Campbell River Project Water Use Plan

JHTMON-6 Campbell Watershed Riverine Fish Production

Implementation Year 2

Reference: JHTMON-6

Fish Passage Study

Study Period: March 1, 2016 to April 30, 2017

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd.

October 23, 2017

JHTMON-6: Campbell Watershed Riverine Fish Production Assessment – Component 2 Fish Passage Study

Year 2 (2016) Annual Report

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EXECUTIVE SUMMARY

As the development of the Campbell River Water Use Plan process reached completion, a number of uncertainties remained regarding flow-habitat relationships in the Campbell River watershed. These uncertainties hindered assessment of benefits to fish from the WUP-recommended operations. The JHTMON-6 Campbell Watershed Riverine Fish Production Assessment was designed to resolve these uncertainties with three separate studies focused on: 1) assessment of flow-habitat relationships; 2) assessment of the impacts of physical barriers on fish migration; and 3) hydrological modelling. The component of JHTMON-6 that is focused on potential impacts of barriers to fish movement, and that is addressed in this report, is the Fish Passage Study, the objective of which are to assess the relationship between barriers and flow in relation to fish migration and to develop fish passage prescriptions in the Quinsam and Salmon rivers. During Year 1 (2015) of this study a literature review was conducted, a workplan was developed, and study sites were selected. This report presents preliminary results from Year 2 during which the barriers themselves were assessed and fish movement was directly evaluated. Year 2 was the first of a two year field program that will continue in Year 3 (2017). After the completion of the Year 3 field program a summary report will be prepared.

Three barrier study sites were established in the Quinsam River (QUN-BAR01, QUN-BAR05, and QUN-BAR07). All sites were bedrock chutes that present potential barriers to fish movement due to the shallowness of water at low flows and high velocities at high flows. Assessment of these barriers involved installation of remote wildlife cameras so that time-lapse photos could be used to relate conditions of these barriers to stream flow rates and there help to assess the relationship between habitat conditions (e.g., wetted width, water depth) and discharge. The time-lapse photos suggest that QUN-BAR01 was the most difficult barrier for fish to pass.

PIT tagging and snorkel surveys were conducted in the Quinsam River to directly evaluate fish movement between barriers QUN-BAR07, QUN-BAR05, and QUN-BAR01. Three stations were established: one located downstream of QUN-BAR07 (downstream site), one located upstream of QUN-BAR05 (middle site), and one located upstream of QUN-BAR01 (upstream site). PIT tag array systems were installed at each station and were monitored from September 27, 2016 to March 7, 2017 for the downstream site, September 27 to October 12, 2016 for the middle site, and October 4 to 8, 2016 and October 24, 2016 to January 5, 2017 for the upstream site. In total, 168 tagged adult Coho Salmon and 20 tagged Steelhead were released. Ten Coho Salmon and two Steelhead tags were detected at the downstream site. No fish were detected at the middle or upstream sites which may have been at least partly due to equipment problems because these PIT tag systems were affected by persistently high flow events in the fall and early winter of 2016 – 2017.

Seven snorkel reaches were established in relation to barriers QUN-BAR01 to QUN-BAR07. Three snorkel surveys were completed in fall and early winter (October 4, 2016 to December 5, 2016) that were conducted to evaluate adult Coho Salmon and Chinook Salmon passage, and four snorkel surveys were conducted during winter and early spring (January 6, 2017 through March 7, 2017) to

evaluate adult Steelhead passage. In total, 17 Coho Salmon, no Chinook Salmon, and one Steelhead were observed in the Quinsam River. Coho Salmon were observed upstream of all barriers except for QUN-BAR01 while the single detected Steelhead was not observed above any barriers. These preliminary results suggest that barriers QUN-BAR07 to QUN-BAR02 are passable by Coho Salmon and, given their higher swimming speed, likely also by Steelhead (although this could not be confirmed).

Three barrier study sites were also established in the Salmon River (SAM-BAR05, SAM-BAR07 and SAM-BAR011). All sites were potential barriers due to the presence of shallow water riffles at low flows. Physical riffle analysis was used to assess barriers for each fish species. In Year 2, the first two of four sets of riffle surveys were conducted. The two sets of surveys were timed to survey the riffles during the two lowest target flow rates: Survey 1 was conducted from August 24 to 25, 2016 and Survey 2 was conducted from September 12 to 13, 2016. Sampling included conducting a bed elevation profile survey along with records of discharge and water levels during the surveys and relating results to species-specific minimum depth criteria. In addition, stage-discharge relationships at the riffle barrier sites were determined by installing temporary water level recorders and relating water level to discharge estimated at the site using data from WSC gauge 08HD032. Results of the physical riffle analysis indicated that all three barriers were unpassable under the flow rates observed in Surveys 1 and 2; however, additional data from the remaining two higher target flow rates, to be collected in Year 3, will be required to fully evaluate passage flows for each barrier.

Thirteen snorkel reaches were established to directly evaluate fish movement between barriers in the Salmon River. Three snorkel surveys were completed in the fall and early winter (October 4, 2016 to December 12, 2016) to evaluate adult Coho and Chinook Salmon passage and four snorkel surveys were completed during the spring (March 21, 2017 through April 27, 2017) to evaluate adult Steelhead passage. In total, 340 Coho Salmon, five Chinook Salmon, and 33 Steelhead were observed in the Salmon River. During the fall and early winter snorkel surveys Coho Salmon were observed upstream of SAM-BAR07 and SAM-BAR11, in the areas both immediately and away from both respective barriers. Chinook Salmon were only observed upstream of SAM-BAR07, but not immediately upstream of the barrier. During the spring snorkel surveys Steelhead were observed upstream of SAM-BAR07 and SAM-BAR11, but not immediately upstream of the barriers. No fish were observed upstream of SAM-BAR05. These preliminary results suggest that SAM-BAR07 was passable for all three species and SAM-BAR11 was passable for Coho Salmon and Steelhead. We were unable to determine whether lack of Chinook Salmon upstream of SAM-BAR11 was due to species-specific passage difficulties or due to survey methodology.

MON-6 Comp 2: Status of Objectives, Management Questions and Hypotheses after Year 2.

Study Objectives	Management Questions	Management Hypotheses	Year 2 Status
The aim of JHTMON-6 is to resolve uncertainty with habitat-flow relationships to determine habitat-flow relationships in the Quinsam and Salmon Rivers, accessibility to habitat upstream of barriers in the Quinsam and Salmon rivers at different flow rates, and resolve the conflicting 1D and R2D modelling results in the Lower Campbell River.	At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam and Salmon Rivers, and is its frequency/duration sufficient to ensure successful migration?	*$H_0$4: Over the range influenced by the impoundment/diversion structure, successful passage of upstream migrants in the diversion donor streams is unrelated to flow.* *$H_0$5: The frequency and duration of flow events outside the range considered to be optimal or near optimal for successful passage (to be defined in consultation with federal and provincial fisheries agencies) are not sufficient to severely impede successful migration of the population.*	Preliminary data and results collected in Yr 2. Full assessment will be undertaken after the completion of the Year 3 field program.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

1. INTRODUCTION

The goal of water use planning is to provide a balance between the competing uses of water, which, for BC Hydro, includes fish and wildlife, recreation, and power generation. Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies, and First Nations. The framework for water use planning requires that a WUP be reviewed on a periodic basis and that monitoring is used to address outstanding management questions in the years following the implementation of a WUP.

As development of the Campbell River Water Use Plan (BC Hydro 2012) reached completion, a number of uncertainties remained. To address these uncertainties, habitat study and monitoring programs were designed to assess whether fish benefits are being realized under the WUP operating regime. The *Campbell Watershed Riverine Fish Production Assessment* (JHTMON-6) comprises one component of the broader effectiveness monitoring study that is being implemented within the Campbell River WUP to address the identified uncertainties. The focus of JHTMON-6, which is itself comprised of three separate studies, is the assessment of flow-habitat relationships, the assessment of the impacts of physical barriers on fish migration, and assessing and resolving results of existing hydrological models developed for the Campbell River WUP.

The component of JHTMON-6 that is focused on potential impacts of barriers to fish movement, and that is addressed in this report, is the Fish Passage Study. The objectives of the Fish Passage Study are to assess the relationship between barriers and flow in relation to fish migration and to develop fish passage prescriptions in the Quinsam and Salmon rivers. The outcomes of this study will help resource managers to better understand the potential biological effects of BC Hydro operations on fish and fish habitat in relation to physical stream barriers. In Year 1 (2015) of this study a background literature review was conducted and preliminary site visits were completed to the Quinsam and Salmon rivers. The literature review compiled existing information on fish populations, known barriers, and diversion operations in the Quinsam and Salmon rivers. The site visits assessed potential barriers identified in the literature review and selected study sites that were appropriate for assessment of barrier effects. Using data collected in the literature review and site visits a workplan was developed for Years 2 and 3 (Marriner *et al.,* 2016). This report presents results from Year 2 during which barrier assessments were conducted and fish movement was evaluated.

1.1. <u>BC Hydro Infrastructure, Operations, and Monitoring Context</u>

BC Hydro owns and operates diversion infrastructure for hydropower production on the Quinsam and Salmon rivers in the Campbell River Watershed, both of which are located near the city of Campbell River on the east coast of Vancouver Island, British Columbia. Details of the diversion infrastructure and operations are provided in BC Hydro (2013), and a brief summary relevant to this project is provided below.

1.1.1. The Quinsam River

The Quinsam River is located on the eastern side of Vancouver Island near the city of Campbell River (Map 1). The Quinsam River is the only major tributary of the lower Campbell River, and flows into the Campbell River approximately 3.4 km upstream from the ocean. The Quinsam River is 45 km in length, has a drainage area of 283 km^2, and has a mean annual discharge (MAD) of 8.5 m^3/s. The Quinsam River flows through four lakes: Lower Quinsam Lake, Middle Quinsam Lake, Upper Quinsam Lake, and Wokas Lake. The main tributaries to the Quinsam River include Flintoff Creek, Cold Creek, and the Iron River.

BC Hydro owns and operates a storage dam at the outlet of Wokas Lake, a diversion dam 47.4 km from the mouth of the Quinsam River, and a diversion canal. Non-diverted water is conveyed to the Quinsam River via an undersluice gate or the free crest weir. Both dams were constructed in 1957.

The Quinsam River Hatchery has been in operation since 1974, and is located 3.3 km upstream from the confluence with the Campbell River. The hatchery has been active in the watershed, augmenting populations of Chinook Salmon, Pink Salmon, Coho Salmon, Cutthroat Trout (*O. clarkii*), and Steelhead (DFO 2009). Smolt and fry life stages that are ready for downstream migration to the ocean are released from the hatchery during the spring. In addition, juvenile Coho Salmon, Steelhead, and (less frequently) Chinook Salmon have been outplanted to the upper watershed since 1978 to promote adult returns upstream of the hatchery (Burt 2003).

1.1.2. The Salmon River

The Salmon River is located in central Vancouver Island with headwaters originating in the Vancouver Island Ranges in the north end of Strathcona Park. The river flows approximately northwest, entering the ocean near the town of Sayward on eastern Vancouver Island (Map 1). The watershed area of the Salmon River is approximately 1,300 km^2 and the MAD is 63.3 m^3/s at the mouth (Burt 2010). Major tributaries of the Salmon River include Grilse Creek, Memekay River, and White River. Approximately 80 km of the Salmon River is accessible to anadromous salmonids (Lill 2002).

BC Hydro owns and operates the Salmon River Diversion infrastructure, which consists of a diversion dam and associated canal located 54.2 km upstream of the mouth, and which was initially constructed in 1958. The diversion dam is a 69 m-long rock-filled timber crib dam that diverts water into the Campbell River watershed. Water is diverted from the mainstem of the Salmon River, via an intake channel, through a radial gate and into a concrete-lined canal that conveys water through a series of lakes (Brewster, Gray, Whymper, and Fry lakes) to the Lower Campbell Lake Reservoir, where the water is used for generation at the Ladore and John Hart hydroelectric projects. Non-diverted water is returned to the mainstem downstream, either via the main spillway, an undersluice gate, a trimming weir, or the fishway. The diversion canal is 7.8 km long with a capacity of 42.5 m^3/s.

A smolt screen was installed 500 m below the diversion canal intake in 1986 to return outmigrating smolts entering the canal to the Salmon River. Additionally, a fishway was constructed at the diversion dam in 1992 to provide improved upstream passage for Coho Salmon and Steelhead (Burt and Robert 2001). However, there have been issues with the performance of both the fish screen and the fish way (Burt 2010) and BC Hydro has decided to decommission the facility

1.2. Management Questions and Hypotheses of JHTMON-6

A number of uncertainties were identified related to evaluation of the effect of BC Hydro operations on aquatic resources in the Campbell River watershed during the development of the Campbell River Water Use Plan (BC Hydro 2012). The primary consequence of these uncertainties is a weak ability to predict changes in fish production in response to operational changes proposed during development of the WUP. Habitat studies that were originally planned to address these uncertainties could not be completed within the time and budget constraints of the WUP process; consequently, a desktop approach that was less data-intensive was adopted to predict how changes to flow would affect fish habitat. This approach was based on a meta-analysis of instream flow studies undertaken elsewhere to predict flow-habitat relationships (Hatfield and Bruce 2000, Bruce and Hatfield, *in preparation*). However, this approach was untested, and its acceptance by the Fish Technical Committee (FTC) was contingent on resolving information gaps related to three key topics (BC Hydro 2013):

1. Habitat-flow relationships in diversion donor streams;
2. Physical barriers to upstream migration in diversion donor streams, which have not been investigated to date; and
3. Hydrological modelling, for which conflicting results were obtained for two models applied to the Lower Campbell River to date.

The JHTMON-6 Campbell Watershed Riverine Fish Production Assessment was designed to resolve these uncertainties by addressing the following four management questions (BC Hydro 2013):

1. What is the empirical relationship between habitat and flow in the Quinsam River diversion route through Miller Creek, and Salmon River mainstem downstream of the diversion, for all salmonid species during their fry, juvenile, and spawning life stages?
2. Are these empirical flow-habitat relationships consistent with the meta-analysis results from other locations?
3. At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam and Salmon Rivers, and is its frequency/duration over this range of flows sufficient to ensure successful migration?
4. What are the key differences between one- and two-dimensional hydraulic modeling approaches to habitat assessment of streams? What are their strengths and weaknesses and what method should be used to model hydraulic/habitat conditions in lower Campbell River?

These questions are designed to be addressed by testing six null hypotheses (BC Hydro 2013):

$H_0$1: Over the range controlled by the diversion, flow does not affect the quantity and quality of fish habitat.

$H_0$2: The empirically derived flow-habitat relationships for each diversion stream do not differ significantly from the predictions made by the Bruce and Hatfield (in progress) meta-analysis model.

