# Campbell River Project Water Use Plan

# JHTMON-6 Campbell Watershed Riverine Fish Production

**Implementation Year 1**

**Reference: JHTMON-6**

**Fish Passage Prescriptions for Diversion Streams - Component 2**

**Study Period: March 1, 2015 to April 30, 2016**

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

**June 28, 2016**

# JHTMON-6 Campbell Watershed Riverine Fish Production

## Component 2: Fish Passage Prescriptions for Diversion Streams Year 1 Report

Prepared for:

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## EXECUTIVE SUMMARY

As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained regarding flow-habitat relationships in the Campbell River watershed. These uncertainties hindered assessment of benefits to fish from the WUP-recommended operations.

The JHTMON-6 Campbell Watershed Riverine Fish Production Assessment was designed to resolve these uncertainties with three separate studies. This Fish Passage Prescriptions for Diversion Streams Year 1 Report relates to the second study: *Fish Passage Prescriptions for Diversion Rivers*. The objective, management questions, hypotheses and current status of the habitat-flow component of JHTMON-6 is summarised below in Table i.

**Table i. Status of the fish passage component of JHTMON-6 after Year 1**

| Study Objective | Management Question | Management Hypotheses | Year 1 (2015/2016) Status |
|---|---|---|---|
| Reduce uncertainty about physical barriers to upstream migration in diversion donor streams: falls and cascades on the Quinsam River and riffles on the Salmon River. | At what range of flows do migrating fish successfully navigate site-specific barriers on the Quinsam and Salmon rivers, and is its frequency/duration sufficient to ensure successful migration? | *$H_0$4: Over the range influenced by the impoundment/diversion structure, successful passage of upstream migrants in the diversion donor streams is unrelated to flow.*<br>*$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.* | Year 1 of this three-year study has been completed. Year 1 involved completing a literature review of salmonid passage requirements on the Quinsam and Salmon rivers. Reconnaissance site visits were undertaken to the study streams and a recommended approach was developed to complete the remainder of this component of JHTMON-6 and address the management question. |

This three-year study combines a literature review of salmonid passage requirements with a field survey of each river at sites with potential fish passage barriers, downstream of diversion structures. The results will be used to define the passage flow requirements of adult salmon migrating upstream of each system. Specifically, the study will address the third of four management questions:

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

This report presents the outcomes of the literature review and our recommended approach to collect physical and biological data in Year 2 and 3 of the study. The review summarizes: the status of fish populations in the Quinsam and Salmon rivers; current knowledge about barriers in the study reaches; historical hydrology data and diversion operations, and; methods to assess fish passage success at barriers. Based on this review, we outline our recommended approach, which is supported by the outcomes of reconnaissance site visits undertaken in October 2015

For both rivers, we plan to conduct a range of physical and biological monitoring activities at three sites to assess fish passage. Monitoring will be undertaken during both Year 2 and 3 of the study. Monitoring will focus on assessing passage success for adult Coho Salmon (*Oncorhynchus kisutch*) and winter steelhead (*O. mykiss*). Upstream of potential barriers, there are large areas of spawning and rearing habitats for these species in both watersheds.

For the Quinsam River, we have identified three monitoring sites that are just downstream of Lower Quinsam Lake, approximately 24.2 km to 24.4 km upstream of the mouth. These sites comprise bedrock shelves that create chutes that are shallow at low flows and present potential velocity barriers at high flows. These sites are ~23.5 km downstream of the dam at the outlet of Wokas Lake, which is the assumed absolute upstream limit to anadromous fish migration. During both years, we will deploy cameras at fixed locations to remotely capture a visual record how flow and habitat conditions change throughout a range of water levels. We also propose to collect measurements of physical variables using field-based barrier survey methods at one site during one field visit in Year 3, with survey location and timing to be determined based on the results of physical and biological data collection in Year 2. In addition, we propose to collect biological data on fish passage by undertaking a PIT tagging study, supported by data collected during snorkel surveys at key migration times. The PIT tagging study is designed to provide precise information about the flow conditions at which tagged fish migrate past potential barriers that are a priority for study. A total of 250 PIT tags will be implanted each year into adult Coho Salmon (*n*~230) and steelhead (*n*~20). Tags will be implanted by Quinsam River Hatchery staff, with fish tagged at, or downstream of, the hatchery. Three PIT tag antenna arrays will be installed downstream of Lower Quinsam Lake to monitor fish passage at different stages through the series of priority barriers. Arrays will be installed for five months from late September through to late February. Data collected at the arrays will be related to flow records collected at the Water Survey of Canada (WSC) hydrometric gauge ~ 1 km downstream to identify the specific flow conditions at which any fish migrate past a partial barrier. Snorkel surveys will be undertaken to augment/validate data collected during physical and biological monitoring. Snorkel surveys will be conducted in the fall to evaluate adult Coho Salmon and Chinook Salmon passage, and during winter to evaluate adult steelhead passage. Surveys will be undertaken within a ~1.3 km reach downstream of Lower Quinsam Lake, with details of all fish observations recorded, including carcasses. This will include: species, location (based on GPS), size class and condition (e.g., bright, moderately-coloured, coloured, post-spawn). Surveys will therefore provide information on the spatial distribution of fish upstream and downstream of the potential barriers during peak migration times. We have budgeted a total of ten days per year to install/maintain antenna arrays and undertake snorkel surveys. This is expected to yield snorkel survey data for ~ eight dates, with the majority of surveys conducted in the fall to monitor salmon passage.

For the Salmon River, we have identified three monitoring sites located in riffle habitats. One site is approximately 2 km downstream of the Paterson Creek confluence, which is ~37 km downstream of the point on the mainstem assumed to the absolute upstream limit to fish migration (where the gradient exceeds 20%). The remaining sites are further downstream in the vicinity of the Memekay River confluence; these are >50 km downstream of the assumed upstream limit. To collect physical measurements at these sites, we propose to use a Critical Riffle Analysis method that is based on procedures developed by the California Department of Fish and Game (CDFG 2012). This will involve undertaking field surveys at three flow conditions. Sensors will be deployed to monitor stage near-continuously across the riffle at each site to measure minimum water depths, which can be related to discharge measured at hydrometric gauges maintained by WSC. As for the Quinsam River, still images of conditions at range of flow conditions will be collected remotely at each site using wildlife cameras. Biological data will be collected by undertaking snorkel surveys and deploying a high resolution video camera. We propose to undertake two snorkel surveys in the fall to evaluate adult Coho and Chinook salmon passage and one snorkel survey during late winter to evaluate adult steelhead passage. Fall snorkel surveys will be undertaken at separate reaches that include the three monitoring sites. Steelhead surveys will be undertaken as part of work scheduled for JHTMON-8, which includes a survey of the 11.5 km Lower Index reach that includes all three monitoring sites. Data collection methods will be consistent with the surveys of the Quinsam River, and will therefore provide information about the distribution and abundance of fish upstream and downstream of potential barriers. A video camera will be deployed at a single site to monitor adult salmon passage during the fall migration period in Year 2 and 3. Video footage will be reviewed to identify instances of fish migrating upstream through riffle habitat, which will be related to flow conditions based on measurements at WSC gauges. The main analysis of video footage will commence after Year 3, when the flow records for the monitoring periods have been compiled.

We will prepare an annual monitoring report at the end of Year 2 that will summarize the methods of work completed in Year 2 and the results of physical monitoring and snorkel surveys. This report will include a recommendation of whether physical monitoring should be undertaken at additional flow conditions in Year 3, and whether any changes should be made to video camera deployments, e.g., deployment locations. Any additional data needs will be detailed, including any additional flow requests to BC Hydro.

Detailed data analysis will be undertaken following Year 3. This will require comparing results of physical and biological monitoring to identify species-specific fish passage flow criteria for each stream. These criteria will then be compared with historic and synthesized flow records to quantify the frequency that passage flow criteria occurred under historical (pre-dam) conditions, and how this may have changed following dam construction, with and without WUP implementation. It will be possible to use a similar approach to assess other flow alternatives, should that be required.

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# 1. INTRODUCTION

## 1.1. Background to JHTMON-6

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 the Campbell River Water Use Plan (BC Hydro 2012) process reached completion, a number of uncertainties remained regarding flow-habitat relationships in the Campbell River watershed. These uncertainties hindered assessment of how the outcomes of the WUP would benefit fish populations. Habitat study work that was originally planned to address these uncertainties could not be completed within the time and budget constraints of the WUP process; consequently, a less data-intensive and desk-based approach was adopted to predict how changes to flow would affect fish habitat. This approach was based on a meta-analysis of instream flow studies undertaken elsewhere to predict flow-habitat relationships (Hatfield and Bruce 2000, Bruce and Hatfield, *in preparation*). This approach was untested, and its acceptance by the Fish Technical Committee was contingent on resolving three key uncertainties (BC Hydro 2013):

1. habitat-flow relationships in diversion donor streams;
2. physical barriers to upstream migration in diversion donor streams; and
3. conflicting results of two hydrological models applied to the Lower Campbell River.

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 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 meta-analysis results?
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 sufficient to ensure successful migration?
4. What are the key differences between one- and two-dimensional hydraulic modeling approaches to habitat assessment of streams? What are their strengths and weaknesses and what method should be used to model hydraulic/habitat conditions in lower Campbell River?

These questions are designed to be addressed by testing six null hypotheses.

### 1.2. Fish Passage Prescriptions for Diversion Rivers

Three independent studies have been designed to separately address the three areas of uncertainty listed above. The work presented in this report is part of a three-year study designed to resolve the second area of uncertainty: *physical barriers to upstream migration in diversion donor streams*. The study is designed to identify fish passage prescriptions for the Quinsam and Salmon rivers. Water is diverted from each of these rivers via BC Hydro diversion facilities to support hydroelectric power generation.

The study includes a literature review and fieldwork to measure fish passage success at known barriers during a range of flow conditions, with specific focus on low flow conditions that are likely to be sensitive to operational conditions at diversion facilities.

Study areas are:

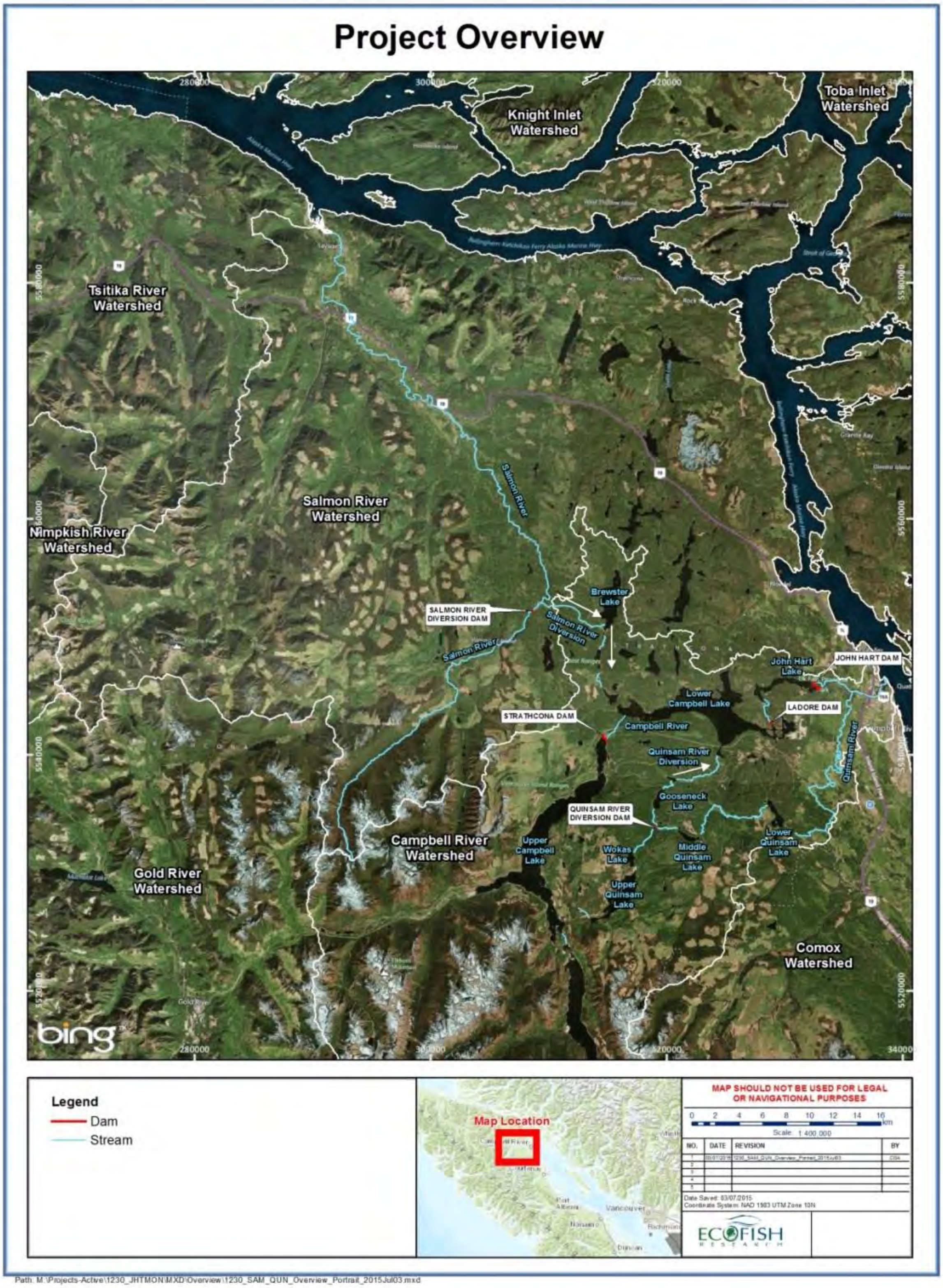
- Quinsam River: from the diversion dam to the confluence of Lower Campbell River; and
- Salmon River: from the diversion dam to the confluence of Memekay River.

This study will primarily address Management Question 3. Two of the six null hypotheses relate to this management question (BC Hydro 2013); these are:

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

*$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*

## Map 1. Location of the Quinsam and Salmon rivers.



### 1.3. Objectives

This report presents a review of existing information about fish passage and a recommended approach to complete the fish passage component (Component 2) of JHTMON-6. The review was based on a literature review and information provided during interviews with individuals who have conducted previous fisheries studies on the rivers over multiple years. The recommended approach was then developed following reconnaissance site visits in October 2015. Further information is provided in respective sections about the sources that were consulted during the review and data collection during site visits.

The objectives of the review were to compile and summarize existing information for the Quinsam and Salmon rivers on:

1. Fish distributions and potential barriers to migration;
2. Hydrology;
3. The threshold attributes (e.g., fall height, water velocity, water depth) of obstructions that hinder passage of fish species of interest on the Quinsam and Salmon rivers. The species of interest are: Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. gorbuscha*), Pink Salmon (*O. kisutch*), steelhead (*O. mykiss*) and resident Rainbow Trout (*O. mykiss*; BC Hydro 2013); and
4. Suitable barrier passage assessment methods.

The review provides context for the recommended approach, which summarizes proposed site selection and methods for fieldwork to be undertaken during 2016 to assess barriers on the Quinsam and Salmon rivers.

Key outcomes of the Year 1 fish passage review are:

1. A clear definition of fish passage thresholds/criteria for all species of interest;
2. Confirmation of stream-specific migration periodicity of all species of interest;
3. A map of known fish barriers in each of the diversion streams, including a chronological listing of all experimental and/or anecdotal observations of fish passage issues;
4. Collation of the necessary hydraulic information that would allow calculation of discharge and other local stream hydraulic conditions at each site of interest based on easily obtained field observations;
5. An assessment of fish passage flow thresholds for each barrier. Such an assessment will allow ranking of sites where flow would have the greatest impact on passage, as well as eliminate sites from the study that are likely to be less sensitive to discharge;
6. Estimates of habitat gains or losses (e.g., stream length) should each potential barrier issue be resolved; and

7. A recommended approach for subsequent years of the program.

A separate memorandum was completed during 2015 that provides an overview of instream flow assessment methods that could be applied during JHTMON-6 (Healey and Hatfield 2015). This topic is not considered in this report.

## 1.4. Watershed Descriptions

### 1.4.1. The Quinsam River

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

BC Hydro owns and operates a storage dam at the outlet of Wokas Lake, a diversion dam 47.4 km from the mouth of the river, and a diversion canal, for the purpose of diverting water to Lower Campbell Reservoir for hydropower production. Non-diverted water is conveyed to the Quinsam River via an undersluice gate or the free crest weir. The dams were both constructed in 1957.

