperature and Flow on Adult Salmon Migration Swim Speed and Delay. Transactions of the American Fisheries Society 135:188–199.

Silvestri, S., and M. Gaboury. 2008. Habitat Assessment and Restoration Opportunities in The Salmon River Watershed, Vancouver Island Project # 06.CBR.06. BC Conservation Foundation, LGL Limited Environmental Research Associates, Nanaimo, BC.

Slaney, P. A. 1980. Salmon River: Potential Anadromous Salmonid Production Above the Diversion. Memorandum to Bob Hootonn. Ministry of Environmet, Lands and Parks, Nanaimo, BC.

Slaney, P. A., and D. Zaldokas. 1997. Fish Habitat Rehabilitation Procedures: Watershed Restoration Technical Circular No. 9. Watershed. Ministry of Environment, Lands and Parks and Ministry of Forests.

Species at Risk Act (S.C. 2002, c. 29). Canada

Stockner, J. G., and K. I. Ashley. 2003. Salmon Nutrients: Closing the Circle.

Tautz, A. F., B. R. Ward, and R. A. Ptolemy. 1992. Steelhead Trout Productivity and Stream Carrying Capacity for River of the Skeena Drainage. Ministry of Environmet, Lands and Parks, Fisheries Branch, Vancouver, BC. Victoria, BC.

Taylor, P., and A. K. Smith. 1973. Development and Application of Spawning Velocity and Depth Criteria for Oregon Salmonids. Transactions of the American Fisheries Society 102:312–316.

Ward, Bruce R; Slaney, P. A. 1993. Egg-to-Smolt Survival and Fry-to-Smolt Density Dependence of Keogh River Steelhead Trout. Canadian special publication of fisheries and aquatic sciences 118:209–217.

Ward, B. R. 2000. Declevity in steelhead (Oncorhynchus mykiss) recruitment at the Keogh River over the past decade. Canadian Journal of Fisheries and Aquatic Sciences 57:298–306.

Ward, B. R., and P. A. Slaney. 1988. Life History and Smolt-to-Adult Survival of Keogh River Steelhead Trout (Salmo gairdneri) and the Relationship to Smolt Size. Canadian Journal of Fisheries and Aquatic Sciences 45:1110–1122.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-Biased Survival in Steelhead Trout (Oncorhynchus mykiss): Back-Calculated Lengths from Adults' Scales Compared to Migrating Smolts at the Keogh River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 46:1853–1858.

Ward, B. R., and J. C. Wightman. 1989. Monitoring steelhead trout at the Keogh River as an index of stock status and smolt-to-adult survival: correlations with other data sources. Ministry of Enviornment, Recreation Fisheries Branch, Fisheries Research and Development Section, Vancouver, BC.

Ward, E. J., J. H. Anderson, T. J. Beechie, G. R. Pess, and M. J. Ford. 2015. Increasing hydrologic variability threatens depleted anadromous fish populations. Global Change Biology 21:2500–2509.

Water Sustainability Act (S.B.C., 2014, c. 15). British Columbia, Canada.

Watkinson, S. 2001. Life after death: the importance of salmon carcasses to watershed function. University of British Columbia.

Wildlife Act (R.S.B.C., 1996, c. 488). British Columbia, Canada.

Williams, J. G. 2008. Mitigating the effects of high-head dams on the Columbia River, USA: Experience from the trenches. Hydrobiologia 609:241–251.

Winter, B., and P. Crain. 2008. Making the case for ecosystem restoration by dam removal in the Elwha River, Washington. Northwest Science 82:13–28.

WSC. 2016. Historical streamflow summary for stations 08HD015, 08HD007, and 08HD006. British Columbia. Environment and Climate Change Canada, Water Survey of Canada, Ottawa, ON. Data accessed on March 6, 2016.

Wong, R., and V. Komori. 1999. Level 1 Fish Habitat Assessment and Restoration Oppertunities for Grilse Creek and Upper Salmon River. Watershed Restoration Program, Courtenay, BC.

Wright, B. E., S. D. Riemer, R. F. Brown, A. M. Ougzin, and K. A. Bucklin. 2007. Assessment of Harbor Seal Predation on Adult Salmonids. Ecological Applications 17:338–351.

Yurk, H., and A. W. Trites. 2000. Experimental Attempts to Reduce Predation by Harbor Seals on Out-Migrating Juvenile Salmonids. Transactions of the American Fisheries Society 129:1360–1366.