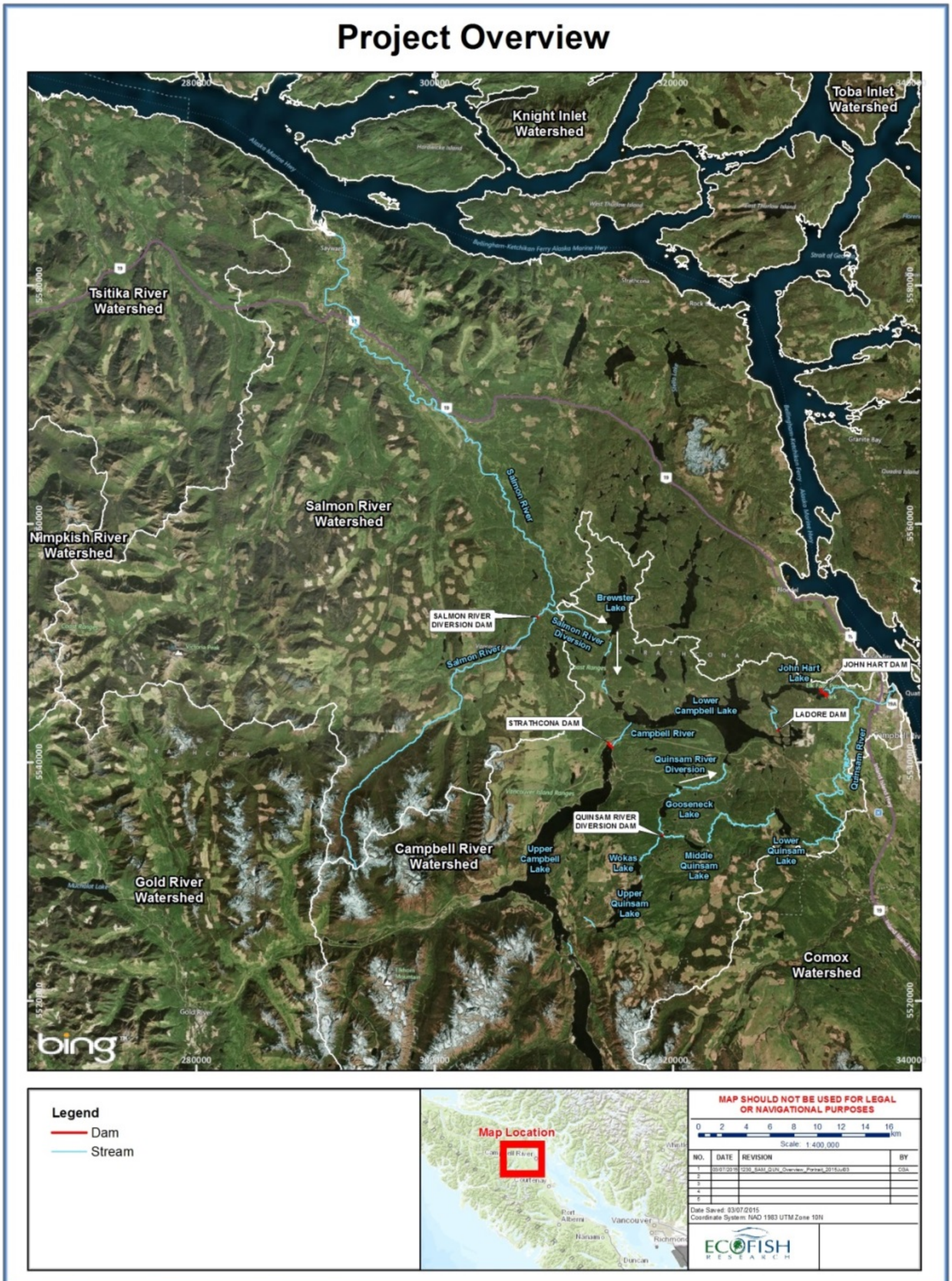
$H_0$3: The frequency and duration of flow events outside the range considered to be optimal or near optimal for maximum habitat availability are not sufficient to cause measurable long term population impacts as indicated by fish abundance assessments.

$H_0$4: Over the range influenced by the impoundment/diversion structure, successful passage of upstream migrants in the diversion donor streams is unrelated to flow.

$H_0$5: The frequency and duration of flow events outside the range considered to be optimal or near optimal for successful passage (to be defined in consultation with federal and provincial fisheries agencies) are not sufficient to severely impede successful migration of the population.

$H_0$6: Habitat-flow relationships derived from hydraulic data collected through 1D (transect based) and River2D (triangular grid based) are not significantly different.

Map 1. Location of the Quinsam and Salmon rivers.



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1.3. Objectives and Scope of the Fish Passage Study

Three independent studies have been designed as part of JHTMON-6, each corresponding to one of the key topics identified by the FTC. The second topic, *physical barriers to upstream migration in diversion donor streams,* is addressed by the Fish Passage Study, which is a three-year study (2015-2018) conducted on the Quinsam and Salmon rivers with objectives of assessing the relationship between barriers and flow in relation to fish migration and to identify fish passage prescriptions for the Quinsam and Salmon rivers. Thus, this study addresses the third of the four JHTMON-6 management questions:

> At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam and Salmon Rivers, and is its frequency/duration sufficient to ensure successful migration?

The two null hypotheses associated with this management question (BC Hydro 2013) are:

> *$H_0$4: Over the range influenced by the impoundment/diversion structure, successful passage of upstream migrants in the diversion donor streams is unrelated to flow; and*
>
> *$H_0$5: The frequency and duration of flow events outside the range considered to be optimal or near optimal for successful passage (to be defined in consultation with federal and provincial fisheries agencies) are not sufficient to severely impede successful migration of the population.*

2. METHODS

The methods employed for assessing the impacts of physical fish barriers to fish movement in relation to flow rate in the Quinsam and Salmon Rivers involved barrier assessments combined with direct assessment of fish movement in relation to barrier locations. Barrier study site locations were selected in Year 1 (October 2015), as described in Marriner *et al.* (2016), based on the outcomes of a review of existing information, interviews with local experts, and the results of reconnaissance site visits. Year 2 methods involved assessment of barriers at the study sites and fish movement through these barriers. Riffle analyses were conducted at Salmon River sites where barriers were shallow water riffles, and wildlife cameras were used at all barrier locations to provide photographic records of habitat conditions during a variety of flows. Direct evaluation of the potential for barriers to inhibit fish migration was conducted through snorkel surveys around barriers in both rivers, and PIT tagging was conducted in the Quinsam River.

2.1. Quinsam River

2.1.1. Barrier Study Sites

Fourteen potential barrier study sites were initially identified on the Quinsam River, three of which were selected for detailed biological and physical monitoring based on the results of site visits: QUN-BAR01, QUN-BAR05, and QUN-BAR07 (Map 2). All three sites are bedrock shelves that create chutes. These sites present potential barriers due to the shallowness of water at low flows and high velocities at high flows. The bedrock chutes are located just downstream of Lower Quinsam

Lake, approximately 24.2 km (QUN-BAR01) to 24.4 km (QUN-BAR07) upstream of the mouth of the Quinsam River.

2.1.2. Barrier Assessments

Standard remote wildlife cameras (e.g., Reconyx brand) were deployed at QUN-BAR01, QUN-BAR05, and QUN-BAR07 to provide visual records of habitat conditions during low flow periods. Cameras, which were deployed on August 17, 2016 and retrieved in the late fall during snorkel surveys, were programed to record photographs at a time-lapse interval of 1 hr. The time-lapse photos were correlated with stream flow rates to help to assess the relationship between habitat conditions (e.g., wetted width, water depth) and discharge at individual barriers. The time-lapse photos will also be used to assist in the site selection process for a field-based physical barrier survey in Year 3 based on methods developed by Reiser *et al.* (2006).

2.1.3. Fish Tagging and Detection

Assessment of fish movement in relation to barriers was conducted in the Quinsam River by: 1) capturing and tagging fish with PIT tags and detecting them through the use of PIT tag antenna arrays; and 2) conducting snorkel surveys.

2.1.3.1. PIT Tagging

The PIT tagging method was adopted from FLNRO and BCCF protocols for Steelhead and Coho Salmon. The method offers efficient tagging, high tag retention, and good external visibility (McCulloch pers. comm. 2016). The tags were premade by attaching a 23 mm HDX PIT tag to a 30 cm piece of Floy FT-4 spaghetti tag material and were inserted through the base of the dorsal fin of captured fish using a stainless steel needle, and then knotted to form a closed loop. The method was modified at the beginning of the winter Steelhead tagging on December 21, 2016. A 0.03 inch diameter welding wire was inserted into the core of the Floy material. This modification was made to increase the strength of the tags, and to prevent the knots from untying, which was deemed necessary after broken tags were recovered by Quinsam Hatchery staff in the trap pond pool, downstream of the fence.

Bright colours were used for spaghetti tag loop materials which allowed PIT-tagged fish (including carcasses) to be visually identified during snorkel surveys and thereby provided the potential to collect additional information about the distribution of tagged fish. This helped snorkel survey crews and Quinsam Hatchery staff to identify instances of potential sampling bias due to altered fish behaviour caused by catching and handling fish (Pine *et al.* 2003), such as observations of tagged fish returning downstream. Three distinct tag colours were used for Coho tagging (pink, blue, white). Pink tags were used from September 23 – October 13, 2016; blue tags were used from October 13 – November 1, 2016; and white tags were used from November 1 – November 10, 2016. Steelhead were randomly tagged with either of the three colours.

Adult Coho Salmon were captured at the Quinsam Hatchery during the start of the Coho Salmon migration period in late September and October during broodstock capture and sorting at the

Quinsam Hatchery fence. Steelhead were captured in December and January by angling in the Quinsam River, downstream of the hatchery fence. Steelhead angling coincided with annual Cutthroat Trout brood stock angling and any Steelhead that were captured incidentally during fall broodstock sorting at the hatchery fence were also tagged. Fish tagged during hatchery broodstock sorting were released upstream of the hatchery fence, and angled Steelhead were released at the point of capture. Fork length, sex, and condition were recorded for each tagged fish along with its PIT tag number.

2.1.3.2. Fish Detection

The movements of tagged fish were monitored using three PIT tag detection systems placed near the barriers of interest, as shown in Map 2. Each PIT tag system consisted of a single antenna connected to a capacitance tuner box, which was connected to an antenna tag reader, supplied by Oregon RFID Inc. The downstream PIT tag system (QUN-PTANT07) was installed a short distance downstream of QUN-BAR07, the middle system (QUN-PTANT05) was installed upstream of QUN-BAR05, and the upstream system (QUN-PTANT01a, QUN-PTANT01b, and QUN-PTANT01c) was installed upstream of QUN-BAR01. The PIT tag systems at the downstream and middle sites (i.e., QUN-BAR07 and QUN-BAR05) were installed on September 27, 2016. The upstream system was first installed at the upstream crest of QUN-BAR01 at QUN-PTANT01a on October 4, 2016. On October 24, 2016, the upstream system was reinstalled at the upstream end of a narrow passage route with fish ladder passage augmentation at QUN-PT01b (see discussion on functionality below). On January 5, 2017, the system was relocated once again to a position approximately 150 m upstream of the falls (QUN-PTANT01c).

Each PIT tag system was powered by a battery bank, which was designed to power the system continuously for 17 days, made up of four 12 volt deep cycle batteries in a weatherproof housing. The capacitance tuner box of the PIT tag system was adjusted to tune the antenna to 134.2 kHz, which is the international standard frequency for low frequency animal tracking. The capacitance tuner box and antenna reader box were placed on the river left bank elevated from streamflow. All PIT tag systems were removed on March 7, 2017.

The antennas of the PIT tag systems were constructed from outdoor contractor grade extension cords or 0 gauge power cables. Materials were spliced together and sealed with epoxy housed in PVC piping sized to fit the antenna materials to extend the length of the antennae. The antenna cables were spanned across the full width of the stream bed in a rectangular shaped ground loop with approximate dimensions of 24.0 m x 0.7 m. (The temporary installation at QUN-PTANT01b did not span the entire wetted width of the Quinsam but was placed in the most likely passage area, and had dimensions of approximately 5.0 m x 1.0 m). To fasten the antenna to the stream bed, rock anchor bolts were drilled into the stream bed, rock hangers were bolted on, and then the antenna wire was fastened to the rock hangers using hose clamps.

The configurations of the antennae are referred to as pass-over antennae, because fish swim over the antenna, rather than through an open loop, as is the case with a vertical pass-through antenna. The antenna read range varied from 35 – 45 cm, therefore, tagged fish swimming within the bottom 35 - 45 cm of the stream would be detected by the reader. Tagged fish that crossed the arrays were recorded with a date and time stamp corresponding with the PIT tag number.

System maintenance was performed bi-weekly during the fall and weekly during the winter months of the monitoring period. During the maintenance inspections, field crews replaced the existing batteries with fully charged batteries, tested both antennas manually using test tags, downloaded data collected by the system reader, and performed diagnostics testing to ensure the system was functioning properly.

Functionality of the PIT tag systems

Both the middle and upstream PIT tag systems were affected by persistently high flow events on the Quinsam River in the fall and early winter of 2016 – 2017, and as a result they were not functional for periods of time and/or relocation of the system was required. The downstream PIT tag antenna array system (QUN-PTANT07) was unaffected by these high flow events and was operational from its installation on September 27, 2016 until the system was removed on March 7, 2017.

The middle PIT tag system (QUN-PTANT05) was only functional briefly following installation on September 27, 2016 because on October 12, 2016, it was found to have been damaged by a tree during a high flow event. Due to persistently high flows, the next safe working window for re-installation of this antenna was January 5, 2017. On January 5, 2017 the antenna was re-installed on the stream bed. During the re-installation process the PIT tag antenna array system's reader was found to be malfunctioning and therefore the crew was unable to re-start the system. On January 16, 2017 the crew attempted to install a new reader; however, the antenna was found to be non-functional and was removed because it had been damaged by debris flow. At this time it was decided that no more attempts would be made to reinstall the PIT tag antenna array system because of the short time remaining in the Year 2 monitoring schedule and the risk was judged to be high that the system would be further damaged by debris flow.