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

### 1.4.2. The Salmon River

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

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

A smolt screen was installed 500 m below the diversion canal intake in 1986 to return outmigrating smolts entering the canal to the Salmon River. Additionally, a fishway was constructed at the diversion dam in 1992 to provide improved upstream passage for Coho Salmon and steelhead (Burt and Robert 2001). There have been issues with the performance of both the fish screen and the fish way (Burt 2010). BC Hydro is currently examining options to address these issues, which include upgrading the fishway or decommissioning the facility (Lamont, pers. comm. 2016). Fish Species and Periodicity

### 1.5. Quinsam River

The Quinsam River supports a variety of anadromous and resident fish species. Fish species present in the Quinsam River system include: Cutthroat Trout (resident and anadromous), Dolly Varden (*Salvelinus malma*), steelhead, Coho Salmon, Chinook Salmon, Chum Salmon (*O. keta*), Pink Salmon, Sockeye Salmon (*O. nerka*), Kokanee (*O. nerka*), Rainbow Trout, Coastrange Sculpin (*Cottus aleuticus*), Threespine Stickleback (*Gasterosteus aculeatus*) and lamprey (*Lampetra* spp.) (Burt 2003, MOE 2015). A synopsis of the life history information for fish species found in the Quinsam River system is provided in Burt (2003). Table 1 shows the periodicity of important species in the system adapted from Burt (2003). Life history information was collected from various sources including: Quinsam Hatchery data files, published literature, snorkel survey data from nearby Campbell Lake streams and personal communications with Quinsam and Vancouver Island hatchery staff (Burt 2003).

**Table 1. Periodicity of important fish species in the Quinsam River system (from BC Hydro files for Campbell River Water Use Plan, dated 2001).**

| Species | Life History Stage | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chinook Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | P | P | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | F | S | | | | | | | |
| Chum Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | | P P | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Juvenile migration | | | F | | | | | | | | | |
| Coho Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | | P P P | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | F | S | | | | | | | | |
| Pink Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | P | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Juvenile migration | | | F | | | | | | | | | |
| Rainbow Trout | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | | | | | | | | | |
| Sockeye Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | F | | | | | | | | | |
| Steelhead (winter run)[1] | Adult migration | | | | | | | | | | | | |
| | Spawning | | | P P | | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | S | | | | | | | | |

Critical times

F = fry migration begins, S = smolt migration begins, P = peak spawning

[1] There are no summer run Steelhead on the Quinsam River.

### 1.6. Salmon River

The Salmon River supports a variety of anadromous and resident fish. Fish species known to inhabit the Salmon River include: Pink Salmon, Coho Salmon, Chum Salmon, Chinook Salmon, Sockeye Salmon, steelhead, Kokanee, Rainbow Trout, Cutthroat Trout (anadromous and resident), Dolly Varden, Coastrange Sculpin, Slimy Sculpin (*C. cognatus*), Threespine Stickleback and lamprey (Burt 2001, MOE 2015). Atlantic Salmon (*Salmo salar*; non indigenous) has also been noted in the Salmon River (Burt 2001, MOE 2015). A summary of the life history periodicity for fish species in the Salmon River is provided in Table 2.

**Table 2. Periodicity of important fish species found in the Salmon River (from BC Hydro files for Campbell River Water Use Plan, dated 2001).**

| Species | Life History Stage | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chinook Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | P P | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | | | | | | | | | |
| Chum Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Juvenile migration | | | | | | | | | | | | |
| Coho Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | | | P P | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | S | | | | | | | | |
| Pink Salmon | Adult migration | | | | | | | | | | | | |
| | Spawning | | | | | | | | P | P | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Juvenile migration | | | | | | | | | | | | |
| Rainbow Trout | Spawning | | | | | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Emergence | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| Steelhead (winter run)[1] | Adult migration | | | | | | | | | | | | |
| | Spawning | | | P P P | P | | | | | | | | |
| | Incubation | | | | | | | | | | | | |
| | Rearing | | | | | | | | | | | | |
| | Juvenile migration | | | | S | | | | | | | | |

Critical times

F = fry migration begins, S = smolt migration begins, P = peak spawning

[1] There are no summer run Steelhead in the JHTMON-6 study reach of the Salmon River.

## 2. FISH SPAWNING AND REARING DISTRIBUTION

### 2.1. Quinsam River

A variety of anadromous salmonids spawn in the Quinsam River; known distributions are shown in Map 4. The distribution of these species is described in Burt (2003) and summarized here. Chum

Salmon are reported to spawn primarily in the lower 3.6 km of the Quinsam River mainstem from the mouth to the counting fence located 300 m upstream of the Quinsam Hatchery. A small number of Chum Salmon migrate upstream of the hatchery, but the species is not likely to migrate upstream of the falls at 10.1 km or 13.3 km upstream of the mouth.

Chinook Salmon are reported to primarily spawn in the lower 3.6 km of the Quinsam River mainstem below the Quinsam Hatchery. There have been reports of small numbers of Chinook Salmon spawning above the hatchery counting fence but the extent of this is uncertain. Historical reports have described Chinook Salmon spawning as far upstream as the falls at 26.3 km from the mouth (Burt 2003).

The spawning distribution of Pink Salmon is well documented; the majority of spawning occurs from the mouth of the Quinsam River to the cascades at 13.3 km[1]. In 2005, four fishways were constructed to improve passage for adult Pink Salmon during low flows, allowing fish as far upstream as the falls at 24.3 km (Van Tine and Sinclair 2006).

Sockeye Salmon spawning distribution in the Quinsam River is not well documented due to small run sizes. Burt (2003) reports the distribution as likely to be limited to downstream of the falls at 26.3 km.

Coho Salmon are reported to spawn throughout the anadromous portion of the mainstem Quinsam River up to the 15 m falls at 41.5 km. Coho Salmon are also reported to spawn in tributaries of the mainstem Quinsam River. Historical reports describe the majority of Coho Salmon spawning between the cascades at 13.3 km upstream to the falls at 24.3 km upstream; however, this was reported prior to investigation of spawning above Lower Quinsam Lake (Burt 2003).

Steelhead are reported to have a similar spawning distribution to Coho Salmon and are described as using the anadromous area up to the 15 m falls at 41.5 km. Steelhead are less likely to use the tributaries than Coho Salmon for spawning (Burt 2003).

A variety of studies on the rearing distribution of salmonids in the Quinsam River watershed is summarized in Burt (2003). The anadromous portion of the Quinsam River is used by juvenile Coho Salmon, steelhead and Cutthroat Trout. Dolly Varden and Coho Salmon are known to rear in tributaries. There is limited information on the rearing distributions of Dolly Varden, Chinook Salmon and Sockeye Salmon.

### 2.2. Salmon River

The distribution of anadromous salmonids in the Salmon River watershed is limited by known barriers or stream gradients greater than 20%. The known distributions of salmonids in the Salmon River watershed is shown in Map 5, based on information presented in Burt (2010). In 1977 a rock

[1] River kilometers. All river kilometers in this report represent the distance upstream from the mouth of the respective river.

and debris barrier was removed from the mainstem Salmon River at 38.2 km, which allowed anadromous salmonids to migrate upstream to the diversion dam located at 54.2 km (Lough *et al*.. 1993). Only a few steelhead and Coho Salmon spawners could migrate past the diversion dam until 1992, when a fishway was constructed to improve access to more spawners (Burt and Robert 2001). Studies in 2009 demonstrated that some obstruction to upstream migration (behavioural or velocity) still existed at the fishway for adult Coho Salmon (Anderson 2009). Coho Salmon and steelhead that make it past the diversion dam are found upstream to the point where stream gradient is greater than 20%, 33.5 km further upstream (Burt and Robert 2001). Chinook Salmon spawners in the Salmon River mainstem are found primarily up to the confluence with the Mememkay River. Burt and Robert (2001) report that little is known of the distribution of resident Rainbow Trout, Cutthroat Trout and Dolly Varden in the Salmon River mainstem, although resident fish distributions are presumed to be at least as extensive as those of anadromous fish. Anadromous Cutthroat Trout are described to spawn upstream to 38.2 km where the rock and debris barrier used to exist; anadromous Dolly Varden are assumed to migrate upstream of the diversion to the gradient barriers (Burt and Robert 2001, Burt 2010).

The mid and upper reaches of the Salmon River provide valuable rearing habitat for juvenile Coho Salmon (Anderson 2009). Since 2008, Fisheries and Oceans Canada (DFO) has either led or supervised monitoring of juvenile Coho Salmon abundance at six sites, including three sites upstream of the diversion dam. This annual monitoring was integrated into the JHTMON-8 monitoring program in 2014. Data for 2014 show that juvenile Coho Salmon biomass ranged from 0 $g/m^2$ (one site) to 7.1 $g/m^2$, with no systematic difference between sites upstream and downstream of the diversion dam (Abell *et al*. 2015). Data for 2015 (reporting underway) show a lower range in observed biomass, with biomass generally lower downstream of the diversion relative to upstream. Work is underway to compile historic data as part of JHTMON-8.

As with Coho Salmon, the mid and upper reaches of the Salmon River, including reaches upstream of the diversion, contain high quality rearing habitats for steelhead (Pellett 2012, 2014). Juvenile steelhead (i.e., juvenile Rainbow Trout with presumed anadromous life history) have been sampled by crews supervised by British Columbia Conservation Foundation (BCCF) at 10 sites since 1998. Sites are located throughout the mid to upper reaches, with five sites upstream of the diversion dam. Between 1998 and 2014, the geometric mean fry per unit[2] (FPU) was 55 (range = 17–136 FPU), which is just below the target of 60 FPU set by provincial biologists. In 2014, annual monitoring was integrated into the JHTMON-8. Data for 2014 show that the arithmetic mean FPU was very similar at sites downstream and upstream of the diversion dam (77.4 FPU and 77.6 FPU respectively), indicating that adult steelhead successfully spawned throughout the watershed that year (Pellett 2014, Abell *et al*. 2015). Data for 2015 (reporting underway) show lower mean density, particularly upstream of the diversion dam (62.1 FPU downstream compared with 8.9 FPU upstream). This indicates that spawning may have been less successful upstream of the diversion in 2015, although

[2] The number of fish (fry) per 100 $m^2$, standardized based on depth and velocity.

there is some uncertainty about this conclusion as the higher density downstream partly reflects particularly high density (207.5 FPU) at a single site.

# 3. REVIEW OF BARRIERS TO FISH MIGRATION

## 3.1. Methods

Barriers can be classified as partial or complete obstructions to migration, depending on the swimming abilities of a given species and flow conditions. Complete barriers are defined as those that are impossible for a species to ascend, regardless of flow. Partial barriers are difficult to ascend or are only passable under certain flow conditions.

The following sections summarize existing information on barriers in the Quinsam and Salmon rivers. Key sources of information were previous literature reviews about each watershed (Burt 2003; 2010) and the Fisheries Information Summary System (FISS) database (MoE 2015). In addition, summaries were supplemented with information provided during interviews with individuals who have extensive experience of conducting fisheries studies in each watershed. To identify key barriers or flow sensitive areas in the Quinsam River, we interviewed David Burt of D. Burt and Associates by e-mail on May 29, 2015. Mr Burt has extensive knowledge of the river and has previously written a detailed literature review about the watershed (Burt 2003). To obtain similar information about the Salmon River, we interviewed James Craig of BCCF by telephone on May 29, 2015. Mr Craig has many years of experience conducting field work on the Salmon River, and he has been extensively involved with steelhead stock production monitoring. Prior to interviews, we provided each individual with a map and table of known barriers on the respective rivers.

Spatial analysis was undertaken using GIS to quantify the habitat gains that would occur if known barriers were resolved. Habitat gains were quantified by calculating the distances between each identified barrier, and the distances between each barrier and the absolute upstream limit to fish migration. For the Quinsam River, the upstream limit to fish migration was assumed to be the outlet of Wokas Lake; for the Salmon River, it was assumed to be the point on the mainstem where the channel gradient exceeds 20%. These estimates are expected to be underestimates since the calculations do not include tributary habitats.

## 3.2. Quinsam River

### 3.2.1. Overview

Multiple partial and complete barriers to upstream migration of adult salmonids have been reported for the Quinsam River.

Burt (2003) describes eight barriers (two of which were removed in 2005). A search of FISS in April 2015 showed 46 obstructions on the Quinsam River mainstem, including all of the existing barriers that were described by Burt. The locations of these barriers, including those visited during the reconnaissance site visits, are shown on Map 4.

The 46 recorded barriers are also listed in Table 3. Table 3 includes comments noted by Burt (2003) and the distances between each barrier and the Quinsam Storage Dam at the outlet of Wokas Lake, which is the assumed absolute upstream limit to fish migration.

Further information about the barriers is summarized in the sections below. Supporting information is lacking for most of the obstructions reported in the FISS database. Most sites would need to be investigated in the field to further characterize each barrier and to determine whether it is passable to fish under some conditions.

**Table 3. Summary of recorded barriers (partial and complete) to fish passage on the Quinsam River. Based on FISS (MoE 2015) and Burt (2003). Barrier #s correspond to barriers shown on Map 4.**

| Barrier # | Obstruction type | Distance upstream from Lower Campbell River confluence (km) | Distance to next upstream barrier (km) | Distance to upper limit of mainstem (Wokas Lake; km) | Comments (Burt 2003) |
|---|---|---|---|---|---|
| 1 | Rocks | 10.0 | 0.1 | 40.7 | |
| 2 | Rocks | 10.1 | 1.8 | 40.6 | |
| 3 | Dam | 11.9 | 1.3 | 38.9 | |
| 4 | Canyon | 13.2 | 0.0 | 37.5 | |
| 5 | Rocks | 13.2 | 0.0 | 37.5 | |
| 6 | Canyon | 13.3 | 0.0 | 37.5 | |
| 7 | Rocks | 13.3 | 0.1 | 37.5 | |
| 8 | Rocks | 13.4 | 0.2 | 37.4 | |
| 9 | Canyon | 13.6 | 8.4 | 37.1 | |
| 10 | Log jam | 22.0 | 2.2 | 28.7 | |
| 11 | Rock | 24.2 | 2.2 | 26.5 | |
| 12 | Cascade | 24.2 | 0.0 | 26.5 | Partial barrier; may be complete barrier to PK; partial barrier to anadromous CT |
| 13 | Rocks | 24.2 | 0.1 | 26.5 | |
| 14 | Rocks | 24.3 | 0.1 | 26.4 | |
| 15 | Falls | 24.4 | 1.8 | 26.3 | Partial barrier |
| 16 | Rock | 26.2 | 0.0 | 24.6 | ~1.3 km section containing a series of small falls and cascades; complete barrier to PK; partial barrier to CO, ST, anadromous CT |
| 17 | Cascade | 26.2 | 0.1 | 24.6 | |
| 18 | Rocks | 26.2 | 0.0 | 24.5 | |
| 19 | Cascade | 26.3 | 0.0 | 24.5 | |
| 20 | Rocks | 26.3 | 0.2 | 24.4 | |
| 21 | Rocks | 26.5 | 0.1 | 24.2 | |
| 22 | Rocks | 26.6 | 0.1 | 24.1 | |
| 23 | Rock | 26.7 | 0.3 | 24.0 | |
| 24 | Rocks | 27.0 | 0.0 | 23.7 | |
| 25 | Rocks | 27.0 | 0.1 | 23.7 | |
| 26 | Rocks | 27.1 | 0.1 | 23.7 | |
| 27 | Rock | 27.1 | 0.1 | 23.6 | |
| 28 | Rocks | 27.2 | 0.0 | 23.5 | |
| 29 | Rocks | 27.3 | 0.1 | 23.5 | |
| 30 | Rocks | 27.3 | 0.0 | 23.4 | |
| 31 | Cascade | 27.3 | 0.0 | 23.4 | |
| 32 | Rock | 27.3 | 0.1 | 23.4 | |
| 33 | Cascade | 27.4 | 0.1 | 23.3 | |
| 34 | Cascade | 27.5 | 13.0 | 23.3 | |

**Table 3. Continued.**

| Barrier # | Obstruction type | Distance upstream from Lower Campbell River confluence (km) | Distance to next upstream barrier (km) | Distance to upper limit of mainstem (Wokas Lake; km) | Comments (Burt 2003) |
|---|---|---|---|---|---|
| 35 | Rocks | 40.5 | 0.9 | 10.2 | |
| 36 | Rocks | 41.4 | 0.0 | 9.3 | |
| 37 | Falls | 41.5 | 0.0 | 9.2 | Complete barrier; upper limit for all anadromous species |
| 38 | Rocks | 41.5 | 0.0 | 9.2 | |
| 39 | Rocks | 41.5 | 0.0 | 9.2 | |
| 40 | Rocks | 41.6 | 0.0 | 9.2 | |
| 41 | Rocks | 41.6 | 0.0 | 9.2 | |
| 42 | Falls | 41.6 | 0.3 | 9.1 | |
| 43 | Rocks | 41.9 | 0.1 | 8.8 | |
| 44 | Rocks | 42.0 | 5.4 | 8.8 | |
| 45 | Quinsam Diversion Dam | 47.4 | 3.3 | 3.3 | Complete barrier: barrier for resident migrations |
| 46 | Quinsam Storage Dam | 50.8 | 0.0 | 0.0 | Complete barrier: barrier for resident migrations |

### 3.2.2. Quinsam River Mouth to Canyon (13.6 km)

A series of nine barriers is recorded in FISS between 10.0 km and 13.6 km upstream of the Quinsam River mouth (see Inset 1 in Map 4). Cascades in this section of the river historically provided a low flow barrier that prevented Pink Salmon upstream migration during most years. In 2005, four cascades in the lower portion of the Quinsam River between 9.5 km and 12.5 km were excavated for fish passage, allowing access for salmon to approximately 14 km of additional habitat (Van Tine and Sinclair 2006). The fishway project was expected to produce a gain of about 17,000 $m^2$ of new spawning habitat, supporting a potential escapement of more than 43,000 Pink Salmon (Burt 2004). The initial assessment of fish passage in the fall of 2005 at the two fishways showed that Pink Salmon encountered no issues with upstream migration over the range of flows experienced. Helicopter surveys estimated that approximately 30,000 spawning Pink Salmon were uniformly distributed upstream of the cascades, as far as the upper cascades downstream of Lower Quinsam Lake (Map 4). The average flow during the fall 2005 Pink Salmon spawning migration was 2.31 $m^3/s$ (range 2.28 to 2.36 $m^3/s$), which was higher than normal flows for that season. It was expected that fish passage would be successful at flows of approximately 1.1 to 1.7 $m^3/s$. Van Tine and Sinclair (2006) indicated that fish passage should be evaluated at flows less than 1.1 $m^3/s$. Studies of out-migrating fry since fishway construction have highlighted the success of the increased availability of spawning habitat for Pink Salmon (Taylor and Anderson 2009). For instance, approximately 73,500 adult Pink Salmon were counted moving upstream of the hatchery counting fence in September

2008, and almost 13.5 million Pink Salmon fry moved downstream past the hatchery fence in the spring of 2009 (Taylor and Anderson 2009).