Zapf-Gilje, R., G. C. Patrick, and R. McLenehan. 2001. Overview of the remediation process at sites with creosote related contamination in soil, groundwater and river sediment. Canadian Journal of Civil Engineering 28:141–154.

Appendix A.

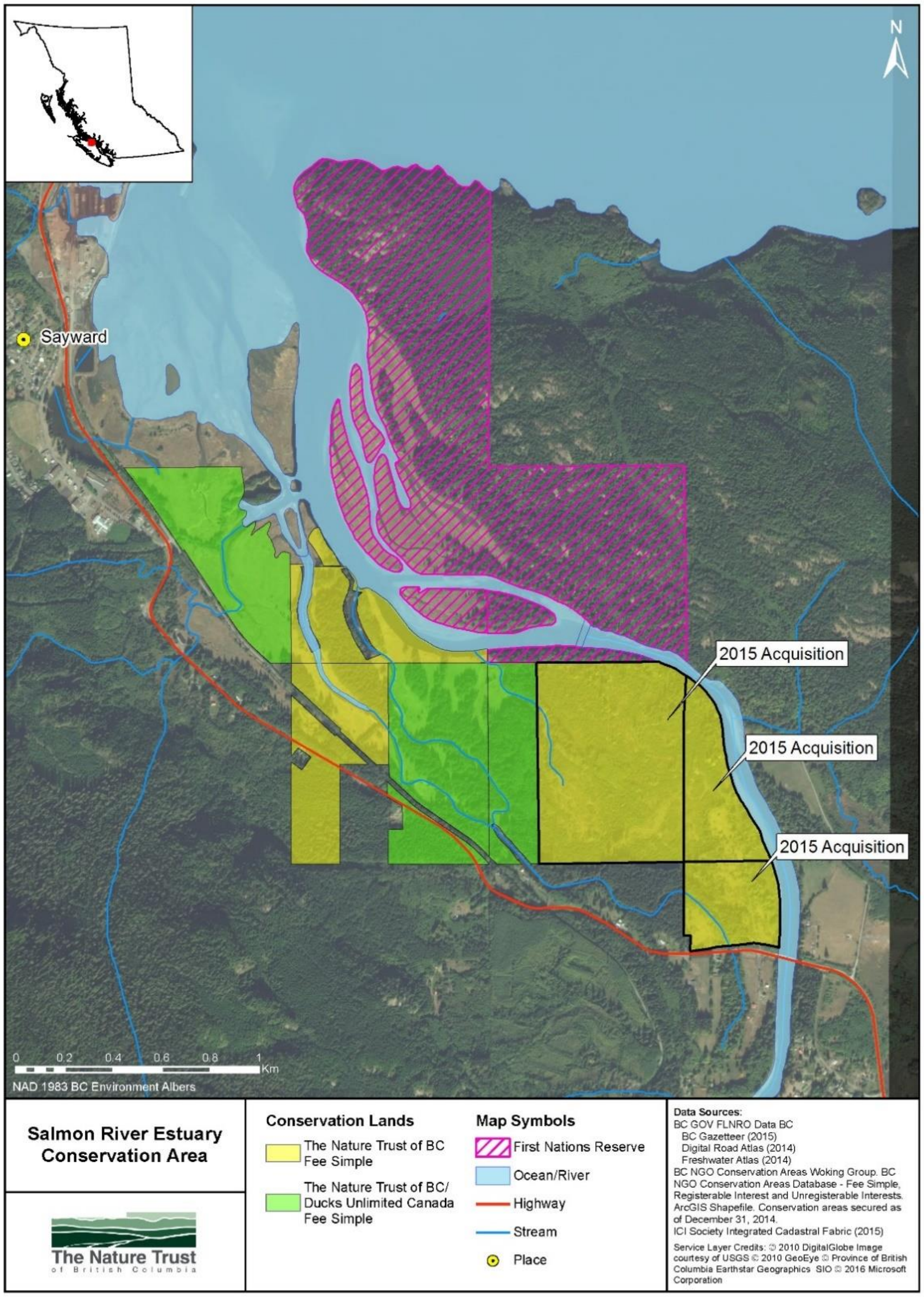

Figure A1. The Salmon River estuary conservation area purchased by the Nature Trust of British Columbia in 1978 and 2015. Sourced from Nature Trust of British Columbia (2017).