The upstream PIT tag antenna array system (QUN-PTANT01a) was functional for most of the monitoring period but due to high flow events was moved on two occasions. This system was initially installed at the upstream crest of QUN-BAR01 (location labelled QUN-PTANT01a) on October 4, 2016. During a high flow event that occurred on October 8, 2016, the system was damaged by a tree. Due to persistently high flows through the month of October, the system remained non-functional until October 24, 2016 when it was re-installed above the upstream end of a wood fish passage augmentation chute constructed approximately 30 m downstream from the upstream end of QUN-BAR01 (location labelled QUN-PTANT01b). This location was serviceable during relatively high flows because it was confined to a smaller channel located downstream of a large stable log jam. The upstream PIT tag antenna array system operated in this location until January 5, 2017 when suitable flows allowed for the reinstallation of the antenna spanning the full width of the river at a location approximately 150 m upstream (QUN-PTANT01c). This third site was a boulder dominated riffle with deeper flow and lower velocities than the initial site. At this location the antenna spanned the full width of the river bed, similar to the initial location. The system ran at this location until it was removed on March 7, 2017. Thus, the upstream system was non-functional from October 8 to October 24, 2016, functioned in a limited capacity (on a side channel) from October 24, 2016 to January 5, 2017, and was fully functional again (spanning the width of the main channel) from January 5 to March 7, 2017.

2.1.4. Snorkel Surveys

Snorkel surveys were undertaken in the Quinsam River to assess the passage of fish past barriers QUN-BAR01 to QUN-BAR07. In total, seven snorkel reaches (QUN-SNK01 to QUN-SNK07, Table 1) were established above and below identified barriers to determine stream reaches where fish occurred and where fish movement was potentially delayed by the barriers (Map 2). QUN-BAR01 was fairly long (~200 m), with the most difficult obstacle located approximately 40 m from the top. Snorkel section QUN-SNK01 started upstream of the barrier, and ended at the top of the main obstacle. QUN-SNK02 started below the main obstacle and ended at the bottom of QUN-SNK01.

Table 1. Quinsam River snorkel survey reach descriptions, October 4, 2016 to March 7, 2017.

Snorkel Reach	Length (m)	Reach Description	
		Start	End
QUN-SNK01	320	280 m upstream of QUN-BAR01	Main obstacle near top of QUN-BAR01
QUN-SNK02	100	Below the main obstacle near the top of QUN-BAR01	Bottom of QUN-BAR01
QUN-SNK03	280	Bottom of QUN-BAR01	Top of QUN-BAR02
QUN-SNK04	210	Bottom of QUN-BAR02	Top of QUN-BAR04
QUN-SNK05	230	Bottom of QUN-BAR04	Top of QUN-BAR05
QUN-SNK06	170	Bottom of QUN-BAR05	Top of QUN-BAR06
QUN-SNK07	350	Bottom of QUN-BAR06	250 m below QUN-BAR07

Snorkel surveys were undertaken in the Quinsam River in the fall and early winter (October 4, 2016 to December 5, 2016) to evaluate adult Coho and Chinook Salmon passage and during the winter and early spring (January 6, 2017 through March 7, 217) to evaluate adult Steelhead passage. Originally, 12 fall snorkel surveys were planned; however, nine snorkel surveys from October 12 to December 2, 2016 were cancelled because flows were too high to safely and effectively snorkel. On each survey date, individual stream sections were surveyed once by two experienced technicians swimming in pairs with the exception of January 6 and 27, 2017, where only a single technician swam the stream due to PIT antenna array system maintenance issues taking more field time than anticipated. Details of all fish observations, including carcasses, were recorded, and photographs were taken at each barrier study site. The information recorded for each fish observation included: species, location (relative to established barriers or reach breaks), visible tags, size class, and condition (e.g., bright, moderately-coloured, coloured, post-spawn) (Table 2). Information on survey conditions were also recorded, including weather, water temperature, and estimated snorkel visibility (Table 2).

Table 2. Variables recorded during the Year 2 snorkel surveys in the Quinsam and Salmon Rivers.

Variable	Unit/Classification
Weather	Observation
Water temperature	°C
Effective visibility	Measured or estimated in meters
Fish species	Coho Salmon (CO), Steelhead/Rainbow Trout (RB/S), Chinook Salmon (CH), and Pink Salmon (PK)
Fish size class	Adults; 150-250mm, 251-350mm, 351-450mm, and >450mm
Fish condition	Bright/moderately coloured/mid-spawn/post-spawn/undetermined
Site photographs	-

2.2. Salmon River

2.2.1. Barrier Study Sites

Eleven potential barrier study sites were initially identified on the Salmon River, three of which were selected for detailed biological and physical monitoring based on the results of site visits: SAM-BAR05, SAM-BAR07 and SAM-BAR011 (Map 3). All sites present potential barriers due to the presence of shallow water riffles at low flows. Site SAM-BAR05, which was assessed to pose the greatest potential barrier to migration, is located approximately 2 km downstream of the Paterson Creek confluence. Sites SAM-BAR07 and SAM-BAR11 are riffles further downstream in the vicinity of the Memekay River confluence.

2.2.2. Barrier Assessments

Barrier assessments in the Salmon River were conducted using a combination of physical riffle analysis and time-lapse photographs taken at each of the three study sites to record habitat conditions during low flow periods. Photographs were taken with a wildlife camera (e.g., Reconyx brand) and were related to flow records to aid understanding of how habitat conditions (e.g., wetted width, water depth) vary with discharge at the individual barriers. Remote cameras were retrieved in November during fall snorkels after the low flow period had ended.

2.2.2.1. Physical Riffle Analysis

Barriers to fish movement that result from shallow water riffles were assessed with physical riffle analysis at low flows when effects to connectivity are likely to be greatest. To assess stream connectivity at low flows, data collection of physical surveys at barriers SAM-BAR05, SAM-BAR07, and SAM-BAR11 were completed following methodology adapted from the Critical Riffle Analysis method described by CDFG (2012). The method is suitable for wadeable, low gradient (< 4%) riffles, with gravel, cobble and boulder substrates. A critical riffle cross-section depth must meet the following conditions to provide connectivity:

- The minimum depth requirements for target species[1] (Table 3);
- At least 10% of the cross-section must be a contiguous portion meeting the minimum depth established for the target species; and
- At least 25% of the cross-section must meet the minimum depth established for the target species.

Thus, based on these criteria, to evaluate whether the riffle cross section at each barrier met the conditions for connectivity, two measures were estimated for each fish species: 1) percent contiguous passable (the percentage of the transect cross-section in which the depth requirement was met within a contiguous stretch for the target species and for which the criteria for connectivity is 10%); and 2) total percent passage (the total percentage of the transect cross-section in which the depth requirement was met for the target species and for which the criteria for connectivity is 25%).

Table 3. Minimum depth criteria for adult and juvenile salmonid passage to be used in riffle-type barrier analysis (based on CDFG 2012).

Species	Life Stage	Minimum Depth (m)
Coho Salmon	Adult	0.21
Chinook Salmon	Adult	0.27
Steelhead	Adult	0.21
	Juvenile (1-2+ years)	0.09
Trout	Adult	0.12
Salmonid	Juvenile (young of year)	0.09

Suitable sites for assessment of connectivity are low-gradient areas of the stream that may become partial or complete barriers to fish passage during low flows. Sites were identified following consultation with experienced staff and field reconnaissance in Year 1 (Marriner *et al.*, 2016). Once a site was selected, a detailed field survey was completed in the field by experienced field technicians, as described in the steps below:

1. The upstream and downstream bounds of the site were established and flagged, a GPS waypoint was collected mid-site, the site was photographed, and initial site documentation was completed.
2. The most critical riffle at the site was identified. To do this, the field team conducted visual assessments and took depth measurements within the site boundaries to identify the most

[1] These are reproduced from CDFG (2012) with the exception of juvenile Steelhead, which was reduced from 0.12 m to 0.09 m to reflect the shorter growing season in BC and, therefore, the typically smaller size of juvenile Steelhead in BC compared to California.

depth-sensitive (i.e., shallowest) critical riffle. This critical riffle was not required to be a cross-section perpendicular to the stream flow and was defined as the shallowest continuous course across the stream channel.

3. A water level data logger (e.g., Solinst Levelogger) was installed along the cross section to monitor water depths and to help derive stage-discharge relationships. The data loggers, along with remote cameras, were retrieved during fall snorkels after the low flow period had ended.
4. A survey transect was established along the course of the critical riffle. Permanent benchmarks were installed on the river left and river right banks, on the first survey, then reused for subsequent surveys. Following this, a bed elevation profile survey was undertaken along the contour of the critical riffle, between the benchmarks established on the river banks. This involved measuring water depth with a stadia rod at fixed intervals along the transect.
5. Discharge was recorded at the time of the survey. If possible, this was obtained from nearby flow gauges. If such data were not available, discharge was measured by field crews at least three times throughout the typical range of flow conditions. A stage-discharge relationship (rating curve) was derived using water level and discharge measurements.
6. One or more time-lapse remote cameras were mounted nearby to provide information on water levels at the riffle barrier site over changing flows. This provided visual validation of the stage-discharge relationship.

The first field survey (Survey #1) was conducted by following all of these steps. Field crews then repeated steps 4 through 6 at different flows during additional visits to identify and categorize passage flows for the target species and life stages. Four targeted flow rates were selected for field surveys: 1.5 m^3/s, 2.0 m^3/s, 3.0 m^3/s, and 4.0 m^3/s; however, the actual flow rates sampled were dependent on the hydrologic characteristics of the study period. The first of these two flow rates were targeted during Year 2 (during Survey #1 and Survey #2, respectively) and the other two flow rates are scheduled to be targeted in Year 3, the results from which will be assessed in conjunction with results from Year 2 surveys (and may be adjusted if required).

The intent was to use the WSC hydrometric gauge on the river's mainstem downstream of the diversion dam (08HD032) to estimate discharge at SAM-BAR05, and the WSC hydrometric gauge on the river mainstem downstream of Kay Creek (08HD007) to estimate discharge at SAM-BAR07 and SAM-BAR11. However, at the time of writing, stream flow data from WSC Gauge 08HD007 was unavailable for August 1 - October 5, 2016. Differences between flows measured at WSC Gauge 08HD007 and 08HD032 are expected because these two sites are several kilometers apart. However, because the data at WSC Gauge 08HD007 were unavailable, the physical riffle analysis results in this report rely on data from WSC Gauge 08HD032. Using WSC Gauge to 08HD032 allows for a direct comparison of flow passing the Salmon River Diversion to each site as well as comparison of the three sites under similar flow conditions. The final report, to be drafted after the 2017 field season, will use the data from WSC Gauge 08HD032.

Discharge was plotted against the percent contiguous and percent total passable transect lengths for the target fish species only for SAM-BAR05. These plots serve as an example of the figures that will be generated and used after Year 3 to determine the passage flows at each of the three barriers.

Stage-Discharge Relationships at Riffle Barrier Sites

The stage-discharge relationships at riffle barrier sites were determined by installing temporary water level recorders at each site (Ruskin RBR or Solinst Levellogger Edge, 0 to 5 m range and 2.5 mm accuracy) and relating data from these recorders to discharge estimated from data collected by WSC gauge 08HD032. The temporary water level recorders were installed at all three barriers on August 24, 2016 (SAM-BAR07) and August 25, 2016 (SAM-BAR05 and SAM-BAR11), and data were downloaded on November 1, 2016. Water level was recorded at 5 minute intervals during this time period. Time lags between the discharge data measured at WSC gauge 08HD032 and each barrier were estimated to account for the distance between the location where the discharge measurements were recorded and the barriers. These time lags were estimated to be 35 mins for SAM-BAR05, and 50 mins for SAM-BAR07 and SAM-BAR11.

The stage-discharge relationship for each site was computed by fitting the nonlinear relationship $Q=C(h-a)^n$, where Q is discharge (m^3/s), h is the stage (m), and C, a, and n are constants governing the relationship. Water surface elevations were recorded and surveyed relative to benchmark during each field survey. Field survey points were then used to validate the stage discharge curves measured by the level loggers. The derived parameters C and n were used to calculate the change in flow ($\Delta m^3/s/hr$) at the temporary water level recorders. Because the objective of this study is to assess low flow barriers, only flows less than 7 m^3/s were included in the analysis.

2.2.3. Snorkel Surveys

Snorkel surveys were undertaken in the Salmon River to assess the potential passage of fish past barriers SAM-BAR05, SAM-BAR07 and SAM-BAR11. In total, 13 snorkel reaches (SAM-SNK01 to SAM-SNK13) were established above and below barriers (Map 3 and Table 4). Snorkel reaches SAM-SNK01 to SAM-SNK10 and SAM-SNK13 were established to assess fish presence downstream and upstream of barriers SAM-BAR07 and SAM-BAR11 as well as the barriers between these two sites: SAM-BAR08, SAM-BAR09, and SAM-BAR10. Snorkel reaches SAM-SNK11 and SAM-SNK12 were established downstream and upstream of barrier SAM-BAR05, respectively.

Table 4. Salmon River snorkel survey reach descriptions, October 3, 2016 to April 27, 2017.

Snorkel Reach	Length (m)	Reach Description	
		Start	End
SAM-SNK01	170	170 m upstream of SAM-BAR11	SAM-BAR11
SAM-SNK02	620	SAM-BAR11	620 m below SAM-BAR11
SAM-SNK03	390	620 m below SAM-BAR11	SAM-BAR10
SAM-SNK04	420	SAM-BAR10	420 m below SAM-BAR10
SAM-SNK05	150	420 m below SAM-BAR10	570 m below SAM-BAR10
SAM-SNK06	550	570 m below SAM-BAR10	410 m above SAM-BAR09
SAM-SNK07	410	410 m above SAM-BAR09	SAM-BAR09
SAM-SNK08	570	SAM-BAR09	SAM-BAR07
SAM-SNK09	1,210	SAM-BAR07	680 m above Big Tree Creek confluence
SAM-SNK10	680	680 m above Big Tree Creek confluence	Big Tree Creek confluence
SAM-SNK13	310	Big Tree Creek confluence	310 m downstream of Big Tree Creek confluence
SAM-SNK11	510	510 m above SAM-BAR05	SAM-BAR05
SAM-SNK12	370	SAM-BAR05	370 m below SAM-BAR05

Snorkel surveys were conducted by swimming upstream and downstream of the barriers and using fish observations to infer fish passage. Snorkel surveys were undertaken in the Salmon River in the fall and early winter (October 3, 2016 to December 12, 2016) to evaluate adult Coho and Chinook Salmon passage and during the spring (March 21, 2017 to April 27, 2017) to evaluate adult Steelhead passage. The Steelhead snorkel surveys were undertaken as part of work planned for JHTMON-8. Originally, 11 fall snorkel surveys were planned; however, seven snorkel surveys from October 20 to December 1, 2016 were cancelled because flows were too high to safely and effectively snorkel (cancelled surveys were on October 20, October 28, November 1, November 25, and December 1). All snorkel reaches were sampled during each snorkel survey except for on October 3, 2016 where snorkel reach 13 was not sampled, and on April 17 and April 27, 2017 where the snorkel reaches were split between the two surveys. Due to the splitting of reaches between surveys, snorkel reaches 11 and 12 were not sampled on April 17, 2017 and were the only snorkel reaches sampled on April 27, 2017. Snorkel surveys were completed in teams of two, following similar methods to those described in section 2.1.1. As an exception, on October 3, 2016, three technicians snorkelled instead of two.