#### 3.2.3. Falls and Cascades at 24.2 km to 24.4 km, Downstream of 'Grouse Nest'

These barriers are numbered 11–15 in Table 3 and Map 4 and are downstream of a site colloquially known as 'Grouse Nest' (Burt 2003). They comprise a series of flat bedrock cascades downstream of 1 m-high falls (Burt 2003). These barriers form a partial barrier to anadromous Cutthroat Trout and may be a complete barrier to Pink Salmon at some flows (Burt 2003).

In 1957, Coho Salmon and Pink Salmon migrations were obstructed in this section at flows of 0.8 to 1.0 $m^3/s$ measured in mid-October (DFO 1957, as described in Burt 2003). The BC Power Commission was asked to provide additional water and Coho Salmon did not pass the falls located at 24.4 km until flows reached 1.6 to 1.7 $m^3/s$ (Burt 2003). The effect of the low flow event on Pink Salmon migration was less well understood because most fish were unable to pass cascade obstructions that existed downstream (at 13.3 km), prior to removal in 2005 (VanTine and Sinclair 2006; see Section 3.2.2).

FISS also contains a record of a log jam further downstream (22.0 km), which is marked as a 'dam' on Map 4. The current status of this is unknown.

#### 3.2.4. Cascades Downstream of Lower Quinsam Lake, 26.3 km to 27.5 km

These barriers are numbered 16–34 in Table 3 and Map 4. In his interview, Mr Burt confirmed that these cascades are the most critical section for flow-related passage issues on the river. He confirmed that, within this section, there are two sets of cascades that provide the greatest obstruction: these are the cascades immediately downstream of the lake outlet (33 and 34 on Map 4) and the cascades ~800 m further downstream (17 and 19 on Map 4). Passage issues relate to the presence of wide bedrock shelves that disperse flow across the channel, resulting in shallow depths. Issues are compounded by the lack of plunge pools at the base of the cascades. At higher flows, Mr Burt confirmed that the presence of smooth inclined bedrock can result in these sites becoming velocity barriers.

These barriers were examined during a habitat inventory in the late 1970s (Lawseth 1979, described in Burt 2003). The lowermost falls in the series at 26.3 km was deemed passable to fish on the right side with sufficient flow. The right side of the falls was 3.9 m high, with a lower step of 2.1 m and an upper step of 1.8 m. The left side of this falls was 4.9 m high and was declared impassable. Further upstream was a 1.5 m high cascade that was believed to be passable. The most upstream obstacle at this location was just downstream of the Lower Quinsam Lake outlet. On the left side there is a falls with two steps; a lower step of 1.2 m high and an upper step of 1.8 m high. On the right side of the river is a 100 m long cascade with a 15% gradient. Lawseth (1979) reported this upper obstacle was a major migration barrier at low flows due to inadequate water depths, and at high flows due to high velocities (Lawseth 1979).

Mr Burt confirmed that the Campbell River Salmon Foundation (CRSF) had plans to conduct work to improve fish passage at the two cascades that pose the greatest impediment to passage. CRSF (2015) confirmed that a project of $120,000 value was completed in 2015 to facilitate passage during a greater range of flows for steelhead and Coho Salmon.

## 3.3. Salmon River

### 3.3.1. Overview

The FISS database lists five barriers on the mainstem Salmon River (MOE 2015). An additional two barriers are described in the review by Burt and Robert (2001), which was updated in 2010 (Burt 2010). These barriers are shown in Map 5, which also shows the location of sites visited in 2015. The barriers are listed in Table 4, which quantifies the distance to the absolute upstream limit of fish distribution. Based on Burt (2010), this was assumed to be the point at which the gradient of the river increases beyond 20%, which is at 72.5 km.

**Table 4. Summary of recorded barriers (partial and complete) to fish passage on the Salmon River. Based on FISS (MoE 2015) and Burt (2010). Barrier #s correspond to barriers shown on Map 5.**

| Barrier # | Obstruction type | Distance upstream from mouth (km) | Distance to next upstream barrier (km) | Distance to upstream limit of fish distribution (km) | Source | Comments |
|---|---|---|---|---|---|---|
| 1 | Shallow riffle | 25.8 | 4.8 | 61.5 | Burt (2010) | |
| 2 | Canyon | 38.2 | 0.7 | 49.1 | Burt (2010) | Historically was partial or complete anadromous barrier. Blasted in 1975/76 and now there is no longer an obstruction. |
| 3 | Falls | 38.9 | 0.7 | 48.4 | MoE (2015) | |
| 4 | Log jam | 39.5 | 0.4 | 47.7 | MoE (2015) | |
| 5 | Falls | 39.9 | 13.9 | 47.4 | MoE (2015) | |
| 6 | Shallow riffle | 50.1 | 1.6 | 37.1 | Burt (2010), MoE (2015) | |
| 7 | Dam | 53.7 | 0.0 | 33.5 | MoE (2015) | Believed to be a partial barrier to CO, ST, and anadromous DV. Ascent at the fishway appears to be flow dependent. Works to improve fish passage are currently underway. |

### 3.3.2. Memekay River to Norberg Creek confluences

Mr Craig confirmed that the main adult steelhead index reach ('Lower Index') extends 11.5 km downstream from the Kay Creek confluence (see Map 5) to 'Pallans' (a recreational drift boat retrieval site). The upstream half of this survey section, from the Kay Creek confluence to the Big Tree Bridge, has no migration barriers and is not sensitive to flows. However, in the lower portion of the section, from approximately 1 km upstream of the confluence with the Memkay River to Pallans, is a very dynamic flat section of the river that contains many gravel bars and is heavily braided. There is potential for shallow riffles in this area to present a migration challenge to fish during low flows. The downstream-most 1.5 km of this index section has changed significantly since the surveys began in 1998. In the past, the river was a single-thread channel, but over the last few years the river has incised the left bank so that the river is now braided. Only ~25% of flow currently passes through the historical channel, with the remaining 75% now flowing through the forest and into log jams, prior to re-joining the mainstem. Mr Craig confirmed that the section of new channel through the forest has not been surveyed due to safety concerns. Mr Craig's description of the area of shallow riffles corresponds to the description by Burt (2010) of a shallow riffle downstream of the Memekay River confluence (25.8 km; see barrier #1 on Map 5). This is downstream of lower JHTMON-6 study section, which extends upstream from the Memekay River confluence (BC Hydro 2013).

A canyon lies upstream of the Lower Index snorkel reach (see barrier # 2 on Map 5). Rock debris in this canyon at 38.2 km was historically a barrier (velocity and vertical obstruction) to upstream fish migration. Blasting was undertaken in 1975 and 1976 to successfully remove this obstruction (Burt 2010). Mr Craig confirmed that this section of the river has never been surveyed by BCCF and, therefore, the current status of any barriers in the canyon is unknown.

Approximately 0.5 km further upstream, 2.5 m-high falls present a barrier to anadromous Cutthroat Trout (Burt 2010).

#### 3.3.3. Norberg Creek to the Salmon River Diversion Dam

This section is the 'Upper Index' adult steelhead snorkel survey reach that has been surveyed during most years since 2000. Mr Craig confirmed that the downstream section of this reach (Norberg Creek to Memekay Mainline Bridge; 5.9 km long) does not generally seem to present issues for adult fish migration. This section contains no flat or flow-sensitive riffles, although there are unstable portions of the river where flow has changed course through the forest resulting in some log jams. A level 1 and level 2 fish habitat assessment was conducted in the summers of 2006 and 2007 from the South Fork Mainline Bridge to the Memekay Mainline Bridge in the mainstem of the Salmon River. The results did not list any obstructions to upstream migration for anadromous salmonids (Silvestri and Gaboury 2008).

Mr Craig confirmed that the upstream section of this reach (Memekay Mainline Bridge to the diversion dam; 5.6 km long) contains shallow riffles that are the most likely place on the Salmon River to become a migration barrier at low flows. Specifically, this section extends downstream from the Paterson Creek confluence for approximately 1–2 km. Here, the river is very wide and flat from bank to bank. This area has always been too shallow for field crews to swim during steelhead snorkel surveys. This area corresponds to shallow riffles at 50.1 km that are recorded as barriers in the FISS database and in Burt (2010; see barrier #6 on Map 5).

#### 3.3.4. The Salmon River Diversion Dam

The Salmon River Diversion includes a fishway yet it poses a potential obstruction to upstream migration of adult Coho Salmon and steelhead. Upgrades to fish passage structures are currently underway at the dam, and these will be the focus of a monitoring program to assess passage success (see Section 1.4.2).

The performance of the fishway has previously been investigated using acoustic tagging studies (Lyderson *et al.* 2008, Anderson 2009, Lyderson *et al.* 2010). Monitoring in 2008 indicated that only 7% of adult Coho Salmon that reached the diversion structure successfully migrated further upstream. Very few fish were found to move successfully through the fishway when the discharge in the Salmon River downstream of the diversion was 10-12 $m^3$/s. The fishway appeared to pose a velocity or behavioural obstruction to fish passage even at low downstream discharges (Anderson 2009). Furthermore, in 2009 no tagged Coho Salmon were found above the fishway, reinforcing the suggestion that upstream passage success at the diversion fishway on the Salmon River is low (Lyderson *et al.* 2010).

Burt (2010) describes the upstream limit for anadromous salmonids in the upper Salmon River watershed as the point at which the gradient of the river increases beyond 20%, at 72.5 km (Map 5). Burt (2010) describes other anadromous fish barriers in tributaries to the Salmon River; these include: 4 m-high rock falls on Grilse Creek at 7.6 km upstream of its confluence with the Salmon River; rock falls in streams draining each of the three Memekay River sub-basins, and; an impassable falls on Bigtree Creek.

# 4. HYDROLOGY AND DIVERSIONS

## 4.1. Quinsam River

### 4.1.1. Diversion Conditions

The Quinsam River Diversion has a design capacity of 8.50 $m^3$/s and a total of 100 million $m^3$ is licensed to be diverted annually (BC Hydro 2012). The WUP stipulates maximum down-ramping rates (Table 5) and minimum flows (when naturally available) in the Quinsam River downstream of the diversion dam (Table 6).

**Table 5. 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 6 Minimum permitted discharge in the Quinsam River (BC Hydro 2012). Applies to hydrometric gauge 08HD021 (see Map 2).**

| 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 |

#### 4.1.2. Historic Discharge Data

The Water Survey of Canada maintains hydrometric gauges at three mainstem sites and one site in the diversion canal, immediately downstream of the diversion dam (see Map 3 for mainstem gauge locations; WSC 2015). Historic data are summarized below for the diversion canal, the mainstem site immediately downstream of the diversion facility (08HD021), and the mainstem site upstream of the confluence with the Campbell River (08HD005). These data have not been "naturalized" to account for storage and diversions.

Historically (1997–2013), MAD in the diversion canal was 1.2 $m^3/s$ (instantaneous range = 0 to 9.0 $m^3/s$), with discharge typically lowest during July through October (mean = 0.2 to 0.3 $m^3/s$; Figure 1; Table 7).

Data for two mainstem sites are presented in Table 8 to Table 9, and Figure 2 to Figure 3. The lowest mean monthly discharge occurs during July through September at both sites, although the magnitude of annual variability is lower at the site that is located immediately downstream of the diversion facility (Figure 2), compared to the site located upstream of the confluence with the Campbell River (Figure 3). Historically, MAD downstream of the diversion is 2.1 $m^3/s$ (1993–2013; Table 8) and 8.6 $m^3/s$ upstream of the confluence with the Campbell River (1956–2013; Table 9). Monthly minimum discharge upstream of the confluence ranges from 0.89 $m^3/s$ (September) to 2.50 $m^3/s$ (May; Table 9). Historic monthly maximum discharge at this site ranges from 7.3 $m^3/s$ (August) to 218 $m^3/s$ (January; Table 9).

**Figure 1.** **Historic discharge data for the Quinsam River Diversion (WSC gauge 08HD026; WSC 2015).**

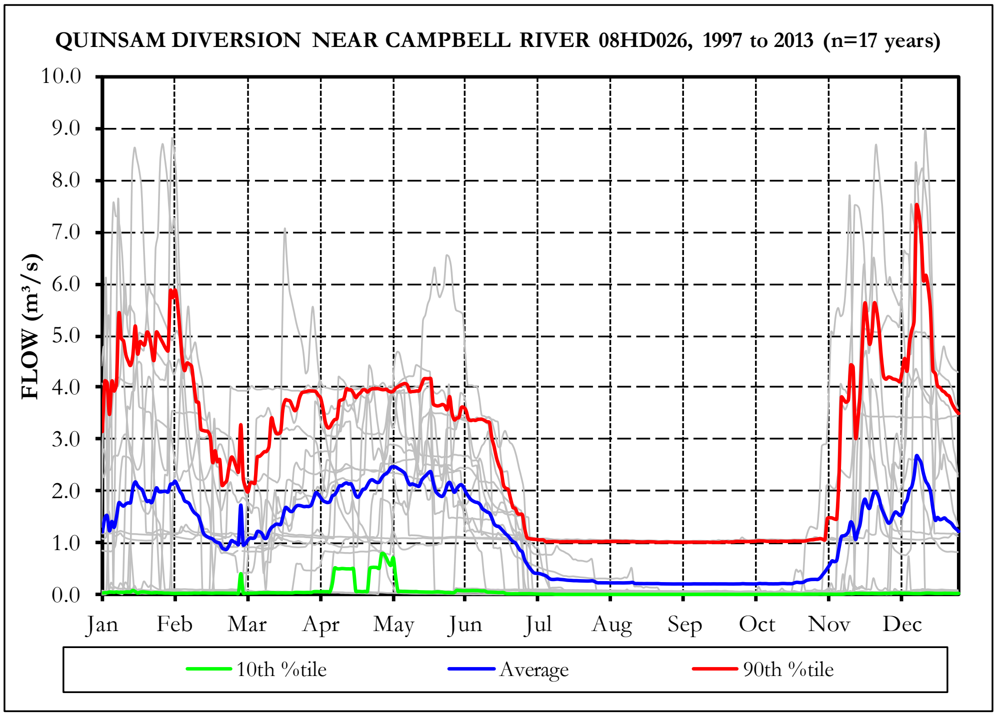



**Table 7.** **Monthly flow statistics for the Quinsam River Diversion near Campbell River 1997–2013, *n* = 13 years (WSC gauge 08HD026; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 1.8 | 0.01 | 9 |
| Feb | 1.3 | 0.01 | 9 |
| Mar | 1.4 | 0.01 | 7.0 |
| Apr | 2.0 | 0.01 | 5.1 |
| May | 2.2 | 0.01 | 6.5 |
| Jun | 1.4 | 0.00 | 5.5 |
| Jul | 0.3 | 0.00 | 1.5 |
| Aug | 0.2 | 0.00 | 1.1 |
| Sep | 0.2 | 0.00 | 1.1 |
| Oct | 0.2 | 0.00 | 1.3 |
| Nov | 1.2 | 0.00 | 9 |
| Dec | 1.7 | 0.00 | 9 |
| **Annual** | 1.2 | 0.00 | 9 |

