Campbell River Project Water Use Plan

Campbell Watershed Riverine Fish Production Assessment

Reference: JHTMON-06

Summary Report :

Component 2 Fish Passage Study Final Program

Study Period: March 1, 2015 to February 28, 2019

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

April 13, 2020

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

Final Program Summary Report

Prepared for:

BC Hydro Water License Requirements
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EXECUTIVE SUMMARY

Background and Objectives

The Campbell River Water Use Plan was prepared in 2012 and describes operating conditions for BC Hydro's Campbell River hydroelectric facilities. When developing the Campbell River Water Use Plan several uncertainties were identified regarding flow-habitat relationships in the Campbell River watershed. The JHTMON-6 Campbell Watershed Riverine Fish Production Assessment was designed to resolve these uncertainties to inform future operations. The JHTMON-6 program includes three components: 1) assessment of flow-habitat relationships; 2) assessment of the impacts of physical barriers on fish migration; and 3) hydrological modelling. This final summary report relates to Component 2, which involved assessing the relationships between flow and the potential for migrating fish to pass barriers in the Quinsam and Salmon rivers. Component 2 was completed over five years (2015–2019). During Year 1, a literature review was conducted, a workplan was developed, and study sites were selected. In Years 2 to 4, barriers were assessed and fish movement was monitored. Final analysis was completed in Year 5.

In fall 2017, the Salmon River Diversion Dam was decommissioned and the JHTMON-6 terms of reference (TOR) were subsequently amended to only focus on the Quinsam River. Accordingly, the management question is not addressed for the Salmon River, although fieldwork undertaken on the Salmon River is summarized.

Component 2 addresses the following management question:

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

The following null hypotheses (two of six listed in the TOR) were tested for the Quinsam River:

$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.

Quinsam River

Management question: *At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam River, and is its frequency/duration over this range of flows sufficient to ensure successful migration?*

The focal species in the Quinsam River are adult Coho Salmon (*Oncorhynchus kisutch*), winter Steelhead (*O. mykiss*), Chinook Salmon (*Oncorhynchus tshawytscha*), and Pink Salmon (*Oncorhynchus gorbuscha).*

Methods - Based on a literature review, consultation with local experts, and reconnaissance site visits completed in Year 1, three key barriers to upstream salmon migration were identified for detailed biological and physical monitoring: QUN-BAR01, QUN-BAR05, and QUN-BAR07. These three barriers are all bedrock chutes located just downstream of Lower Quinsam Lake, approximately 24.2 km to 24.4 km upstream of the mouth. These barriers were identified as the most critical partial barriers to upstream passage due to their physical characteristics. QUN-BAR01 is the furthest upstream of the three barriers and it was identified as the upstream limit of Pink Salmon migration. It was identified that Coho Salmon, Steelhead, and Chinook Salmon could potentially migrate upstream past this barrier but passage success was believed to be highly dependent on flow conditions.

Passive Integrated Transponder (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 in Years 2 to 4. Three PIT tag detection arrays were established in Year 2 and used throughout Years 2 to 4: 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 arrays were installed every year at each station in late September and were monitored until the end of February.

A total of 571 tags were applied to Coho Salmon, and 40 tags were applied to Steelhead during the three years of tagging. Overall, approximately 8% of tagged fish for each species, 45 Coho and three Steelhead, were detected by the PIT tag detection systems. Flows at the time of Coho Salmon and Steelhead detections ranged from 2.04 m^3/s to 32.50 m^3/s.

A total of 17 snorkel surveys were completed in the autumn from September to November (2016, 2017, 2018) to evaluate adult Coho and Chinook Salmon passage at QUN-BAR01 to QUN-BAR07. All three species were observed upstream of QUN-BAR07 and QUN-BAR05 but none of the species were observed upstream of QUN-BAR01 during snorkel surveys. In addition, six snorkel surveys were completed during the winter in December through late-February (2016/2017, 2017/2018 and 2018/19) to evaluate adult Steelhead passage. In total, 80 Coho Salmon, 842 Pink Salmon, no Chinook Salmon, and three Steelhead were observed in the Quinsam River during the fall snorkel surveys in 2016, 2017 and 2018. No Steelhead, Coho, or Pink Salmon were observed during the winter snorkel surveys. Challenging flow and visibility conditions likely influenced the lack of observations during the winter snorkel surveys.

Results – Overall, the results of this study indicate that operations of the Quinsam River Diversion did not preclude the successful passage of upstream migrant fish.

In Years 3 and 4, three to four barrier assessments were completed at each of QUN-BAR01, QUN-BAR05, and QUN-BAR07. Based on PIT tagging results, QUN-BAR01 and QUN-BAR07 were passable by Coho Salmon and Steelhead at a flow of 2.64 m^3/s, but not passable at flows of 2.36 m^3/s or lower. QUN-BAR05 was passable by Coho Salmon and Steelhead at flows of 2.36 m^3/s and 2.64 m^3/s, but not passable at a flow of 1.02 m^3/s.

Ranges of flow at which individual species can pass each barrier could be defined more precisely but this would require additional monitoring at different flows. Alternatively, hydraulic modelling could be used to more precisely assess the range of flows suitable for passage, although this would require detailed analysis and would likely also require additional data collection.

Review of flow data showed that the proportion of flow diverted from the Quinsam River into the Diversion Canal was low. Further, the Diversion Dam is over 20 km upstream of the barrier sites and diversion of flow did not seem to have a clear effect on flow measured near the barriers studied downstream of Lower Quinsam Lake.

Results are considered below in the context of the two null hpotheses.

$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*

At the conclusion of this study the null hypothesis is neither accepted nor rejected. Results showed that upstream passage of the focal species was clearly related to flow. However, over the three years of study operation of the diversion structure was not observed to affect fish passage. In order to accept or reject the null hypothesis further assessment of the diversion structure operations is required to determine under what conditions fish passage is affected.

Coho Salmon and Steelhead were able to successfully pass all barriers examined in the Quinsam River, although passage success depended on flow. All three barriers were passable at flows of approximately 2.64 m^3/s and greater, but thresholds of lower flow were identified for each barrier below which passage was seemingly not possible.

Physical barrier surveys and observations from snorkel surveys and PIT tagging indicate that passage requires flows greater than the minimum flows prescribed in the WUP, which range seasonally from 0.6-2.0 m^3/s. Flows were highly variable during the migration period over the course of the three years of monitoring and provided multiple opportunities for successful migration, even during periods of active diversion.

$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.*

Upstream fish passage past barriers occurred annually during the first and second flow spikes associated with the first autumn rain events after the summer low flow period. The flows observed during these events allowed for upstream migration and flow diversion did not preclude successful passage. During the three years of monitoring, flows occurred during the migration periods that were lower than the minimum flows required to allow upstream passage; however, these lower flows did not appear to substantively impede successful migration for many individuals over the course of the migration timing window.

The test of $H_0 5$ requires setting optimal passage flows in consultation with federal and provincial fisheries agencies. This has not yet been completed by BC Hydro and would presumably require consideration of the results of this report. A test of $H_0 5$ cannot be completed until these optimal flows are set. In the meantime, we note that results from this study indicate that flows were highly variable during the migration period over the course of the three years of monitoring and provided multiple opportunities for successful migration, even during periods of active diversion.

Salmon River

The decommissioning of the Salmon River Diversion Dam in the summer/fall of 2017 returned the river to an unregulated flow regime. As a result, BC Hydro operations no longer affect this river. Therefore, answering the management question for the Salmon River is no longer applicable and tests of $H_0 4$ and $H_0 5$ are not warranted. Monitoring completed prior to the decommisioning is summarized to provide a record of this work as it nonetheless informs general understanding of fisheries in the watershed.

A literature review and reconnaissance site visits completed in Year 1 identified three partial barriers in the Salmon River for detailed biological and physical monitoring: one partial barrier in the vicinity of the Paterson Creek confluence (SAM-BAR05) and two partial barriers further downstream in the vicinity of the Memekay River confluence (SAM-BAR07 and SAM-BAR011). All three sites were potential barriers due to the presence of shallow water riffles at low flows. Critical Riffle Analyses completed in Year 2 indicated that none of the three barriers surveyed were passable at flows of 0.55 m^3/s to 1.93 m^3/s, measured at WSC gauge 08HD032. Surveys at higher flows (i.e., 3.0 and 4.0 m^3/s) were not completed and therefore threshold passage flows were not determined.

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. Snorkel survey results included 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, indicating 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 the absence of Chinook Salmon upstream of SAM-BAR11 was due to species-specific passage difficulties or due to survey timing or frequency.

Table i. JHTMON-6 Component 2: status of objectives, management questions and hypotheses.

Study Objectives	Management Question	Management Hypotheses	Status
The objective of Component 2 of JHTMON-6 is to resolve uncertainty about the flows at which fish can migrate upstream past physical barriers (falls and cascades) in the Quinsam River. The Salmon River was also initially included in the study; however, the program terms of reference were revised in 2018 to omit this river from the study.	At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam River, and is the frequency/duration of such flow events 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$5: The frequency and duration of flow events outside the range considered to be optimal or near optimal for successful passage (to be defined in consultation with federal and provincial fisheries agencies) are not sufficient to severely impede successful migration of the population.*	Quinsam River Coho Salmon and Steelhead were able to successfully pass all barriers in the Quinsam River, at least under some of the observed flows. Passage detections ranged from 2.04 m^3/s to 32.50 m^3/s and all three barriers studied were passable at flows of approximately 2.64 m^3/s and greater. These results indicate that passage conditions require flows greater than those prescribed as minimum flows in the WUP, which ranged seasonally from 0.6-2.0 m^3/s. **$H_0$4** - Residual flows in the mainstem were highly variable during periods of migration and were typically much greater than the amount of flow diverted particularly during flow spikes associated with autumn rain events. Residual flows over the course of the three years of monitoring provided multiple opportunities for successful migration, even during periods of active diversion. **$H_0$5** - Fish passage at barriers occurred annually during the first and second flow increases of autumn. The flows observed during these events allowed for upstream migration and flow diversion did not preclude migration. During the three years of monitoring, flows lower than the optimal range for passage occurred, but did not appear to impede successful migration for many individuals.

			The test of $H_0$5 requires setting of optimal passage flows in consultation with federal and provincial fisheries agencies. This has not yet been completed by BC Hydro and would presumably require consideration of the results of this report. <u>Salmon River</u> The Salmon River Diversion Dam was decommissioned in the summer/fall of 2017, removing instream flow controls and returning the river to an unregulated flow regime. As a result, BC Hydro operations no longer have a direct effect on flows in the Salmon River and the management question is no longer applicable.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

1. INTRODUCTION

1.1. Background to Water Use Planning

Water use planning exemplifies sustainable work in practice at BC Hydro. The goal is to provide a balance between the competing uses of water that include 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 there is expected to be monitoring 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 regarding whether or not fish benefits are being realized under the WUP operating regime. To address these uncertainties, fish habitat study and monitoring programs were designed. The *Campbell Watershed Riverine Fish Production Assessment* (JHTMON-6) is one component of the broader effectiveness monitoring study that is being implemented within the Campbell River WUP to address these uncertainties and access whether fish benefits are being realized under the WUP operating regime. There are three key components investigated as part of JHTMON-6, each of which is a separate study: 1) the assessment of flow-habitat relationships; 2) the assessment of the impacts of physical barriers on fish migration; and 3) the assessment and evaluation of conflicting results of existing hydrological models developed for the Campbell River WUP.

Component 2 of JHTMON-6, referred to as the Fish Passage Study, assessed potential effects of barriers to fish movement. The objectives of the study are to assess fish passage in relation to flow and to develop fish passage prescriptions in the Quinsam and Salmon rivers. The outcomes of this study will help resource managers better understand the potential biological effects of BC Hydro operations on fish movements over physical 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 examined potential barriers identified in the literature review and selected a subset that were appropriate for detailed assessment. Results of the Year 1 study, plus a workplan developed to guide assessment during subsequent years were presented in the Year 1 interim report (Marriner *et al.,* 2016). Interim reports were written in Years 2 and 3, summarizing the annual field monitoring completed (Marriner *et al.*, 2017; Marriner *et al.*, 2018). This report presents findings from Years 1 to 4, summarizing the overall results of the Fish Passage Study.

The Salmon River Diversion Dam was decommissioned in the summer/fall of 2017. Therefore, the Salmon River diversion operations have ceased and no longer affect hydrology or fish in the Salmon watershed. BCH directed the study team to remove components of JHTMON-6 relating to the

Salmon River. The evaluation of fish migration past barriers on the Salmon River was completed in Years 1 and 2 but was not completed in Years 3 or 4. Results from these first two years are included in this final report.

1.2. BC Hydro Infrastructure, Operations, and Monitoring Context

1.2.1. Overview

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).

1.2.2. The Quinsam River and Diversion

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, flowing 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 8.50 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.

The Quinsam River Hatchery has been in operation since 1974, and is located 3.3 km upstream from the confluence of the Quinsam River with the Campbell River. The hatchery has been active in the watershed, augmenting populations of Chinook Salmon, Pink Salmon, Coho Salmon, Cutthroat Trout, 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).

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.

A total of 100 million m^3 is licensed to be diverted annually and the design capacity of the Quinsam River Diversion is 8.50 m^3/s. The WUP stipulates maximum down ramping rates (Table 1) and minimum flows (when naturally available) in the Quinsam River downstream of the diversion dam (Table 2). Flows and ramping rates in the Quinsam River are as recorded at WSC gauge station 08HD021 (Quinsam River at Argonaut Bridge) downstream of the diversion dam, and in the Quinsam Diversion Canal as recorded at WSC gauge station 08HD026 (BC Hydro 2012) (Map 2).

Table 1. Quinsam River maximum permitted down ramping rates (BC Hydro 2012).

Stream	Discharge (m^3/s)	Maximum down ramping rate ($m^3/s/h$)
Quinsam River	> 4.0	8.5
	≤ 4.0	1.0
Quinsam Diversion	> 2.0	N/A
	≤ 2.0	1.0

Table 2. Minimum permitted discharge in the Quinsam River (BC Hydro 2012).

Date	Minimum discharge in Quinsam River (m^3/s)
Jan 1 to Apr 30	2.0
May 1 to Oct 31	1.0
Nov 1 to Dec 31	0.6

1.2.3. The Salmon River and Diversion

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 was accessible to anadromous salmonids (Lill 2002), up until the fall of 2017.

BC Hydro owned and operated the Salmon River Diversion infrastructure, which consisted 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 was a 69 m-long rock-filled timber crib dam that diverted water into the Campbell River watershed. Water was diverted from the mainstem of the Salmon River, via an intake channel, through a radial gate and into a concrete-lined canal that conveyed water through a series of lakes (Brewster, Gray, Whymper, and Fry lakes) to the Lower Campbell Lake Reservoir, where the water was used for generation at the Ladore and John Hart hydroelectric projects. Non-diverted water was returned to the mainstem downstream, either via the main spillway, an undersluice gate, a trimming weir, or the fishway. The diversion canal was 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 were issues with the performance of both the fish screen and the fish way (Burt 2010). In the fall of 2017 BC Hydro decommissioned the facility.

1.3. Management Questions and Hypotheses of JHTMON-6

As the Campbell River Water Use Plan (WUP) process reached completion, a number of uncertainties remained with respect to the effect of BC Hydro operations on aquatic resources. The primary consequence of these uncertainties was a weak ability to predict changes in fish production in response to operational changes proposed during development of the WUP.

Acceptance of the WUP was contingent on resolving information gaps related to three key components (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?

This report addresses uncertainty #3. (Other work under JHTMON-6 is complete or ongoing to address management questions #1, #2 and #4.) Management question #3 will be assessed by testing the following null hypotheses (two of six listed in the TOR; BC Hydro 2013):

> *$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.

1.4. Objectives and Scope of the Fish Passage Study

The Fish Passage Study, which addresses the second JHTMON-6 component, *physical barriers to upstream migration in diversion donor streams,* is a four-year study (2015-2019) conducted on the Quinsam and Salmon Rivers. Objectives of this study are to assess the relationship between barriers and flow in relation to fish migration and to identify fish passage prescriptions for the Quinsam and Salmon Rivers.

Project Overview

Legend

- Dam
- Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2 4 6 8 10 12 km

Scale: 1:300,000

NO.	DATE	REVISION	BY
1			
2			
3			
4			
5			

Date Saved: 12/03/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_SAM_QUN_Overview_Portrait_2019Mar12.mxd

2. METHODS

The methods employed for assessing the impacts of physical fish barriers to fish movement in relation to flow in the Quinsam and Salmon Rivers involved barrier assessments combined with direct assessments 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. In Years 2, 3, and 4 methods involved assessment of the barriers at the study sites and of fish movement through these barriers. Evaluation of the potential for barriers to inhibit fish migration was conducted through snorkel surveys at barriers, barrier assessment surveys, PIT tagging and wildlife cameras.

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 reconnaissance site visits completed in Year 1: QUN-BAR01, QUN-BAR05, and QUN-BAR07 (Map 2). These three were selected as the most significant of those visited (Marriner *et al.*, 2016). QUN-BAR01 is the final potential barrier before Lower Quinsam Lake. All three sites are bedrock shelves that create chutes. These sites are potential migration 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 (Marriner *et al.,* 2016).

2.1.2. Barrier Assessments

2.1.2.1. Wildlife Camera Deployment

In Year 2, 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 flows to help to assess the relationship between habitat conditions (e.g., wetted width, water depth) and discharge at individual barriers. The time-lapse photos were used to assist in the site selection process for a field-based physical barrier surveys in Years 3 and 4 based on methods developed by Reiser *et al.* (2006).

2.1.2.2. Barrier Assessment Surveys

There is no single recognized or Resources Information Standards Committee (RISC) certified assessment method for identifying and assessing barriers to fish passage. Our barrier assessment was based on the method for assessing falls and chutes (cascades) provided in Reiser *et al.* (2006) and Parker (2000). For the purpose of this assessment, falls are defined by an abrupt change in water velocity, where the water passing over the top of the falls separates from the stream bed and plunges in a free-fall trajectory, whereas a chute is defined by a steep gradient where the water does not separate from the stream bed. A schematic diagram (Figure 1) describes the method, which uses ground surveys and subsequent calculations to examine whether fish are capable of passing each type of barrier by jumping or swimming.

In this study barrier surveys on the Quinsam River are focused on fish passage at low flows to assess the effects of fish migration against flow diversion in the Quinsam River. A summary of the migration periods, jumping and swimming capabilities for various adult salmonids is shown in Table 3. Each barrier was surveyed three to four times under different flows. The goal of surveying at a variety of flows was to capture the minimum passage flow within the range of flows surveyed.

The barrier surveys were completed during the summer and fall of Years 3 and 4. A single barrier survey was completed at QUN-BAR01 on November 7, 2017. Three additional surveys were completed at each of QUN-BAR01, QUN-BAR05 and QUN-BAR07 in 2018. They were completed on August 18-19, September 17, and October 19, 2018.

QUN-BAR01 is approximately 80 m long and composed of a series of chutes and two falls over bedrock, and contains a number of manmade modifications, such as fish ladders and channel deepenings to improve fish passage potential by increasing flow depths and decreasing velocity at the modifications (Marriner *et al.* 2016).

QUN-BAR05 is approximately 32 m long and similar to QUN-BAR01 it is composed of a series of chutes, falls, and man-made modifications, such as fish ladders and channel deepenings. The man-made modifications are focused along the river right passage routes, while the channel center and river left routes are unmodified.

QUN-BAR07 is approximately 37 m long and is composed of bedrock chutes spanning across the channel. Unlike the other two barriers, it has with no man-made passage augmentations.

Each barrier is composed of a combination of chutes, falls, and/or man-made modifications and provides a number of potential passage routes to fish migrating past the respective barrier. As fish ascending the barriers they are required to pass through a combination of passage routes. The barrier surveys identified and assessed each individual potential passage route, and assessed which combination of potential passage routes fish are likely to use while ascending the respective barrier.

During the barrier surveys, the following measurements were taken: plunge pool depth (d_{pp}), water depth at the crest (d_c), chute length (LS), vertical drop (H), vertical distance from the bottom of the barrier to the crest of the barrier (Z), distance from the standing wave to the base of the falls (X), angle of the chute if applicable (S_p), angle of the bed upstream of a falls (S_c), wetted width, channel width, and water velocity at crest (V_c). Velocity measurements were taken with a Swoffer meter. The other barrier measurements were collected with a combination of meter sticks, meter tapes, rangefinders, and clinometers. Where measurements could not be taken, they were conservatively estimated and these occurrences are specifically stated. Measurements are depicted in Figure 1. FH represents the vertical distance from the downstream water surface elevation to the barrier crest, θ_o is the initial leaping angle, and Xsw is the distance from the location of the impact of the falling water to the standing wave.

Table 3. Typical swimming capabilities and maximum jump heights for various adult salmonids (from Reiser *et al.* 2006 and Parker 2000).