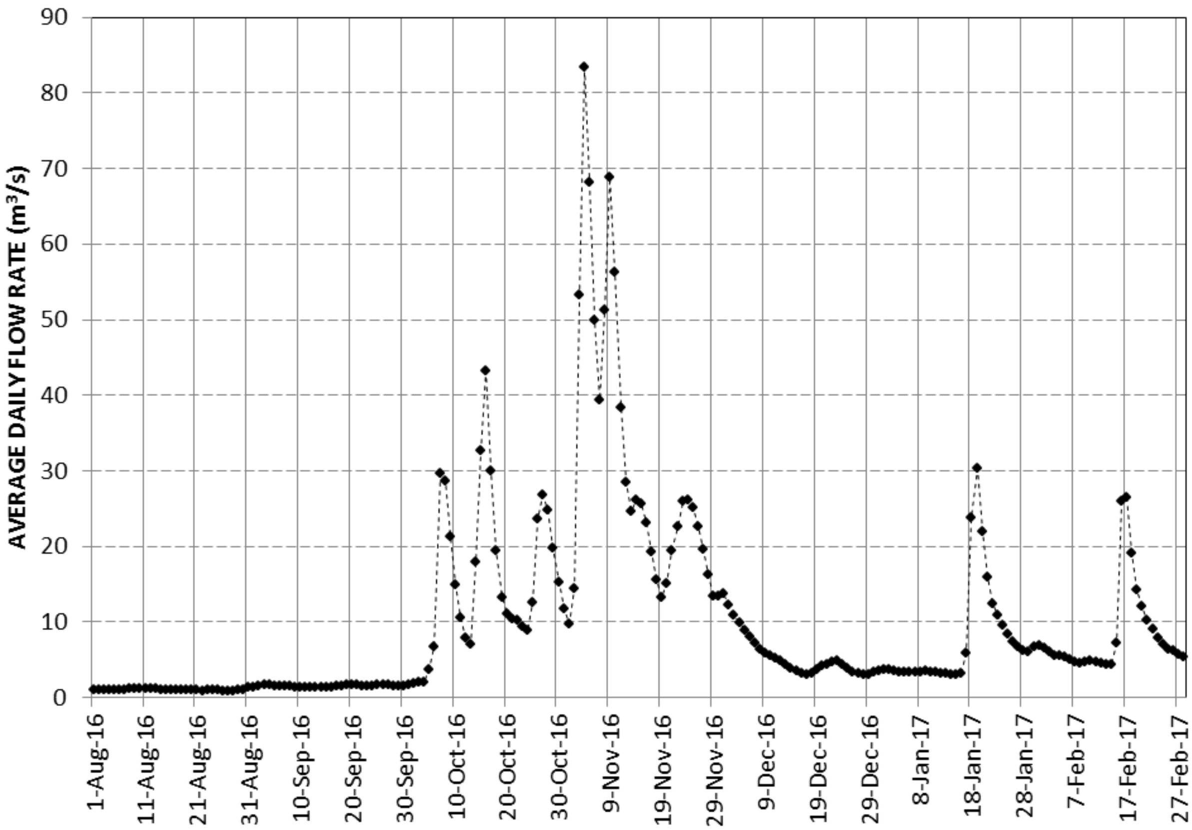
3. RESULTS

3.1. Quinsam River

3.1.1. Barrier Assessments

Qualitative assessment of the time-lapse photos collected at QUN-BAR01, QUN-BAR05, and QUN-BAR07 indicated that QUN-BAR01 was the most limiting to fish passage. These observations agreed with snorkel survey results in Section 3.1.3. Between August 1, 2016 and February 28, 2017, flow at the WSC gauge 08HD027 ranged from approximately 0.89 m^3/s to 83.5 m^3/s (Figure 1).

Figure 1. Average daily discharge from August 1, 2016 to February 28, 2017 on the Quinsam River below Lower Quinsam Lake, measured at WSC gauge 08HD027.



3.1.2. Fish Tagging and Detection

3.1.2.1. Fish Tagging

A total of 168 tags were applied to Coho Salmon, and 20 tags were applied to Steelhead (Table 5). All Coho and 3 Steelhead were captured and tagged during fence broodstock sorting at the Quinsam Hatchery fence while the remaining Steelhead were all captured by angling in December and January and then tagged. A total of 17 tagged Coho were captured a second time at the hatchery fence, and one tagged Steelhead was captured a second time by angling. A total of 19 broken tags were recovered in the trap pool near the hatcher fence in October and November. This finding led to improvements in the tag design to include a 0.03 inch diameter wire core during winter Steelhead tagging (see Section 2.1.3.1).

Table 5. Summary of PIT/Floy tag applications on the Quinsam River in the fall and winter of 2016/2017.

Species	Tagging Date	Floy Tag Colour	No. of Tags Applied	No. of Fish Recaptured
Coho	23-Sep-16	Pink	2	0
	29-Sep-16	Pink	9	0
	5-Oct-16	Pink	18	0
	12-Oct-16	Pink	26	0
		Pink	0	1
	13-Oct-16	Pink	21	0
		Pink	0	1
		Blue	3	0
	14-Oct-16	Blue	14	0
	18-Oct-16	Blue	22	
		Pink	0	1
	19-Oct-16	Pink	0	2
	20-Oct-16	Blue	0	1
	26-Oct-16	Blue	0	1
	27-Oct-16	Blue	8	0
		Blue	0	1
		Pink	0	1
	31-Oct-16	Blue	3	0
		Blue	0	1
	1-Nov-16	Blue	0	2
		Blue	23	0
		White	11	0
	3-Nov-16	Blue	0	3
	7-Nov-16	Blue	0	1
		White	5	0
	10-Nov-16	Blue	0	1
		White	3	0
Total			***168***	***17***
Steelhead	28-Sep-16	Blue	1	0
	5-Oct-16	Blue	1	0
	18-Oct-16	Blue	1	0
	21-Dec-16	Blue	5	0
	23-Dec-16	Pink	2	0
		Blue	2	0
	29-Dec-16	White	2	0
	30-Dec-16	Blue	1	0
	10-Jan-17	White	0	1
	11-Jan-17	Blue	1	0
	23-Jan-17	Pink	1	0
		Blue	1	0
		White	1	0
	25-Jan-17	White	1	0
Total			***20***	***1***

3.1.2.2. Fish Detection

Downstream Site

Of the total 188 tagged fish released, only 12 individual fish were detected on the downstream PIT tag antenna array system: ten Coho Salmon and two Steelhead (Table 6). As described in Section 2.1.3.2, this system was functional during the entire monitoring period.

Table 6. Summary of PIT tagged Steelhead (ST) and Coho Salmon (CO) that were detected by the PIT tag antenna arrays on the Quinsam River between September 27, 2016 and March 7, 2017.

Reader	Date Tagged	Species	Fork Length (mm)	Sex (M/F)	[1] Condition (1-5)	Missing Adipose (Y/N)	CWT (Y/N)	[2] Previously PIT/Floy tagged (Y/N)	PIT Tag Number	Detection			
										Start Date	Start Time	End Date	End Time
Downstream	29-Sep-2016	CO	696	M	1	Y	N	N	900_228000307872	06-Oct-2016	4:30:47 AM	10-Oct-2016	7:50:09 PM
Downstream	05-Oct-2016	CO	555	M	2	N	N	N	900_228000307881	08-Oct-2016	3:42:28 PM	11-Oct-2016	3:54:31 PM
Downstream	05-Oct-2016	CO	580	M	1	N	N	N	900_228000307880	15-Oct-2016	3:31:18 AM	18-Oct-2016	5:19:19 PM
Downstream	05-Oct-2016	ST	679	M	1	N	N	N	900_228000307989	18-Oct-2016	11:41:20 AM	18-Oct-2016	11:41:24 AM
Downstream	12-Oct-2016	CO	742	M	2	N	N	N	900_228000307852	18-Oct-2016	11:55:12 AM	18-Oct-2016	3:44:42 PM
Downstream	12-Oct-2016	CO	434	M	2	N	N	N	900_228000307762	19-Oct-2016	9:34:34 AM	02-Nov-2016	6:55:54 AM
Downstream	13-Oct-2016	CO	722	F	1	N	N	N	900_228000307884	20-Oct-2016	12:05:43 PM	26-Oct-2016	5:09:20 PM
Downstream	13-Oct-2016	CO	714	M	1	N	N	N	900_228000307859	20-Oct-2016	12:25:14 PM	22-Oct-2016	9:40:56 AM
Downstream	29-Sep-2016	CO	727	M	2	N	N	N	900_228000307804	20-Oct-2016	5:55:51 PM	20-Oct-2016	11:37:19 PM
Downstream	12-Oct-2016	CO	638	M	2	N	N	N	900_228000307903	21-Oct-2016	2:20:52 PM	24-Oct-2016	6:19:52 PM
Downstream	13-Oct-2016	CO	650	M	1	N	N	N	900_228000307868	22-Oct-2016	10:38:37 AM	24-Oct-2016	2:15:43 PM
Downstream	23-Dec-2016	ST	790	M	1	N	N	N	900_228000307987	23-Feb-2017	1:31:09 PM	25-Feb-2017	10:01:01 PM

[1] Condition: (1)= bright, (2)= moderately coloured, (3)= mid spawn, (4)= post spawn, (5) = undetermined

[2] Previously PIT/Floy tagged: Yes = fish that was previously tagged this fall, and was captured a second time; N = fish has not been previously PIT/Floy tagged

Middle Site

No fish were observed passing the middle site using the PIT tag antenna array system. This may have been due to the lack of functionality of this system (Section 2.1.3.2) throughout the majority of the monitoring period.

Upstream Site

No fish were observed passing the upstream site using the PIT tag antenna array system. This may have been partly due to limited of functionality of this system (Section 2.1.3.2) although it was functional over at least a portion of the river bed for the majority of the monitoring period.

3.1.3. Snorkel Surveys

In total, three snorkel surveys were completed in the fall (October 4, 2016 to December 5, 2016) to evaluate adult Coho and Chinook Salmon passage and four snorkel surveys were completed during the winter (January 6, 2017 through March 7, 2017) to evaluate adult Steelhead passage (Table 7). Conditions varied among snorkel surveys: higher visibility and lower flows were recorded during the early fall snorkel surveys than during those conducted in February and March.

Table 7. Summary of snorkel survey conditions in Quinsam River.

Date	Snorkel Reaches	Total Effort (HH:MM:SS)	# of Swimmers	Water Temp °C[1]	Estimated Flow (m^3/s)[1]	Estimated Visibility (m)[1]
4-Oct-16	QUI-SNK01-QUI-SNK07	04:00:00	2	14	2	6
6-Oct-16	QUI-SNK01-QUI-SNK07	02:30:00	2	14	n/c	n/c
5-Dec-16	QUI-SNK01-QUI-SNK07	01:50:00	2	6	n/c	n/c
6-Jan-17	QUI-SNK01-QUI-SNK07	02:00:00	1	n/c	n/c	n/c
27-Jan-17	QUI-SNK01-QUI-SNK07	00:55:00	1	n/c	n/c	2
3-Feb-17	QUI-SNK01-QUI-SNK07	01:05:00	2	5	6	2
7-Mar-17	QUI-SNK01-QUI-SNK07	01:05:00	2	4	n/c	3-4

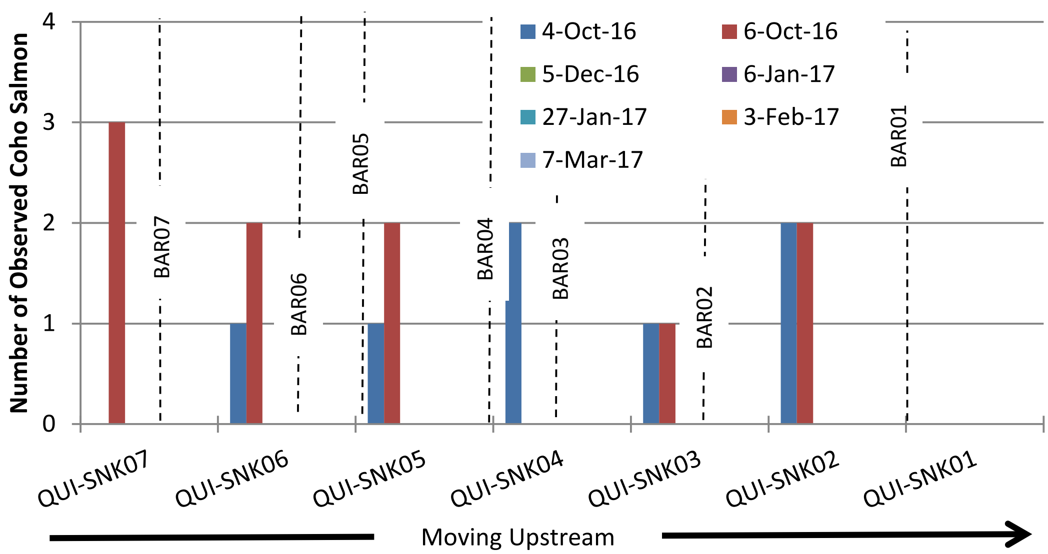
[1] n/c represents data not collected

In total, 17 Coho Salmon and no Chinook Salmon were observed in the Quinsam River during the two October snorkel surveys (Figure 2). No fish were observed during the snorkel surveys in other months. Only a single Steelhead was observed in the Quinsam River. This Steelhead was observed in October downstream of all the barriers. No Steelhead were observed during the winter or spring survey. It is noted that a single tagged Steelhead was observed on February 28, 2017 in the upper canyon portion of the Campbell River during a snorkel survey completed as part of the JHTMON15 project. The field technician confirmed the fish was tagged through the dorsal fin, as per the tagging methods used in this study, but was not able to confidently identify the tag colour.

Coho Salmon were found upstream of all barriers except for QUN-BAR01. It is important to note that several barriers (QUN-BAR02, QUN-BAR03, QUN-BAR06, and QUN-BAR07) were within snorkel reaches and therefore fish found in these snorkel reaches could not be verified as being located upstream or downstream of the barriers. Cumulative Coho Salmon observation plots were generated for QUN-BAR07, QUN-BAR05, QUN-BAR01 to compare the number of fish observed downstream and upstream of the barriers (Figure 3). Since snorkel reach QUN-SNK07 included sections below and above QUN-BAR07, we assume that fish observed in QUN-SNK07 were downstream of the barrier in this figure.