**Figure 2. Historic discharge data for the Quinsam River at Argonaut Bridge (WSC gauge 08HD021; WSC 2015).**

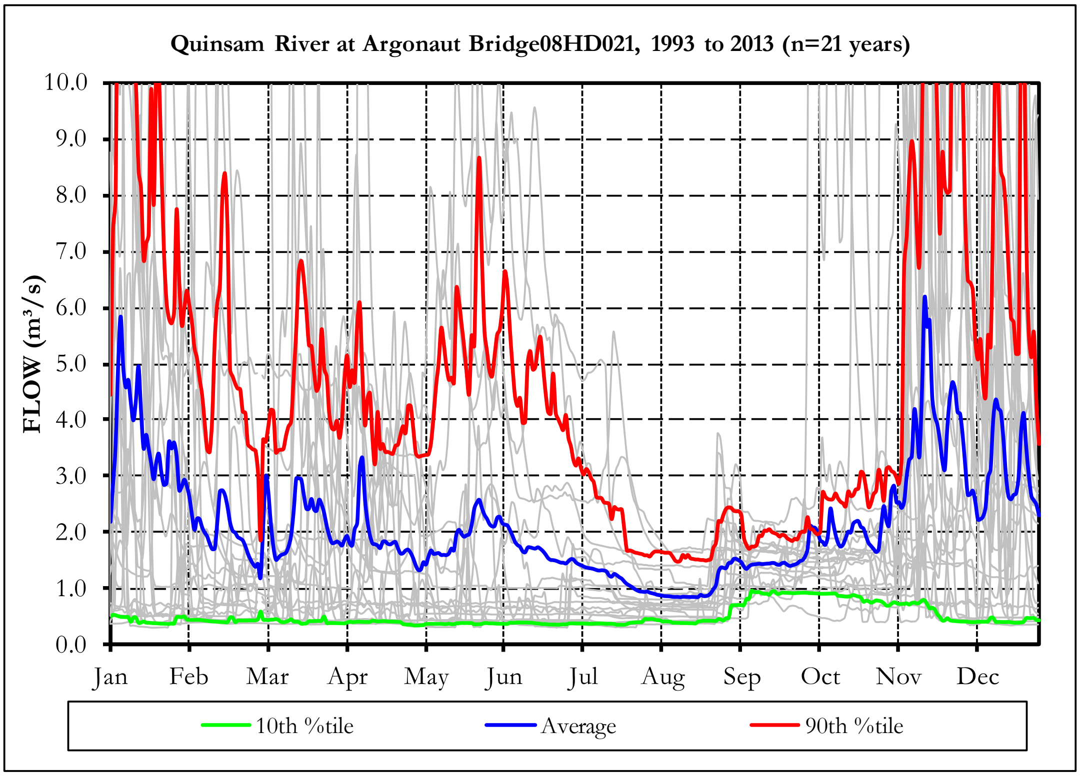



**Table 8. Monthly flow statistics for the Quinsum River at Argonaut Bridge 1993–2013, *n* = 21 years (WSC gauge 08HD021; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 3.6 | 0.31 | 46 |
| Feb | 2.0 | 0.38 | 15 |
| Mar | 2.2 | 0.34 | 32.4 |
| Apr | 1.9 | 0.31 | 31.9 |
| May | 1.9 | 0.30 | 11.8 |
| Jun | 1.7 | 0.29 | 10.1 |
| Jul | 1.2 | 0.31 | 5.5 |
| Aug | 0.9 | 0.36 | 3.8 |
| Sep | 1.4 | 0.47 | 3.2 |
| Oct | 2.0 | 0.40 | 20.9 |
| Nov | 3.7 | 0.41 | 46 |
| Dec | 3.0 | 0.34 | 20 |
| **Annual** | 2.1 | 0.29 | 46 |

**Figure 3. Historic discharge data for the Quinsam River near the confluence with the Campbell River (WSC gauge 08HD005; WSC 2015).**

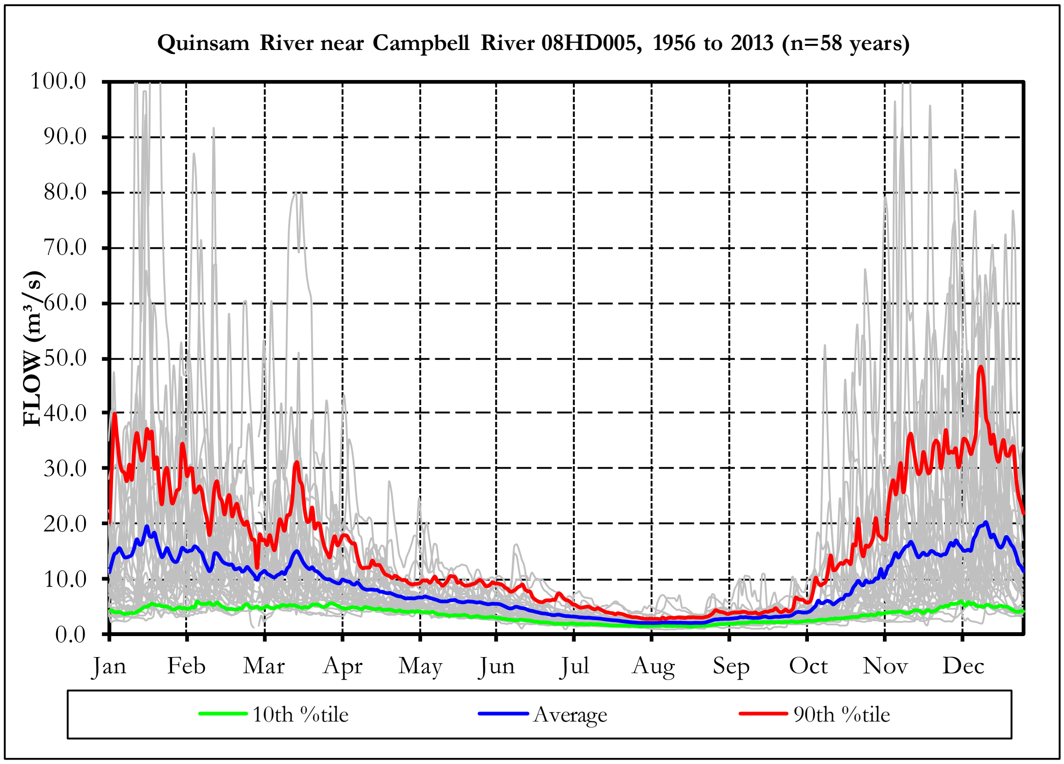



**Table 9. Monthly flow statistics for the Quinsam River near the confluence with the Campbell River 1956–2013, $n$ = 58 years (WSC gauge 08HD005; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 15.3 | 2.28 | 218 |
| Feb | 13.1 | 1.22 | 91 |
| Mar | 11.6 | 1.56 | 79.9 |
| Apr | 8.1 | 1.91 | 57.8 |
| May | 6.2 | 2.50 | 24.6 |
| Jun | 4.5 | 1.10 | 18.2 |
| Jul | 2.8 | 1.05 | 10.9 |
| Aug | 2.2 | 0.96 | 7.3 |
| Sep | 3.1 | 0.89 | 14.1 |
| Oct | 6.5 | 1.50 | 93.8 |
| Nov | 13.8 | 1.70 | 147 |
| Dec | 16.4 | 1.87 | 107 |
| **Annual** | 8.6 | 0.89 | 218 |

## 4.2. Salmon River

### 4.2.1. Diversion Conditions

The Salmon River Diversion Canal has a maximum design discharge capacity of 45 $m^3/s$ and a total of 493.4 million $m^3$ is licensed to be diverted annually (BC Hydro 2012). The WUP stipulates maximum down ramping rates for the Salmon River and the diversion canal (Table 10), maximum diversion flows to enhance fish screen efficiency (Table 11), and minimum flows that must be maintained in the Salmon River downstream of the diversion dam when sufficient flows are naturally available (4.0 $m^3/s$; BC Hydro 2012).

**Table 10. Salmon River maximum permitted down ramping rates (BC Hydro 2012).**

| Stream | Salmon River discharge ($m^3/s$) | Salmon River maximum down ramping rate ($m^3/s/h$) |
|---|---|---|
| Salmon River | < 8.0 | 1.0 |
| | 8.0 to 10.0 | 2.0 |
| | >10.0 | 10.0 |
| Salmon River Diversion Canal | 0 to 43.0 | 10.0 |

**Table 11. Salmon River maximum permitted diversion flows (BC Hydro 2012).**

| Date | Maximum diversion ($m^3/s$) | Fish screen operation |
|---|---|---|
| Jan 1 to Mar 31 | 43 | N/A |
| Apr 1 to Dec 31 | 15 | On |

### 4.2.2. Historic Discharge Data

The Water Survey of Canada maintains hydrometric gauges at three mainstem sites and one site in the diversion canal, immediately downstream of the diversion dam (see Map 3 for mainstem gauge locations; WSC 2015). Historic data are summarized below for the diversion canal, and the two mainstem locations that are sited furthest upstream. These data have not been “naturalized” to account for storage and diversions.

Historically (1993–2010), MAD in the diversion canal has been 4.6 $m^3/s$ (instantaneous range = 0 to 42 $m^3/s$), with discharge typically lowest during July through September (mean = 0.1 to 1.1 $m^3/s$; Table 12). Monthly mean discharge is highest in April (8.7 $m^3/s$) and May (10.3 $m^3/s$; Table 12).

Historic (1981–2012) MAD upstream of the diversion is 13.8 $m^3/s$, with monthly mean discharge ranging from 2.4 $m^3/s$ (August) to 24.2 $m^3/s$ (November; Figure 5; Table 13). Downstream of the diversion, historic (1960–2012) annual mean discharge at the site upstream of the Memekay River confluence is 14.1 $m^3/s$, with monthly mean discharge ranging from 2.9 $m^3/s$ to 26.8 $m^3/s$ (Figure 6; Table 14). Maximum monthly mean discharge at this site ranges from 33.4 $m^3/s$ (August) to 385 $m^3/s$ (January); minimum monthly mean discharge ranges from 0.30 $m^3/s$ (September) to 2.61 $m^3/s$ (March).

**Figure 4. Historic discharge data for the Salmon River Diversion (WSC gauge 08HD020; WSC 2015).**

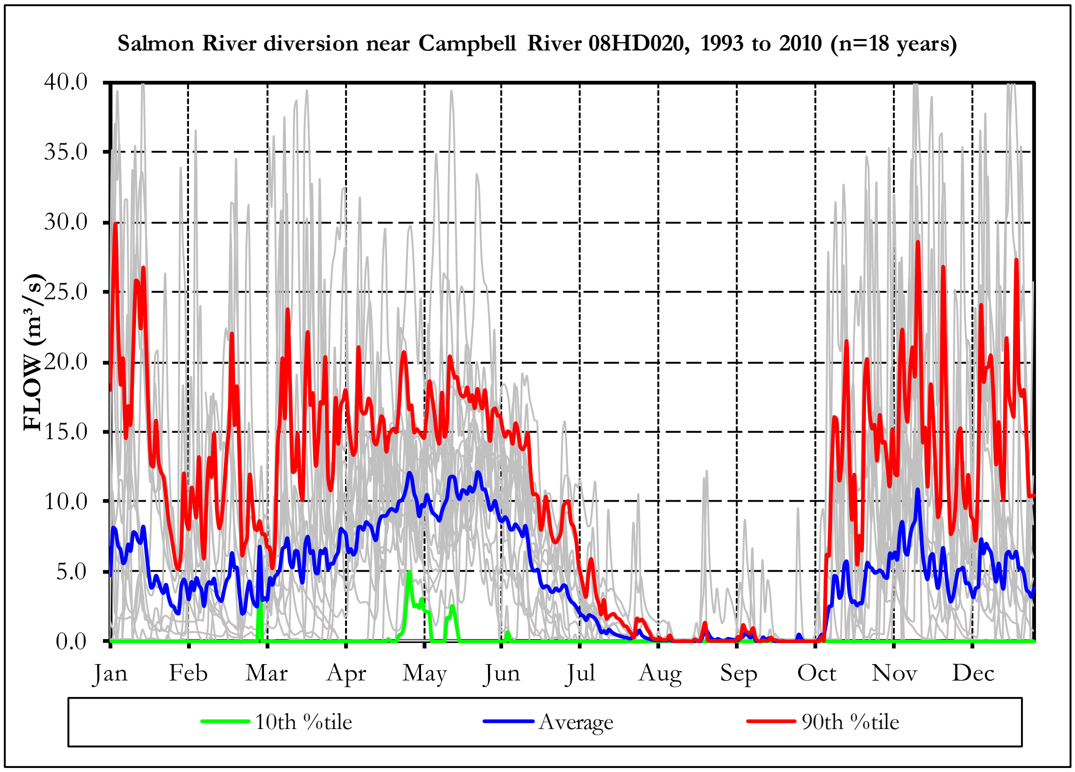


**Table 12. Monthly flow statistics for the Salmon River Diversion 1993–2010, *n* = 18 years (WSC gauge 08HD020; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 5.3 | 0.00 | 42 |
| Feb | 3.8 | 0.00 | 36 |
| Mar | 5.6 | 0.00 | 39.5 |
| Apr | 8.7 | 0.00 | 32.4 |
| May | 10.3 | 0.00 | 39.4 |
| Jun | 6.1 | 0.00 | 22.3 |
| Jul | 1.1 | 0.00 | 11.5 |
| Aug | 0.1 | 0.00 | 12.2 |
| Sep | 0.2 | 0.00 | 9.4 |
| Oct | 2.8 | 0.00 | 34.6 |
| Nov | 6.0 | 0.00 | 41 |
| Dec | 5.0 | 0.00 | 41 |
| **Annual** | 4.6 | 0.00 | 42 |

**Figure 5. Historic discharge data for the Salmon River, above the Salmon River Diversion (WSC gauge 08HD015; WSC 2015).**

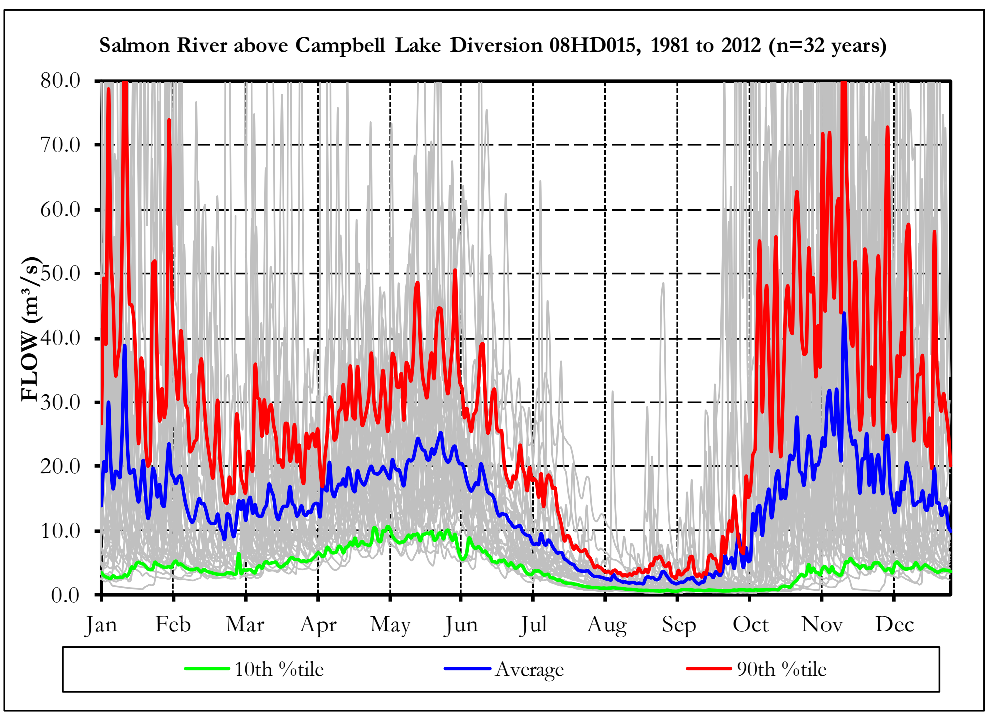


**Table 13.** **Monthly flow statistics for the Salmon River, above the Salmon River Diversion 1981–2012, *n* = 32 years (WSC gauge 08HD015; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 19.3 | 1.00 | 306 |
| Feb | 13.0 | 2.32 | 135 |
| Mar | 13.6 | 2.55 | 166.0 |
| Apr | 17.3 | 3.69 | 193.0 |
| May | 21.2 | 4.51 | 91.1 |
| Jun | 15.4 | 2.62 | 116.0 |
| Jul | 6.2 | 0.63 | 64.4 |
| Aug | 2.4 | 0.16 | 48.5 |
| Sep | 3.1 | 0.24 | 111.0 |
| Oct | 15.0 | 0.37 | 210.0 |
| Nov | 24.2 | 0.68 | 273 |
| Dec | 15.7 | 0.71 | 175 |
| **Annual** | 13.8 | 0.16 | 306 |