Species	Life Stage	Sustained Velocity (m/s)	Prolonged Velocity (m/s)	Burst Velocity (m/s)	Max. Jumping Height (m)	Min. Swimming Depth (m)	Fish Body Length (m)	Adult Migration	Source
Dolly Varden and Bull Trout	Adult	-	0.74	-	-	-	0.32-0.42	*Aug-Oct*	Mesa *et al.* 2006
	Juvenile	-	0.48-0.55	-	-	-	0.11-0.23	-	Mesa *et al.* 2006
Coho salmon	Adult	0-1.04	1.04-3.23	3.23-6.55	2.19	0.17	0.7	Aug-Oct	Reiser *et al.* 2006
	Juvenile (120 mm)	-	0.4-0.6	-	0.5	-	0.12	n/a	Parker 2000
	Juvenile (50 mm)	-	0.2-0.4	-	0.3	-	0.05	n/a	Parker 2000
Chinook salmon	Adult	0-1.04	1.04-3.29	3.29-6.82	2.38	0.17	0.91	Jun-Aug	Reiser *et al.* 2006
	Juvenile (120 mm)	-	0.4-0.6	-	0.5	-	0.12	n/a	Parker 2000
	Juvenile (50 mm)	-	0.2-0.4	-	0.3	-	0.05	n/a	Parker 2000
Chum salmon	Adult	0-0.79	0.79-2.34	2.34-4.57	1.21	0.17	0.73	*Oct-Nov*	Reiser *et al.* 2006
Cutthroat and Rainbow trout	Adult	0-0.9	0.9-1.8	1.8-4.3	1.5	-	-	*Mar-June*	Parker 2000
	Juvenile (120 mm)	0-0.4	0.4-0.7	0.7-1.1	0.6	-	0.12	n/a	Parker 2000
	Juvenile (50 mm)	0-0.1	0.1-0.3	0.3-0.4	0.3	-	0.05	n/a	Parker 2000
Pink salmon	Adult	0-0.79	0.79-2.34	2.34-4.57	1.21	0.17	0.58	Jul-Aug	Reiser *et al.* 2006
Steelhead	Adult	0-1.40	1.4-4.17	4.17-8.07	3.35	0.17	0.7	Mar-Apr	Reiser *et al.* 2006
Sockeye salmon	Adult	0-0.97	0.97-3.11	3.11-6.27	2.10	0.17	0.55	*Aug-Sep*	Reiser *et al.* 2006
	Juvenile (125 mm)	0-0.5	0.5-0.7	-	-	-	0.125	n/a	Parker 2000
	Juvenile (50 mm)	0-0.2	0.2-0.4	0.4-0.6	-	-	0.05	n/a	Parker 2000

Adult migrations shown in italics are estimates based on our peridicity data.

The assessment of a fish's ability to successfully pass a barrier depends on the nature of the barrier (i.e., falls or chute). For a fish to be able to successfully ascend a falls barrier it must be capable of leaping from the plunge pool to the top of the falls and then be able to swim upstream. For a fish to be able to ascend a chute or a cascade it must be capable of swimming up the chute and/or leaping over the barrier. Leaping and swimming abilities differ widely by species (Table 3).

The assessment of fish passage at falls is based on comparing the maximum jump height to the length and height that is required for a fish to jump over a falls. The ability of a fish species to pass a falls was determined based on Figure 4 in Reiser *et al.* 2006 (Figure 1).

The assumption that the maximum jump height can be met assumes that the plunge pool depth is sufficient for the fish to achieve a maximum jump height. Powers and Osborn (1985) indicated that for fish's ability to jump not to be reduced, the penetration of falling water should be less than the plunge pool depth, and the plunge pool depth should be greater than or equal to the length of the migrating fish.

A fish's ability to ascend a falls also depends on its ability to transition from jumping to swimming at the top of the falls. For this to be successful the swimming capability of the fish must be greater than the crest velocity (V_{dc}). Given that a fish at the end of a jump has consumed some energy, we used the lower range of burst velocity and compared this with the crest velocity following Reiser *et al.* (2006). In other words, successful transition from jumping to swimming resulted if the lower range of burst velocity is greater than V_{dc}.

Figure 1. Schematic drawing of a chute-type and fall-type potential barrier (from Reiser *et al.* 2006).

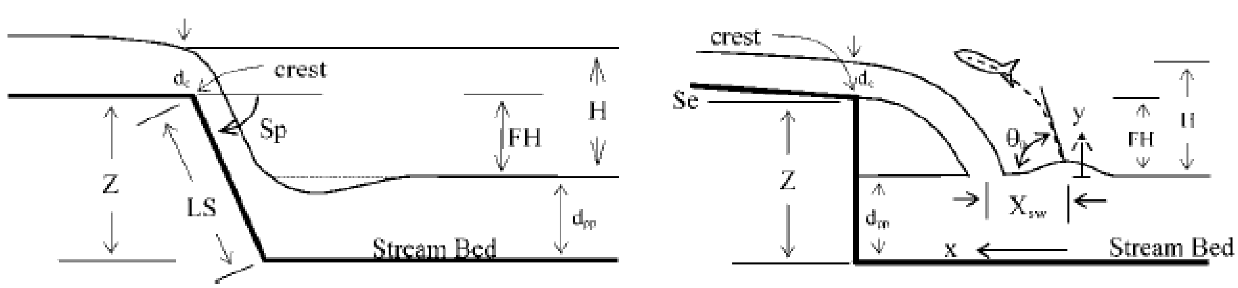

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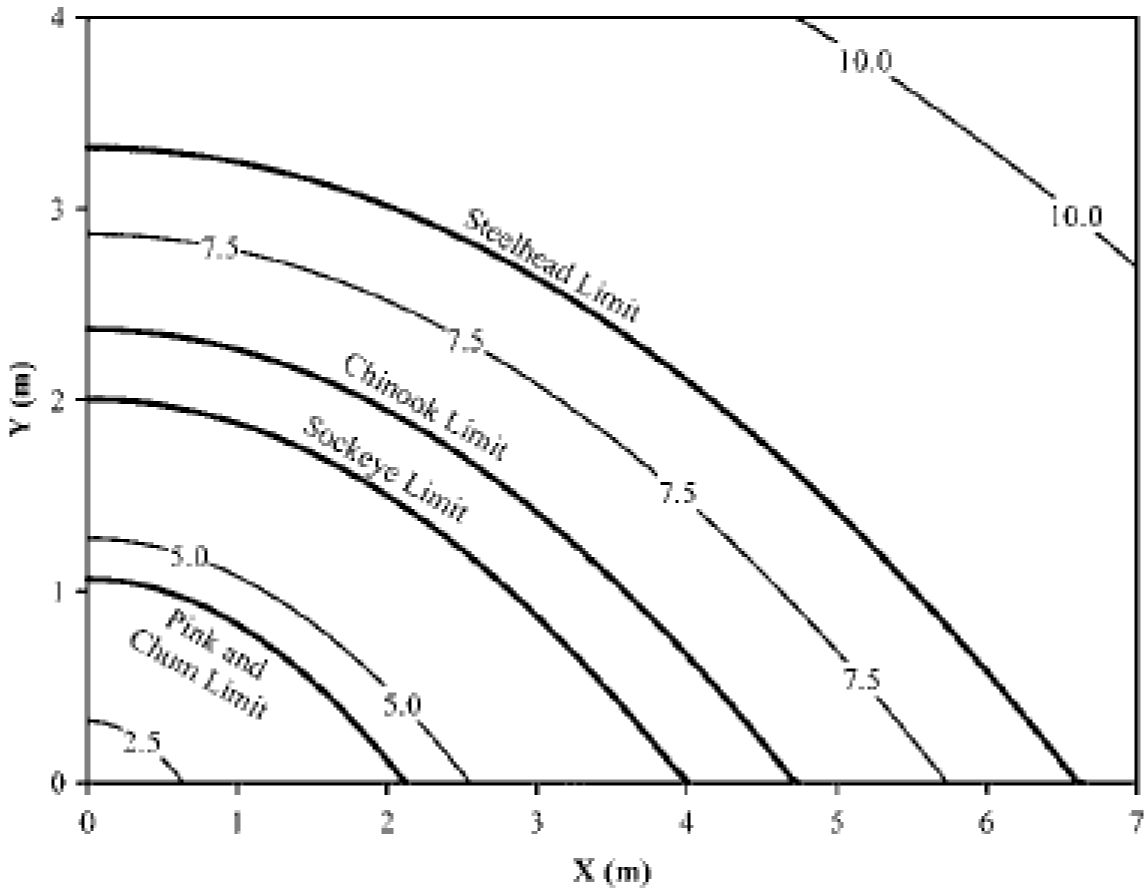
Figure 2. Horizontal travel distance (X) and vertical height (Y) limits for difference salmonid species based on burst swimming speed velocities. The numbers on the curves are exit velocities (from Reiser *et al.* 2006).



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. In Years 3 and 4, a 0.03 inch diameter welding wire core was inserted inside each spaghetti tag. The wire core minimized tag loss by increasing the strength of the tags and reducing knot failure. The spaghetti tags were inserted through the base of the dorsal fin of captured fish using a stainless steel needle, and were then knotted to form a closed loop (Figure 3 and Figure 4).

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. During the three years of PIT tagging three distinct tag colours were used for Coho salmon and Steelhead tagging: pink, white, and blue.

Adult Coho Salmon were captured for PIT tagging at the Quinsam Hatchery during the start of the Coho Salmon migration period from late September to mid-November during broodstock capture and sorting at the Quinsam Hatchery fence. Steelhead were captured in December, January, and February by angling in the Quinsam River, downstream of the hatchery fence. 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, wild/hatchery, and condition were recorded for each tagged fish along with its PIT tag number.

Figure 3. Example PIT tag assembly shown on a transect tape for scale (cm). Assembly is composed of a 23 mm HDX PIT tag shrink wrapped to a 30 cm piece of bright pink Floy FT-4 spaghetti tag with a wire core, then knotted to form a closed loop.

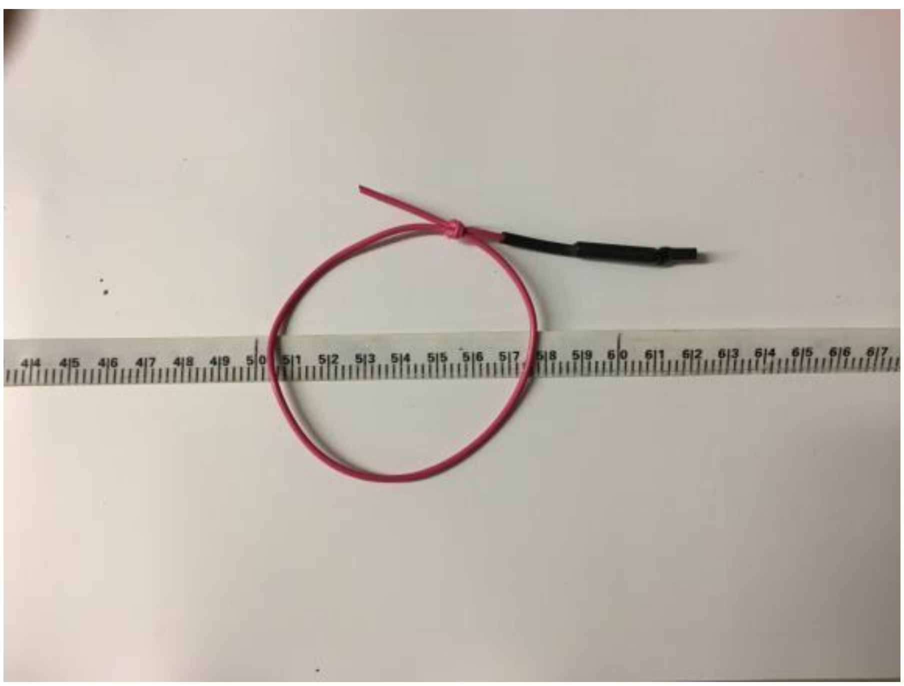


Figure 4. PIT tagged (white) adult Steelhead caught on December 23, 2017. Field staff is preparing to release the fish.

2.1.3.2. Fish Detection

The movements of tagged fish were monitored using three PIT tag detection systems (supplied by Oregon RFID Inc.) placed near the barriers of interest, as shown in Map 2. Each PIT tag detection system consisted of a single antenna connected to a capacitance tuner box, which was connected to an antenna tag reader. The downstream 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-PTANT01) was installed upstream of QUN-BAR01. At the start of the PIT tag monitoring program the upstream system was 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 full discussion on functionality in Marriner *et al.* (2016)). On January 5, 2017, the system was relocated once again to a position approximately 150 m upstream of the falls (QUN-PTANT01c). The QUN-PTANT01c location was used throughout the remainder of the monitoring program.

Each PIT tag detection system was powered by a battery bank, designed to power the system continuously for up to 17 days, was made up of four 12-volt deep cycle batteries in a weatherproof housing. The capacitance tuner box of the 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.

The antennas of the PIT tag detection systems were constructed from outdoor contractor grade extension cords. Materials were spliced together and sealed with epoxy housed in PVC piping sized to fit the antenna materials and 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. 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. The antenna read range varied from 35 – 45 cm; thus 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. All fish were tagged downstream of the PIT Tag detection systems. Therefore, fish that were detected once at a single PIT Tag detection system were assumed to be traveling in the upstream direction. In cases where a fish was detected numerous times at a single PIT Tag detection system, a detailed assessment of the detection data was completed to determine the direction of travel. The direction of travel for fish detected at multiple PIT Tag detection systems was determined by reviewing the time stamp they were detected at each system, then comparing each system's position on the river relative to the other systems.

System maintenance was performed bi-weekly during the fall and weekly to twice 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.

In Year 2, QUN-PTANT07 was installed on September 27, 2016 and was operational until the system was removed on March 7, 2017. Both QUN-PTANT05 and QUN-PTANT01 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 system relocation was required. QUN-PTANT05 was only functional from September 27 to October 12, 2016. QUN-PTANT01 was functional from October 4 to October 7, 2016. Then it was non-functional from October 8 to October 24, 2016, followed by a period of functional in a limited capacity from October 24, 2016 to January 5, 2017, and was fully functional again from January 5 to March 7, 2017. Full discussion on functionality of QUN-PTANT01 and QUN-PTANT05 is presented in Marriner *et al.* (2016).

In Year 3, all three PIT tag detection systems remained in place and were not damaged by high flows. The PIT tag detection systems were installed on September 15, 2017, activated on September 28, 2017, and removed on March 2, 2018. QUN-PTANT01 and QUN-PTANT07 operated continuously from September 28, 2017 to March 2, 2018. However, QUN-PTANT05 failed on October 19, 2017 and the station was not operational again until October 27, 2017 when a replacement reader was installed.

In Year 4, all three PIT tag detection systems remained in place throughout the season. QUN-PTANT05 was not damaged by high flow; however, QUN-PTANT01 and QUN-PTANT07 were. The PIT tag detection systems were installed on September 10 and 11, 2018, activated on September 26, 2018, and removed on February 28, 2019. QUN-PTANT01 was damaged on December 24, 2018 and non-functional until February 5, 2019. QUN-PTANT05 operated continuously from September 26, 2018 to February 28, 2019. QUN-PTANT07 was damaged and non-functional from October 6 to October 19, 2018 and November 30 to December 20, 2018.

2.1.3.3. Fish Detections and the Quinsam River Hydrograph

An assessment of fish detections and corresponding flows at the WSC gauge stations 08HD021, 08HD026 and 08HD027 was completed for the duration of the project when PIT antenna arrays were installed (Years 2 – 4). This assessment was completed to address the management question and null hypothesis discussed above in Section 1.3.

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, 10 snorkel reaches (QUN-SNK01 to QUN-SNK07; Table 4) 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). In Year 3, additional snorkel reaches were defined to verify fish presence upstream and downstream of QUN-BAR02, QUN-BAR03, QUN-BAR06, and QUN-BAR07. QUN-BAR01 was approximately 200 m in length, with the most difficult obstacle located approximately 40 m from the upstream end. Snorkel section QUN-SNK01 started upstream of the barrier and ended upstream of the main obstacle. Cumulative Coho Salmon observation plots were generated for QUN-BAR07, QUN-BAR05, and QUN-BAR01 to compare the number of fish observed downstream and upstream of the barriers.

Snorkel surveys to evaluate adult Coho Salmon and Steelhead passage were undertaken in the Quinsam River at regular intervals as conditions allowed from (September to November) and winter (December to February) in Years 2, 3 and 4. On each survey date, individual stream sections were surveyed once by two experienced technicians swimming in pairs. 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 5). Information on survey conditions were also recorded, including weather, water temperature, and estimated snorkel visibility.

Table 4. Quinsam River snorkel survey reach descriptions.

Snorkel Reach	Zone	Easting	Northing	Site Length (m)	Description	Historic Name[1]	Interpretation of fish location relative to barrier (2017 reach breaks)
QUN-SNK08US	10U	330679	5533442	320	280 m upstream of QUN-BAR01	SNK01US	Above BAR01
QUN-SNK08DS	10U	330916	5533379		Main obstacle near top of QUN-BAR01	SNK01DS	
QUN-SNK09US	10U	330968	5533366	100	Below the main obstacle near the top of QUN-BAR01	SNK02US	Midway up BAR01 - but below most difficult section near the top (long barrier)
QUN-SNK09DS	10U	331061	5533296		Bottom of QUN-BAR01	SNK02DS	
QUN-SNK10US	10U	331065	5533292	280	Bottom of QUN-BAR01	SNK03US	Below BAR01, above BAR02
QUN-SNK10DS	10U	331202	5533172		Top of QUN-BAR02	SNK03DS	
QUN-SNK11US	10U	331206	5533169	124	Top of QUN-BAR02	-	Midway up BAR02 (long barrier)
QUN-SNK11DS	10U	331325	5533173		Bottom of QUN-BAR02	SNK04US	
QUN-SNK12US	10U	331328	5533170	44	Bottom of QUN-BAR02	-	Below BAR02, above BAR03
QUN-SNK12DS	10U	331375	5533155		Top of QUN-BAR03	-	
QUN-SNK13US	10U	331392	5533152	79	Bottom of QUN-BAR03	-	Below BAR03, above BAR04
QUN-SNK13DS	10U	331481	5533133		Top of QUN-BAR04	SNK04DS	
QUN-SNK14US	10U	331484	5533132	230	Bottom of QUN-BAR04	SNK05US	Below BAR04, above BAR05
QUN-SNK14DS	10U	331710	5533161		Top of QUN-BAR05	SNK05DS	
QUN-SNK15US	10U	331717	5533159	146	Bottom of QUN-BAR05	SNK06US	Below BAR05, above BAR06
QUN-SNK15DS	10U	331861	5533133		Top of QUN-BAR06	SNK06DS	
QUN-SNK16US	10U	331872	5533138	81	Bottom of QUN-BAR06	SNK07US	Below BAR07, above BAR07
QUN-SNK16DS	10U	331960	5533132		Top of QUN-BAR07	-	
QUN-SNK17US	10U	331969	5533129	250	Bottom of QUN-BAR07	-	Below BAR07
QUN-SNK17DS	10U	332207	5533156		250 m below QUN-BAR07	SNK07DS	

[1] Snorkel reach reported in Years 1 to 3.

Table 5. Variables recorded during snorkel surveys in the Quinsam River.

Variable	Unit/Classification
Weather	Field observation.
Water Temperature	Measured in degrees Celsius (°C).
Water Visibility	Measured or estimated in meters.
Fish Species	Coho Salmon (CO); Steelhead/Rainbow Trout (ST/RB); Chinook Salmon (CH); Pink Salmon (PK).
Fish size class	Adults: 150 - 250 mm, 251 - 350 mm, and > 450 mm
Fish condition	Bright/Moderately coloured; mid spawn; post-spawn; undetermined.

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 the Year 1 reconnaissance site visits: SAM-BAR05, SAM-BAR07 and SAM-BAR011 (Map 3) (Marriner *et al.* 2016). 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 in the late summer and fall of 2016. 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 2016 during fall snorkels after the low flow period had ended.

2.2.2.1. Critical Riffle Analysis

Barriers to fish movement that result from shallow water riffles were assessed 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 (CRA) method described by CDFG (2012). The method is suitable for wadable, 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 6);
- 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 6. 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

[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.

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 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 flows were initially 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 flows sampled were dependent on the hydrologic characteristics of the study period. The first of these two flows were targeted during Year 2 (during Survey #1 and Survey #2, respectively) and the other two flows were to be scheduled in Year 3. However, Year 3 field work was cancelled after BC Hydro decommissioned the Salmon River Diversion facility in the summer/fall of 2017.

The WSC hydrometric gauge on the river's mainstem downstream of the diversion dam (08HD032) was used to estimate discharge at SAM-BAR05, SAM-BAR07 and SAM-BAR11. 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.

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 five 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 7). 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 7. Salmon River snorkel survey reach descriptions, October 3, 2016 to February 28, 2019.

Snorkel Reach	Length (m)	Reach Descripition	
		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 to evaluate adult Coho and Chinook Salmon passage and during the spring to evaluate adult Steelhead passage. The Steelhead snorkel surveys were undertaken as part of work planned for JHTMON-8. A total of 28 snorkel surveys were conducted between October 4, 2016 and February 28, 2019. In some cases, snorkel surveys were cancelled because flows were too high to safely and effectively snorkel, however this snorkel survey was typically completed later when flows returned to a safe range. Snorkel surveys were completed in teams of two, following similar methods to those described in Section 2.1.

3. RESULTS

3.1. Quinsam River

3.1.1. Barrier Assessments

3.1.1.1. QUN-BAR01

The four barrier assessment surveys at QUN-BAR01 were conducted under flows of 0.99, 1.66-1.70, 2.36, and 2.64 m^3/s (Table 8).

During the initial barrier survey, a total of 10 potential passage routes were identified and assessed within QUN-BAR01, see Figure 5. The first survey also identified two potential upstream paths of travel for fish to swim past the overall barrier. Subsequent surveys assessed the potential passage routes with a focus on those within the potential upstream paths of travel (Table 8).

The easiest path for fish to ascend the overall barrier is to swim past Route 1, then Route 2 or 3, followed by Route 4, then Route 7, and finally Route 10 (Figure 5). For fish following these potential paths, the overall barrier was considered passable at a flow of 2.64 m^3/s, but not passable at flows of 0.99 to 2.36 m^3/s. Below, each of the potential passage routes is discussed starting at the downstream end of QUN-BAR01 and moving upstream.

Table 8. Barrier assessment surveys collected at QUN-BAR01 on the Quinsam River between November 7, 21018 and October 19, 2018.