Figure 2. Observations in snorkel sites in relation to barriers for a) Coho Salmon and b) Steelhead. Representative barrier locations are presented with dashed lines, note that x-axis distances are not to scale.

a) Coho Salmon



b) Steelhead

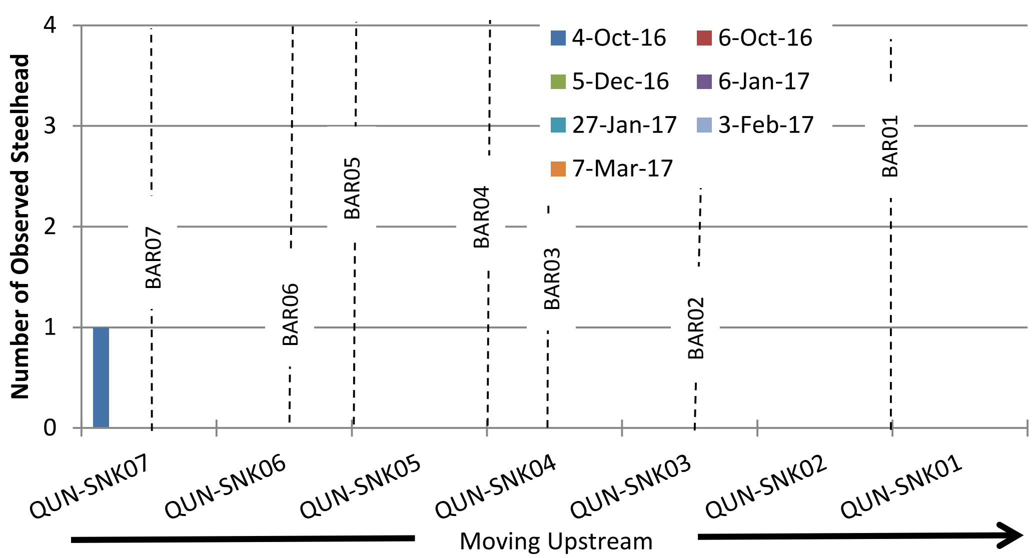
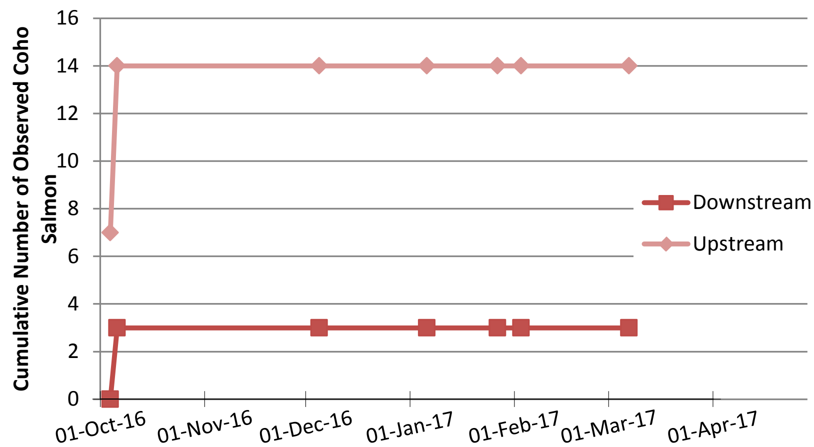
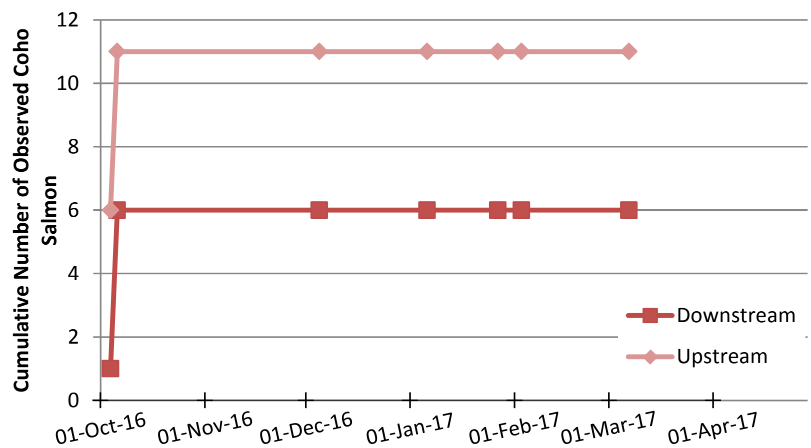


Figure 3. Cumulative plots for Coho Salmon displaying fish observed upstream and downstream of a) QUN-BAR07, b) QUN-BAR05, and c) QUN-BAR01.

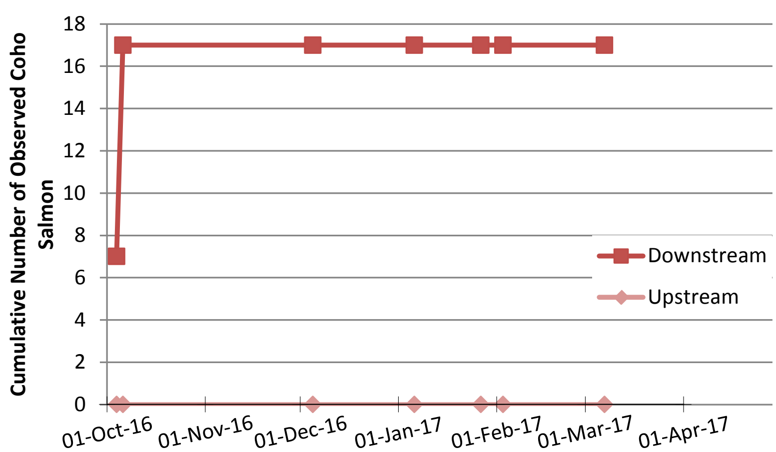
a) QUN-BAR07



b) QUN-BAR05



c) QUN-BAR01



3.2. Salmon River

3.2.1. Physical Riffle Analysis

The mean daily flow rates were 0.58 m^3/s and 0.55 m^3/s during Survey #1 (targeted flow was 1.5 m^3/s; Section 2.2.2.1), which was conducted on August 24 and August 25, 2016, respectively. The second survey (Survey #2) took place September 12 and 13, 2016 (SAM-BAR07 and SAM-BAR11 on September 12 and SAM-BAR05 on September 13) when the mean daily stream flow rates were 1.93 m^3/s and 1.63 m^3/s, respectively (targeted flow was 2.0 m^3/s; Section 2.2.2.1).

None of the three barriers met either the percent contiguous or total percent passage criteria for the Critical Riffle Analysis for any target species (Table 8, Table 9, and Table 10). All three barriers were therefore deemed unpassable under the flow rates observed in Surveys 1 and 2. These results were anticipated because the flows observed during Surveys 1 and 2 were the lowest two flows targeted in the work plan. Further, actual flows were lower than the targeted flows for both surveys, which increased the likelihood of negative results.

Discharge was plotted against the percent contiguous and percent total passable transect lengths for adult Steelhead, adult Coho Salmon, adult Chinook Salmon, adult trout, and juvenile salmonids for SAM-BAR05 (Figure 4). SAM-BAR05 was found not passable for any of the species assessed, under the percent contiguous or total criteria at the flows observed in Surveys 1 and 2. Although this relationship was not presented for SAM-BAR07 or SAM-BAR11, these barriers were also demonstrated to be not passable under the percent contiguous or total criteria at the flows observed in Surveys 1 and 2.

Table 8. SAM-BAR05 Critical Riffle Analysis field assessment results as measured on August 25 and September 13, 2016. Criteria for connectivity are 10% for percent contiguous and 25% for percent total passage.

Survey	Flow (m^3/s)	Steelhead (adult)		Coho Salmon (adult)		Chinook Salmon (adult)		Trout (adult)		Salmonid (juvenile)	
		% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passabl	% Contiguous Passable	% Total Passable	% Contiguous Passable
1	0.55	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	6.17%	3.70%	22.22%	4.94%
2	1.63	1.23%	0.00%	1.23%	0.00%	0.00%	0.00%	8.64%	2.47%	17.28%	2.47%

Table 9. SAM-BAR07 Critical Riffle Analysis field assessment results as measured on August 24 and September 12, 2016. Criteria for connectivity are 10% for percent contiguous and 25% for percent total passage.

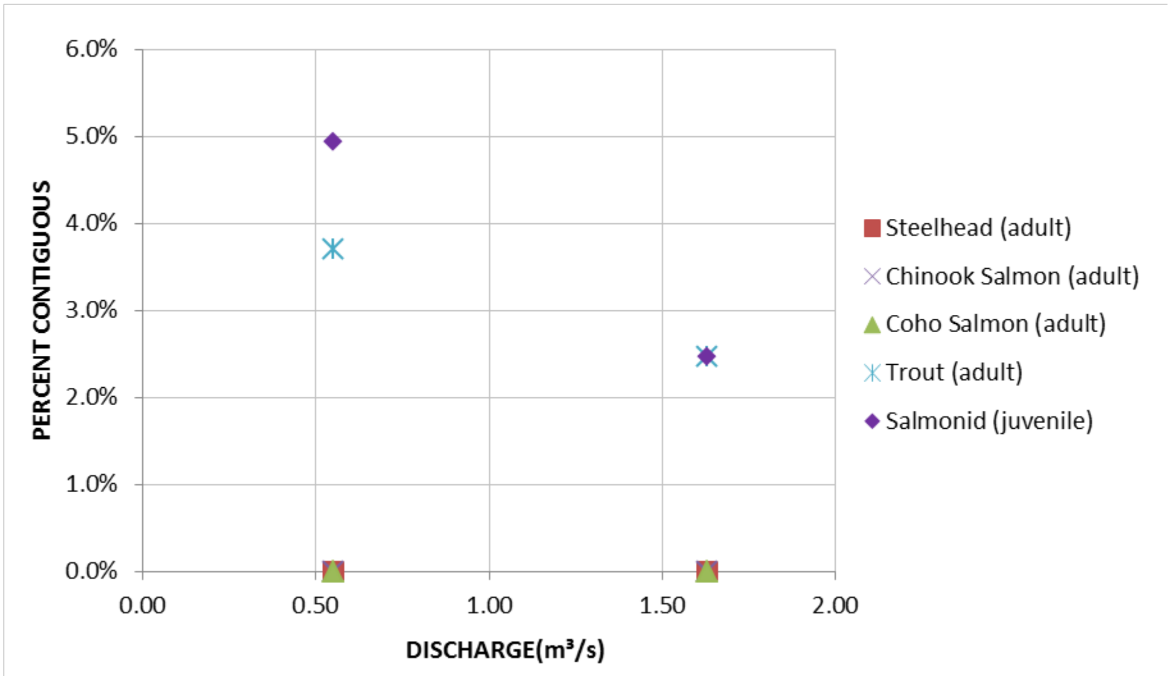
Survey	Flow (m^3/s)	Steelhead (adult)		Coho Salmon (adult)		Chinook Salmon (adult)		Trout (adult)		Salmonid (juvenile)	
		% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable
1	0.58	0.22%	0.00%	0.22%	0.00%	0.22%	0.00%	3.65%	0.54%	10.32%	2.17%
2	1.93	6.50%	2.53%	6.50%	2.53%	2.53%	1.44%	10.83%	4.69%	14.80%	7.94%

Table 10. SAM-BAR11 Critical Riffle Analysis field assessment results as measured on August 25 and September 12, 2016. Criteria for connectivity are 10% for percent contiguous and 25% for percent total passage.

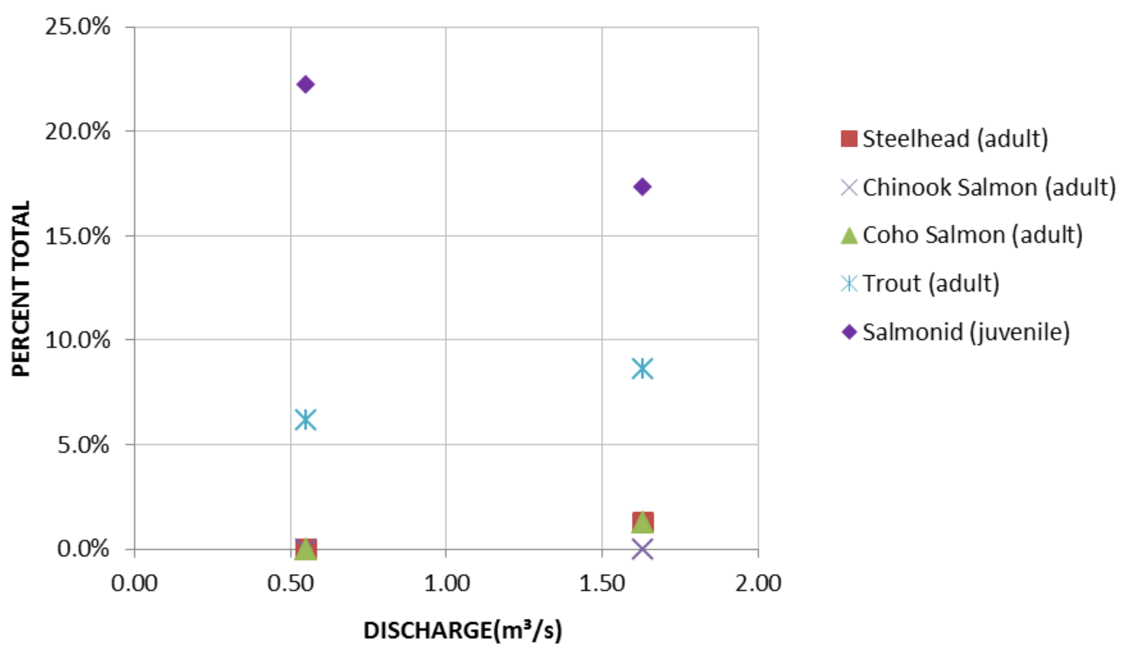
Survey	Flow (m^3/s)	Steelhead (adult)		Coho Salmon (adult)		Chinook Salmon (adult)		Trout (adult)		Salmonid (juvenile)	
		% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable	% Total Passable	% Contiguous Passable
1	0.55	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.96%	0.00%	4.15%	0.64%
2	1.93	0.64%	0.00%	0.64%	0.00%	0.00%	0.00%	5.74%	2.55%	12.76%	3.83%

Figure 4. Percentage of a) contiguous passable transect length and b) of total passable transect length at SAM-BAR05 during Surveys 1 and 2.

a) Contiguous passable transect length



b) Total passage transect length



3.2.1.1. Stage-Discharge Relationships at Riffle Barrier Sites

Between August 1 and October 31, 2016, flow at the WSC gauge 08HD032 ranged from approximately 0.51 m^3/s to 107.53 m^3/s (Figure 5). The stage-discharge relationships generated from stage data from each barrier site and discharge from WSC gauge 08HD032 are presented in Figure 6. Rating parameters and flow ranges for stage-discharge curves, which were obtained from the stage-discharge curves for each of the three barriers to describe each of the stage-discharge relationships are provided in Table 11.