**Figure 6.** **Historic discharge data for the Salmon River, upstream of the Memekay River confluence (WSC gauge 08HD007; WSC 2015).**

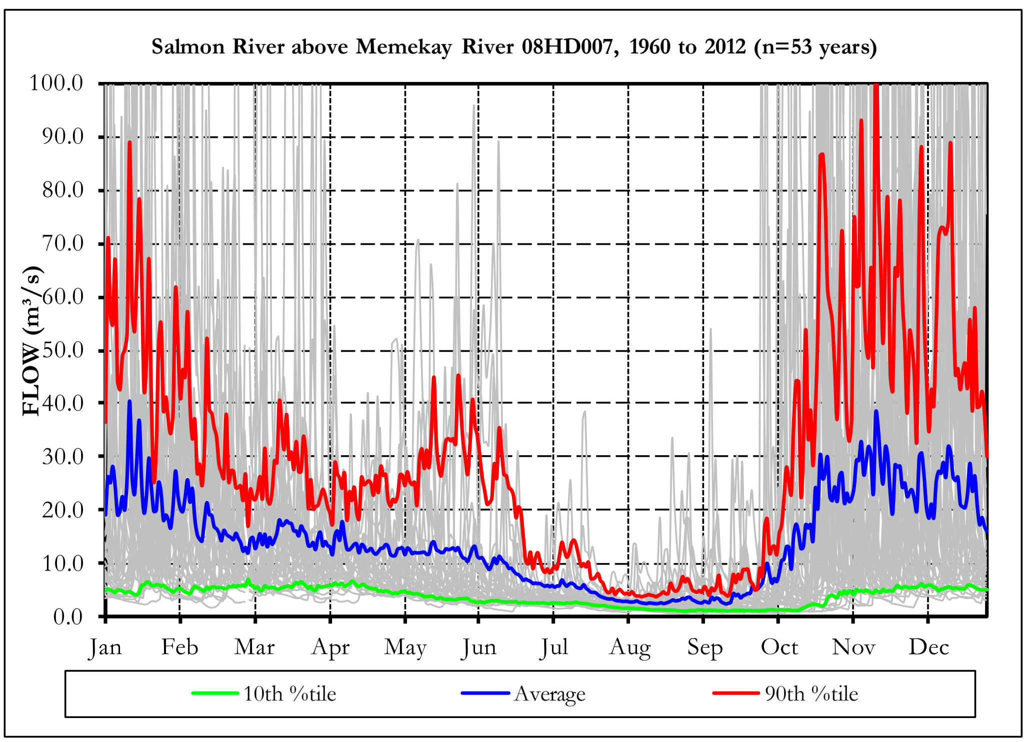


**Table 14. Monthly flow statistics for the Salmon River, upstream of the Memekay River confluence 1960–2012, *n* = 53 years (WSC gauge 08HD007; WSC 2015).**

| Month | Discharge ($m^3/s$) | | |
|---|---|---|---|
| | Mean | Min | Max |
| Jan | 23.8 | 2.33 | 385 |
| Feb | 17.1 | 1.50 | 275 |
| Mar | 15.2 | 2.61 | 214.0 |
| Apr | 13.1 | 2.53 | 209.0 |
| May | 12.2 | 1.83 | 88.2 |
| Jun | 9.0 | 0.81 | 95.7 |
| Jul | 5.0 | 0.74 | 72.2 |
| Aug | 2.9 | 0.31 | 33.4 |
| Sep | 3.8 | 0.30 | 142.0 |
| Oct | 16.6 | 0.67 | 314.0 |
| Nov | 26.8 | 0.87 | 382 |
| Dec | 23.7 | 1.80 | 320 |
| **Annual** | 14.1 | 0.30 | 385 |

## 5. REVIEW OF BARRIER PASSAGE ASSESSMENT METHODS

A literature review was conducted to identify existing methods for assessing passage past natural barriers. Passage assessment methods were categorized based on how the barrier prohibits passage. A barrier may obstruct passage by having characteristics that exceed a fish's swimming and/or leaping abilities, i.e., it results in current velocity that is too fast for a fish to swim through, or the barrier is too high for a fish to leap over. These conditions typically occur at chutes and falls, which typically have high flow velocities and/or present physically high barriers. Alternatively, a barrier may obstruct passage because it does not provide adequate water depth for fish to swim through. This occurs in low-gradient riffle habitat where water depth may not be sufficient for fish passage during low flows. Based on this, we considered two separate categories of barrier during the review: falls-type barriers (which include chutes and cascades), and riffle-type barriers. Passage evaluation methods for each barrier type are summarized below.

### 5.1. Falls-Type Barriers

For the purpose of this review, 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. A chute is defined by a steep gradient where the water does not separate from the stream bed. This barrier category also includes cascades (steep stepped riffles; Johnston and Slaney 1996), which can function as a barrier in a similar way to chutes.

5.1.1. Field-Based Assessment

This section describes the standardized approach to barrier assessments for assessing falls and chutes (or cascades) that has been developed by Reiser *et al.* (2006) and Parker (2000).

Where possible, surveys of the barrier should be conducted over the range of flows that occur during the migration periods of the species present; where multiple surveys are not possible, a single survey should be conducted at conditions that are typical of the migration period, or at flow conditions that are of specific interest. Migration periods, jumping capabilities and swimming capabilities for individual species are shown in Table 15.

During the surveys, detailed measurements of the barrier are taken. The hydraulic and geometric data collected (Figure 7) are channel width, wetted width, plunge pool depth $d_{pp}$, vertical drop $H$, chute angle $S_p$, barrier height $Z$, vertical distance from the downstream pool water surface to the water surface at the crest $H$, water depth at the crest $d_c$, flow depth of the downstream pool $d_{pp}$, chute length $LS$, chute angle $S_p$, angle of the bed upstream of a falls $S_e$, vertical distance from the downstream water surface elevation to the barrier crest $FH$, initial leaping angle $\theta_0$, distance from the standing wave to the base of the falls $X$, distance from the location of the impact of the falling water to the standing wave $X_{sw}$, and velocity at the barrier crest $V_C$. Velocity measurements are typically taken with a current velocity meter. Geometric barrier data are collected with a combination of meter sticks, measuring tapes, rangefinders, and clinometers. Where measurements cannot be taken, they are conservatively estimated and these occurrences are specifically stated.

**Figure 7. Schematic drawing of a chute-type (left) and fall-type barrier (right; from Reiser *et al.* 2006).**

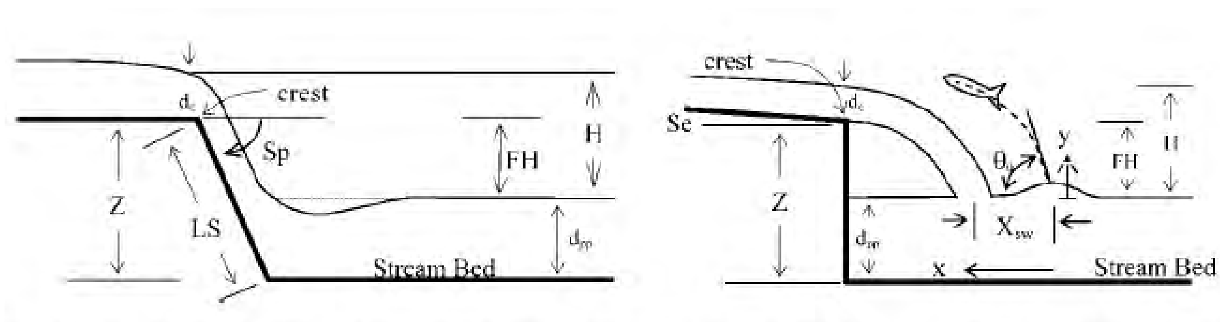


**Table 15. Typical swimming capabilities and maximum jump heights for various adult salmonids (from Reiser *et al.* 2006 and Parker 2000).**

| 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[1] | Source |
|---|---|---|---|---|---|---|---|---|---|
| **Coho Salmon** | Adult | 0-1.04 | 1.04-3.23 | 3.23-6.55 | 2.19 | 0.17 | 0.7 | Sept–Dec | 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 | Jul–Nov | 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–Dec | Reiser *et al.* 2006 |
| **Cutthroat and Rainbow trout** | Adult | 0-0.9 | 0.9-1.8 | 1.8-4.3 | 1.5 | - | - | Variable | 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–Oct | Reiser *et al.* 2006 |
| **Steelhead** | Adult | 0-1.40 | 1.4-4.17 | 4.17-8.07 | 3.35 | 0.17 | 0.7 | Jan–May | 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–Oct | 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 |

[1]Migration times span ranges for both rivers and were reproduced from BC Hydro files for Campbell River Water Use Plan, dated 2001. See separate periodicity charts for each river for further information.

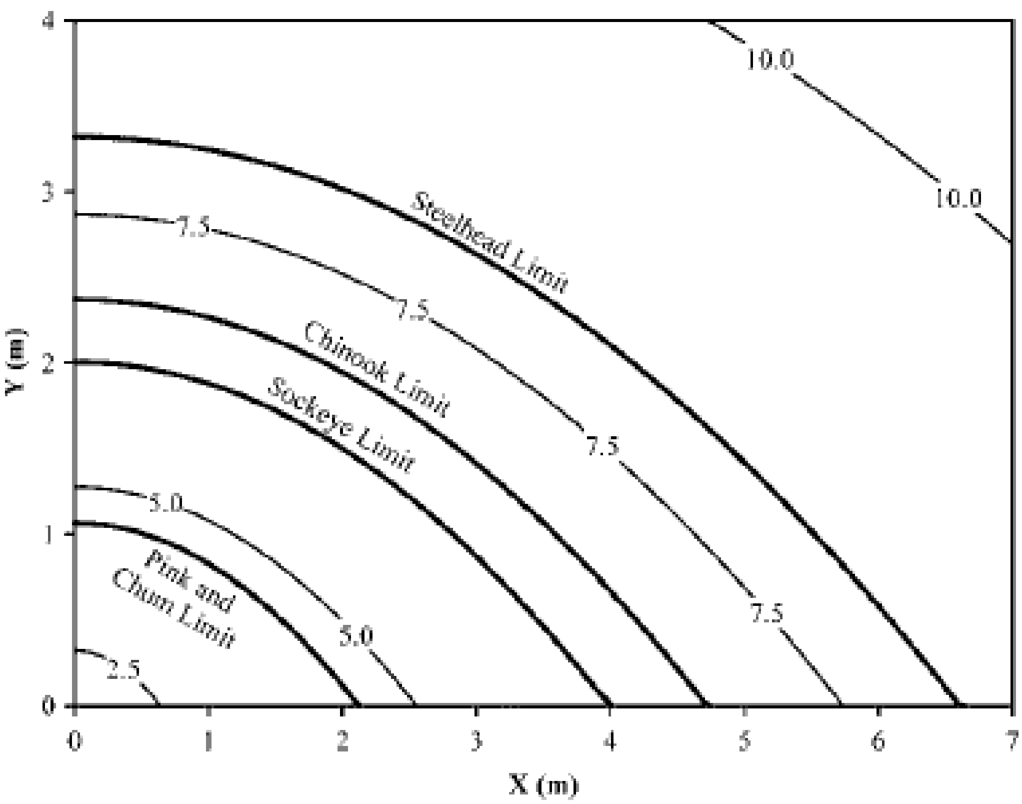
The ability of a fish to successfully pass a barrier depends on the nature of the barrier (i.e., falls or chute). For a fish to be able to successfully ascend a falls-type barrier, it must be capable of leaping from the plunge pool to the top of the falls and then be able to swim upstream. For a fish 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 15).

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 is determined based on Figure 4 in Reiser *et al.* 2006 (reproduced here in Figure 8). Burst swimming speeds for Dolly Varden are not available in the literature, but critical swimming speeds of Bull Trout (similar to Dolly Varden) are similar to resident Rainbow Trout (Mesa *et al.* 2004).

The assumption that the maximum jump height can be met requires that the plunge pool depth is sufficient for the fish to achieve a maximum jump height. Powers and Osborn (1985) indicated that maximum jump height requires that 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. Reiser *et al.* (2006) support an approach of assuming that the first condition is always met and evaluating the second condition based on the largest fish length observed during fish sampling (Table 15).

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 occur, 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, Reiser *et al.* (2006) recommend that the lower range of burst velocity is compared to the crest velocity. In other words, successful transition from jumping to swimming would result if the lower range of burst velocity is greater than $V_{dc}$. A conservative approach is to omit minimum crest water depth from inclusion in an assessment.

**Figure 8. Horizontal travel distance (X) and vertical height (Y) limits for difference salmonid species based on burst swimming speed velocities. The numbers indicated on the contours are the exit velocities of the fish (reproduced from Reiser *et al.* 2006).**




5.1.2. Hydraulic Habitat Modelling

Three-dimensional (3-D) computer modelling is a suitable alternative to the field-based method described above, although measurements of a range of physical parameters are still required to configure a hydraulic model. In practice, a detailed topographic survey of each barrier is required to develop a geometric mesh that can be used to configure models. Measurements of flow velocities and depths on a minimum of three dates are then required to validate/calibrate models.

Modelling can be used to quantify flow hydrodynamics in 3-D over chutes and falls-type barriers, and can also be used to estimate a stage-discharge relationship. Output variables include: instantaneous velocity vectors, energy parameters, and turbulent energy parameters. Therefore, in addition to minimum (or optimal) water depths for target species (described in Section 5.2), values of hydrodynamic parameters related to the swimming capabilities and preferences of target species are used to determine the optimum flow conditions over barriers for successful fish passage.

#### 5.1.3. Summary of Criteria for Fish Passage at Falls-Type Barriers

Three passage criteria are listed below. For a fish to pass a chute-type barrier, either: a) criteria 1 and 2 must be met; or b) criterion 3 must be met:

1. A fish's burst velocity must be greater than the average chute velocity. Table 15 summarizes burst swimming speeds for various Pacific salmon and trout species.
2. A fish can pass the full barrier length within 15 seconds while swimming at burst velocity.
3. A fish can leap past the barrier. See passage criteria described below for falls-type barriers.

For a fish to achieve passage past a falls-type barrier, each of the following criteria must be met:

1. A fish's maximum jumping ability is greater than the jumping requirements of the barrier.
2. Plunge pool depth allows the maximum jump height to be achieved.
   a. Maximum jump height requires that the penetration of falling water should be less than the plunge pool depth (Powers and Osborn 1985); and
   b. Plunge pool depth should be greater than or equal to the length of the migrating fish. To assess this condition, Reiser *et al.* (2006) recommends using the largest fish length observed during fish sampling.
3. A fish must be able to transition from jumping to swimming at the top of the falls. For this to occur, 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, Reiser *et al.* (2006) recommend using the lower range of burst velocity and comparing this to the crest velocity. In other words, successful transition from jumping to swimming would result if the lower range of burst velocity is greater than $V_{dc}$.

### 5.2. Riffle-Type Barriers

#### 5.2.1. Critical Riffle Analysis Method

The method described here has been adapted from the Critical Riffle Analysis method described by CDFG (2012) to assess stream connectivity at low flows. The method is suitable for wadeable, low gradient (< 4%) riffles, with gravel, cobble and boulder substrates. A critical riffle cross-section depth must meet the following parameters:

- The minimum depth requirements for target species[3] (Table 16).

[3] 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.

- At least 10% of the cross-section must be a contiguous portion meeting the minimum depth established for the target species.
- At least 25% of the cross-section must meet the minimum depth established for the target species.

**Table 16. 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 are low-gradient areas of the stream that may become partial or complete barriers to fish passage during low flows. Sites should be identified following consultation with experienced staff and reconnaissance. Once a site has been selected, a detailed site assessment is completed in the field by experienced field technicians, as described in the steps below.

1. The upstream and downstream bounds of the site are established and flagged, a GPS waypoint is collected mid-site, the site is photographed, and initial site documentation is completed.
2. The most critical riffle at the site should then be identified. To do this, the field team should conduct visual assessments and take depth measurements within the site boundaries to identify the most depth-sensitive (i.e., shallowest) critical riffle. Note that the critical riffle is not required to be a cross-section perpendicular to the stream flow and is defined as the shallowest continuous course across the stream channel.
3. A survey transect is then established along the course of the critical riffle. Permanent benchmarks are installed on the river left and river right banks. Then, a bed elevation profile survey is undertaken along the contour of the critical riffle, between the benchmarks established on the river banks. This involves measuring water depth with a stadia rod at fixed intervals along the transect.
4. A water level data logger (e.g., Solinst Levelogger) is installed along the cross section to monitor water depths and to help derive stage-discharge relationships.