Date	Flow[1] (m^3/s)	No. of Passage Routes	Route No.	Barrier Type (Fall/Chute)	Plunge Pool Depth (m)	Vertical Drop (m)	Depth at Crest (m)	Wetted Width at Crest (m)	Length (X or LS) (m)	Slope (S_e or S_p) (%)	Crest Velocity (m^3/s)	Passable at Observed Flow
08-Nov-2017	1.66	10	1	Chute	0.60	0.70	0.10	20.00	4.00	6.00	1.50	No
	1.66	10	2	Chute	2.33	1.20	0.14	1.90	2.20	50.00	2.08	No
	1.66	10	3	Chute	0.44	1.05	0.34	5.30	10.00	16.00	1.45	Yes
	1.66	10	4	Chute	0.16	2.10	0.11	3.20	9.00	20.00	3.06	No
	1.66	10	5	Chute	1.70	4.50	0.05	6.60	20.20	18.00	2.35	No
	1.66	10	6	Falls	0.62	1.60	0.05	6.20	3.40	98.00	2.23	No
07-Nov-2017	1.70	10	7	Chute	0.25	1.20	0.15	1.36	10.40	14.00	2.31	No
	1.70	10	8	Chute	0.30	1.15	0.03	14.10	7.50	15.00	1.68	No
	1.70	10	9	Chute	0.16	0.71	0.02	5.00	3.60	15.00	1.18	No
08-Nov-2017	1.66	10	10	Chute	0.25	1.40	0.22	12.60	25.00	8.00	1.50	Yes
19-Aug-2018	0.99	10	1	Chute	-	-	-	-	-	-	-	No
	0.99	10	2	Chute	2.50	0.86	0.27	-	3.05	29.26	1.69	Yes
	0.99	10	3	Chute	0.15	1.08	0.41	-	5.19	15.94	1.86	No
	0.99	10	4	Chute	0.22	1.40	0.25	-	8.04	17.30	2.28	Yes
	0.99	10	5	Chute	-	-	-	-	-	-	-	No
	0.99	10	6	Falls	0.46	1.74	0.15	-	5.05	35.44	1.65	No
	0.99	10	7	Chute	0.08	1.24	0.24	-	8.36	12.90	1.33	No
	0.99	10	8	Chute	0.18	1.15	0.04	-	7.29	18.14	0.98	No
	0.99	10	9	Chute	-	-	-	-	-	-	-	No
	0.99	10	10	Chute	0.15	0.77	0.14	-	16.28	4.80	0.67	No

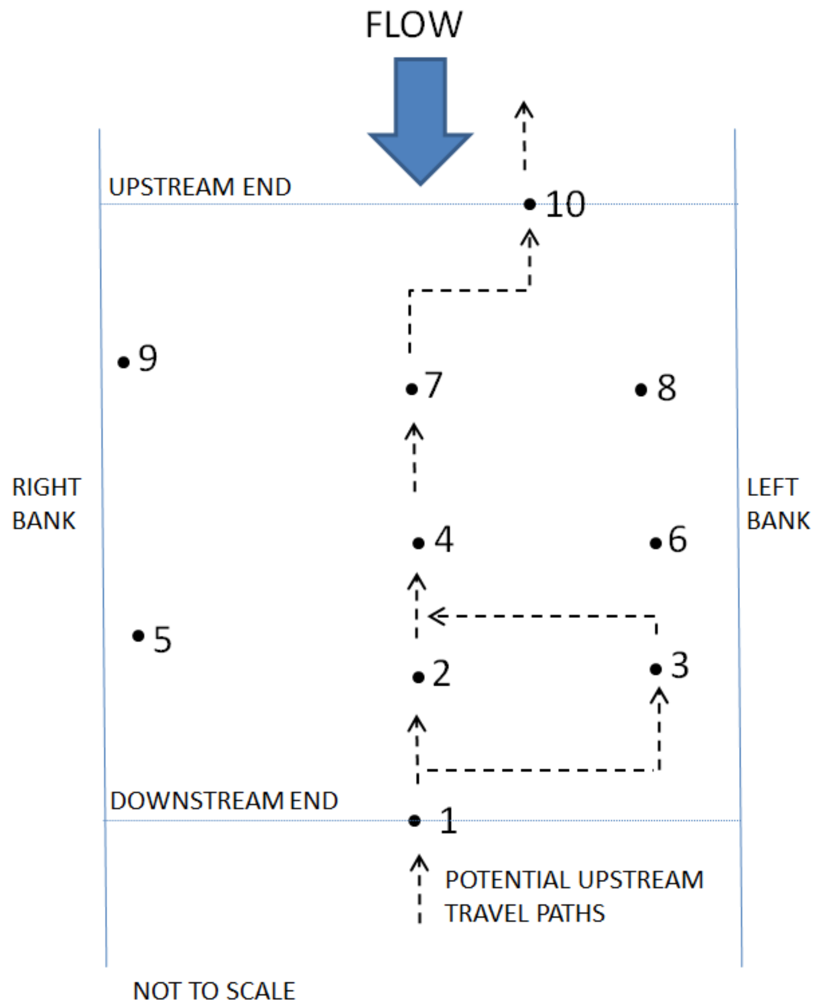
[1] Mean daily flow rate, as measured recorded at the nearby WSC Gauge 08HD027.

Table 8. Continued.

Date	Flow[1] (m^3/s)	No. of Passage Routes	Route No.	Barrier Type (Fall/Chute)	Plunge Pool Depth (m)	Vertical Drop (m)	Depth at Crest (m)	Wetted Width at Crest (m)	Length (X or LS) (m)	Slope (S_e or S_p) (%)	Crest Velocity (m^3/s)	Passable at Observed Flow
17-Sep-2018	2.64	10	1	Chute	0.70	-	0.10	34.00	5.00	15.00	1.43	Yes
	2.64	10	2	Chute	2.55	-	0.30	1.90	2.20	50.00	2.00	Yes
	2.64	10	3	Chute	0.45	-	0.31	6.40	9.00	18.00	1.51	Yes
	2.64	10	4	Chute	0.32	-	0.35	3.50	9.60	20.00	1.95	Yes
	2.64	10	5	Chute	2.20	-	0.10	10.00	18.00	17.00	2.20	No
	2.64	10	6	Falls	1.80	1.50	0.08	13.90	3.50	100.00	1.63	No
	2.64	10	7	Chute	0.32	-	0.23	1.40	7.30	16.00	1.58	Yes
	2.64	10	8	Chute	0.33	-	0.13	14.70	11.00	14.00	1.85	No
	2.64	10	9	Chute	0.18	-	0.05	10.50	6.40	10.00	1.46	No
	2.64	10	10	Chute	0.25	-	0.18	17.70	24.20	5.00	1.37	Yes
19-Oct-2018	2.36	10	1	Chute	-	-	-	-	-	-	-	Yes
	2.36	10	2	Chute	2.30	0.90	0.40	-	-	-	1.92	Yes
	2.36	10	3	Chute	0.10	-	0.55	-	-	-	2.18	No
	2.36	10	4	Chute	1.00	0.70	0.20	-	-	-	2.00	Yes
	2.36	10	5	Chute	-	-	-	-	-	-	-	No
	2.36	10	6	Falls	0.60	1.80	0.15	-	-	-	1.80	No
	2.36	10	7	Chute	0.12	-		-	-	-	2.04	No
	2.36	10	8	Chute	0.32	-	0.13	-	-	-	1.98	No
	2.36	10	9	Chute	-	-	-	-	-	-	-	No
	2.36	10	10	Chute	-	-	0.20	-	-	-	1.05	Yes

[1] Mean daily flow rate, as measured recorded at the nearby WSC Gauge 08HD027.

Figure 5. **Plan view schematic of QUN-BAR01 and the respective potential passage routes for upstream migrating fish.**



Route 1

The first potential passage route was a wide chute, spanning the river channel, at the downstream end of QUN-BAR01 (Figure 6). At a flow of 1.66 m^3/s, the route was 4 m long, with a gradient of 6% (Table 8). This route was considered passable at flows of 2.36 m^3/s and above, but not passable at flows 1.66 m^3/s and less.

Figure 6. Looking upstream at QUN-BAR01 passage Route 1, a wide chute spanning the river channel, assessed on November 8, 2017.

Route 2

The second potential passage route was within a falls section of the barrier where a man-made slotted fish ladder was situated in the center of the channel at the lower end of QUN-BAR01, downstream of Route 4 (Figure 7). The ladder was constructed of large logs, fastened to the river bed, that funnel flow through a single pool. At a flow of 1.66 m^3/s, the route had a 1.2 m high drop and a depth of 0.14 m at the crest (Table 8). This route was considered passable at flows of 0.99, 2.36 and 2.64 m^3/s, and not passable at a flow of 1.66m^3/s. At higher flows, it was anticipated this route will be used, as well as Route 3, to pass the downstream part of the barrier.

Figure 7. Looking upstream at QUN-BAR01 passage Route 2, a falls on river left, assessed on November 8, 2017.

Route 3

The third potential passage route was a chute situated along the river left of the channel at the lower end of QUN-BAR01, downstream of Route 6 (Figure 8). It appeared as though this chute may have been previously deepened to increase fish passage through it. At a flow of 1.66 m^3/s, the route was 10.0 m long, with a gradient of 16% (Table 8). This route was considered passable at flows of 1.66 and 2.64 m^3/s and not a passable at flows of 0.99 and 2.36 m^3/s. The variance in passability between 1.66 and 2.36 m^3/s may be the result of the barrier measurements collected at slightly different positions along the route. However, it was anticipated that this route was passable above 2.64 m^3/s. This route and Route 2 were likely the two passage route options for the downstream end of the barrier.

Figure 8. Looking upstream at QUN-BAR01 passage Route 3, a chute on river left, assessed on November 8, 2017.

Route 4

The fourth potential passage route was located in the middle of QUN-BAR01 within a section of chute where there was another man-made slotted fish ladder situated in the center of the channel (Figure 9). The ladder was constructed of large logs, fastened to the river bed, that funnel flow through a series of two pools. At a flow of 1.66 m^3/s, the route was 9.0 m long, with a gradient of 20% (Table 8). This route was considered not passable at a flow of 1.66 m^3/s, and passable at flows of 0.99, 2.36, and 2.64 m^3/s. This route was likely the main passage route past the barrier's middle section at higher flows. Fish were expected to swim through Route 4 and travel upstream to Route 7.

Figure 9. Looking upstream at QUN-BAR01 passage Route 4, assessed on November 8, 2017, which contains a man-made slotted fish ladder in the centre of the channel.

Route 5

The fifth potential passage route was a natural bedrock chute situated along the river right of the channel in the middle of QUN-BAR01 (Figure 10). At a flow of 1.66 m^3/s, this route was 20.2 m long, with a gradient of 18% (Table 8). This route was considered not passable at any of the flows observed. This was not likely a limiting barrier because fish would likely travel up Route 4 on their way to Route 7 at the upper end of the barrier.

Figure 10. Looking downstream at QUN-BAR01 passage Route 5, natural bedrock chute on river right, assessed on November 8, 2017.

Route 6

The sixth potential passage route was a natural falls situated along the river left of the channel in the middle of QUN-BAR01, adjacent to Route 4 (Figure 11). At a flow of 1.66 m^3/s, the route had a 1.6 m high drop and a depth of 0.05 m at the crest (Table 8). This route was considered not passable under all of the observed flow conditions but was not likely a limiting barrier because fish would likely travel up Route 4 on their way to Route 7 at the upper end of the barrier at higher flows.

Figure 11. Looking upstream at QUN-BAR01 passage Route 6, a natural falls on river left, assessed on November 8, 2017.

Route 7

The seventh potential passage route was within a chute section of the barrier where a man-made slotted fish ladder was situated in the center of the channel at the upper end of QUN-BAR01 (Figure 12). The ladder was constructed of large logs, fastened to the river bed that funnels flow through a series of three pools. At a flow of 1.66 m^3/s, this route was 10.4 m long, with a gradient of 14% (Table 8). The route was considered not passable under flows of 0.99, 1.66, and 2.36 m^3/s, and passable at 2.64 m^3/s. This was likely the main passage route past the barrier's upper section at higher flows.

Figure 12. Looking downstream at QUN-BAR01 passage Route 7, assessed on November 7, 2017, which contains a man-made slotted fish ladder in the centre of the channel.

Route 8

The eighth potential passage route was a natural bedrock chute situated along the river left of the channel at the upper end of QUN-BAR01 adjacent to Route 1 (Figure 13). At a flow of 1.66 m^3/s, the route was 7.50 m long, with a gradient of 15% (Table 8). The route was considered not passable under all of the observed flow conditions and based on the relatively lower depth, it was considered less passable than Route 7. Thus, this route was not likely to be a limiting barrier because fish would likely travel up Route 7 instead of Route 8 to get past the upper section of the barrier (Figure 14) at higher flows.

Figure 13. Looking upstream at QUN-BAR01 passage Route 8, assessed on November 7, 2017, which is a natural bedrock chute on river left.

Figure 14. Looking upstream at QUN-BAR01 passage Route 7 (centre of channel), Route 8 (on river left), and Route 9 (on river right), on November 7, 2017.

Route 9

The ninth potential passage route was a natural bedrock chute situated along river right of the channel at the upper end of QUN-BAR01 (Figure 15). At a flow of 1.66 m^3/s, the route was 3.6 m long, with a gradient of 15% (Table 8). This route was considered not passable under all of the observed flow conditions. This was not likely a limiting barrier because fish would likely travel up Route 7 instead of Route 9 to get past the upper section of the barrier (Figure 14) because Route 7 had a greater flow depth than Route 9.

Figure 15. Looking downstream at QUN-BAR01 passage Route 9, a natural bedrock chute on river right, assessed on November 7, 2017.

Route 10

The tenth potential passage route was the upstream crest of QUN-BAR01. A portion of the crest along the river left bank has been previously deepened by rock removal (Figure 16). At a flow of 1.66 m^3/s, the route is 25 m long, with a gradient of 8% (Table 8). This route was considered passable at flows of 1.66 m^3/s and above.

Figure 16. Looking river right to river left at QUN-BAR01 passage Route 10, a chute at the upstream crest of QUN-BAR01, assessed on November 8, 2017.

3.1.1.2. QUN-BAR05

The three barrier assessment surveys at QUN-BAR05 were conducted under flows of 1.02, 2.36, and 2.64 m^3/s (Table 9). During the initial barrier survey, a total of 6 potential passage routes were identified and assessed within QUN-BAR05, see Figure 17. The first survey also identified two potential upstream paths of travel for fish to swim past the overall barrier. Subsequent surveys assessed these two potential passage routes (Table 9).

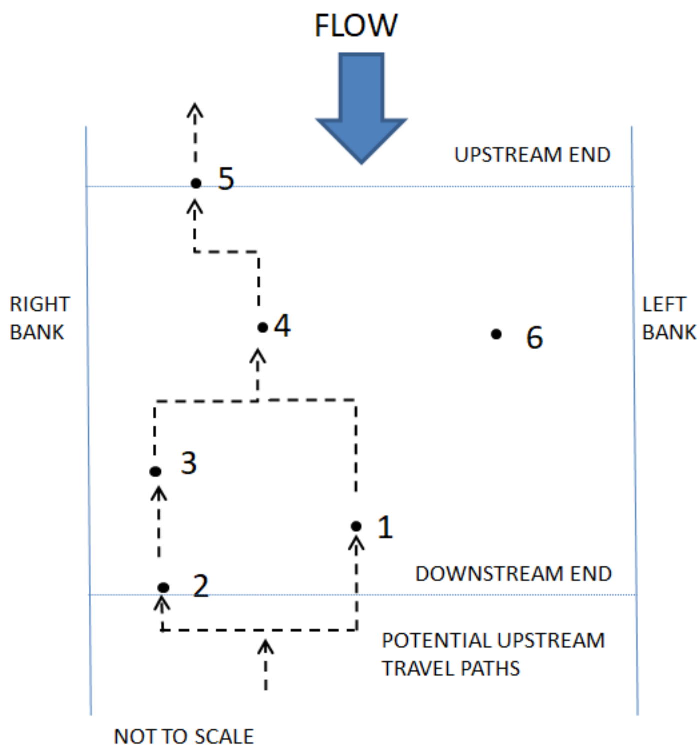
The first potential upstream path is to swim past Route 1, then Route 4, and finally Route 5. Alternatively, fish may ascend via Route 2, then Route 3, followed by Route 4 and Route 5. Route 6 was considered the most difficult potential route to pass and was not passable during each of the three surveys conducted. The overall barrier was considered passable at flows of 2.36 and 2.64 m^3/s; however, it was considered not passable at a flow of 1.02 m^3/s.

Table 9. Barrier assessment surveys collected at QUN-BAR05 on the Quinsam River between August 18 and October 19, 2018.

Date	Flow[1] (m^3/s)	No. of Passage Routes	Route No.	Barrier Type (Fall/Chute)	Plunge Pool Depth (m)	Vertical Drop (m)	Depth at Crest (m)	Wetted Width at Crest (m)	Length (X or LS) (m)	Slope (S_e or S_p) (%)	Crest Velocity (m^3/s)	Passable at Observed Flow
18-Aug-2018	1.02	6	1	Chute	0.60	1.42	0.05	-	7.08	23.69	2.72	No
18-Aug-2018	1.02	6	2	Falls	0.45	0.30	0.18	-	-	-	-	Yes
18-Aug-2018	1.02	6	3	Falls	0.10	0.50	0.23	-	-	-	-	No
18-Aug-2018	1.02	6	4	Falls	0.87	1.30	0.10	-	-	-	0.80	No
18-Aug-2018	1.02	6	5	Chute	0.17	0.07	0.39	-	5.15	2.97	0.80	Yes
18-Aug-2018	1.02	6	6	Falls	-	-	-	-	-	-	-	No
17-Sep-2018	2.64	6	1	Chute	0.51	0.00	0.15	3.50	3.00	22.00	1.92	Yes
17-Sep-2018	2.64	6	2	Falls	-	-	-	-	-	-	-	Yes
17-Sep-2018	2.64	6	3	Falls	0.60	0.00	0.35	5.00	8.70	-	2.83	Yes
17-Sep-2018	2.64	6	4	Falls	0.85	1.10	0.04	12.40	2.00	-		Yes
17-Sep-2018	2.64	6	5	Chute	-	-	-	-	-	-	-	Yes
17-Sep-2018	2.64	6	6	Falls	0.35	0.00	0.08	19.40	12.00	-	1.67	No
19-Oct-2018	2.36	6	1	Chute	0.55	-	0.05	-	-	-	3.29	No
19-Oct-2018	2.36	6	2	Falls	-	-	-	-	-	-		Yes
19-Oct-2018	2.36	6	3	Falls	0.45	1.00	0.25	-	-	-	2.96	Yes
19-Oct-2018	2.36	6	4	Falls	1.10	1.30	0.28	-	-	-	1.50	Yes
19-Oct-2018	2.36	6	5	Chute	-	-	-	-	-	-	-	Yes
19-Oct-2018	2.36	6	6	Falls	-	-	-	-	-	-	-	No

[1] Mean daily flow rate, as measured recorded at the nearby WSC Gauge 08HD027.

Figure 17. Plan view schematic of QUN-BAR05 and the respective potential passage routes for upstream migrating fish.



Route 1

The first potential passage route was a chute with manmade passage augmentation, to the right of the channel's center, at the downstream end of QUN-BAR05 (Figure 18). At a flow of 1.02 m^3/s, the route was 7.08 m long with a gradient of 23.7% (Table 9). This route was considered passable at a flow of 2.64 m^3/s, but not passable at flows of 2.36 m^3/s and less. One potential upstream path was for fish to swim through Route 1, then upstream to Routes 4 and 5 to pass the barrier (Figure 17).

Figure 18. **Looking upstream at the river right portion of QUN-BAR05 on August 18, 2018. Route 1, a chute with manmade passage augmentation shown is in the foreground.**

Route 2

The second potential passage route was a falls, along the channel's river right, at the downstream end of QUN-BAR05 (Figure 19). At a flow of 1.02 m^3/s, the route had a 0.25 m high drop and a crest depth of 1.6 m (Table 9). This route was considered passable at all three flows surveyed. One potential upstream path was for fish to swim upstream through Routes 2, 3, 4 and 5 to pass the barrier (Figure 17).

Figure 19. Looking upstream at the river right bank of QUN-BAR05 on September 17, 2018. Route 2, a smaller falls seen is in the foreground; and Route 3, a larger falls seen is in the background.

Route 3

The third potential passage route was a falls, along the channel's river right, at the lower end of QUN-BAR05 (Figure 19). At a flow of 1.02 m^3/s, the route had a 0.5 m high drop and a crest depth of 0.23 m (Table 9). This route was considered passable at flows of 2.36 and 2.64 m^3/s and not passable at 1.02 m^3/s.

Route 4

The fourth potential passage route was a large falls, along the channel's river right, at the middle of QUN-BAR05 (Figure 20). At a flow of 1.02 m^3/s, the route had a 1.3 m high drop and a crest depth of 0.1 m (Table 9). This route was considered passable at flows of 2.36 and 2.64 m^3/s, and not passable at 1.02 m^3/s.

Figure 20. Looking upstream at the river right bank of QUN-BAR05 on September 17, 2018. Route 4, a large falls is shown.

Route 5

The fifth potential passage route was a chute, along the channel's river right, at the upstream end of QUN-BAR05. At a flow of 1.02 m^3/s, the route was 5.2 m long with a slope of 3.0% (Table 9). This route was considered passable at all flows surveyed.

Route 6

The sixth potential passage route was a large falls, spanning the river left portion of the channel at QUN-BAR05 (Figure 21). This route was not surveyed under any flow conditions as it was considered not passable and unlikely to be used for upstream migration.

Figure 21. Looking upstream at the river left portion of QUN-BAR05 on September 17, 2018. Route 6, a large falls is shown.

3.1.1.3. QUN-BAR07

The three barrier assessment surveys at QUN-BAR07 were conducted at flows of 1.02, 2.36, and 2.6 m^3/s (Table 10). During the initial barrier survey, a total of 4 potential passage routes were identified and assessed within QUN-BAR07, see Figure 22. The first survey also identified two potential upstream paths of travel for fish to swim past the overall barrier. Subsequent surveys assessed these two potential passage routes (Figure 22).