Figure 5. Average daily discharge from August 1, 2016 to October 31, 2016 on the Salmon River below the Campbell Lake Diversion, measured at WSC gauge 08HD032.

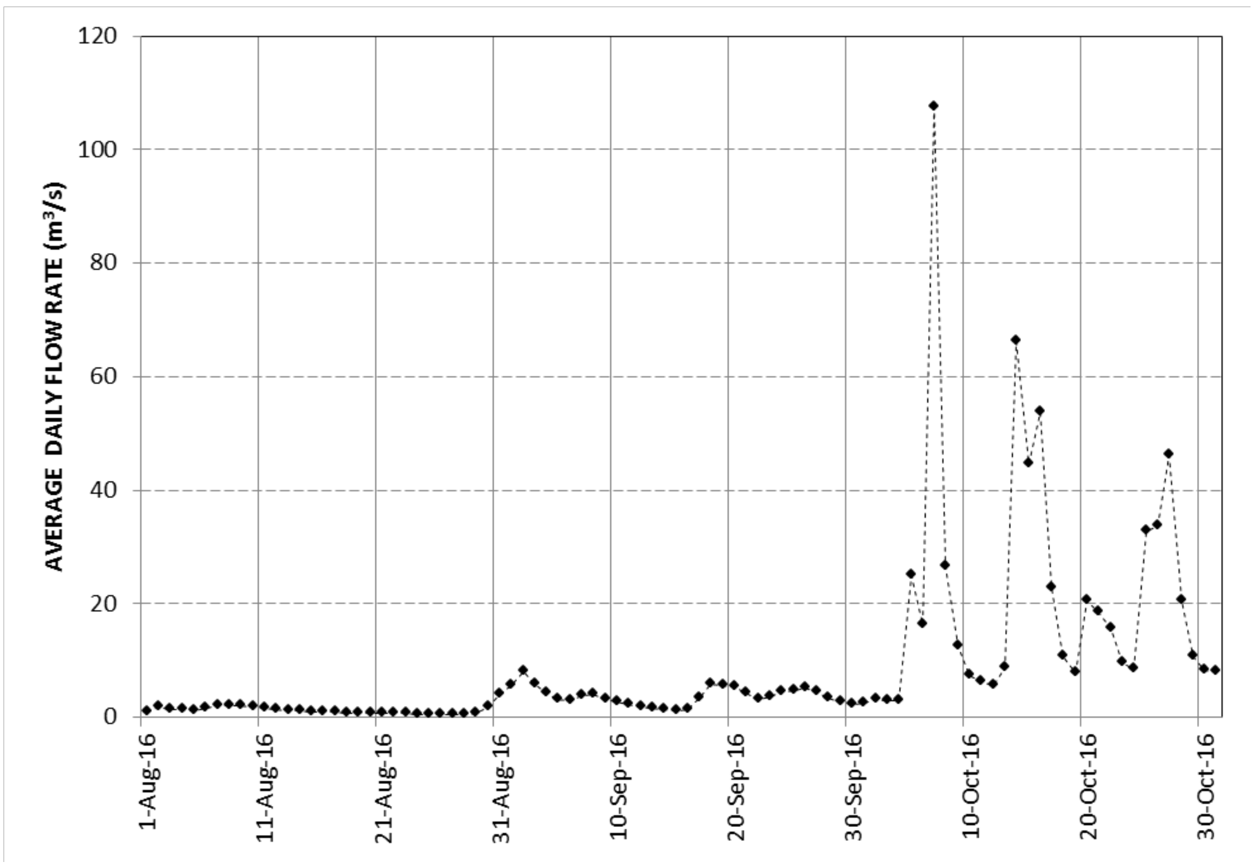
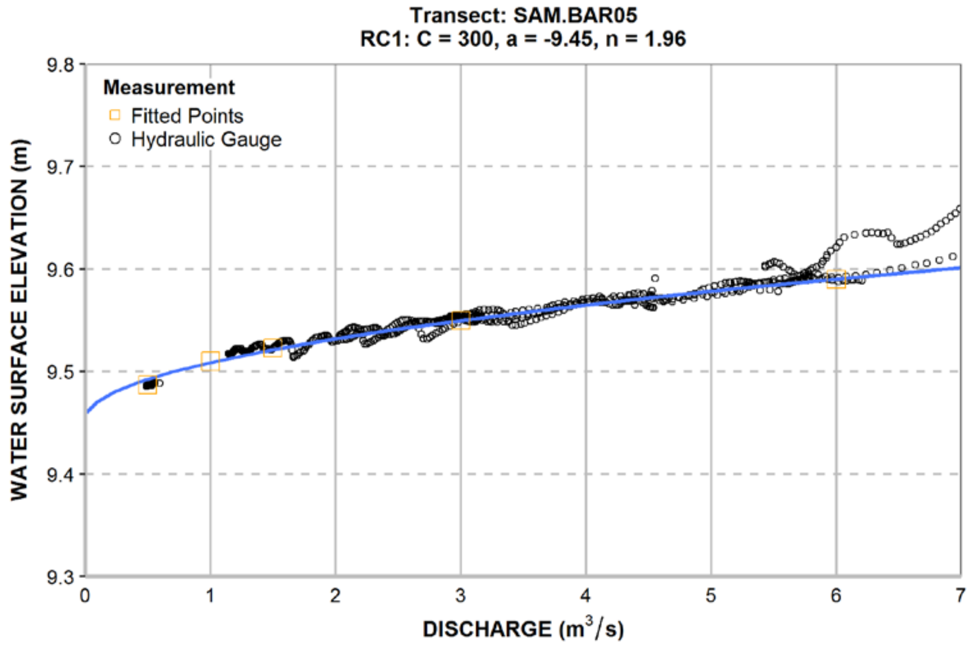
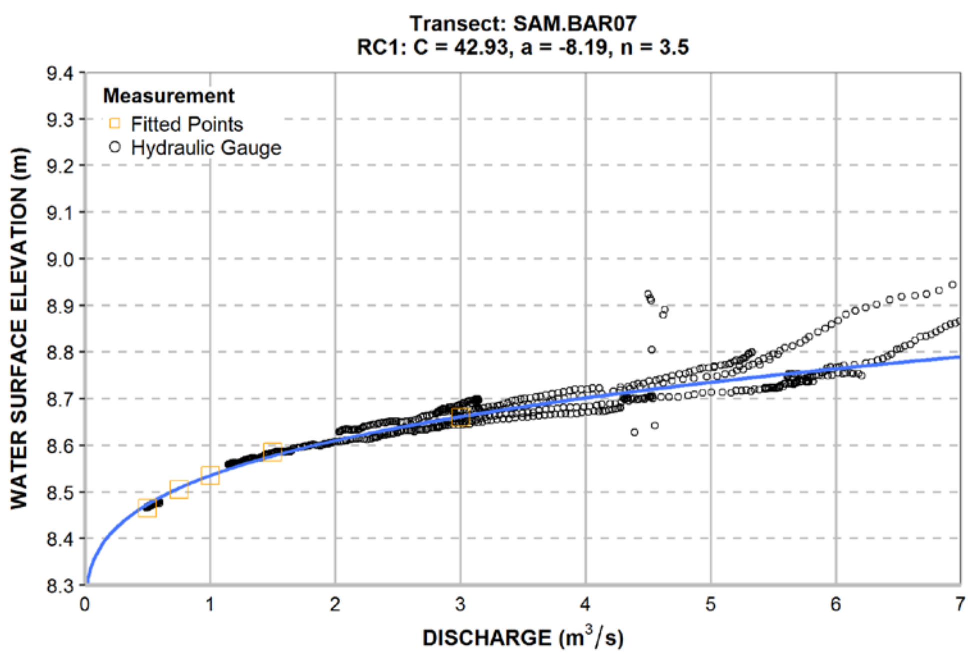


Figure 6. Stage-Discharge relationships measured at riffle barriers on the Salmon River (a) SAM-BAR05, (b) SAM-BAR07, and (c) SAM-BAR11.

a) SAM-BAR05



b) SAM-BAR07



c) SAM-BAR11

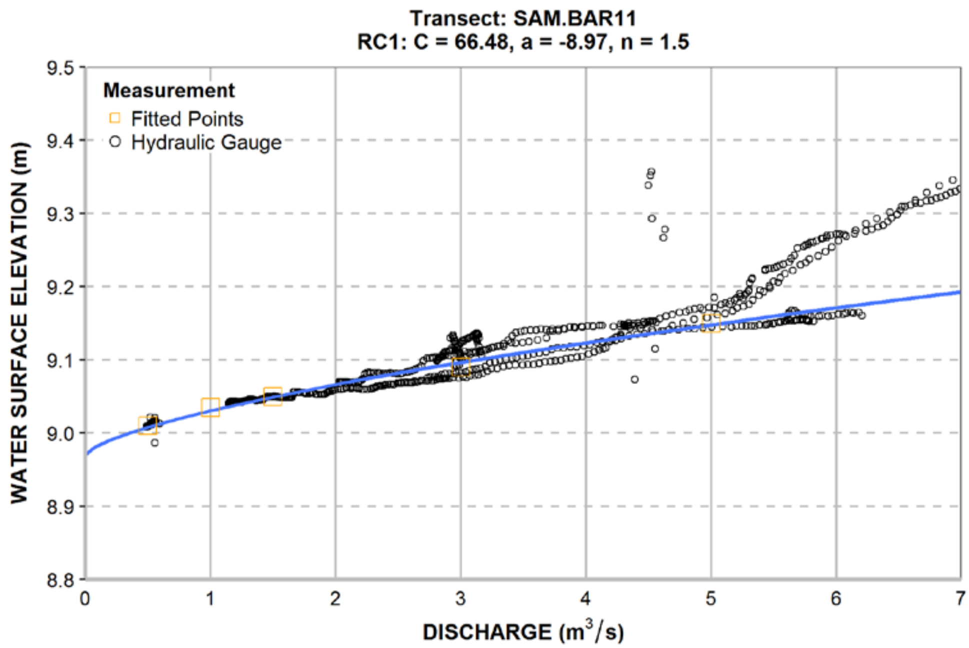


Table 11. Rating parameters and flow ranges for stage-discharge curves at SAM-BAR05, SAM-BAR07, and SAM-BAR11 on the Salmon River.

Barrier	Flow Range[1] (m^3/s)	Parameters		
		C	n	a
SAM-BAR05	0.488-5.50	300	1.96	-9.45
SAM-BAR07	0.488-5.00	42.93	3.5	-8.19
SAM-BAR11	0.488-5.00	66.48	1.5	-8.97

[1]Flow range based on WSC gauge 08HD032

3.2.2. Snorkel Surveys

In total four snorkel surveys were completed in the fall and early winter (October 3, 2016 to December 12, 2016) to evaluate adult Coho and Chinook Salmon passage and three were completed during the spring (March 21, 2017 to April 27, 2017) to evaluate adult Steelhead passage (Table 12). Flows and visibility were lowest during the December survey and highest in November, March, and April.

Table 12. Summary of snorkel survey conditions in Salmon River.

Date	Snorkel Reaches	Total Effort (HH:MM:SS)[1]	# of Swimmers	Water Temp °C	Estimated Flow (m^3/s)[2]	Estimated Visibility (m)
3-Oct-16	1-10	07:30:00	3	11.0	6	6
	11-12	04:30:00	3	11.0	6	6
1-Nov-16	1-10,13	03:00:00	2	9.0	8	5
	11-12	05:00:00	2	9.0	8	5
18-Nov-16	1-10, 13	03:02:00	2	7.0	14	5
	11-12	03:30:00	2	7.0	14	5
12-Dec-16	1-10,13	01:54:00	2	3.5	5	3
	11-12	02:52:00	2	3.5	5	3
21-Mar-17	1-10,13	n/a	2	3.0	13	6
	11-12	n/a	2	3.0	13	6
17-Apr-17	1-10,13	n/a	2	4.8	15	7
27-Apr-17	11-12	n/a	2	5.5	n/c	7

[1] n/a represents data not available as snorkel swims were conducted during surveys for MON-8. Total effort for all snorkel sites is available but snorkel effort for MON-6 sites were not specified.

[2] n/c represents data not collected

In total, 340 Coho and five Chinook Salmon were observed during snorkel surveys (Figure 7). Coho Salmon were observed during surveys conducted in October and November while Chinook Salmon were only observed during the survey conducted on October 3, 2016. Coho Salmon were observed upstream of all barriers except for SAM-BAR05, while Chinook were observed upstream of all barriers expect for SAM-BAR11 and SAM-BAR05. Cumulative plots of Coho and Chinook Salmon at barriers SAM-BAR05, SAM-BAR11, and SAM-BAR07 are provided in Figure 8 and Figure 9, respectively.

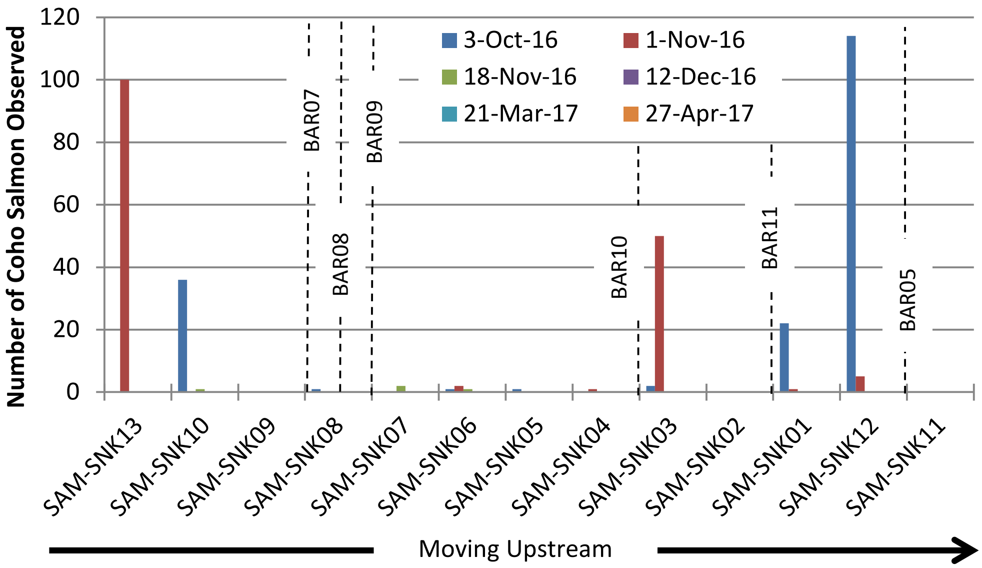
In total, 33 Steelhead were observed during snorkel surveys (Figure 7), all on March 21, 2017. Steelhead were found throughout the river and were observed upstream of all barriers except for SAM-BAR05. Cumulative plots of Steelhead at barriers SAM-BAR05, SAM-BAR11, and SAM-BAR07 are provided in Figure 10.