5. In addition to water levels, discharge should be recorded at the time of the survey. If present, this may be obtained from nearby flow gauges exist. If such data are not available, discharge should be measured by field crews at least three times throughout the typical range of flow conditions. A stage-discharge relationship (rating curve) should then be derived using water level and discharge measurements.
6. One or more time-lapse remote camera may be mounted nearby to observe water levels at the cross section over changing flows. This will provide visual validation of the stage-discharge relationship.
7. Field crews should repeat steps 3 through 5, at different flows during two to five additional visits to identify and categorize passage flows for the target species and life stages.

#### 5.2.2. Hydraulic Habitat Modelling

The field-based approach described above allows a stage-discharge relationship to be developed that can be used to determine the flow that corresponds to the minimum passable water levels for various fish species and life stages of interest.

The empirical approach described above can be extended with the use of 1-, 2-, or 3-dimensional computer models. 1-D modelling software, such as HEC-RAS or USGS Fort Collins PHABSIM, can be used to produce the cross-sectional water depth and corresponding average velocity over a select range of discharges. However, at relatively low water levels, 1-D modelling results will be affected by a number of variables, including substrate size and heterogeneity. Therefore, the applicability of such methods to assessing riffle-type barriers will depend on the individual site characteristics. A minimum of three cross-sectional transect depth profiles, as well as water depth and discharge measurements at three different flow conditions at each cross section are required to accurately simulate flow conditions. Further information about 1-D hydraulic habitat monitoring is provided in the overview of instream flow assessment methods that was completed as part of JHTMON-6 (Healey and Hatfield 2015).

2-D and 3-D modelling software can also be used to simulate low flow conditions over a shallow riffle area in more detail. Both can be used regardless of substrate characteristics to simulate detailed flow conditions and water depths over a range of flows. 2-D models produce detailed depth-averaged flow conditions, including localized flow patterns in the vicinity of large substrate such as boulders. River2D is a commonly used 2-D model that has custom outputs that can be used to estimate the habitat suitability for target fish species, i.e., areas where current velocity is suitable. Therefore, in addition assessing fish passage based on minimum depths for individual species (as described in 5.2.1), 2-D and 3-D models can be used to examine habitat suitability based on velocity.

3-D modelling can be used to derive detailed estimates of flow hydrodynamics in three dimensions. Output variables include: instantaneous velocity vectors, kinetic energy, turbulent kinetic energy, and vorticity. Outputs can be compared with habitat preferences and swimming capability of target species to determine minimum flow criteria for shallow riffles. Detailed bed topographic surveys are required to develop geometric meshes required to configure 2-D and 3-D models. Additionally, water depth and discharge measurements at a minimum of three different flow conditions are required to calibrate and validate simulations.

#### 5.2.3.Summary of Criteria for Fish Passage at Riffle-Type Barriers

As described above in Section 5.2.1, the criteria for passage through a riffle-type barrier are flow depth dependent. In order to achieve passage, the following criteria must be met at most critical transect across a potential riffle barrier:

1. At least 10% of the entire transect length must be a contiguous portion with the minimum depth established for the target species.
2. At least 25% of the entire transect length must meet the minimum depth established for the target species.

Minimum depth requirements for salmonid and trout species are summarized above in Table 16. These species-specific values can be validated for a specific system using snorkel surveys to observe fish migration under specific flow conditions. Results of such surveys can be used to make necessary adjustments to assessments to reflect differences between fish populations and streams.

### 5.3. Consecutive Barriers

Fish may be required to pass two or more consecutive barriers in order to move through a passage-limiting section of stream. This is the case for a set of connected falls or cascades where fish are required to pass all of the barriers in order to successfully continue their migration. Under these circumstances, each barrier is assessed separately for passage, as described above. Additional biological monitoring (e.g., snorkel surveys) can provide information about whether consecutive barriers present particular passage issues.

## 6. RECONNAISSANCE SITE VISITS

### 6.1. Purpose

A detailed, empirical study of all potential barriers on the Quinsam and Salmon rivers is beyond the scope and budget of this study. It was therefore necessary to identify sections of river and barrier types that should be the focus of fieldwork to characterize barriers and provide information to assess flow management alternatives. In doing so, we have made a tacit assumption that the characterization of the selected barriers is sufficient to assess flow management alternatives for each river.

Potential sites were first identified based on the outcomes of the review of existing information and interviews with local experts (Section 3). We then undertook reconnaissance site visits to potential sites in October 2015. The purpose of the visits was to:

1. Confirm the presence of barriers identified during the background review.

2. Rank likely importance of barriers.
3. Select sites that will be examined during more-detailed fieldwork.
4. Identify appropriate methods specific to each barrier for further physical and biological assessment as part of more detailed fieldwork.

This section describes the rationale for the initial site selection, and the methods and outcomes of the reconnaissance site visits.

### 6.2. Rationale for Selecting Sites to Visit

Based on our review of existing information (Section 3.2), we chose to visit two general areas of the Quinsam River. The first area was between 10.0 km and 13.6 km upstream of the Quinsam River mouth (see Inset 1 on Map 4). The background review indicated that this area includes multiple barriers, although work had been undertaken in 2005 to improve passage at cascades that posed the greatest obstruction (Section 3.2.2). The second area was downstream of Lower Quinsam Lake, where bedrock shelves create chutes that are shallow at low flows and present potential velocity barriers at high flows (see Inset 2 on Map 4). This area was identified as the most critical for flow-related fish passage issues during our review (Section 3.2.3). Two of the bedrock chutes (one immediately downstream of the lake outlet, and the second approximately 800 m downstream) were physically altered by Campbell River Salmon Foundation in 2015; however, we understand that detailed monitoring of this work has not been conducted.

We also visited two general areas on the Salmon River. The first area comprised wide shallow riffles that extend downstream of the the Paterson Creek confluence for approximately 1-2 km (SAM-BAR01-06 on Map 5). This area was identified as the most crucial area for flow-related fish passage issues during our review of existing information about barriers on the Salmon River (Section 3.3.3). The second area was downstream of the Big Tree Creek confluence (Map 5), which was identified by Mr Craig (BCCF) as another area where shallow riffles may present a barrier during low flows (Section 3.3.2).

### 6.3. Reconnaissance Site Visit Methods

Reconnaissance site visits were conducted during early October 2015 when flow conditions were at near annual low flows. Visits to the Quinsam River were conducted on October 06 and 07; visits to the Salmon Rivers were conducted on October 05 and 07.

The field crew was led by an experienced fisheries technician and a water resources engineer. The field crew walked the identified sites to identify and map barriers. All candidate field sites and potential barriers were georeferenced with a GPS. Photographs were taken of each barrier to identify barrier type, and upstream migration route(s) of fish passage. Where relevant, the following physical variables were measured or estimated in the field: barrier length, width, slope, fall heights, water depth, and jump heights.

### 6.4. Reconnaissance Site Visit Outcomes

Photographs, descriptions and field notes for each barrier are provided separately for the Quinsam River in Appendix A and the Salmon River in Appendix B. These appendices include maps of the locations of each barrier that was visited; locations are also shown on Map 4 and Map 5 (see 'BAR' sites). Information collected during the site visits was used to develop a recommended approach for detailed biological and physical monitoring to be undertaken during JHTMON-6. This is described in the next section.

## 7. RECOMMENDED APPROACH – DATA COLLECTION

### 7.1. Overview

We propose to collect physical measurements of habitat characteristics using methods that are appropriate for the specific habitat units to be sampled. These measurements will be collected during the low flow period (July–early September), when it will be easiest to schedule surveys to target the desired low flow conditions. Measurements will be compared with established fish passage criteria for species of interest (Table 15; Table 16) to examine fish passage. On both rivers, wildlife cameras will be installed at three sites to provide visual records of habitat conditions at low flow periods. In addition, we propose to collect biological data relating to fish passage during Year 2 and Year 3 by: 1) undertaking a passive integrated transponder (PIT) tagging study on the Quinsam River; 2) deploying a video camera on the Salmon River to monitor fish passage at a priority barrier during the range of flows that occur during Coho Salmon and Chinook Salmon migration periods; 3) undertaking snorkel surveys on both rivers during key migration times.

Our proposal to undertake a PIT tagging study on the Quinsam River reflects an opportunity to collaborate with other organizations to extend the scope of the biological monitoring for the fish passage assessment that was originally developed (BC Hydro 2013). This will allow us to more comprehensively address the relevant JHTMON-6 management question, while concurrently supporting wider research objectives relating to evaluating fish passage on the Quinsam River. Specifically, we have identified an opportunity to collaborate with the Quinsam River Hatchery who are committed to tagging adult Coho Salmon and steelhead at the hatchery site (Map 2), providing that PIT tags and direction can be provided under the auspices of JHTMON-6 (Frisson, pers. comm. 2016). We propose to install PIT tag antenna arrays to monitor subsequent fish passage at the series of bedrock cascades and chutes located downstream of Lower Quinsam Lake (see Inset 2 in Map 4). These barriers have been identified as priority sites to study for JHTMON-6 (Section 7.2.1). Conducting a PIT tagging study would extend the scope of the biological monitoring that was originally developed for this project, which involved collecting biological data using only bank walks and snorkel surveys (BC Hydro 2013). These methods provide only a 'snapshot' of fish distribution and cannot provide precise information about the flows at which fish migrate upstream past a potential barrier, which is necessary to comprehensively address Management Question 3 (Section 1.2). By contrast, data collected using PIT tagging methods can be used to identify the precise time at which a fish migrates past an array site (including nighttime), which can then be related to near-continuous flow records collected at WSC gauges (Map 2). In addition, the priority sites are located at bedrock shelves that were the focus of a project in 2015 to improve fish passage for Coho Salmon and steelhead, funded by the CRSF (Section 3.2.4). In addition to improving the design of JHTMON-6, the CRSF has confirmed that fish passage monitoring at these sites would also support their objectives to evaluate the performance of the fish passage improvements. Following discussion with BC Hydro, we are currently examining the feasibility of obtaining financial support from the CRSF for the additional cost of the proposed PIT tagging study.

On the Salmon River, we propose to deploy a high resolution video camera to passively monitor fish passage throughout the fall sampling periods. A video camera will be deployed to monitor adult salmon migration only. Video cameras will not be used to monitor adult steelhead migration because low fish abundance and, potentially, poor viewing conditions (e.g., due to low light conditions in winter) are expected to limit the utility of this technique. Instead, video footage of Coho Salmon passage during the fall will be used to aid evaluation of steelhead passage success, based on the knowledge that steelhead swimming capabilities are generally superior to those of Coho Salmon (Table 15; Reiser *et al.* 2006). As with the proposed PIT tagging study on the Quinsam River, deploying video cameras will allow us to precisely identify the discharge at which fish migrate upstream of a potential barrier. Our decision to use video camera technology to support data collection reflects that this is an established method for monitoring adult salmonid migration (Hatch *et al.*, 1994), and that Ecofish has experience with using such technology to monitor salmon populations in other watersheds (e.g., Lewis *et al.* 2016). Based on our experience elsewhere, we have assumed that the quality of video camera footage will be sufficient to identify a fish migrating upstream through riffle habitat. We will validate this assumption during Year 2 by reviewing footage collected in the initial stages of data collection. Relative to tagging methods, we recognize that there is likely to be higher uncertainty associated with the use of video cameras to determine whether a fish has migrated past a barrier under some circumstances, e.g., during low light conditions. For the Salmon River, we selected the use of video camera technology over tagging methods because tagging methods are more expensive to deploy and there is not the same opportunity to collaborate with other parties to conduct a tagging study as there is for the Quinsam River. However, we anticipate that deploying a video camera will allow us to identify the specific flow conditions at which fish migrate past a partial barrier much more precisely than by only making inferences based on snorkel surveys and/or bank walks.

Snorkel surveys will be undertaken on both rivers during low flow conditions, although the specific conditions that are sampled will be constrained by the conditions occurring during migration periods. Surveys will provide information on the spatial distribution of fish upstream and downstream of the potential barriers during peak migration times. The aims of the surveys are to: 1) confirm presence/absence of target species; 2) identify any instances of fish holding immediately downstream of potential barriers, indicating potential fish passage issues, and; 3) identify fish present upstream of potential barriers, which will provide information about the ease of fish passage past the downstream barrier. Snorkel survey results will be used to augment and validate the results of the other monitoring activities. We have designed the data collection to maximize opportunities to combine tasks for the separate monitoring activities into individual field trips.

We recognize that our proposed field work for both rivers differs from the JHTMON-6 Terms of Reference (TOR), which recommend conducting a minimum of 14 survey days per diversion stream per season to directly visually monitor passage events during fluctuating flows (BC Hydro 2013). We believe that our proposed methods are preferable to that study design because our ability to address the relevant management question (i.e., at what range of flows do migrating fish successfully navigate site-specific barriers?) will be less-constrained by the specific flow conditions that are encountered during biological surveys. Specifically, this is because: 1) we propose to conduct physical monitoring during the low flow period (July–early September; Figure 2; Figure 6) when the probability of encountering target low flow conditions is greater than during the peak migration periods; 2) we propose to use passive biological sampling techniques (PIT tagging or a video camera) to collect data for the duration of the peak migration periods, thus allowing us to sample a much greater range of flow conditions than relying only on periodic site visits. Despite these relative advantages of our proposed methods, we nonetheless recognize that the study is reliant on natural variability in flow conditions to provide a range of test flows

## 7.2. Quinsam River

### 7.2.1. Overview

Based on the results of the reconnaissance site visits (Appendix A), we selected three sites for detailed biological and physical monitoring on the Quinsam River. These sites are: QUN-BAR1, QUN-BAR5 and QUN-BAR7 (Map 4). All three sites are bedrock chutes located within a ~1 km section downstream of Lower Quinsam Lake, approximately 24 km upstream of the mouth. During the reconnaissance site visits (Appendix A), potential barriers at these sites were evaluated as being the most significant of those that we visited. We consider that three sites is the maximum number that can be monitored in detail with the resources available.

Details of proposed assessment methods are summarized in Table 17. We propose to conduct detailed monitoring at these sites during Year 2 and Year 3.

### 7.2.2. Physical Monitoring

A wildlife camera will be deployed at each of the three sites during Year 2 to provide visual records of habitat conditions at low flow periods. Cameras will be deployed during August and retrieved in October during the snorkel surveys. Standard remote wildlife cameras will be deployed (e.g., Reconyx brand) and programed to record a still image at regular intervals (e.g., daily). These photos can then be related to flow records to aid understanding of how habitat conditions (e.g., wetted width, water depth) vary with discharge at individual barriers.

In addition, we will collect measurements of physical variables using field-based barrier survey methods described in Section 5.1.1, based on Reiser *et al.* (2006). Sampling will be undertaken in

Year 3 during low flow conditions in July through September. Sampling will be undertaken at a single barrier during a single flow condition. Sampling location (barrier) and target flow will be confirmed following analysis of physical and biological data collected during Year 2; however, it is likely that sampling will occur at QUN-BAR5 because this was ranked as the most significant barrier during the reconnaissance site visits (Table 17). The three priority barriers are all located within a ~1 km section (Inset 2, Map 4) and, therefore, passage through this section and into Lower Quinsam Lake is ultimately limited by conditions at the barrier that impedes passage the most. Physical conditions at the other two sites will be inferred based on measurements at the sampled barrier, and estimated based on analysis of images from wildlife cameras. The WSC hydrometric gauge downstream of Lower Quinsam Lake (08HD027; Map 2) will be monitored to assist with scheduling site visits. This gauge is ~1 km downstream of the sites and there are no permanent tributary inflows between the sites and this gauge. We therefore propose to use measurements collected at this gauge to estimate discharge at each site. We do not plan to measure discharge at individual sites, and the complex channel morphology at the sites is not suited to such measurements. We do not plan to install water level loggers on the Quinsam River as barriers are expected to comprise velocity or leap barriers, as opposed to minimum depth barriers that are the focus of fieldwork on the Salmon River. The requirement for monitoring stage will be reviewed at the end of Year 2.

#### 7.2.3. Biological Monitoring

##### 7.2.3.1. PIT Tagging

A total of ~250 PIT tags per year will be inserted in adult Coho Salmon and steelhead captured at or downstream of the Quinsam River Hatchery (Map 2) in Year 2 and 3. PIT tag antenna arrays will be installed to monitor subsequent upstream migration of fish in the vicinity of the priority barriers.

Prior to tagging each year, three PIT tag antenna arrays will be installed in late September to monitor the passage of tagged fish at the priority barriers (see Inset 2 on Map 4). One array will be installed a short distance (< 150 m) downstream of QUN-BAR7 (the most downstream of the three priority barriers); a second array will be installed between QUN-BAR5 and QUN-BAR4, and; a third array will be installed at the outlet of Lower Quinsam Lake, immediately upstream of QUN-BAR1US. The arrays will remain in place each year until the end of February to capture the duration of the Coho Salmon adult migration period and the majority of the steelhead adult migration period (Table 1).