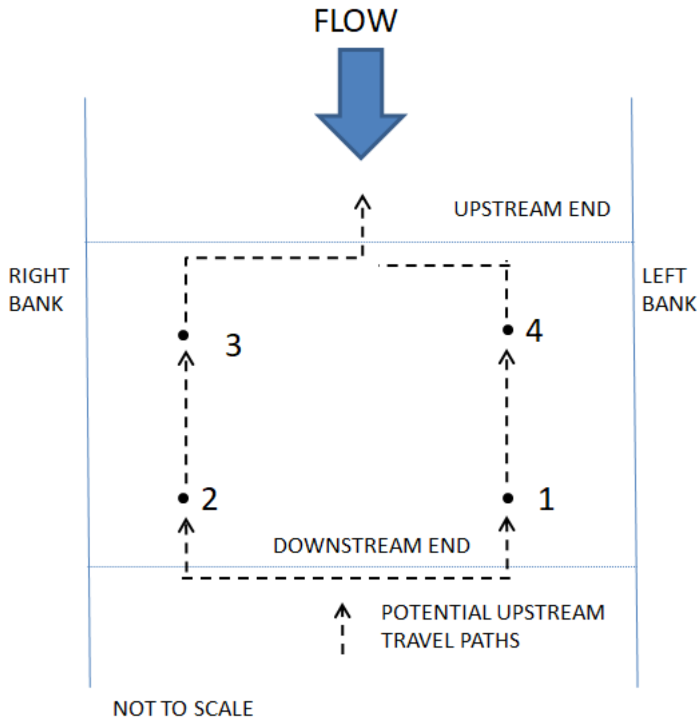
The first potential upstream path is to swim past Route 1 then Route 4. Alternatively, fish may ascend via Route 2, then Route 3. The overall barrier was considered passable at a flow of 2.64 m^3/s; however, it was considered not passable at flows of 1.02 and 2.36 m^3/s. Below, each of the potential passage routes is discussed starting at the downstream end of QUN-BAR07 and moving upstream.

Table 10. Barrier assessment surveys collected at QUN-BAR07 on the Quinsam River between August 18 and October 19, 2018.

Date	Flow (m^3/s)	No. of Passage Routes	Route No.	Barrier Type (Fall/Chute)	Plunge Pool Depth (m)	Vertical Drop (m)	Depth at Crest (m)	Wetted Width at Crest (m)	Length (X or LS) (m)	Slope (S_e or S_p) (%)	Crest Velocity (m^3/s)	Passable at Observed Flow
18-Aug-2018	1.02	4	1	Chute	0.12	0.35	0.10	-	5.40	7.00	2.42	No
18-Aug-2018	1.02	4	2	Falls	1.15	0.25	1.60	-	-	-	1.00	Yes
18-Aug-2018	1.02	4	3	Falls	1.60	0.77	0.09	-	-	-	1.75	No
18-Aug-2018	1.02	4	4	Chute	0.12	1.14	0.22	-	20.50	5.60	0.63	No
17-Sep-2018	2.64	4	1	Chute	0.60	-	-	15.00	6.50	12.00	2.70	Yes
17-Sep-2018	2.64	4	2	Falls	0.50	-	0.13	8.70	2.90	11.00	1.69	Yes
17-Sep-2018	2.64	4	3	Falls	0.16	0.70	0.04	11.10	3.50	20.00	1.66	No
17-Sep-2018	2.64	4	4	Chute	0.60	-	0.11	9.30	15.40	7.00	1.65	Yes
19-Oct-2018	2.36	4	1	Chute	0.80	-	0.13	-	-	-	1.30	No
19-Oct-2018	2.36	4	2	Falls	0.65	-	0.20	-	-	-	1.60	Yes
19-Oct-2018	2.36	4	3	Falls	1.60	0.85	0.08	-	-	-	1.66	No
19-Oct-2018	2.36	4	4	Chute	0.38	-	0.25	-	-	-	2.75	Yes

[1] Mean daily flow rate, as measured recorded at the nearby WSC Gauge 08HD027.

Figure 22. Plan view schematic of QUN-BAR07 and the respective potential passage routes for upstream migrating fish.



Route 1

The first potential passage route was a chute, along the channel's river left, at the downstream end of QUN-BAR07 (Figure 23). At a flow of 1.02 m^3/s, the route was 5.4 m long with a gradient of 7% (Table 10). This route was considered passable at a flow of 2.64 m^3/s, but not passable at flows of 2.36 m^3/s and less. One potential upstream path was for fish to swim through Route 1 and upstream to Route 4 to pass the barrier (Figure 22).

Figure 23. Looking upstream at the river left portion of QUN-BAR07 on August 18, 2018. Route 1, a chute is in the foreground; and Route 4, a chute is in the background.

Route 2

The second potential passage route was a falls, along the channel's river right, at the downstream end of QUN-BAR07 (Figure 24). At a flow of 1.02 m^3/s, the route had a 0.25 m high drop and a crest depth of 1.6 m (Table 10). This route was considered passable at all three flows surveyed. One potential upstream path was for fish to swim through Route 2 and upstream to Route 3 to pass the barrier (Figure 22).

Figure 24. Looking upstream at the river right side of QUN-BAR07 on August 18, 2018. Route 2, a falls is in the foreground; and Route 3, a falls is in the background.

Route 3

The third potential passage route was a falls, along the channel's river right, at the upstream end of QUN-BAR07 (Figure 24). At a flow of 1.02 m^3/s, this route had a 0.77 m high drop and a crest depth of 0.09 m (Table 10). This route was considered not passable at all three flows surveyed. However, at higher flows fish would likely able to swim through Routes 2 and 3 in sequence to pass the barrier.

Route 4

The fourth potential passage route was a chute, along the channel's river left, at the upstream end of QUN-BAR07 (Figure 23). At a flow of 1.02 m^3/s, the route was 20.5 m long with a gradient of 5.6% (Table 10). This route was considered passable at flows of 2.36 m^3/s and above, but not passable at flows below this. At flows of 2.64 m^3/s and greater fish would be able to pass the overall barrier by swimming through Routes 1 and 4 in sequence.

3.1.2. Fish Tagging and Detection

3.1.2.1. Fish Tagging

A total of 571 tags were applied to Coho Salmon, and 40 tags were applied to Steelhead during the three years of tagging (Table 11Table 12Table 13Table 14).

Tagged Coho ranged in fork length from 414 to 865 mm. Most condition categories were recorded as moderately coloured (n = 223) or mid-spawn (n = 215), 85 were classified as bright, and 48 were undetermined. Tagged Steelhead were 600 to 930 mm in length and were classified as bright (n = 26), moderately coloured (n = 12), and mid-spawn (n = 2) (Table 15).

A total of 75 tagged Coho were recaptured at the hatchery fence. No Steelhead were recaptured at the fence; however, two tagged Steelhead were captured a second time during angling.

Table 11. Program summary of PIT/Floy tag applications on the Quinsam River in the fall and winter of 2016/2017, 2017/2018, and 2018/2019.

Species	Year	# of Tags Applied	# of Fish Recaptured
Coho	2018-2019	215	25
	2017-2018	188	33
	2016-2017	168	17
Total Coho		*571*	*75*
Steelhead	2018-2019	6	0
	2017-2018	14	1
	2016-2017	20	1
Total Steelhead		*40*	*2*
Total Coho + Steelhead		**611**	**77**

Table 12. Summary of PIT/Floy tag applications on the Quinsam River in the fall and winter of 2016/2017 (Marriner *et al.*, 2017).

Species	Tagging Date	Floy Tag Colour	# of Tags Applied	# of Fish Recaptured
Coho	23-Sep-2016	Pink	2	0
	29-Sep-2016	Pink	9	0
	05-Oct-2016	Pink	18	0
	12-Oct-2016	Pink	26	0
		Pink	0	1
	13-Oct-2016	Pink	21	0
		Pink	0	1
		Blue	3	0
	14-Oct-2016	Blue	14	0
	18-Oct-2016	Blue	22	
		Pink	0	1
	19-Oct-2016	Pink	0	2
	20-Oct-2016	Blue	0	1
	26-Oct-2016	Blue	0	1
	27-Oct-2016	Blue	8	0
		Blue	0	1
		Pink	0	1
	31-Oct-2016	Blue	3	0
		Blue	0	1
	01-Nov-2016	Blue	0	2
		Blue	23	0
		White	11	0
	03-Nov-2016	Blue	0	3
	07-Nov-2016	Blue	0	1
		White	5	0
	10-Nov-2016	Blue	0	1
		White	3	0
Total Coho			**168**	**17**
Steelhead	28-Sep-2016	Blue	1	0
	05-Oct-2016	Blue	1	0
	18-Oct-2016	Blue	1	0
	21-Dec-2016	Blue	5	0
	23-Dec-2016	Pink	2	0
		Blue	2	0
	29-Dec-2016	White	2	0
	30-Dec-2016	Blue	1	0
	10-Jan-2017	White	0	1
	11-Jan-2017	Blue	1	0
	23-Jan-2017	Pink	1	0
		Blue	1	0
		White	1	0
	25-Jan-2017	White	1	0
Total Steelhead			**20**	**1**

Table 13. **Summary of PIT/Floy tag applications on the Quinsam River in the fall and winter of 2017/2018 (Marriner *et al.,* 2018).**

Species	Tagging Date	Floy Tag Colour	# of Tags Applied	# of Fish Recaptured[1]
Coho	26-Sep-2017	White	9	0
	02-Oct-2017	White	3	0
	13-Oct-2017	White	3	0
	18-Oct-2017	White	16	1
	20-Oct-2017	White	29	1
	25-Oct-2017	Pink	1	0
	25-Oct-2017	White	3	1
	26-Oct-2017	Pink	6	0
	27-Oct-2017	Pink	8	0
	30-Oct-2017	Pink	11	0
	03-Nov-2017	Pink	14	0
	08-Nov-2017	Pink	7	0
	10-Nov-2017	Pink	7	0
	14-Nov-2017	Blue	23	0
	14-Nov-2017	Pink	14	1
	14-Nov-2017	White	0	5
	15-Nov-2017	Blue	26	8
	15-Nov-2017	Pink	0	3
	15-Nov-2017	White	0	3
	17-Nov-2017	Blue	5	5
	17-Nov-2017	Pink	0	2
	17-Nov-2017	White	0	3
	20-Nov-2017	Blue	3	0
Total Coho			**188**	**33**
Steelhead	13-Dec-2017	Blue	1	0
	19-Dec-2017	Blue	3	0
	21-Dec-2017	Blue	1	0
	23-Dec-2017	Blue	1	1
	23-Dec-2017	White	3	0
	19-Jan-2018	Blue	1	0
	20-Jan-2018	Blue	1	0
	26-Feb-2018	Blue	1	0
	01-Mar-2018	Blue	1	0
	05-Mar-2018	Blue	1	0
Total Steelhead			**14**	**1**

[1] Includes fish recaptured more than once.

Table 14. Summary of PIT/Floy tag applications on the Quinsam River in the fall and winter of 2018/2019.

Species	Tagging Date	Floy Tag Colour	# of Tags Applied	# of Fish Recaptured
Coho	24-Sep-2018	Pink	1	0
	25-Sep-2018	Pink	1	0
	26-Sep-2018	Pink	6	0
	27-Sep-2018	Pink	14	0
	02-Oct-2018	Pink	7	0
	03-Oct-2018	Pink	16	0
	05-Oct-2018	Pink	10	6
		White	2	10
	09-Oct-2018	Pink	7	4
		White	18	3
	10-Oct-2018	White	4	0
	11-Oct-2018	White	27	1
	12-Oct-2018	White	8	0
	17-Oct-2018	Blue	6	0
		White	3	0
	18-Oct-2018	Blue	1	0
	19-Oct-2018	Blue	1	0
	24-Oct-2018	Blue	11	0
	29-Oct-2018	Blue	3	0
	30-Oct-2018	Blue	3	0
	31-Oct-2018	Blue	9	1
	01-Nov-2018	Blue	27	0
	02-Nov-2018	Blue	7	0
	05-Nov-2018	Blue	23	0
Total Coho			**215**	**25**
Steelhead	03-Oct-2018	Blue	1	0
	10-Dec-2018	Blue	1	0
	27-Dec-2018	Blue	1	0
	15-Jan-2019	Blue	1	0
	25-Jan-2019	Blue	2	0
Total Steelhead			**6**	**0**

Table 15. Summary of sex, fork length, condition, and hatchery reared Coho Salmon and Steelhead captured at the Quinsam River Fish Hatchery fence and by angling in Years 2, 3, 4.

Species	Sex (M/F)	n	Fork Length (mm)			Condition[1]			# Missing Adipose
			Mean	Min	Max	Mean	Min	Max	
Coho	F	260	651	463	810	2.1	1	3	0
	M	311	656	414	865	2.3	1	3	0
Total Coho		**571**	**654**	**414**	**865**	**2.2**	**1**	**3**	**0**
Steelhead	F	28	752	640	876	1.4	1	3	0
	M	12	759	600	930	1.5	1	3	0
Total Steelhead		**40**	**754**	**600**	**930**	**1.4**	**1**	**3**	**0**

[1] 1 = bright, 2 = moderately-coloured, 3 = mid-spawn, 4 = post-spawn.

3.1.2.2. Fish Detection

Of the total 571 Coho Salmon and 40 Steelhead tagged and released, 45 Coho (7.9%) and three Steelhead (7.5%) were detected by the PIT tag detection systems (Table 16 toTable 18). Five Coho were detected by multiple antenna arrays: one was detected by all three stations, three were detected by the downstream and middle station, and one was detected by the downstream and upstream station. Flows corresponding to Coho detections ranged from 2.04 m^3/s to 32.50 m^3/s, with a mean of 7.79 m^3/s. All three Steelhead were detected at the downstream array. Flows corresponding to Steelhead detections ranged from 7.78 m^3/s to 19.20 m^3/s, with a mean of 13.68 m^3/s. All flows presented here are from data collected at WSC gauge 08HD027 located approximately 1.9 km downstream of the upstream end of QUN-BAR01 (Map 2).

Downstream Site (QUN-PTANT07)

Over the three years of PIT tag monitoring all of the 45 Coho salmon and three Steelhead detected were detected at the downstream site. In Year 2 (2016-2017), 10 Coho Salmon and two Steelhead were detected on the downstream PIT tag antenna array system. Coho Salmon were detected from October 6 to 22, 2016 (median = October 19, 2016), 3 to 21 days after tagging (mean = 9 days). The two Steelhead detected by the downstream site were tagged on October 5 and December 23, 2016, and detected on October 18, 2016 and February 23, 2017, 13 and 62 days after tagging (mean = 38 days), respectively. Flows at the time of Coho detections ranged from 6.69 m^3/s to 32.50 m^3/s, with a mean of 15.34 m^3/s. Flows at the time of Steelhead detections ranged from 7.78 m^3/s to 13.49 m^3/s, with a mean of 13.49 m^3/s (Table 16).

In Year 3 (2017-2018), 18 Coho and one Steelhead were detected by the downstream PIT tag detection system. Coho Salmon were detected from October 18 to November 1, 2017 (median = October 20, 2017), two to 23 days after tagging (mean = 11 days). The one Steelhead detected by the downstream site was captured on December 13, 2017 and detected on

February 7, 2018 (56 days after capture). Flows at the time of Coho detections ranged from 2.46 m^3/s to 8.59 m^3/s, with a mean of 6.12 m^3/s. The Steelhead was detected at a flow of 14.05 m^3/s (Table 17).

In Year 4 (2018-2019), 16 Coho were detected by the downstream PIT tag detection system. Coho Salmon were detected from September 30 to November 7, 2018 (median = October 31, 2018), 2 to 32 days after tagging (mean = 14 days). Flows at the time of Coho detections ranged from 2.04 m^3/s to 12.15 m^3/s, with a mean of 5.66 m^3/s (Table 18).

Middle Site (QUN-PTANT05)

Over the three years of PIT tag monitoring three Coho salmon were detected at the middle site. In Year 2 (2016-2017), 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 throughout the majority of the monitoring period (Marriner *et al.*, 2017).

In Year 3 (2017-2018), three Coho salmon and no Steelhead were detected by the middle PIT tag antenna system. The three Coho identified at the middle site were tagged between September 26 and October 18 and reached the middle site on October 19 (n = 2) and October 27, 2017 (n = 1). Coho Salmon at the middle site were detected six to 23 days after tagging (mean = 13 days) and 0 to 7 days after passing the downstream site (mean = 3 days). All Coho Salmon detected by the middle site were previously detected by the downstream site. However, one Coho Salmon detected at the upstream site passed the middle site during the period it was not operating (October 19 to October 27, 2017). Flows at the time of Coho detections ranged from 4.96 m^3/s to 7.96 m^3/s, with a mean of 6.63 m^3/s (Table 17).

In Year 4 (2018-2019), one Coho salmon and no Steelhead were detected by the middle PIT tag antenna site. The Coho identified at the middle site was tagged on October 11 and reached the middle site on November 2, 2108. It was detected at the middle station 22 days after tagging and two days after passing the downstream site. The flow at the time of the Coho salmon detection was 5.23 m^3/s (Table 18).

Upstream Site (QUN-PTANT01)

A total of two Coho Salmon, both detected during the fall of 2017, and no Steelhead were detected by the upstream antenna array. One Coho was detected by all three PIT tag antenna systems: it was captured on September 26, 2017, detected by the downstream and middle sites on October 19 (23 days after capture), and detected by the upstream site on October 25 (29 days after capture). The second Coho was captured on October 18, 2017, detected by the downstream site on October 20, 2017 (two days after capture) and then detected by the upstream site on October 26, 2017 (eight days after capture). This fish was not detected by the middle site because it moved past the site when the PIT tag antenna system was not functional (October 19 to October 27, 2017). Flows corresponding to the two Coho detections were 4.83 m^3/s and 5.36 m^3/s, respectively (Table 17).

A size comparison was completed for all Coho tagged over the three year monitoring period to assess if there was a size difference of the two Coho that passed the upstream reader compared to the overall set of Coho tagged (Table 19). Overall the fork lengths ranged from 414 mm to 865 mm, with an average length of 654 mm. The two fish that passed the upstream barrier had fork lengths in the 15^{th} (510 mm) and 71^{st} percentiles (732 mm), respectively. This did not indicate a relation between fork length and capability of individual Coho to pass the upstream barrier.

Table 16. Summary of PIT tagged Steelhead (ST) and Coho Salmon (CO) that were detected by the PIT tag detection systems on the Quinsam River between September 27, 2016 and March 7, 2017 (Marriner *et al.*, 2017).

Species	Capture Date	PIT Tag Number	Fork Length (mm)	Sex (M/F)	[1] Condition (1-5)	Missing Adipose (Y/N)[2]	Previously Tagged (Y/N)[3]	QUI-PTANT07 Downstream			
								Arrival Date/Time		Flow Rate[4] (m^3/s)	Days from Capture
Coho	29-Sep-2016	228000307872	696	M	1	Y	N	06-Oct-2016	4:30:47	6.69	7
	05-Oct-2016	228000307881	555	M	2	N	N	08-Oct-2016	15:42:28	28.50	3
	05-Oct-2016	228000307880	580	M	1	N	N	15-Oct-2016	3:31:18	32.50	10
	12-Oct-2016	228000307852	742	M	2	N	N	18-Oct-2016	11:55:12	19.20	6
	12-Oct-2016	228000307762	434	M	2	N	N	19-Oct-2016	9:34:34	13.20	7
	13-Oct-2016	228000307884	722	F	1	N	N	20-Oct-2016	12:05:43	11.00	7
	13-Oct-2016	228000307859	714	M	1	N	N	20-Oct-2016	12:25:14	11.00	7
	29-Sep-2016	228000307804	727	M	2	N	N	20-Oct-2016	17:55:51	11.00	21
	12-Oct-2016	228000307903	638	M	2	N	N	21-Oct-2016	14:20:52	10.20	9
	13-Oct-2016	228000307868	650	M	1	N	N	22-Oct-2016	10:38:37	10.10	9
Steelhead	05-Oct-2016	228000307989	679	M	1	N	N	18-Oct-2016	11:41:20	19.20	13
	23-Dec-2016	228000307987	790	M	1	N	N	23-Feb-2017	13:31:09	7.78	62

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

[2] Y = Adipose fin is missing; N = adipose fin intact.

[3] Y = Fish captured in fall of 2016 and subsequently recaptured; N = Fish was not recaptured after initial tagging.

[4] Average daily flow rate in the Quinsam as measured at WSC Gauge 08HD027.

Table 17. Summary of PIT tagged Steelhead (ST) and Coho Salmon (CO) that were detected by the PIT tag detection systems on the Quinsam River between September 27, 2017 and March 7, 2018 (Marriner *et al.*, 2018).