All three species were found upstream of barrier SAM-BAR07 indicating that fish are able to pass this barrier. Steelhead and Coho Salmon were also found upstream of SAM-BAR11, but no Chinook Salmon were found upstream of this barrier. Thus, results indicate that SAM-BAR07 is passable for all species and SAM-BAR11 is passable for some species. However, we cannot evaluate whether the lack of observed Chinook Salmon upstream of SAM-BAR11 was due to species-specific passage difficulties or due to survey methodology (sampling frequency) because it is possible that fish that passed upstream of the barrier moved prior to the November survey and were therefore not detected. Similarly, although no fish were found upstream of SAM-BAR05, we cannot confirm that this barrier is impassable due to the limited number of surveys conducted during the Coho and

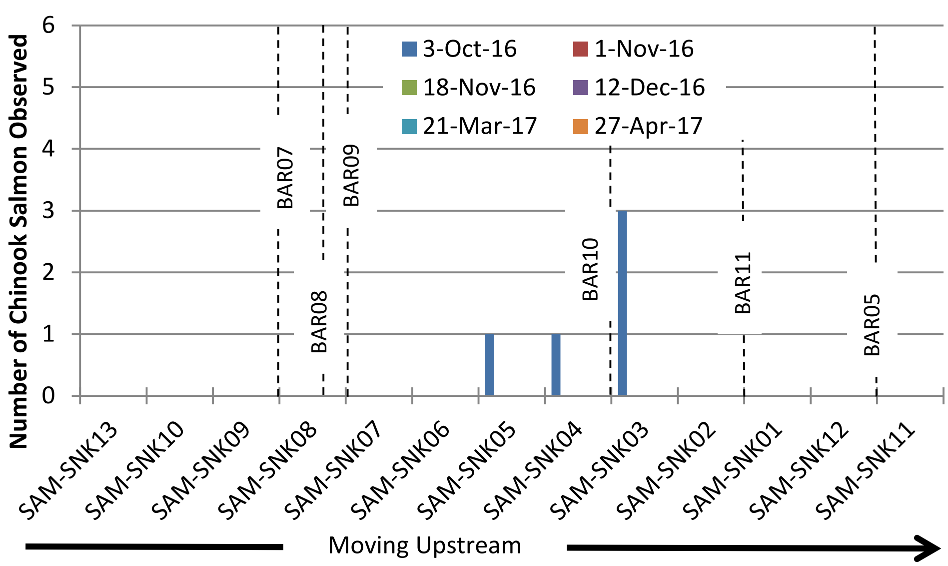
Chinook Salmon spawning period in October and November and the limited number of snorkel reaches surveyed upstream of SAM-BAR05.

Figure 7. Observations within snorkel sites in relation to barriers for a) Coho Salmon, b) Chinook Salmon, and c) Steelhead. Representative barrier locations are presented with dashed lines, note that x-axis distances are not to scale.

a) Coho Salmon



b) Chinook Salmon



c) Steelhead

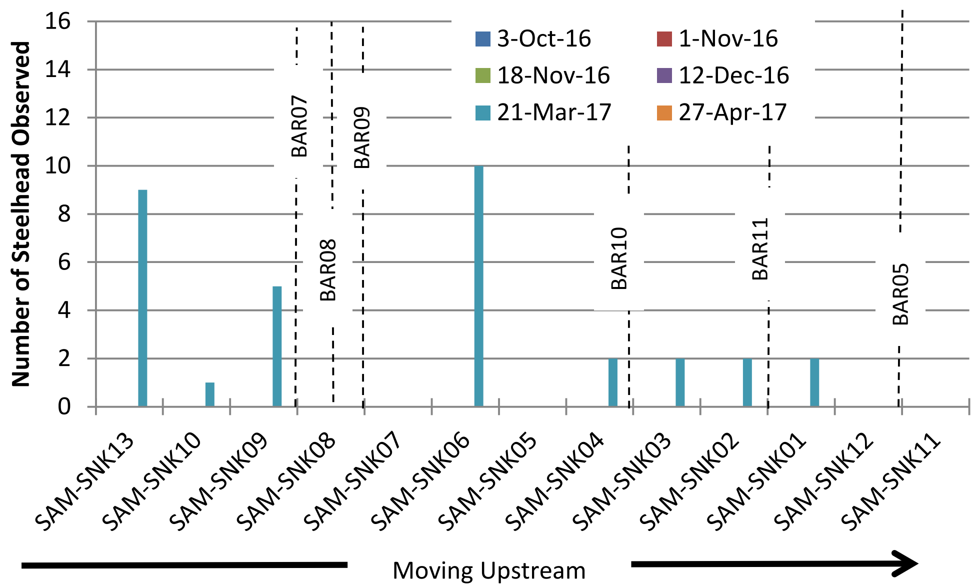
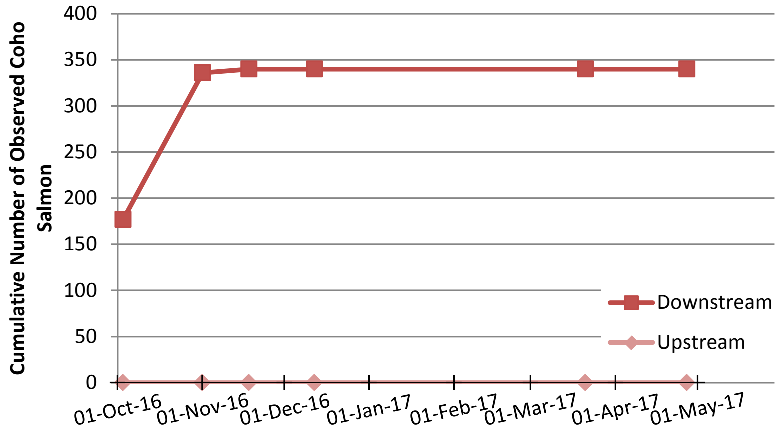
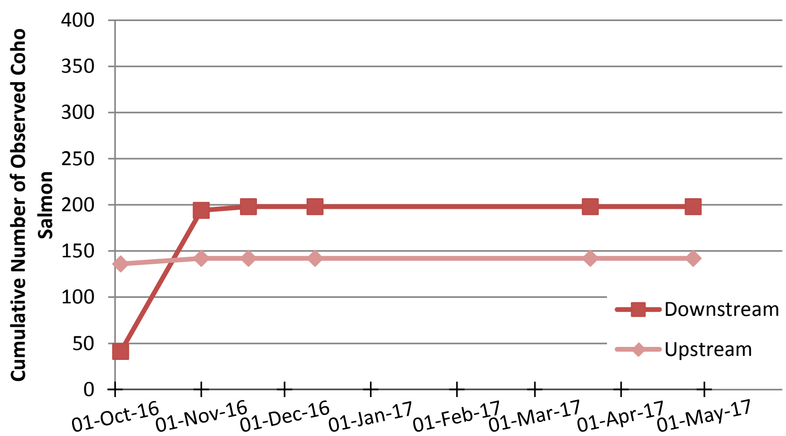

Number of Steelhead Observed
0
2
4
6
8
10
12
14
16
3-Oct-16
1-Nov-16
18-Nov-16
12-Dec-16
21-Mar-17
27-Apr-17
BAR07
BAR08
BAR09
BAR10
BAR11
BAR05
SAM-SNK13
SAM-SNK10
SAM-SNK09
SAM-SNK08
SAM-SNK07
SAM-SNK06
SAM-SNK05
SAM-SNK04
SAM-SNK03
SAM-SNK02
SAM-SNK01
SAM-SNK12
SAM-SNK11
Moving Upstream

Figure 8. Cumulative plots for Coho Salmon displaying fish observed upstream and downstream of a) SAM-BAR05, b) SAM-BAR11, and c) SAM-BAR07.

a) SAM-BAR05



b) SAM-BAR11



c) SAM-BAR07

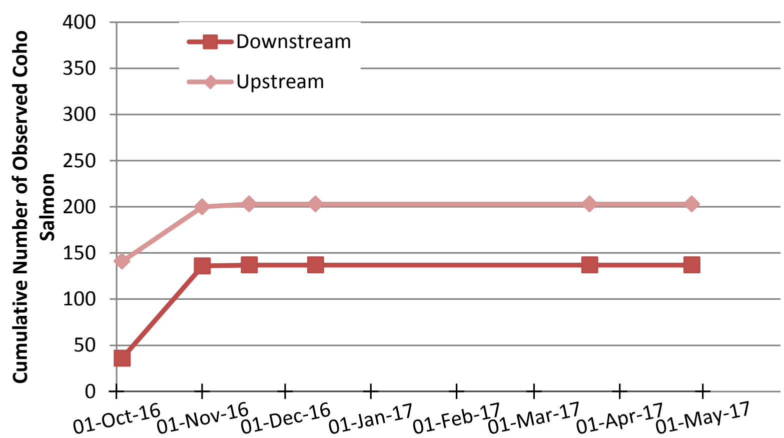
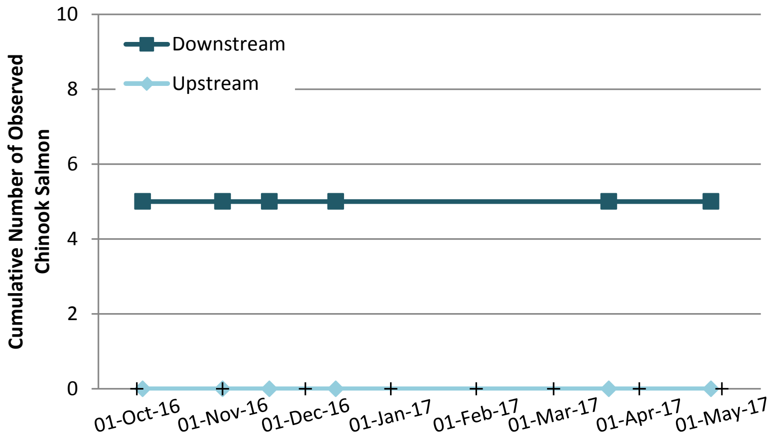
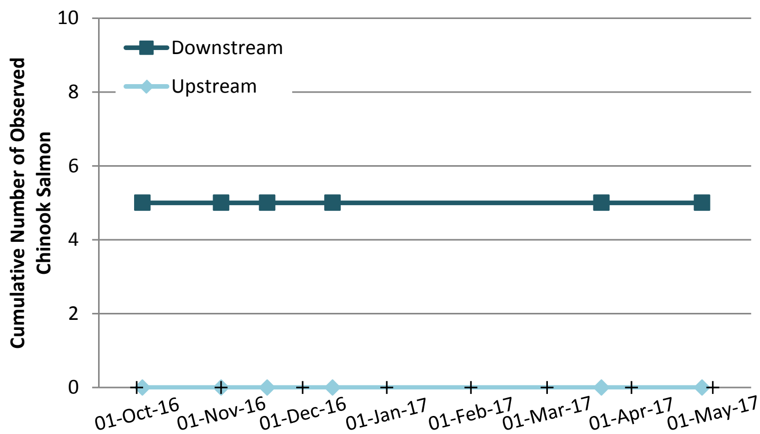


Figure 9. Cumulative plots for Chinook Salmon displaying fish observed upstream and downstream of a) SAM-BAR05, b) SAM-BAR11, and c) SAM-BAR07.

a) SAM-BAR05



b) SAM-BAR11



c) SAM-BAR07

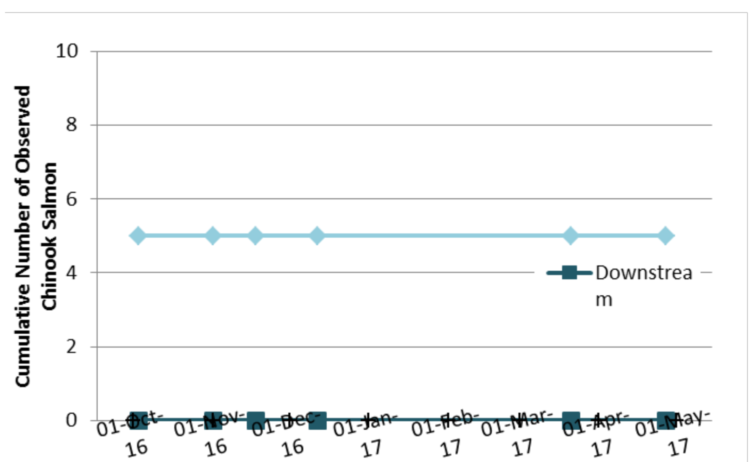
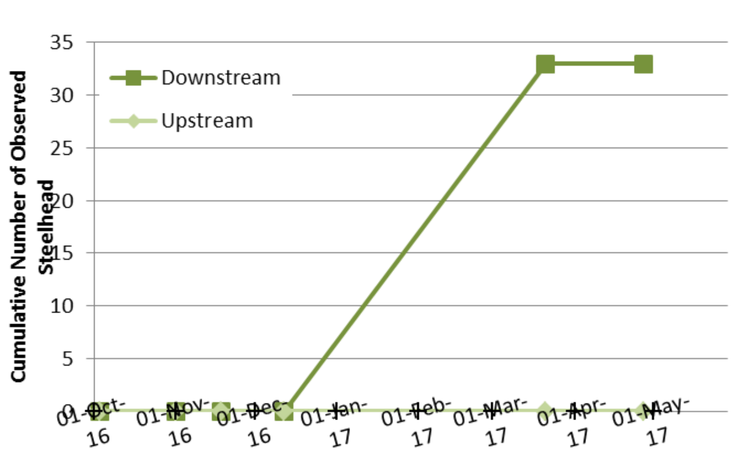
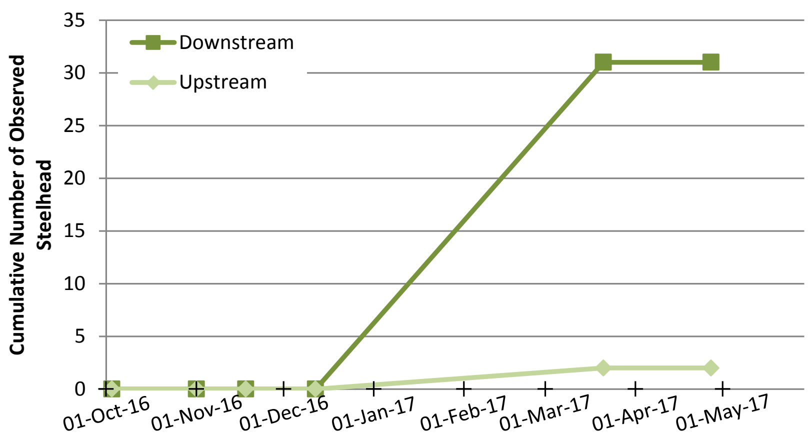


Figure 10. **Cumulative plots for Steelhead observed upstream and downstream of a) SAM-BAR05, b) SAM-BAR11, and c) SAM-BAR17.**

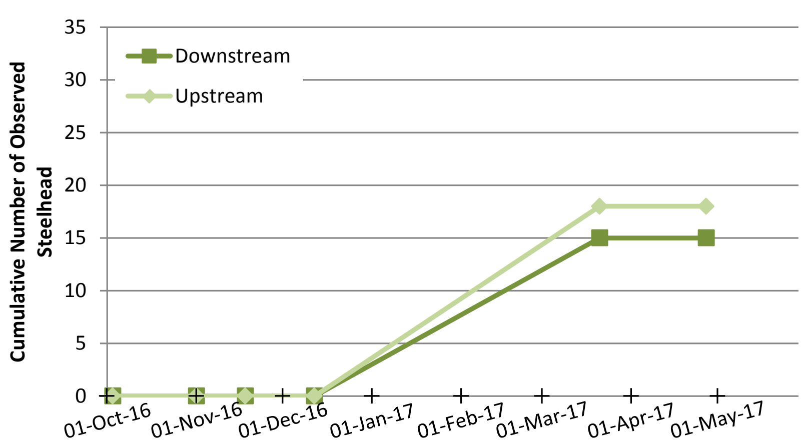
a) SAM-BAR05



b) SAM-BAR11



c) SAM-BAR07



4. DISCUSSION

Year 2 was the first year of a two year field study to assess potential migration barriers on the Quinsam and Salmon rivers. The field study plan is weighted relatively equally between Year 2 and Year 3. Therefore, the Year 2 report presents preliminary results only. A final full analysis will be undertaken in Year 3 after the completion of the field study.