Adult Coho Salmon will be captured at the Quinsam Hatchery during the start of the Coho Salmon migration period in late September and October (Table 1). A target of ~230 Coho Salmon will be implanted with PIT tags. Fish in pre-spawn condition will be selected to provide a sample that is representative of the size of fish present. The following information will be recorded for each tagged fish: PIT tag number, fork length, sex and condition. Tagged fish will be released at the point of capture.

Adult steelhead will be captured in December or January during annual coastal Cutthroat Trout brood stock capture work undertaken in the lower Campbell River by Quinsam River Hatchery staff. A target of ~20 fish will be caught by angling. Information will be recorded as for Coho Salmon and tagged fish released at the point of capture.

In addition to PIT tags, all fish will be tagged with a spaghetti tag, consisting of a loop of coloured vinyl tubing attached to the body of the fish. This will allow PIT-tagged fish (including carcasses) to be visually identified during snorkel surveys to provide additional information about the distribution of tagged fish. It will also help 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), e.g., observations of tagged fish returning downstream.

##### 7.2.3.2. Snorkel Surveys

We propose to undertake snorkel surveys in the fall (October 1 to November 7) to evaluate adult Chinook Salmon and Coho Salmon passage and during the winter (December through February) to evaluate adult steelhead passage. Snorkel surveys will be combined with work to maintain the PIT tag antenna arrays (Section 7.2.3.1). We have budgeted a total of ten days per year for Year 2 and 3 to conduct snorkel surveys and maintain the arrays; therefore, we expect to conduct snorkel surveys on a maximum of eight days as a day will be required each for installing and removing the arrays. Snorkel surveys will predominantly be undertaken in the fall to monitor adult salmon passage. We anticipate that low fish density and, potentially, high flows in winter may limit the value of using snorkel surveys to evaluate adult steelhead passage. Accordingly, steelhead snorkel surveys will only be undertaken opportunistically while maintaining PIT tag antenna arrays to maximise efficient use of resources.

Snorkel surveys will be undertaken by a crew of two experienced fisheries technicians. Snorkel surveys will start at Lower Quinsam Lake and proceed downstream for ~1.3 km to downstream of QUI-BAR07 (see Inset 2 in Map 4). As such, the surveys will also provide information about the other barriers in this section. Details of all fish observations will be recorded, including carcasses. This will include: species, location (based on GPS), size class and condition (e.g., bright, moderately-coloured, coloured, post-spawn).

## 7.3. Salmon River

### 7.3.1. Overview

Based on the results of the reconnaissance site visits (Appendix B), we selected three sites for detailed biological and physical monitoring on the Salmon River. These sites are: SAM-BAR5, SAM-BAR7 and SAM-BAR11 (Map 4). Site SAM-BAR5 consists of riffles, approximately 2 km downstream of the Paterson Creek confluence. Of the sites that were visited, this site was assessed to pose the greatest potential barrier to migration. Sites SAM-BAR7 and SAM-BAR11 are riffles further downstream in the vicinity of the Memekay River confluence.

Details of proposed assessment methods are summarized in Table 17. We propose to conduct detailed monitoring at these sites during Year 2 and Year 3.

### 7.3.2. Physical Monitoring

We will collect measurements of physical variables using the Critical Riffle Analysis method described in Section 5.2.1, based on CDFG (2012). Sampling will be undertaken in Year 2 and 3 during low flow conditions in July through September. Two flow conditions will be sampled in Year 2 and one flow condition sampled in Year 3. The following three flow conditions will be targeted: 1.5 $m^3/s$, 2.0 $m^3/s$ and 4.0 $m^3/s$ although the actual flows sampled will depend on the hydrologic characteristics of the study period. The WSC hydrometric gauge on the river mainstem downstream of the diversion dam (08HD032; Map 3) will be used to estimate discharge at SAM-BAR5, while the WSC hydrometric gauge on the river mainstem downstream of Kay Creek (08HD007; Map 3) will be used to estimate discharge at SAM-BAR7 and SAM-BAR11. We will deploy sensors to near-continuously monitor stage at each site, consistent with the methods outlined in Section 5.2.1. We do not propose to measure discharge directly at each site and we note that error associated with any such measurements would be high due to the shallow water depth and uneven bed morphology that characterize riffle habitats.

In addition, a wildlife camera will be deployed at each of the three sites during Year 2 to provide visual records of habitat conditions at low flow period. Cameras will be deployed during the initial site visit and retrieved in late October during the snorkel surveys (see below). Standard remote wildlife cameras will be deployed (e.g., Reconyx brand) and programed to record a still image at regular intervals (e.g., daily). These photos can then be related to flow records to aid understanding of how habitat conditions (e.g., wetted width, water depth) vary with discharge at individual barriers.

### 7.3.3. Biological Monitoring

#### 7.3.3.1. Video Camera Deployment

A high resolution video camera will be deployed at a single barrier to evaluate adult salmon passage during low flow conditions in the fall (October 1 to October 31) during both Year 2 and 3. The primary objective is to monitor Coho Salmon passage. We anticipate that the video camera will be deployed at SAM-BAR05 (Map 5), which is ranked as the highest priority barrier based on its potential to pose passage issues (Table 17). The location will be reviewed following Year 2 monitoring to confirm whether it is desirable to continue monitoring at this site in Year 3, or whether a separate site should be monitored.

The video camera will be fitted with a polarized filter (to reduce glare) and deployed on the river bank, directed downwards towards the river surface. The aim of the deployment is to identify any adult salmon that migrate upstream through riffle habitat. The camera will be deployed during the first snorkel survey and retrieved following the final survey in the fall. We propose to undertake the main analysis of video footage following Year 3 (see Section **Error! Reference source not found.** elow); however, it will be necessary to review a sample of footage during Year 2 monitoring to check that the quality is sufficient and to confirm whether the camera angle and recording settings are optimized. Based on our experience in other watersheds (Lewis *et al*. 2016), we assume that it will be possible to identify individual fish migrating upstream through a riffle, although this assumption will be verified in Year 2.

7.3.3.2. Snorkel Surveys

We propose to collect biological data on fish passage by undertaking snorkel surveys during key migration times during both Year 2 and 3. We propose to undertake two snorkel surveys in the fall (October 1 to October 31) to evaluate adult Coho Salmon passage. Based on fish distributions presented in Burt (2003; Map 5), the upstream limit of Chinook Salmon distribution is expected to be downstream of the study sites; however, the biological monitoring will provide an opportunity to verify this. To survey SAM-BAR5, we propose to undertake snorkel surveys from ~200 m upstream to ~200 m downstream of the potential barrier (Map 4). To survey SAM-BAR7 and SAM-BAR11, we propose to survey the reach from upstream of SAM-BAR11 to downstream of SAM-BAR7 (~3.1 km; Map 4).

We also propose to undertake one snorkel survey at each barrier during late winter/early spring (March 01 to April 15) to evaluate adult steelhead passage. The steelhead survey will be undertaken as part of work planned for JHTMON-8. This surveys will therefore include the whole Lower Index survey reach (11.5 km; see Section 3.3.2), and may therefore provide biological information about additional barriers.

Snorkel survey methods and data collection will be consistent with the descriptions above for the Quinsam River (Section 7.2.3.1).

## 7.4. Fieldwork Summary Table

**Table 17. Summary of JHTMON-6 fieldwork plan. Barrier locations are shown on Map 4 and Map 5.**

| River | Habitat | Target Species | Flow Range | Year | Rank | Barrier | Physical Monitoring (Y2 and Y3) | | | Biological Monitoring | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Method | Timing | Duration | Method | Timing | Duration and Frequency |
| **Quinsam** | Bedrock chutes | Steelhead, Coho Salmon, Chinook Salmon | 1 - 5 m$^3$/s | **Year 2** | Q1 | QUI-BAR05 | Standard field-based methods; deploy remote camera at each barrier. | Deploy wildlife cameras at each barrier. | Camera deployment: August–October | Deploy PIT tags ($n$=250) to monitor adult Coho Salmon ($n$~230) and steelhead ($n$~20). Monitor passage using three antenna arrays in vicinity of barriers.<br>Snorkel surveys from approximately 500 m upstream of QUI-BAR01 to pool below QHI-BAR07 (~1.8 km). Surveys will encompass all potential barriers and be conducted in both years. | PIT tagging<br>Coho Salmon: Late September–October<br>Steelhead: December–January<br>Arrays deployed: Late September–February<br><br>Snorkel surveys<br>Coho and Chinook salmon: October 1 to November 7.<br>Steelhead: Jan 15 to February 31. | A total of ten days/year will be spent on installing/maintaining PIT tag antenna arrays and undertaking snorkel surveys during fall and winter. |
| | | | | | Q2 | QUI-BAR07 | | | | | | |
| | | | | | Q3 | QUI-BAR01 | | | | | | |
| | | | | **Year 3** | Q1 | QUI-BAR05 | | Collect detailed physical measurements at 1 site during 1 flow condition. Survey location/timing to be confirmed based on Year 2 results. Deploy wildlife cameras at each barrier. | 1 site visit during low flow period (July–September). Camera deployment: August–October. | | | |
| | | | | | Q2 | QUI-BAR07 | | | | | | |
| | | | | | Q3 | QUI-BAR01 | | | | | | |
| **Salmon** | Riffle | Steelhead, Coho Salmon, Chinook Salmon | 1 - 4 m$^3$/s | **Year 2** | S1 | SAM-BAR05 | Critical Riffle Analysis; deploy water level logger and remote camera at each barrier. | Conduct 2 surveys at separate flows. Target flows for study: 1.5 m$^3$/s, 2.0 m$^3$/s and 4.0 m$^3$/s. | 2 site visits during low flow period (July–September) | Snorkel Survey conducted 1 km above and 1 km below barrier.<br>A video camera will be installed to monitor a single barrier during the fall - this is anticipated to be SAM-BAR05 | Video camera<br>October<br><br>Snorkel surveys<br>Coho Salmon: Oct 1 to Oct 31.Steelhead: March 15 to April 15. | **Fall:** Two surveys will be conducted during Coho Salmon migration. The first survey will be late September/early October and the second survey will be late October. One video camera will be deployed for the duration of the period between the first and second survey.<br><br>**Late winter/early spring:** Steelhead survey conducted as part of JHTMON-8. |
| | | | | | S2 | SAM-BAR11 | | | | Snorkel Survey from Kay Creek to Memekey Confluence (includes SAM-BAR11 and SAM-BAR07) | | |
| | | | | | S3 | SAM-BAR07 | | | | Snorkel Survey from Kay Creek to Memekey Confluence (includes SAM-BAR11 and SAM-BAR07) | | |
| | | | | **Year 3** | S1 | SAM-BAR05 | | Conduct 1 survey at outstanding target flow. | 1 site visit during low flow period (July–September) | As Year 2 | | |
| | | | | | S2 | SAM-BAR11 | | | | As Year 2 | | |
| | | | | | S3 | SAM-BAR07 | | | | As Year 2 | | |

# 8. RECOMMENDED APPROACH – DATA ANALYSIS AND REPORTING

## 8.1. Data Management

All data will be entered, quality assured and managed through a secure database. Data will be available for export in any format necessary to support the data analysis, or requested by BC Hydro.

## 8.2. Analysis of Physical Data

Analysis of physical monitoring data will commence at the end of Year 2. The analysis will first involve compiling discharge data measured at the WSC hydrometric gauges identified in Section **Error! Reference source not found.** to derive time series of discharge at each site for the onitoring periods. Photographs collected remotely at each site will be collated into a sequence of increasing discharge (in Graphics Interchangeable Format) to evaluate the hydraulic conditions at each site relative to prevailing discharge. For the Salmon River sites, stage data collected at each site using loggers will be validated using direct measurements collected during field visits. Relationships will then be derived between stage data collected at each site and discharge estimated for each site based on measurements at the WSC gauges. This will allow minimum discharge criteria to be defined that correspond to species-specific minimum depth criteria (Table 16). Relationships between discharge and minimum water depth will be extrapolated across each transect based on bed profile survey data. Initial data analysis at the end of Year 2 will be used to confirm which flow condition should be targeted on each river during physical monitoring field surveys in Year 3.

At the end of Year 3, measured values of physical parameters appropriate to each barrier type will be compared with ranges identified in literature (Table 15, Table 16) to determine whether each barrier is expected to be passable for individual priority species at the flow conditions that were sampled. For the Salmon River, the expected outcomes of the physical monitoring will be identification of the minimum discharge at which individual barriers are expected to be passable for priority species, based on fish passage criteria defined in the literature. For the Quinsam River, detailed physical information obtained at one site during fieldwork in Year 3 will provide evidence to support wider assessment of fish passage criteria, based on consideration of biological data.

## 8.3. Analysis of Biological Data

Biological monitoring data will be collated and reviewed at the end of Year 2, with the main analysis undertaken at the end of Year 3. Following Year 2, snorkel survey results will be summarized using appropriate tables and figures. To provide context, the timing of snorkel surveys, PIT tag antenna array deployment and video camera monitoring will be plotted on a hydrograph that spans the adult upstream migration periods for priority species. PIT tag data will be reviewed to evaluate whether arrays on the Quinsam River should be repositioned in Year 3. Samples of video footage from the Salmon River will be reviewed during and after the Year 2 camera deployment to confirm the assumption that fish can be observed migrating through a riffle and whether camera settings (e.g., viewing angle, magnification) are optimal for observing fish passage. Based on Year 2 results, a decision will be made regarding whether to monitor the same barrier with the video camera in Year 3, or whether to relocate the camera to monitor alternative sites. A potential reason for relocating the cameras could be the failure to observe passage of any fish, indicating that fish were completely impeded by a barrier further downstream.

Following Year 3, all snorkel survey results will be compiled and the main analysis of PIT tag data and video footage will be undertaken. Critical flow periods to analyze will be selected by reviewing the discharge records for PIT tag antenna array and camera deployment periods. Periods will be selected that correspond to those sampled during physical monitoring so that predictions from analysis of physical data can be validated. Additional periods may then be selected that correspond to flows outside of the target ranges to further explore the flow–passage success relationship for each barrier. Analysis of Year 2 data will be undertaken in combination with Year 3 data at the end of the monitor to ensure that the analysis of PIT tag data and video footage is undertaken as efficiently as possible; i.e., the flows monitored during Year 3 will influence which periods in Year 2 will be analyzed. Data collected at PIT tag antenna arrays will be analyzed to determine the proportion (%) of tagged fish that migrated past each array, while both video footage and PIT tag data will be analyzed to determine the specific flow conditions at which fish passage was recorded. Analysis will include examining whether passage is influenced by factors such as: species; fork length; time of day; sex; whether stage is increasing or receding, and; air/water temperature (based on data collected at mainstem sites on each stream during JHTMON-8).

Video analysis will require a technician to review footage for critical flow periods and record all fish observations. At this stage, we estimate that it will be necessary to review six hours of footage per day from a total period of 2–3 weeks. To maximize efficiency, video footage will be reviewed at enhanced playback speed and we estimate that 2 × playback speed will provide an optimal balance between efficiency and ensuing that individual fish can be clearly detected. We expect that it will not be possible to use motion capture software to assist with reviewing video footage because the camera will monitor the full stream width and therefore a moving fish will comprise only a small proportion of the image.

### 8.4. Synthesizing Results to Address the Management Question

The analysis of physical and biological data described above will provide separate lines of evidence regarding fish passage criteria. Any discrepancies between the physical and biological monitoring results will be reviewed by experienced fish biologists to ultimately define flow passage criteria for each site. For the Salmon River, we expect the criteria to either comprise minimum discharge thresholds above which riffles are passable, or confirmation that the potential barriers are passable at the minimum flow conditions sampled (target = 1.5 $m^3/s$). For the Quinsam River, flow passage criteria may comprise both lower and upper discharge thresholds that respectively reflect the minimum discharge at which the depth of water on bedrock shelves is sufficiently deep, and the discharge above which high water velocity at chutes prohibits passage. We anticipate that the flow criteria will be defined with greater precision for the Salmon River barriers because fewer hydraulic variables need to be considered (primarily minimum depth) and the deployment of water level loggers will allow minimum depth to be estimated with precision across a wide range of flows. Separate criteria will be developed for each target species (Table 17). This analysis will test $H_0 4$ (Section 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.*

The next step will be to compare the species- and stream-specific passage flow criteria with series of discharge for the following records:

- the periods of record prior to water diversion;
- periods following implementation of WUP operations; and
- discharge records for periods following water diversion that are predicted had the diversion dams not been constructed.

This analysis will quantify the frequency that passage flow criteria occurred under historical (pre-dam) conditions and how this may have changed following dam construction, with and without WUP implementation. Assessment of additional flow alternatives will be possible using these data and the analysis approach. This analysis will be used to test $H_0 5$ (Section 1.1):

*$H_0 5$: 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*

Finally, the passage criteria will be compared with MAD of respective streams and presented as a proportion of MAD. These can then be compared to BC Ministry of Environment standards and policies regarding environmental flow needs.