Species	Capture Date	Pit Tag Number	Fork Length (mm)	Sex (M/F)	Condition (1 - 5)[1]	Missing Adipose (Y/N)[2]	Previously Tagged (Y/N)[3]	QUI-PTANT07 (Downstream)			QUI-PTANT05 (Middle)			QUI-PTANT01 (Upstream)		
								Arrival Date/Time	Flow Rate[4] (m^3/s)	Days from Capture	Arrival Date/Time	Flow Rate[4] (m^3/s)	Days from Capture	Arrival Date/Time	Flow Rate[4] (m^3/s)	Days from Capture
Coho	26-Sep-2017	228000592906	700	M	1	N	N	19-Oct-2017 03:06:32	6.99	23	n/a	-	n/a	n/a	-	n/a
		228000592962	760	F	1	N	N	19-Oct-2017 15:43:14	8.45	23	n/a	-	n/a	n/a	-	n/a
		228000592915	630	M	1	N	N	18-Oct-2017 18:39:57	8.59	22	n/a	-	n/a	n/a	-	n/a
		228000592950	570	M	2	N	N	19-Oct-2017 02:30:29	6.94	23	19-Oct-2017 10:38:06	7.90	23	25-Oct-2017 01:58:06	5.36	29
	2-Oct-2017	228000592923	550	M	1	N	N	19-Oct-2017 02:41:37	6.94	17	n/a	-	n/a	n/a	-	n/a
		228000592922	610	F	1	N	N	19-Oct-2017 05:37:31	7.34	17	n/a	-	n/a	n/a	-	n/a
	13-Oct-2017	228000592925	530	M	2	N	N	18-Oct-2017 19:25:18	5.92	5	19-Oct-2017 11:14:29	7.96	6	n/a	-	n/a
		228000592961	755	M	2	N	N	20-Oct-2017 05:20:18	8.57	7	n/a	-	n/a	n/a	-	n/a
	18-Oct-2017	228000592937	469	F	2	N	N	29-Oct-2017 19:49:37	3.09	11	n/a	-	n/a	n/a	-	n/a
		228000592944	575	M	2	N	N	21-Oct-2017 02:56:19	7.12	3	n/a	-	n/a	n/a	-	n/a
		228000592958	548	M	2	N	N	21-Oct-2017 00:07:54	7.36	3	n/a	-	n/a	n/a	-	n/a
		228000592952	565	F	2	N	N	20-Oct-2017 11:35:17	8.28	2	27-Oct-2017 12:00:00	4.02	9	n/a	-	n/a
		228000592951	732	M	2	N	N	20-Oct-2017 21:08:47	7.60	2	n/a	-	n/a	26-Oct-2017 00:57:38	4.83	8
	20-Oct-2017	228000592907	675	F	2	N	N	28-Oct-2017 00:38:54	3.78	8	n/a	-	n/a	n/a	-	n/a
		228000592943	702	M	2	N	N	30-Oct-2017 05:18:24	2.98	10	n/a	-	n/a	n/a	-	n/a
		228000592949	665	F	2	N	N	25-Oct-2017 20:19:14	3.41	5	n/a	-	n/a	n/a	-	n/a
		228000592910	610	F	1	N	N	26-Oct-2017 22:47:34	4.31	6	n/a	-	n/a	n/a	-	n/a
		228000593031	695	M	2	N	N	01-Nov-2017 21:22:37	2.46	2	n/a	-	n/a	n/a	-	n/a
Steelhead	13-Dec-2017	228000592970	630	M	1	N	N	07-Feb-2018 06:09:41	14.05	56	n/a	-	n/a	n/a	-	n/a

[1] 1 = Bright, 2 = moderately coloured, 3 = pre-spawn, 4 =post-spawn, 5 = undetermined.
[2] Y = Adipose fin is missing; N = adipose fin intact.
[3] Y = Fish captured in fall of 2017 and subsequently recaptured; N = Fish was not recaptured after initial tagging.
[4] 1-hr leading average flow rate in the Quinsam as measured at WSC Gauge 08HD027.

Table 18. Summary of PIT tagged Steelhead (ST) and Coho Salmon (CO) that were detected by the PIT tag detection systems on the Quinsam River between September 26, 2018 and February 28, 2019.

Species	Capture Date	PIT Tag Number	Fork Length (mm)	Sex (M/F)	Condition (1-5)[1]	Missing Adipose (Y/N)[2]	Previously Tagged (Y/N)[3]	QUI-PTANT07 (Downstream) Arrival Date/Time	QUI-PTANT07 (Downstream) Flow Rate[4]	QUI-PTANT07 (Downstream) Days from Capture	QUI-PTANT05 (Middle) Arrival Date/Time	QUI-PTANT05 (Middle) Flow Rate[4]	QUI-PTANT05 (Middle) Days from Capture	QUI-PTANT01 (Upstream) Arrival Date/Time	QUI-PTANT01 (Upstream) Flow Rate[4]	QUI-PTANT01 (Upstream) Days from Capture
CO	26-Sep-2018	228000389825	520	M	1	N	N	30-Sep-2018 04:36:59	2.60	4	n/a	-	n/a	n/a	-	n/a
	27-Sep-2018	228000389797	565	M	2	N	N	05-Oct-2018 05:35:46	3.71	8	n/a	-	n/a	n/a	-	n/a
	02-Oct-2018	228000389800	640	M	2	N	N	21-Oct-2018 19:55:48	2.14	20	n/a	-	n/a	n/a	-	n/a
	03-Oct-2018	228000389790	625	M	2	N	N	03-Nov-2018 12:29:00	8.55	32	n/a	-	n/a	n/a	-	n/a
	05-Oct-2018	228000389828	685	M	2	N	N	31-Oct-2018 00:11:12	3.28	26	n/a	-	n/a	n/a	-	n/a
		228000389871	680	M	2	N	N	03-Nov-2018 00:25:19	8.62	25	n/a	-	n/a	n/a	-	n/a
		228000389878	720	M	2	N	N	02-Nov-2018 19:22:15	8.29	25	n/a	-	n/a	n/a	-	n/a
		228000389972	600	M	2	N	N	20-Oct-2018 19:48:30	2.24	12	n/a	-	n/a	n/a	-	n/a
	11-Oct-2018	228000389873	455	M	-	N	N	23-Oct-2018 04:04:40	2.04	12	n/a	-	n/a	n/a	-	n/a
		228000389980	480	M	-	N	N	20-Oct-2018 22:46:59	2.25	10	n/a	-	n/a	n/a	-	n/a
		228000389979	675	M	-	N	N	30-Oct-2018 23:54:02	3.28	20	02-Nov-2018 00:51:29	5.23	22	n/a	-	n/a
	17-Oct-2018	228000389778	585	F	2	N	N	04-Nov-2018 01:19:42	9.69	18	n/a	-	n/a	n/a	-	n/a
	24-Oct-2018	228000389859	605	M	3	N	N	31-Oct-2018 19:57:52	3.53	8	n/a	-	n/a	n/a	-	n/a
	01-Nov-2018	228000389913	590	M	3	N	N	04-Nov-2018 08:37:18	12.15	3	n/a	-	n/a	n/a	-	n/a
	05-Nov-2018	228000389994	555	M	3	N	N	07-Nov-2018 08:34:30	8.89	2	n/a	-	n/a	n/a	-	n/a
		228000389894	735	M	3	N	N	07-Nov-2018 03:51:24	9.29	2	n/a	-	n/a	n/a	-	n/a

[1] 1 = Bright, 2 = moderately coloured, 3 = pre-spawn, 4 = post-spawn, 5 = undetermined.

[2] Y = Adipose fin is missing; N = adipose fin intact.

[3] Y = Fish captured in fall of 2018 and subsequently recaptured; N = Fish was not recaptured after initial tagging.

[4] 1-hr leading average flow rate in the Quinsam as measured at WSC Gauge 08HD027.

Table 19. Summary of PIT tagged Coho Sizes by Year.

Year	# of Fish Sampled	Fork Length (mm)			
		Min	Avg	Max	S.D.
2016-2017	168	414	652	800	80.4
2017-2018	188	440	680	863	75.9
2018-2019	215	455	633	865	80.5
All Years	571	414	654	865	81.3

3.1.2.3. Fish Detections and the Quinsam River Hydrograph

In Years 2 – 4, all 45 Coho Salmon detections coincided with the first and second flow increases of the autumn (Figure 25 - Figure 27), as observed at WSC gauge station 08HD027. The flow increases corresponded to the time period of approximately October 1 to November 10 annually. One of the three Steelhead detections corresponded with the fall Coho Salmon passage period, while the other two occurred on the declining side of the hydrograph during winter storms in February.

The hydrograph plots (Figure 25 - Figure 27) indicate that flow diversion, through the Quinsam Diversion Canal (WSC gauge station 08HD026), did not preclude fish from passing the migration barriers below Lower Quinsam Lake. Flows observed at WSC gauge station 08HD027 provided passage windows in Years 2 – 4.

Figure 25. 2016 Quinsam River PIT fish detections versus average daily flow at gauge station WSC 08HD027.

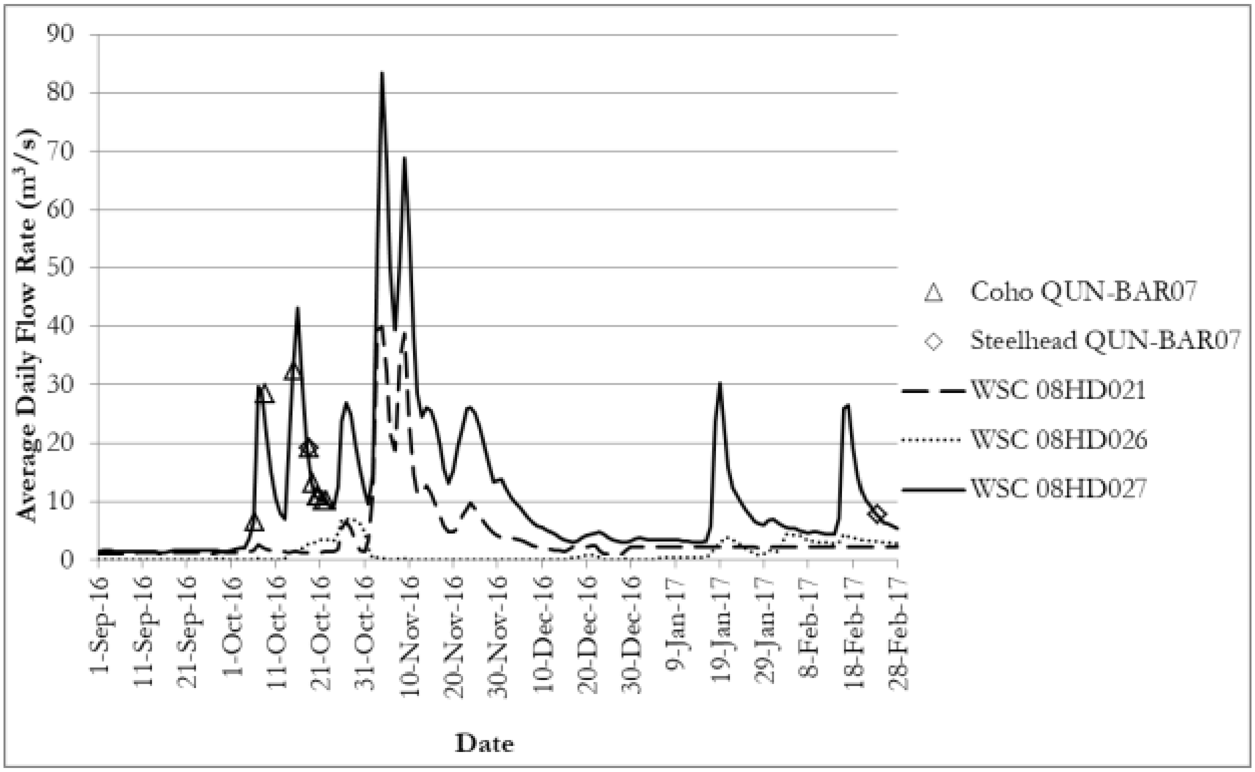


Figure 26. 2017 Quinsam River PIT fish detections versus average daily flow at gauge station WSC 08HD027.

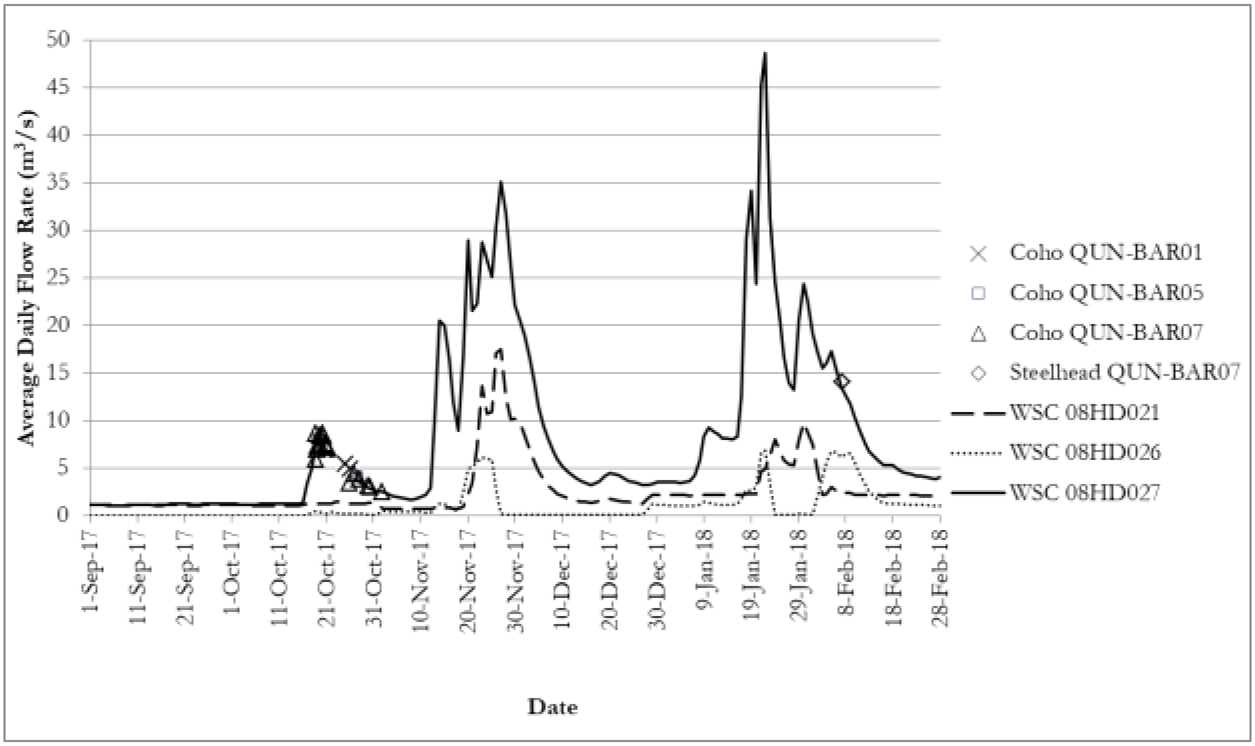
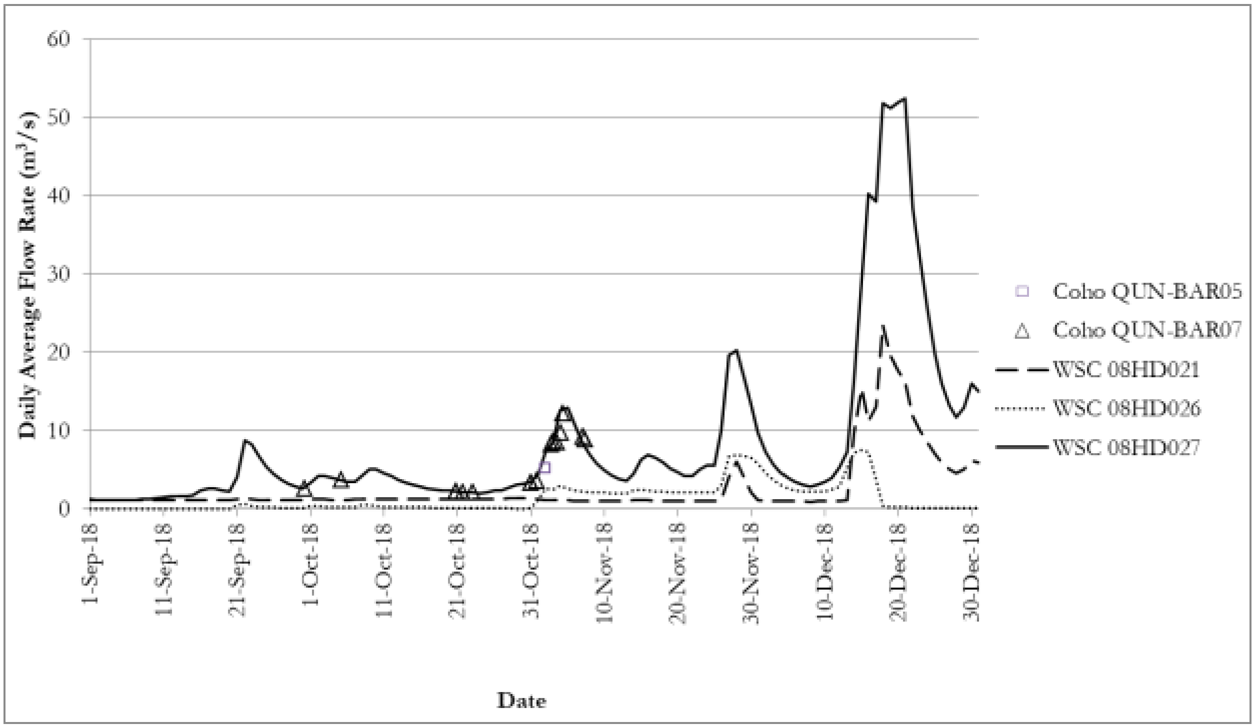


Figure 27. 2018 Quinsam River PIT fish detections versus average daily flow at gauge station WSC 08HD027.



3.1.3. Snorkel Surveys

During the monitoring program, a total of 17 snorkel surveys were completed in the fall between September and November 2016, 2017, and 2018 to evaluate adult Coho and Chinook Salmon passage. In addition, 11 snorkel surveys were completed during the winter months of December to late-February (2016/2017, 2017/2018 and 2018/19) to evaluate adult Steelhead passage (Table 20). Conditions varied among snorkel surveys: higher visibility and lower flows were recorded during snorkel surveys conducted prior to mid-October than during those conducted later in the fall/winter.

In total, 94 Coho Salmon, 842 Pink Salmon, and four Steelhead were observed in the Quinsam River during the fall snorkel surveys in 2016, 2017, and 2018 (Figure 28). Steelhead, Coho, or Pink Salmon were not observed during any of the winter snorkel surveys. However, challenging flow and visibility conditions likely influenced observations during the winter snorkel surveys and may be part of the reason fish were not observed in this period. During winter snorkel surveys visibility was consistently low, less than 2 metres, and observations were inhibited by flows that were higher than those during the fall snorkel surveys (see Figure 25 to Figure 27). Coho Salmon and Steelhead were observed the furthest upstream (to the middle of QUN-BAR01), while Pink Salmon were observed downstream of QUN-BAR01.

Coho Salmon were observed as early as September 26th and as late as November 20th. They were observed as far upstream as the downstream end of QUN-BAR01 (QUN-BAR01 DS), but not upstream of QUN-BAR01 (QUN-BAR01 US) (Figure 28a). Movement to QUN-BAR01 typically occurred late in the fall, with peak observations occurring from late October to early November. Earlier in the fall, Coho were located as far upstream as QUN-BAR02 but were most abundant downstream of QUN-BAR05.

Pink Salmon were observed in 2017 and 2018 from the first survey in September and were observed as late as mid-October. Pinks were observed downstream of QUN-BAR01, but not above (Figure 28b). Counts of Pink Salmon were highest between QUN-BAR07 and QUN-BAR05, and fish were not observed upstream of QUN-BAR05 until early October.

A single Steelhead was observed on October 4th, 2016, downstream of QUN-BAR07 but was not observed on any subsequent surveys. Three Steelhead observations were made in 2017 from October 10 to October 16, as far upstream as the middle of QUN-BAR01 (Figure 28c). No Steelhead were observed upstream of QUN-BAR01, suggesting that the Steelhead observed in the middle of QUN-BAR01 moved to habitats up or downstream of snorkel survey reaches after October 16, 2017.

Cumulative plots demonstrate that Coho Salmon typically moved past the downstream barrier (QUN-BAR07) during the month of October and into November (Figure 29a). The consistent observation of Coho Salmon upstream of QUN-BAR07 suggests that individuals of this species are able to pass this barrier and may time passage to coincide with flow increases. In 2016 through 2018, the number of Coho Salmon observed upstream of QUN-BAR05 typically increased from

September up until the last survey. No Coho were observed upstream of QUN-BAR01 during snorkel surveys; however, the number of Coho observed downstream of the barrier increased steadily during the fall of all years (Figure 29c).

As noted in Section 3.1.2.3, fish observations during snorkel surveys appeared to coincide with flow increases in the fall Figure 29. The flow increases corresponded to the time period of approximately October 1 to November 10 annually. In 2016, flow increased to 29.6 m3/s on October 7, then remained above 7.0 m3/s through October into November increasing three additional times with a maximum peak flow of 83.5 m3/s on November 4. Fish were observed at all three barriers during two snorkel surveys that coincided with the flow increase peaking on October 7. The next survey was not completed until December 5. The persistent high flows observed likely provided a long opportunity for upstream passage. However, the high flows resulted in low visibility and safety concerns for survey crews, which led to a reduced number of snorkel surveys being completed and fewer fish observed than in subsequent years. In 2017, flow increased to 8.2 m3/s on October 20, then decreased to 1.66 m3/s on November 8. Fish were observed during snorkel surveys from September 28 to November 3, with increased fish observations upstream of QUN-BAR05 and QUN-BAR07 during and after the October 20 peak flow. In 2018, flow increased to 8.7 m3/s on September 22, decreased to 2 m3/s on October 24, then increased again to 13 m3/s on November 5. Fish were observed during snorkel surveys from September 26 to November 20.