The Year 2 field program dealt with challenging field conditions caused by severe weather throughout the fall and winter of 2016/17. As a result, additional field effort was spent to complete the Year 2 field program as planned (Marriner *et al.*, 2016). A memorandum was prepared for BC Hydro in November of 2016 explaining the field challenges to that point (Murphy *et al.*, 2016). In addition to the challenging field conditions, a number of lessons were learned over the course of the Year 2 field program. On the Quinsam River, additional effort was required to complete weekly maintenance of the three PIT antenna readers from early December to the end of February (when the readers were removed for the season). During these winter months the cold temperatures reduce the PIT reader battery life to 5-8 days. On the Salmon River, the snorkel swims required approximately 10% more field time than was initially budgeted.

For Year 3 we recommend that additional physical barrier surveys be completed on the Quinsam River. The initial field program included effort for a single barrier to be surveyed at one flow. We recommend increasing effort include physical barrier surveys at all three barriers under three different flow rates. The additional surveys will allow a better understanding of hydraulics at the barriers over a range of flows. This will then be used in parallel with snorkel and PIT data to determine a range of suitable passage flows for upstream migrating fish.

Factoring in the Year 2 field challenges, the lessons learned, and recommended additional physical barrier surveys on the Quinsam River in Year 3, it is anticipated that additional budget will be needed to complete the Year 3 field program as planned. Provided below is a short discussion on the results from the Year 2 field study.

4.1. Quinsam River

Year 2 results from barrier assessments, PIT tagging, and snorkeling suggested that most barriers were passable by Coho Salmon. Results from snorkel surveys indicated that all barriers except QUN-BAR01 are passable for Coho Salmon because this species was observed upstream of all barriers except for QUN-BAR01. Only a single Steelhead was observed that was downstream of all the barriers; thus the ability of Steelhead to pass the barriers could only be inferred from the results for Coho Salmon given that Steelhead have a higher swimming speed. Results from PIT tagging were inconclusive because, although ten Coho Salmon and two Steelhead were detected on the downstream PIT tag antenna array system, no detections were obtained from the middle or upstream systems.

4.2. Salmon River

Physical Riffle Analysis completed in Year 2 during Surveys 1 and 2 indicated that all three barriers surveyed were not passable at flow of 0.55 m^3/s to 1.93 m^3/s. Surveys that will be conducted to target the other two higher flows (3.0 m^3/s, and 4.0 m^3/s, as measured at WSC Gauge 08HD032) are scheduled for the late summer/early fall of 2017. It is recommended that these target flows are maintained for Years 3 as planned.

Observations of Coho Salmon and Steelhead upstream of all barriers except for SAM-BAR05, and observations of Chinook Salmon upstream of all barriers except for SAM-BAR11 and SAM-BAR05, indicated that barriers SAM-BAR07 to SAM-BAR10 are passable for all three species and SAM-BAR11 is passable for some species. However, we were unable to determine whether lack of Chinook Salmon upstream of SAM-BAR11 was due to species-specific passage difficulties or due to survey methodology (sampling timing or frequency).

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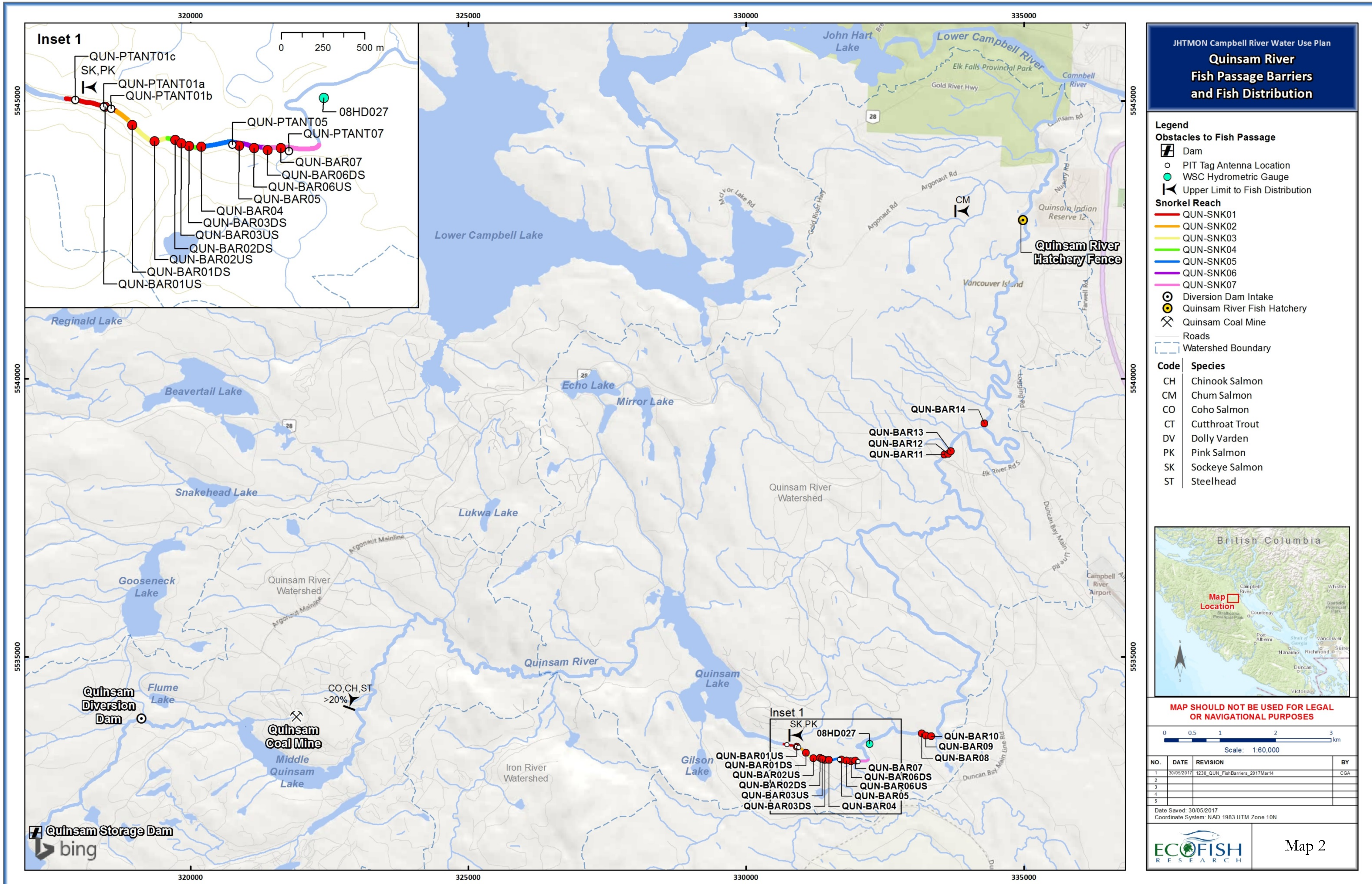
PROJECT MAPS



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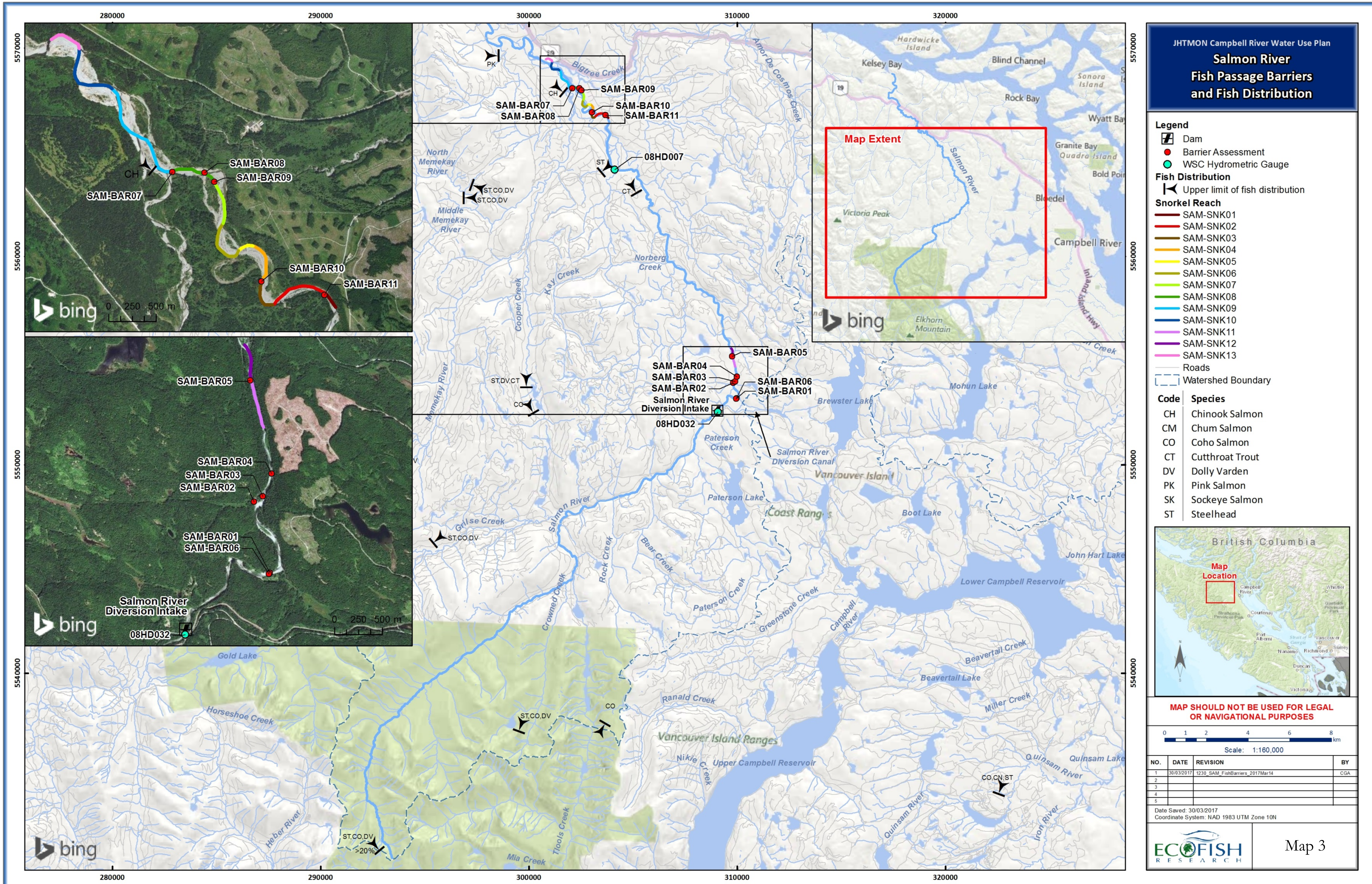

JHTMON Campbell River Water Use Plan
Salmon River
Fish Passage Barriers
and Fish Distribution
Legend
Dam
Barrier Assessment
WSC Hydrometric Gauge
Fish Distribution
Upper limit of fish distribution
Snorkel Reach
SAM-SNK01
SAM-SNK02
SAM-SNK03
SAM-SNK04
SAM-SNK05
SAM-SNK06
SAM-SNK07
SAM-SNK08
SAM-SNK09
SAM-SNK10
SAM-SNK11
SAM-SNK12
SAM-SNK13
Roads
Watershed Boundary
Code Species
CH Chinook Salmon
CM Chum Salmon
CO Coho Salmon
CT Cutthroat Trout
DV Dolly Varden
PK Pink Salmon
SK Sockeye Salmon
ST Steelhead
British Columbia
Map Location
MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES
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Date Saved: 30/03/2017
Coordinate System: NAD 1983 UTM Zone 10N
ECOFISH RESEARCH
Map 3
Map Extent
SAM-BAR01
SAM-BAR02
SAM-BAR03
SAM-BAR04
SAM-BAR05
SAM-BAR06
SAM-BAR07
SAM-BAR08
SAM-BAR09
SAM-BAR10
SAM-BAR11
08HD007
08HD032
Salmon River Diversion Intake
Salmon River Diversion Canal
Salmon River
Vancouver Island
Coast Ranges
Vancouver Island Ranges
Lower Campbell Reservoir
Upper Campbell Reservoir
Campbell River
Paterson Lake
Brewster Lake
Mohun Lake
Boot Lake
John Hart Lake
Beavertail Lake
Gold Lake
Quinsam Lake
Quinsam River
Memekay River
North Memekay River
Middle Memekay River
Heber River
Bigtree Creek
Amor De Cosmos Creek
Norberg Creek
Kay Creek
Cooper Creek
Grilse Creek
Paterson Creek
Rock Creek
Bear Creek
Crowned Creek
Greenstone Creek
Ranald Creek
Beavertail Creek
Miller Creek
Horseshoe Creek
Nikle Creek
Tools Creek
Mia Creek
Iron River
Kelsey Bay
Blind Channel
Rock Bay
Wyatt Bay
Granite Bay
Quadra Island
Bold Point
Bloedel
Victoria Peak
Elkhorn Mountain
Hardwicke Island
Sonora Island
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