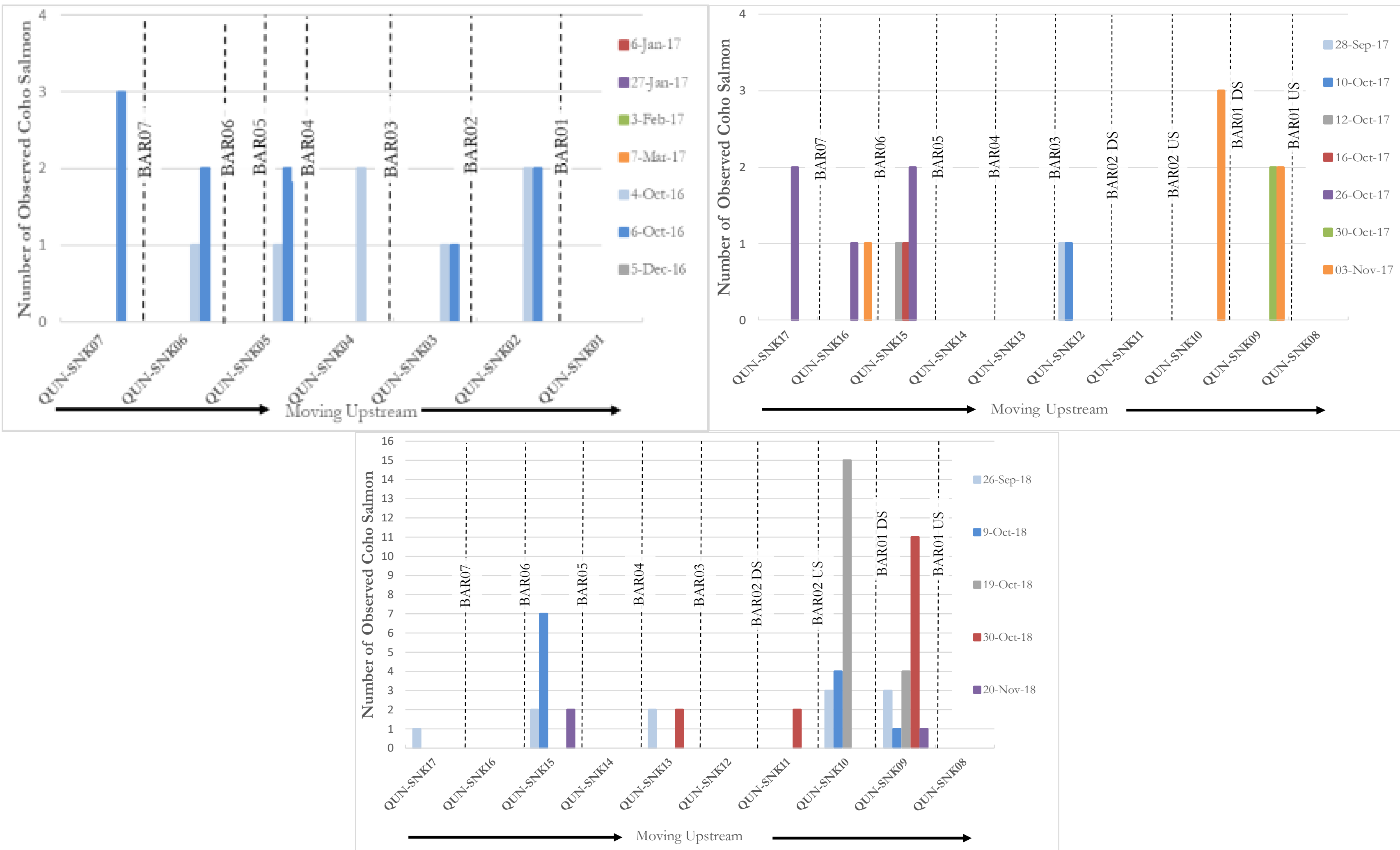
Table 20. Summary of snorkel survey conditions in Quinsam River.

Date	Snorkel Reaches	Total Effort (HH:MM:SS)	# of Swimmers	Water Temp. (˚C)	Estimated Flow (m^3/s)[1]	Estimated Visibility (m)
28-Sep-2017	QUI-SNK08 to QUI-SNK17	03:00:00	2	16.5	1.25	5.5
02-Oct-2017	QUI-SNK08 to QUI-SNK17	02:50:00	2	13.2	1.24	5.5
05-Oct-2017	QUI-SNK08 to QUI-SNK17	03:00:00	2	15	1.25	6.5
10-Oct-2017	QUI-SNK08 to QUI-SNK17	02:20:00	2	10.4	2	4
12-Oct-2017	QUI-SNK08 to QUI-SNK11	02:28:00	2	10.7	4	4.5
16-Oct-2017	QUI-SNK08 to QUI-SNK17	02:00:00	2	11.1	1.3	6
19-Oct-2017	QUI-SNK08 to QUI-SNK17	01:20:00	2	10.9	10	0.75
26-Oct-2017	QUI-SNK08 to QUI-SNK17	02:16:00	2	9.8	4	2
30-Oct-2017	QUI-SNK08 to QUI-SNK17	01:56:00	2	8.7	3	3-4
03-Nov-2017	QUI-SNK08 to QUI-SNK17	01:18:00	2	n/c	n/c	3-4
27-Dec-2017	QUI-SNK08 to QUI-SNK17	n/c	2	4	n/c	n/c
02-Jan-2018	QUI-SNK08 to QUI-SNK17	n/c	2	4	n/c	3
19-Feb-2018	QUI-SNK08 to QUI-SNK17	03:00:00	2	2	n/c	1-3
26-Sep-2018	QUI-SNK08 to QUI-SNK17	03:24:00	2	14.5	n/c	2.5
09-Oct-2018	QUI-SNK08 to QUI-SNK17	03:42:00	2	11.5	n/c	2-3
19-Oct-2018	QUI-SNK08 to QUI-SNK17	02:30:00	2	n/c	2.2	3
30-Oct-2018	QUI-SNK08 to QUI-SNK17	02:50:00	2	10	n/c	1-2
20-Nov-2018	QUI-SNK08 to QUI-SNK17	02:46:00	2	7	n/c	0.5-2.0
07-Dec-2018	QUI-SNK08 to QUI-SNK17	03:10:00	2	4.5	n/c	n/c
19-Feb-2019	QUI-SNK08 to QUI-SNK17	02:20:00	2	3	7	5.6
28-Feb-2019	QUI-SNK08 to QUI-SNK17	03:30:00	2	3	n/c	5-6

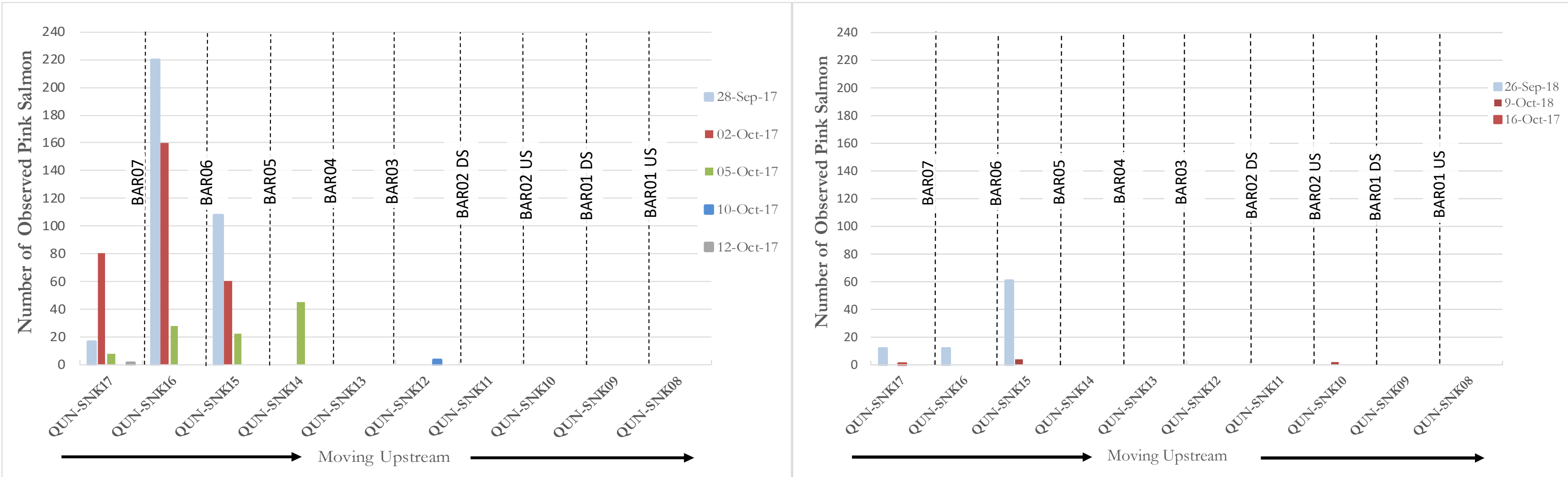
[1]n/c indicates that data was not collected.

Figure 28. Observations in snorkel sites in relation to barriers for a) Coho Salmon, b) Pink 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) Pink Salmon (none observed in 2016)



c) Steelhead (none observed in 2018/19)

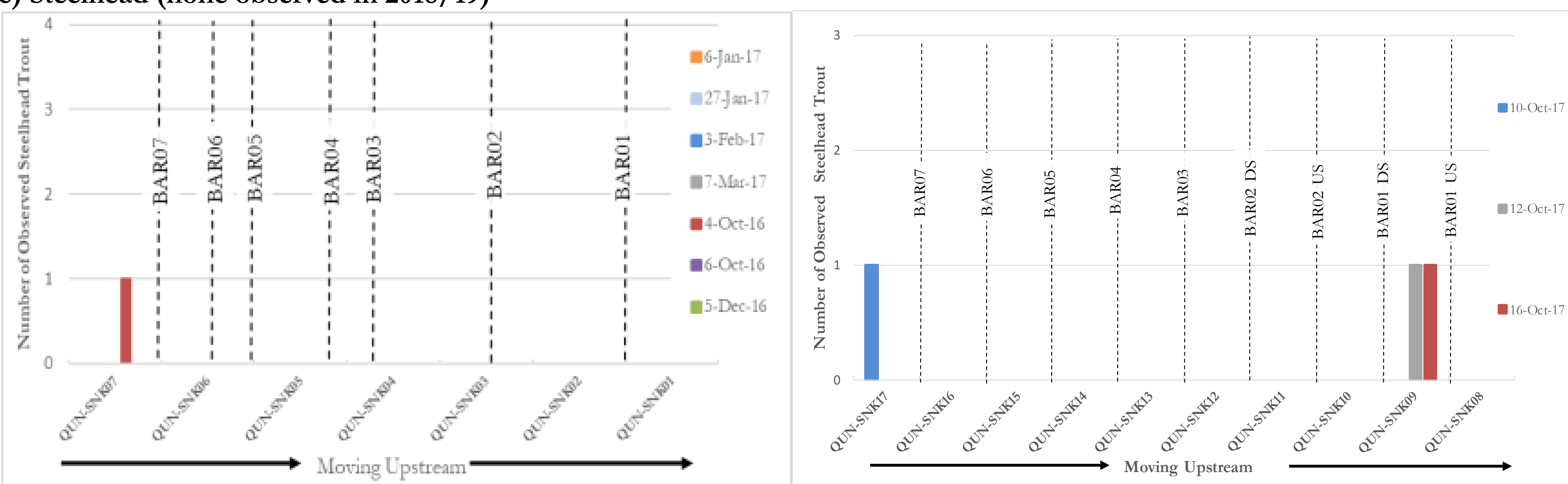
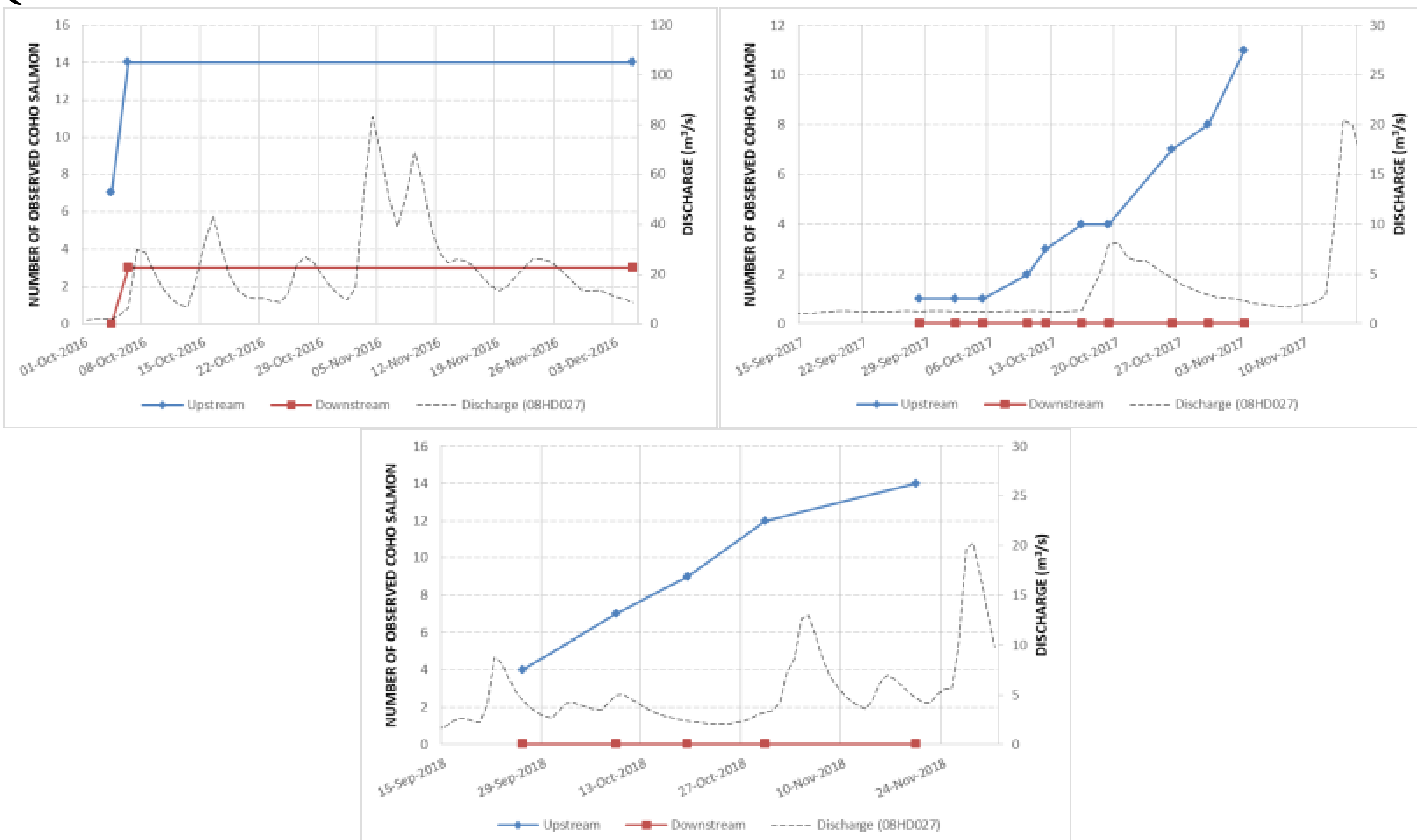


Figure 29. Cumulative plots for Coho Salmon displaying fish observed upstream and downstream of a) QUN-BAR07, b) QUN-BAR05, and c) QUN-BAR01. Flow, as measured at WSC gauge station 08HD027, is also plotted for each time period. In 2016, there were consistently high flows for the duration of the Coho Salmon migration period. This resulted in poor visibility and snorkel safety concerns and as a result a reduced number of snorkel surveys were completed.

a) QUN-BAR07



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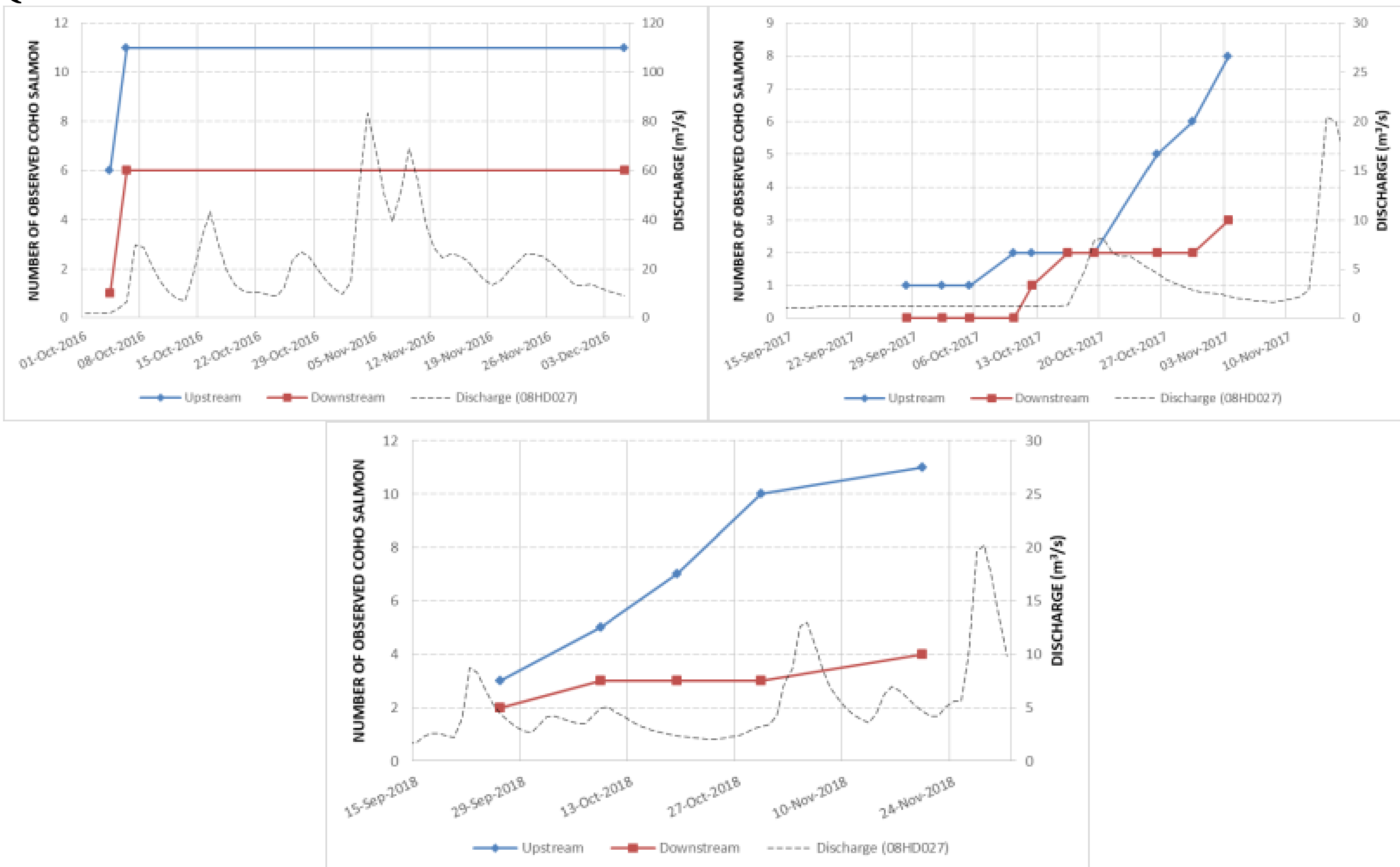
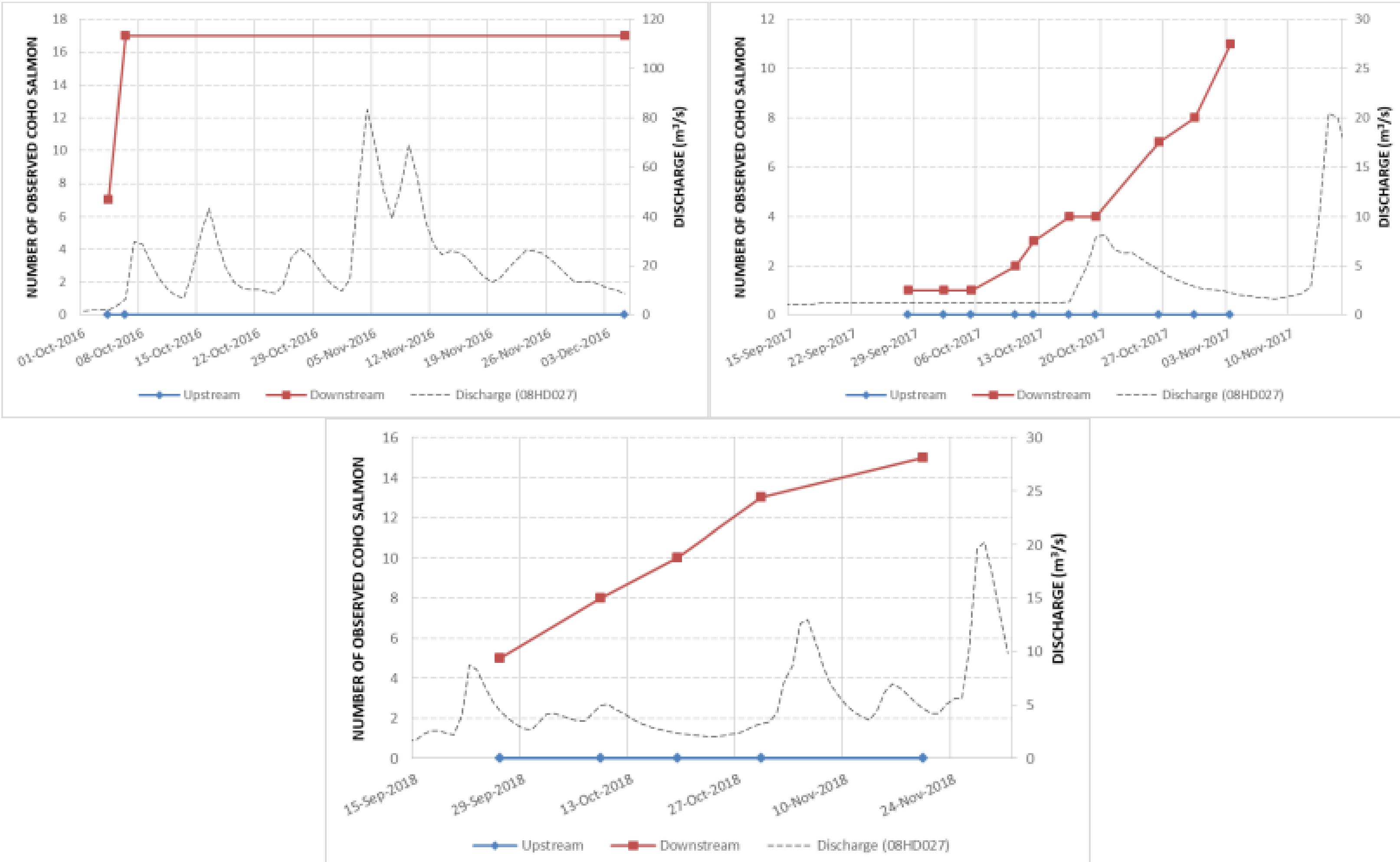
b) QUN-BAR05


NUMBER OF OBSERVED COHO SALMON
DISCHARGE (m³/s)
01-Oct-2016 08-Oct-2016 15-Oct-2016 22-Oct-2016 29-Oct-2016 05-Nov-2016 12-Nov-2016 19-Nov-2016 26-Nov-2016 03-Dec-2016
15-Sep-2017 22-Sep-2017 29-Sep-2017 06-Oct-2017 13-Oct-2017 20-Oct-2017 27-Oct-2017 03-Nov-2017 10-Nov-2017
15-Sep-2018 29-Sep-2018 13-Oct-2018 27-Oct-2018 10-Nov-2018 24-Nov-2018
Upstream
Downstream
Discharge (08HD027)

c) QUN-BAR01



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3.2. Salmon River

3.2.1. Barrier Assessments

The mean daily flows 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 flows 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 CRA method for any target species (Table 21, Table 22, and Table 23). All three barriers were therefore deemed unpassable under the flows 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 not passable results.

Table 21. SAM-BAR05 Critical Riffle Analysis field assessment results as measured on August 25 and September 13, 2016. Criteria for connectivity are 10% for percent contingous 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 22. SAM-BAR07 Critical Riffle Analysis field assessment results as measured on August 24 and September 12, 2016. Criteria for connectivity are 10% for percent contingous 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 23. SAM-BAR11 Critical Riffle Analysis field assessment results as measured on August 25 and September 12, 2016. Criteria for connectivity are 10% for percent contingous 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%

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 30). The stage-discharge relationships generated from stage data from each barrier site and discharge from WSC gauge 08HD032 are presented in Figure 31. 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 24.

Figure 30. 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.

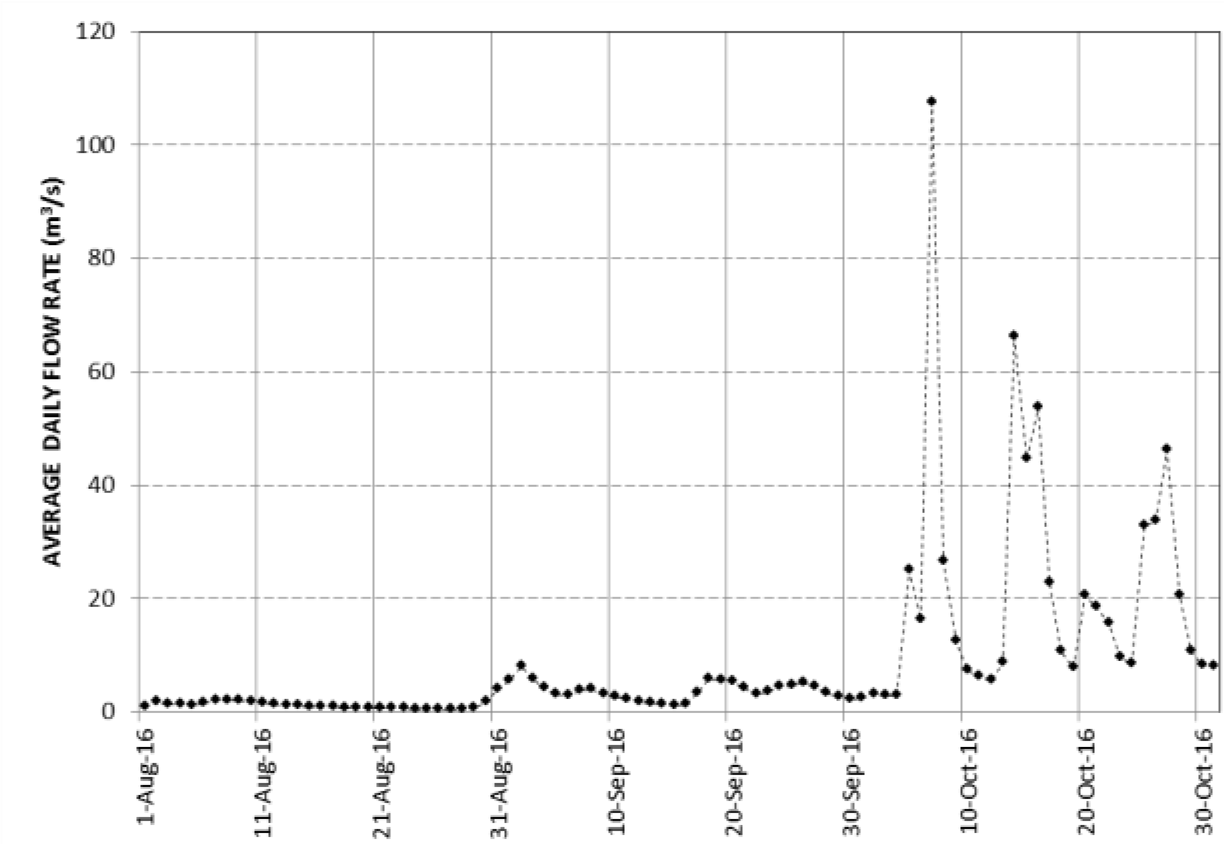
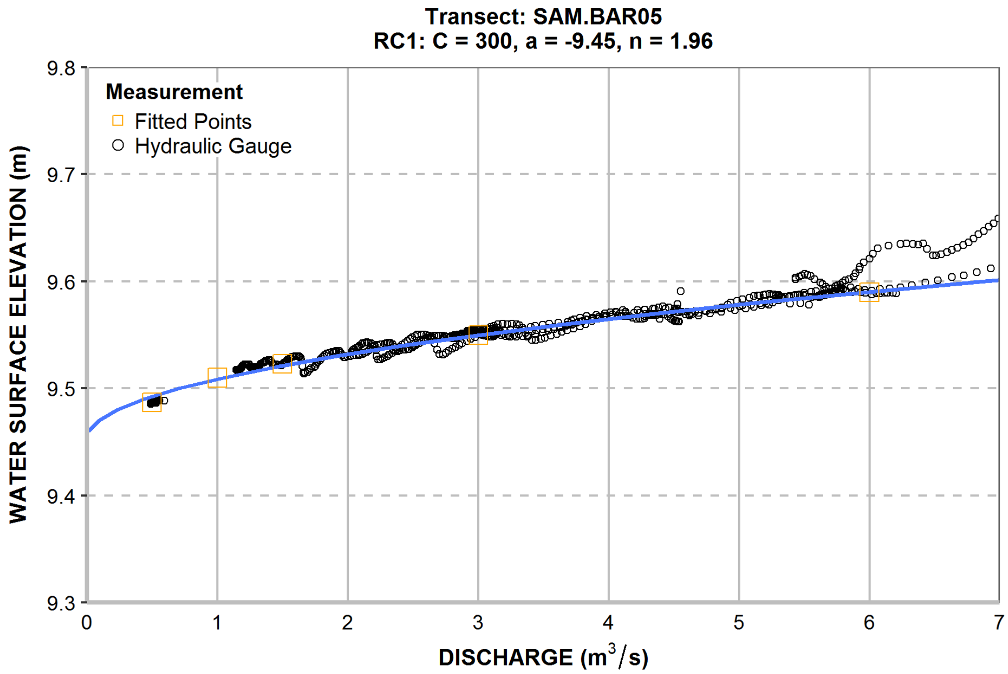
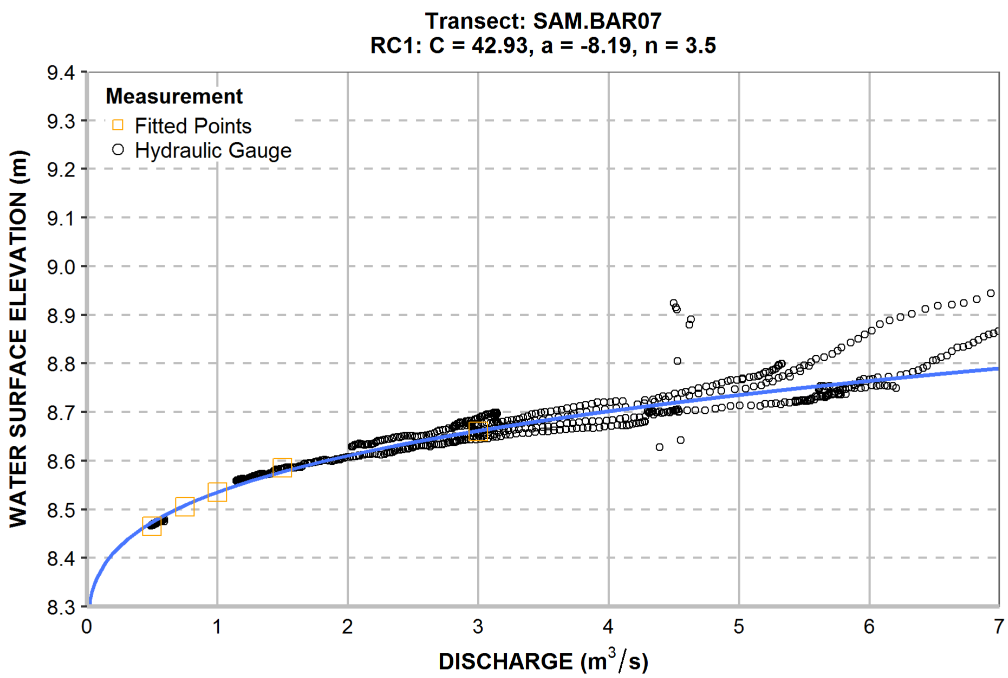


Figure 31. Stage-Discharge relationships measured at riffle barriers on the Salmon River (a) SAM-BAR05, (b) SAM-BAR07, and (c) SAM-BAR11.

a) SAM-BAR05



b) SAM-BAR07



c) SAM-BAR11

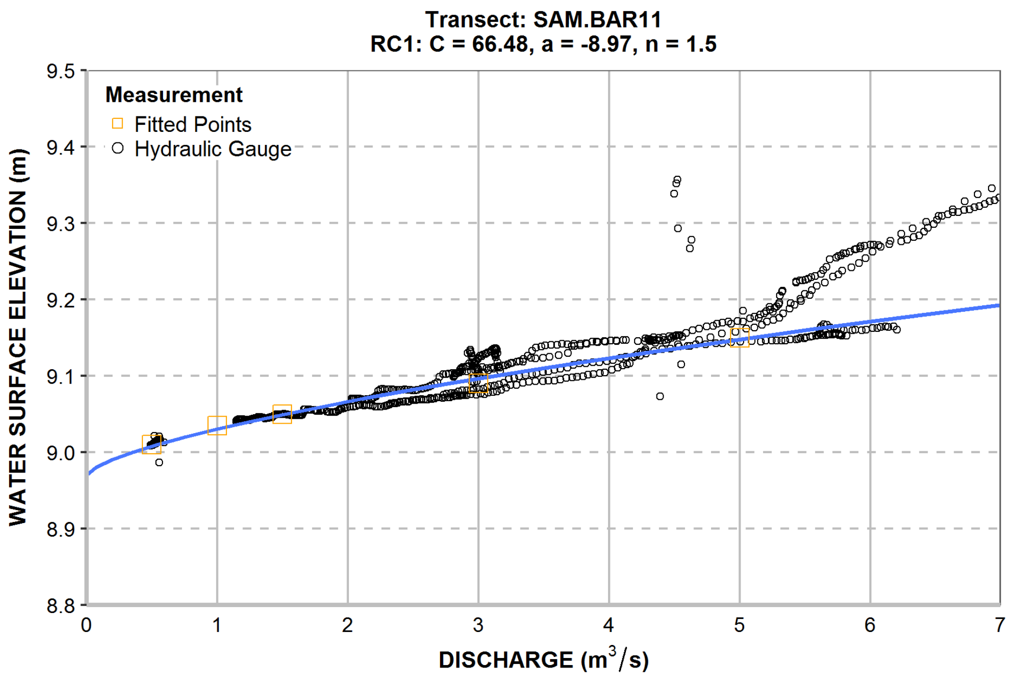


Table 24. Rating parameters and flow ranges for stage-discharge curves at SAM-BAR05, SAM-BAR07, and SAM-BAR11 on the Salmon River.

Barrier	Flow Range[1] (m³/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 25). Flows and visibility were lowest during the December survey and highest in November, March, and April.

Table 25. 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)
03-Oct-2016	1-10	07:30:00	3	11.0	6	6
	11-12	04:30:00	3	11.0	6	6
01-Nov-2016	1-10,13	03:00:00	2	9.0	8	5
	11-12	05:00:00	2	9.0	8	5
18-Nov-2016	1-10, 13	03:02:00	2	7.0	14	5
	11-12	03:30:00	2	7.0	14	5
12-Dec-2016	1-10,13	01:54:00	2	3.5	5	3
	11-12	02:52:00	2	3.5	5	3
21-Mar-2017	1-10,13	n/a	2	3.0	13	6
	11-12	n/a	2	3.0	13	6
17-Apr-2017	1-10,13	n/a	2	4.8	15	7
27-Apr-2017	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 32). 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 33 and Figure 34, respectively.

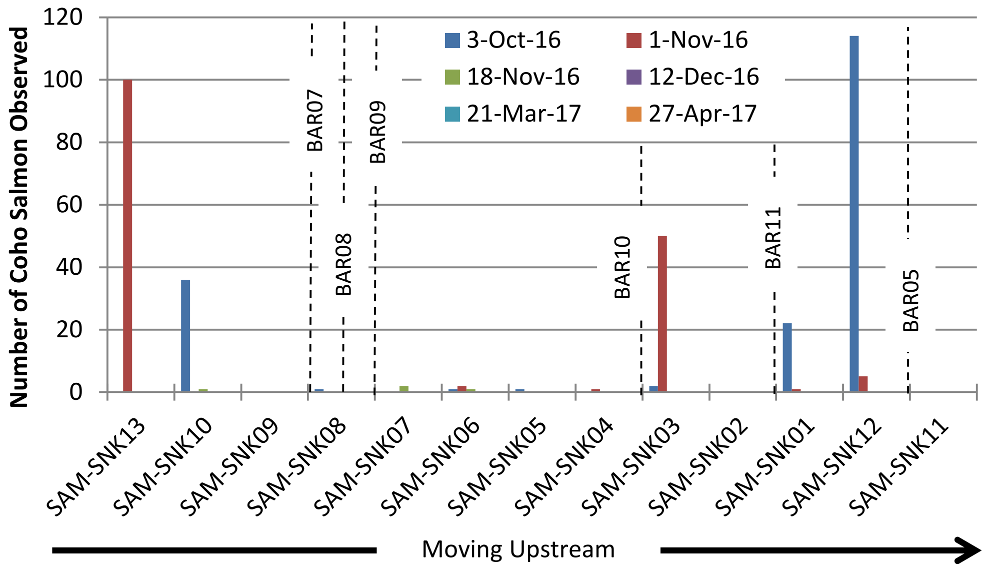
In total, 33 Steelhead were observed during snorkel surveys (Figure 32), all on March 21, 2017. Steelhead were found throughout the river and were observed upstream of all barriers except for SAM-BAR05. Cumulative plots of Steelhead at barriers SAM-BAR05, SAM-BAR11, and SAM-BAR07 are provided in Figure 35.

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

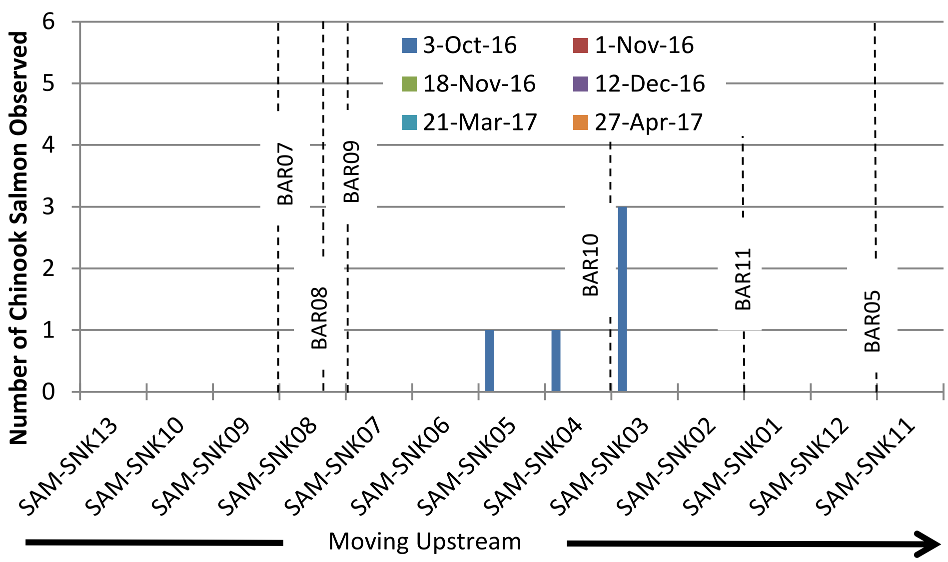
Chinook Salmon spawning period in October and November and the limited number of snorkel reaches surveyed upstream of SAM-BAR05.

Figure 32. 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

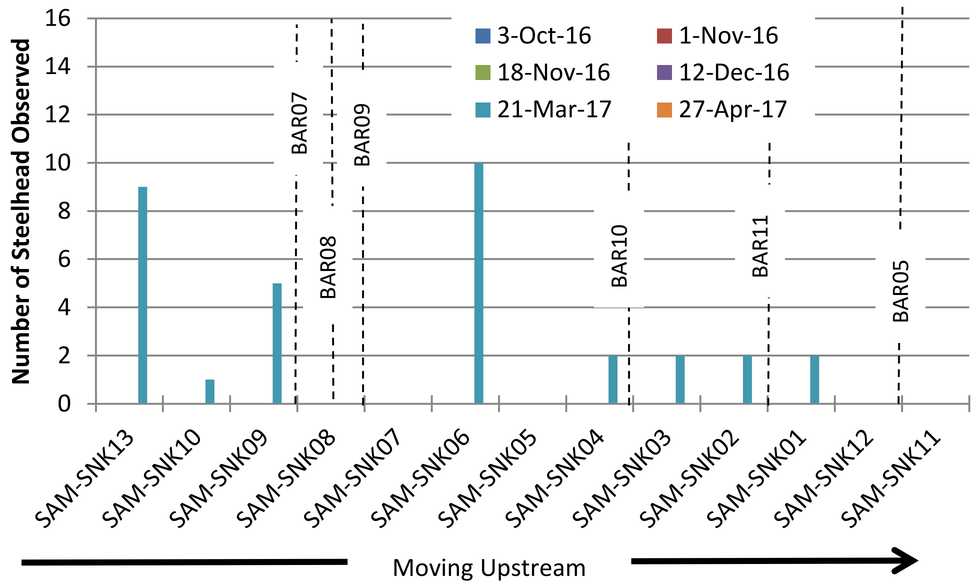
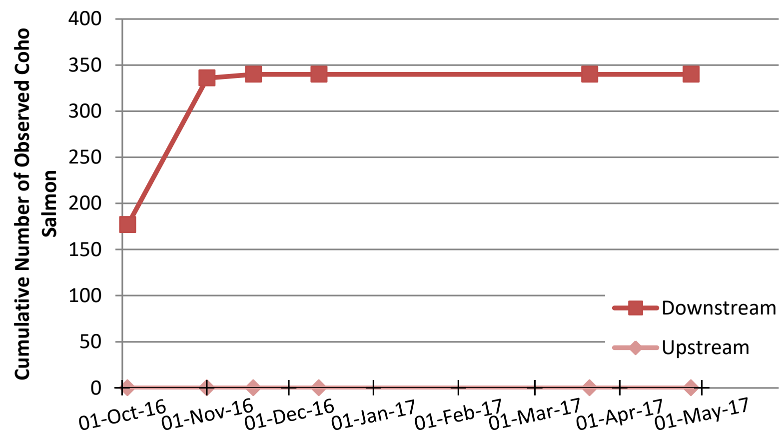
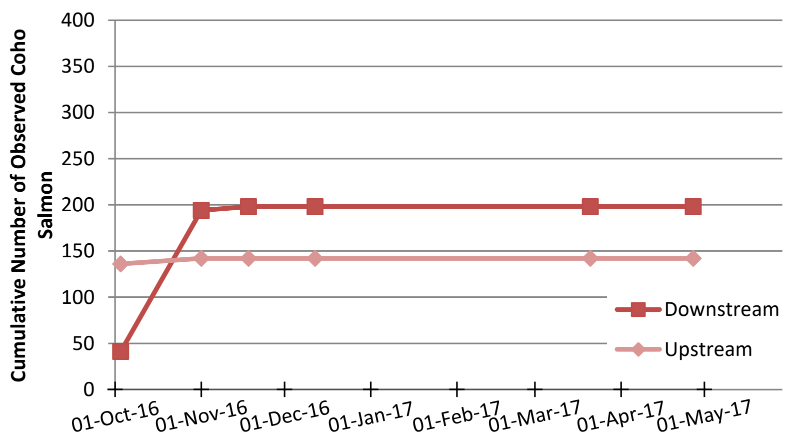

16
14
12
10
8
6
4
2
0
Number of Steelhead Observed
3-Oct-16
1-Nov-16
18-Nov-16
12-Dec-16
21-Mar-17
27-Apr-17
BAR07
BAR08
BAR09
BAR10
BAR11
BAR05
SAM-SNK13
SAM-SNK10
SAM-SNK09
SAM-SNK08
SAM-SNK07
SAM-SNK06
SAM-SNK05
SAM-SNK04
SAM-SNK03
SAM-SNK02
SAM-SNK01
SAM-SNK12
SAM-SNK11
Moving Upstream

Figure 33. 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

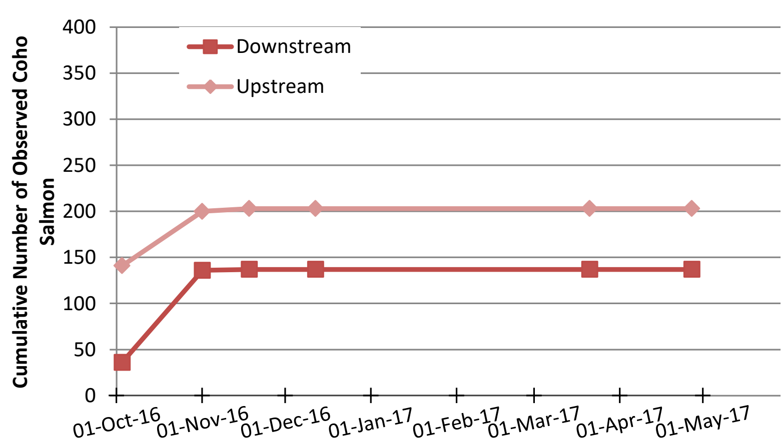
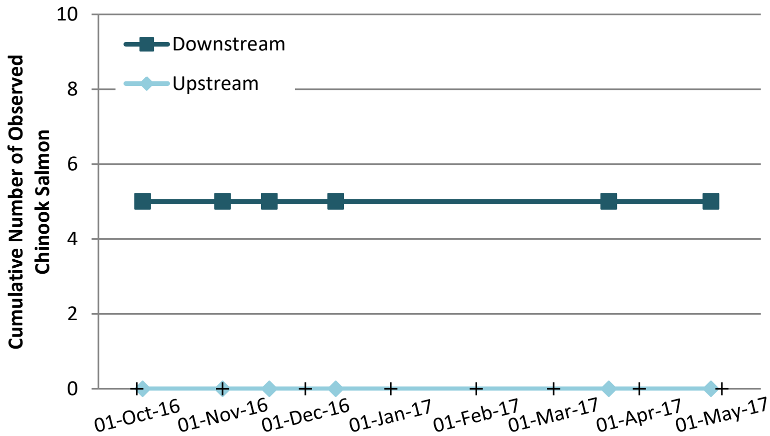
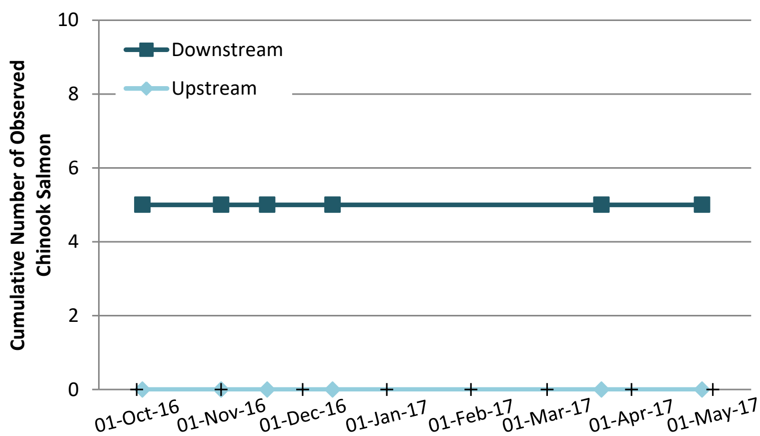


Figure 34. Cumulative plots for Chinook Salmon displaying fish observed upstream and downstream of a) SAM-BAR05, b) SAM-BAR11, and c) SAM-BAR07.

a) SAM-BAR05



b) SAM-BAR11



c) SAM-BAR07

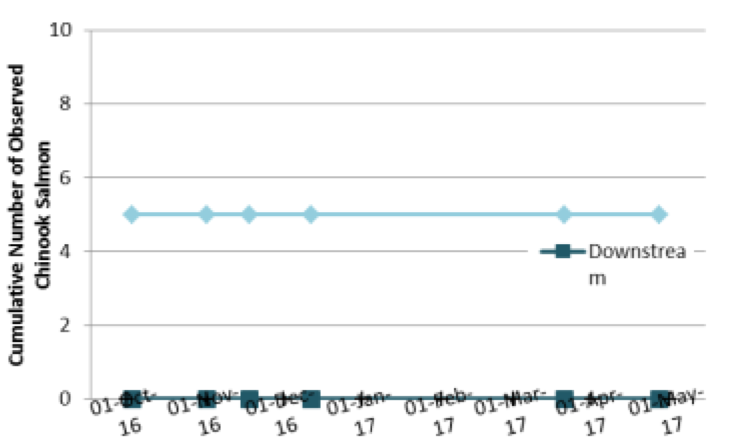


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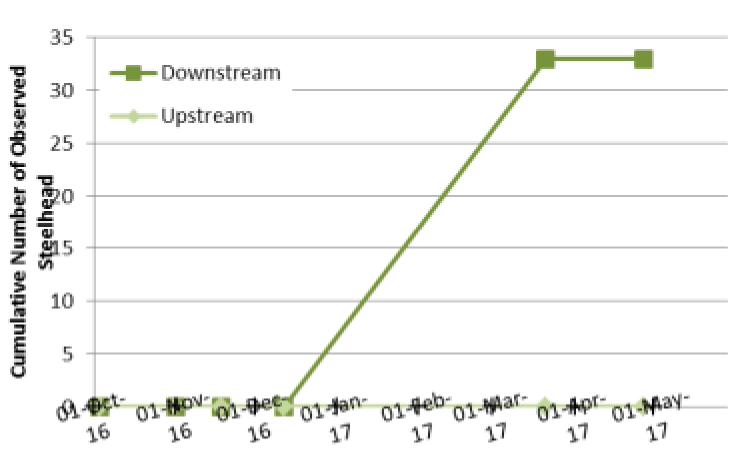
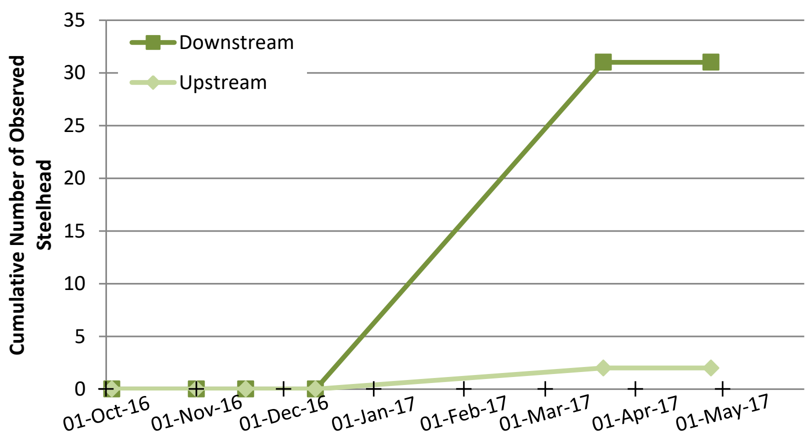
Figure 35. **Cumulative plots for Steelhead observed upstream and downstream of a) SAM-BAR05, b) SAM-BAR11, and c) SAM-BAR17.**

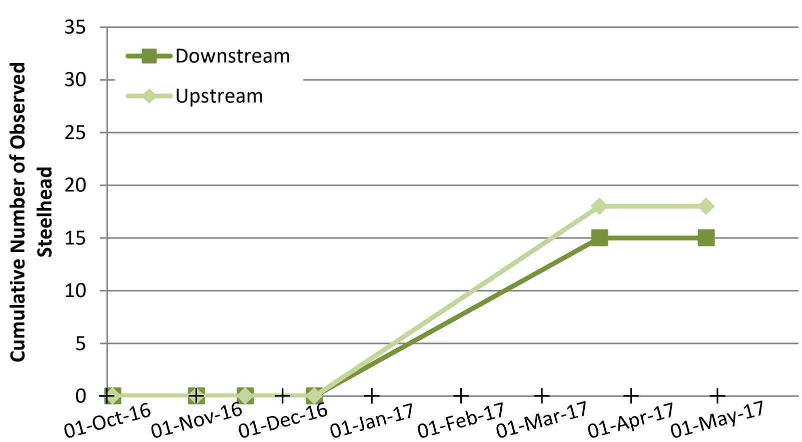
a) SAM-BAR05



b) SAM-BAR11



c) SAM-BAR07



4. DISCUSSION

Year 4 was the third and final year of the field study designed to assess potential migration barriers on the Quinsam and Salmon rivers to address Management Question #3 and the related Management Hypotheses. This report presents a summary of results for all years of the monitoring program.

4.1. Quinsam River

Results from barrier assessments, PIT tagging, and snorkel surveys suggest that Coho Salmon are able to successfully pass all barriers examined in the Quinsam River, and therefore all barriers downstream of the uppermost barrier examined. Coho Salmon were observed between the downstream and upstream ends of QUN-BAR01 during snorkel surveys and were detected above this barrier by the upstream PIT tag antenna system. Steelhead were also observed between the downstream and upstream ends of QUN-BAR01 during snorkel surveys but were not detected by the upstream nor middle PIT tag antenna systems. The observation of Coho Salmon at the upstream PIT tag systems suggests that the barrier was also navigable by Steelhead given their burst swimming speed and jumping capabilities, which are greater than Coho Salmon. The discrepancy in detections between Coho and Steelhead is likely related in part to the considerable difference in the number of fish tagged of each species (Table 11).

Barrier assessments conducted at QUN-BAR01 and QUN-BAR07 indicated that these barriers were passable by Coho Salmon and Steelhead at a flow of 2.64 m^3/s, but not passable at flows of 2.36 m^3/s or lower (Table 8 and Table 10). Barrier assessments conducted at QUN-BAR05 indicated that the barrier was passable by Coho Salmon and Steelhead at flows of 2.36 and 2.64 m^3/s, but not passable at a flow of 1.02 m^3/s (Table 9). Barrier assessments were conducted at flows observed at the time of physical surveys; more precise evaluation of flow thresholds for passage would require additional surveys at different flows or use of detailed hydraulic modelling methods, such as three dimensional computational fluid dynamics modelling.

The PIT tagging results showed Coho Salmon passage at flows ranging from 2.04 to 32.50 m^3/s and Steelhead passage at flows ranging from 7.78 to 19.20 m^3/s. The tagging results suggest that upstream migration was timed around flow spikes related to autumn rainfall events. These results also indicate that fish are generally migrating upstream past barriers at flows higher than the minimum passage flows identified during barrier assessments.

Overall, approximately 8% of all tagged fish were detected by the PIT tag detection systems. There are a number of potential explanations for the high percentage of fish that were not detected. The PIT tag detection systems were located 20.9 - 21.1 km upstream of the Coho tagging site at the Quinsam River Diversion fence. A portion of tagged fish likely selected spawning sites downstream of the PIT tag readers and would not have attempted to pass. Some fish may have attempted to ascend the barriers but were unable to and subsequently selected downstream spawning sites.

Other potential reasons for less than 100% detection relate to operational limitations of the PIT tag detection systems. For example, some fish may have passed the PIT tag detection systems at levels in the water column above the readers' maximum read height (30 - 50 cm) and therefore may have gone undetected. Also, PIT tag detection system outages occurred periodically and were caused by instream debris (e.g., large logs and sediment) damaging the antennae during high flow events. These outages occurred during high flow events that also triggered upstream fish migration and fish passing the PIT tag detection systems may have been missed during the outages.

The passage results of this study indicate that flow diverted from the Quinsam River to the Diversion Canal did not preclude the successful passage of upstream migrant fish. Review of the river and diversion hydrographs showed the proportion of diverted flow was low and did not appear to closely relate to realized passage at the barriers studied below Lower Quinsam Lake.

The following sections provide tests and discussions of the relevant management hypotheses, which relate to Management Question #3.

4.1.1. $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.

Results from this study suggest that Coho Salmon and Steelhead were able to successfully pass all barriers examined in the Quinsam River, at least under some of the observed flows. Results indicated that all three barriers studied were passable at flows of approximately 2.64 m^3/s and greater, based on the physical characteristics of the barriers. More precise evaluation of flow thresholds for passage would require additional surveys at different flows or use of detailed hydraulic modelling methods.

A qualitative review of the hydrograph data in combination with results of snorkel surveys and PIT tagging indicates that fish passage occurred over a range of flows as indicated especially by the cumulative fish observations upstream of barriers. Residual flows in the mainstem (i.e., the flows remaining after diversion) were variable during periods of migration and the residual flows were typically much greater than the amount of flow diverted particularly during flow spikes associated with autumn rain events.

The test of $H_0$4 is not simple because passage conditions depend on available flow in the river. Physical barrier surveys and observations from snorkel surveys and PIT tagging indicate that passage conditions require flows greater than those prescribed as minimum flows in the WUP (Table 2). Flows were highly variable during the migration period over the course of the three years of monitoring and provided multiple opportunities for successful migration, even during periods of active diversion.

4.1.2. H_05: 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.

Results of the snorkel surveys and PIT tagging indicated that fish passage past barriers occurred annually during the first and second flow increases of autumn. The flows observed during these events allowed for upstream migration and was not precluded by flow diversion. During the three years of monitoring, flows lower than the optimal range for passage occurred, but did not appear to substantively impede successful migration for many individuals over the course of the migration timing window.

The test of H_05 requires setting of optimal passage flows in consultation with federal and provincial fisheries agencies. This has not yet been completed by BC Hydro and would presumably require consideration of the results of this report. A test of H_05 cannot be completed until these optimal flows are set. In the meantime, we note that results from this study indicate that flows were highly variable during the migration period over the course of the three years of monitoring and provided multiple opportunities for successful migration, even during periods of active diversion.

4.2. Salmon River

The Salmon River field program was discontinued after one year of the field study (Year 2) because BC Hydro decommissioned the diversion infrastructure. Critical Riffle Analyses completed in Year 2 during Surveys 1 and 2 indicated that none of the three barriers surveyed were passable at flows of 0.55 m^3/s to 1.93 m^3/s. With the field program being discontinued after Year 2, additional surveys targeting higher flows (i.e., 3.0 and 4.0 m^3/s) were not completed. Therefore, the surveys did not determine the passage flows for SAM-BAR05, SAM-BAR07 and SAM-BAR11. Snorkel survey results included 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, indicating 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).

The management questions developed by the Campbell River WUP for the Salmon River were designed to address uncertainties with respect to the effect of BC Hydro operations on aquatic resources. The decommissioning of the Salmon River Diversion Infrastructure in the summer/fall of 2017 removed the instream flow controls and returned the river to an unregulated flow regime. As a result, BC Hydro operations no longer have a direct effect this river. Therefore, answering the management question for the Salmon River is no longer applicable and tests of H_04 and H_05 cannot be completed.

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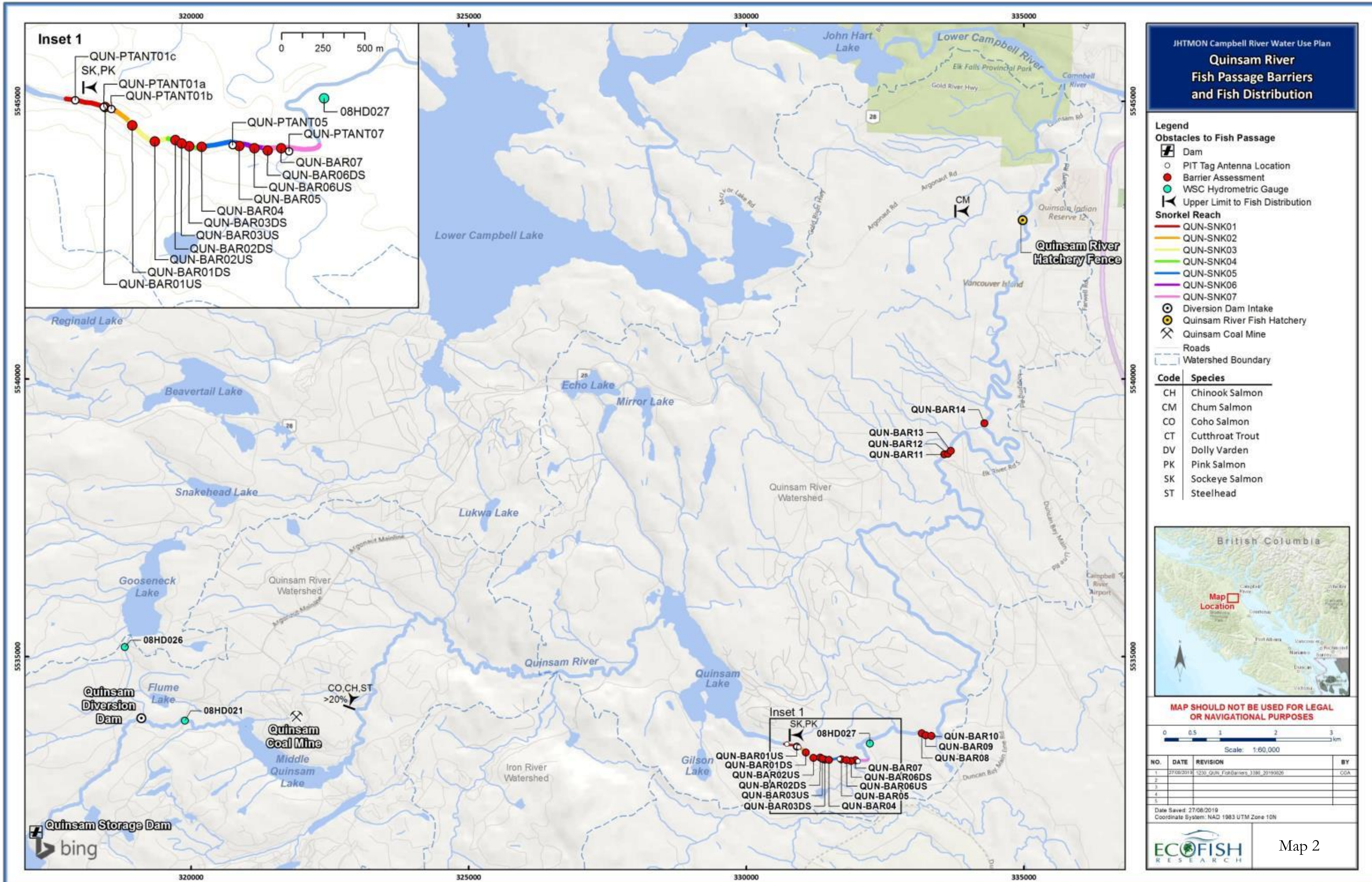
PROJECT MAPS



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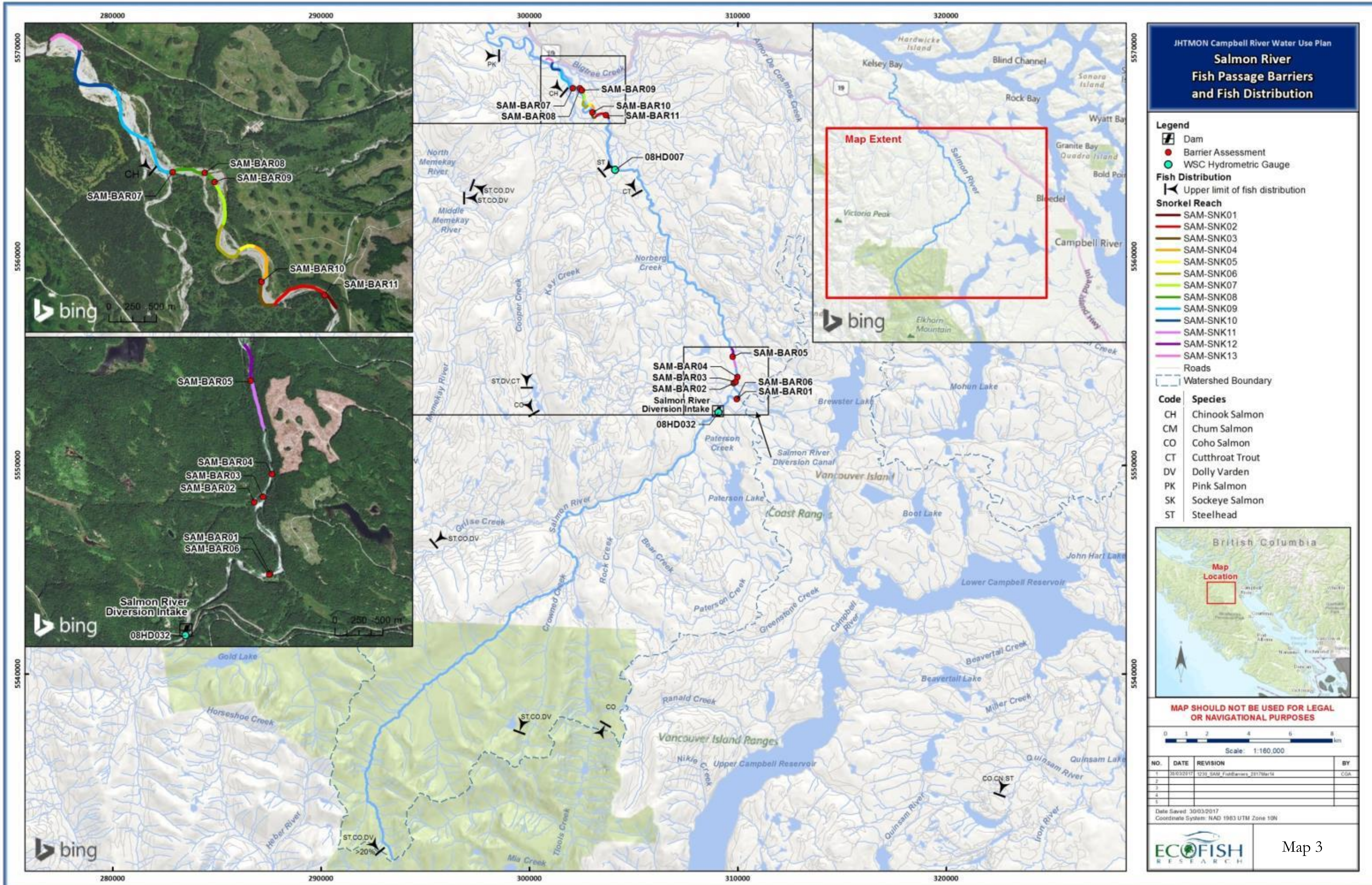

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