### 8.5. Reporting

Individual reports will be prepared for the fish passage component of JHTMON-6 that are separate from the other components of the monitor. A Year 2 annual data report will summarize the methods of work completed in Year 2 and the results of physical monitoring, PIT tag monitoring and snorkel surveys. This will include a recommendation of whether any changes will be made to PIT tag antenna array or video camera deployment, e.g., deployment locations. Any additional data needs will be detailed, including any additional flow requests to BC Hydro.

The Year 3 final report will be prepared that:

1) re-iterates the objective and scope of the study;
2) presents the methods of data collection and analysis;
3) describes the compiled data set and presents the results of all analyses;
4) presents the results of all hypothesis tests;

5) addresses Management Question 3 (Section 1.1) based on the results observed; and
6) discusses how these results relate to current BC Hydro operations, and the necessity and/or possibility for future change.

Each of these reports will be submitted in the spring of the year following the data collection periods.

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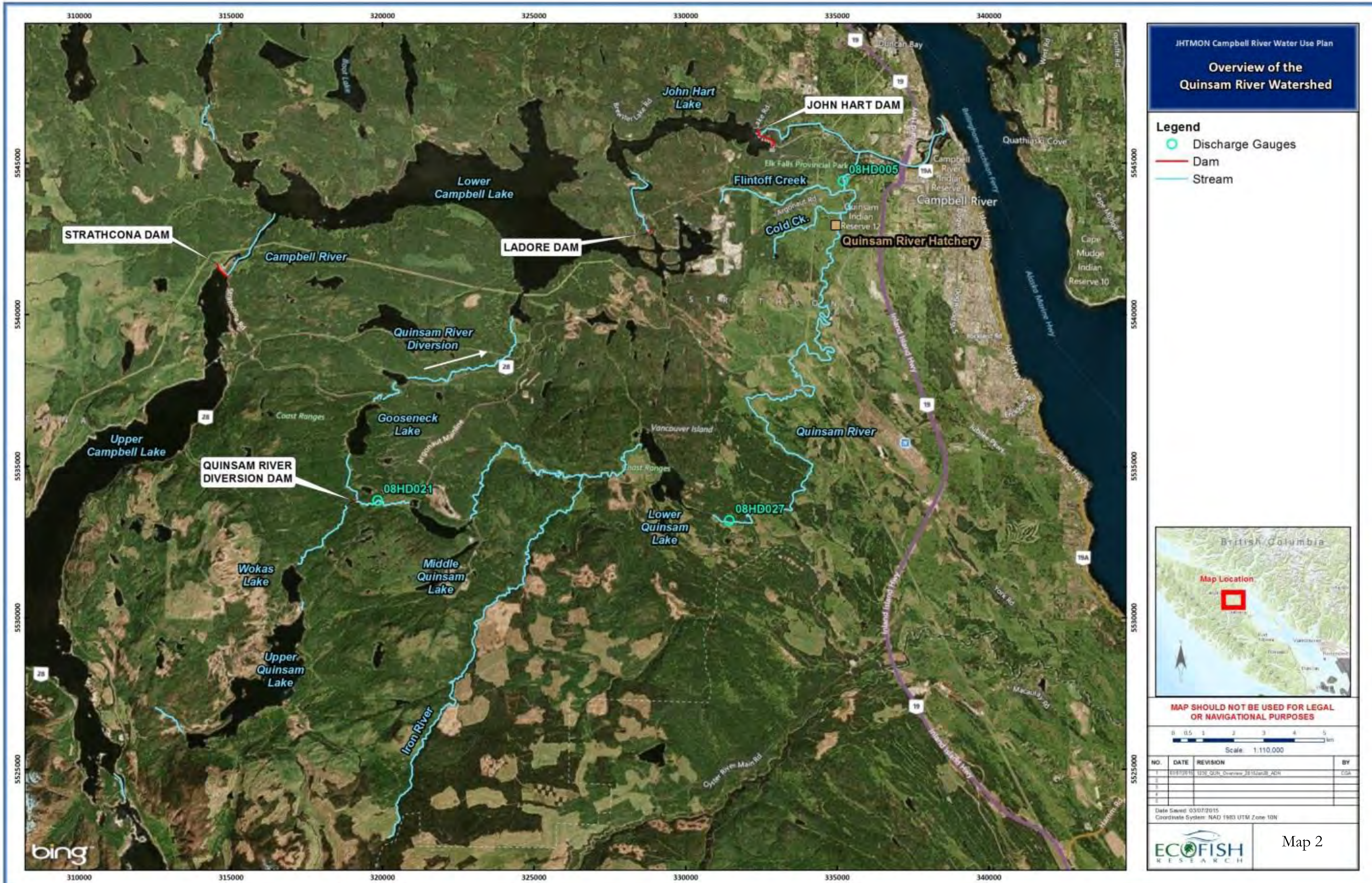
## PROJECT MAPS

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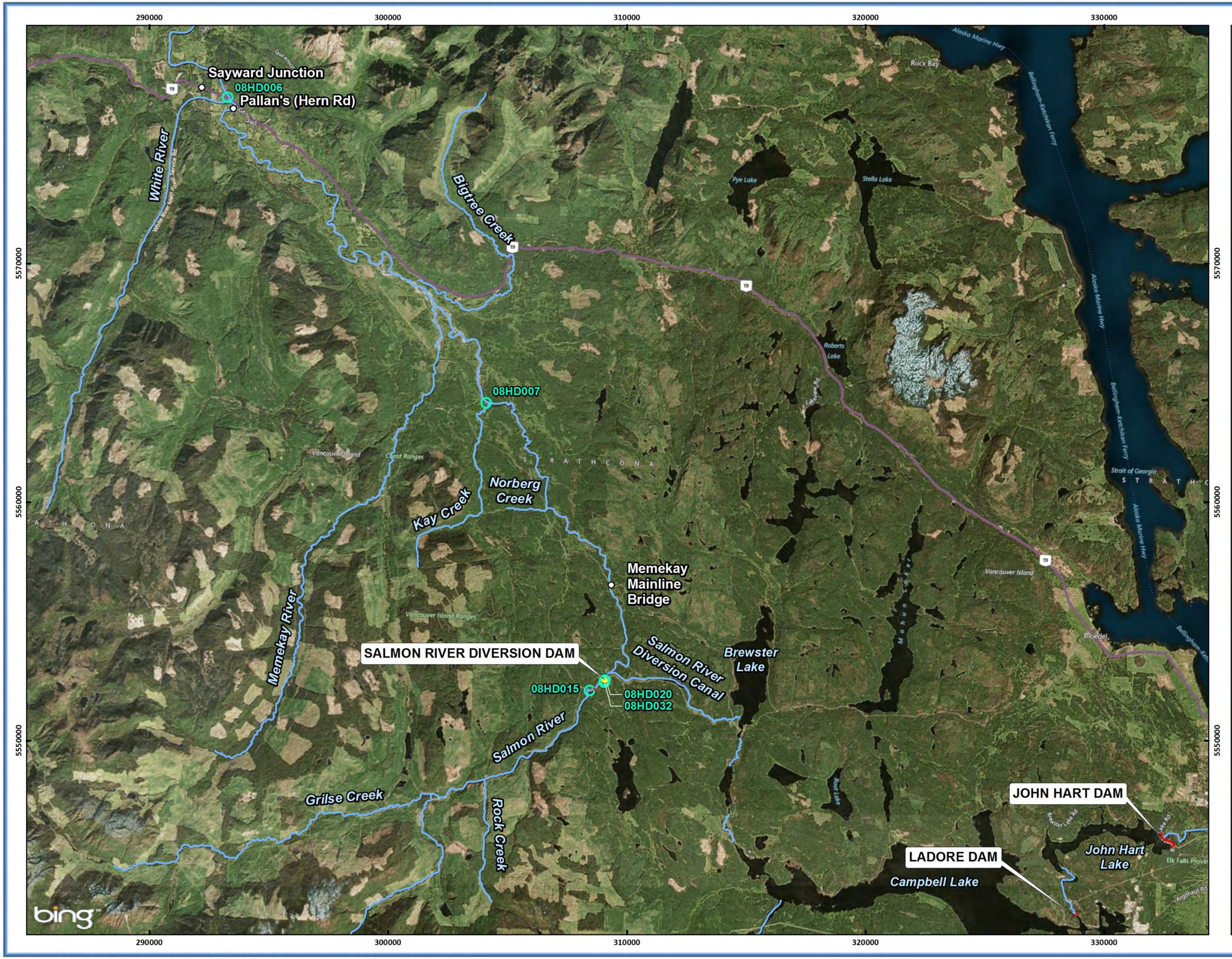


# JHTMON Campbell River Water Use Plan

## Overview of the Salmon River Watershed

**Legend**

- Discharge Gauges
- Salmon River Diversion Intake


**MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES**

0 0.5 1 2 3 4 5 km

Scale: 1:150,000

| NO. | DATE | REVISION | BY |
|---|---|---|---|
| 1 | 07/03/2016 | 1230_JHT_SalmonRiverOverview_2015Feb24_ADN | CGA |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

Date Saved: 07/03/2016
Coordinate System: NAD 1983 UTM Zone 10N

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Map 3

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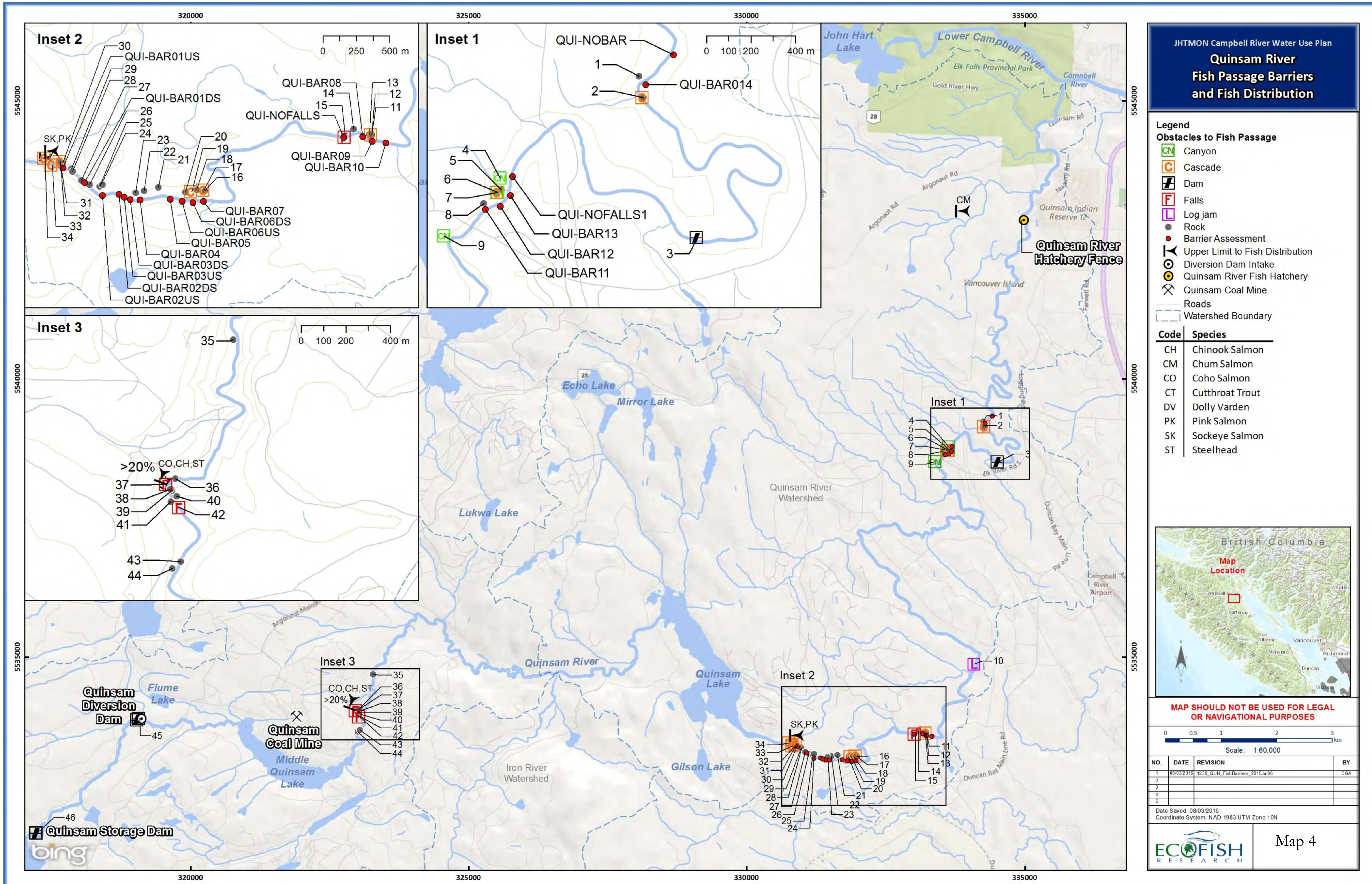


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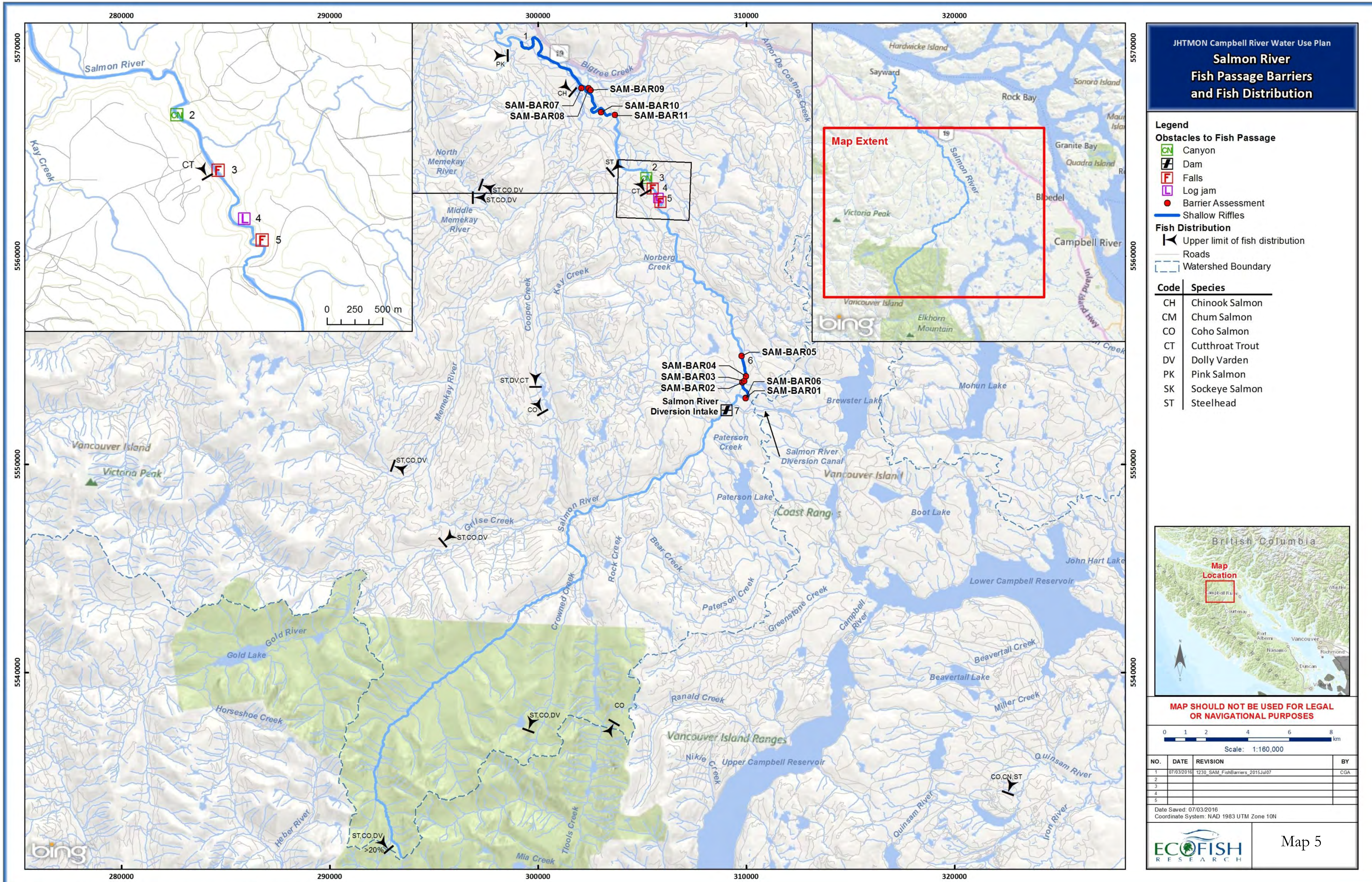


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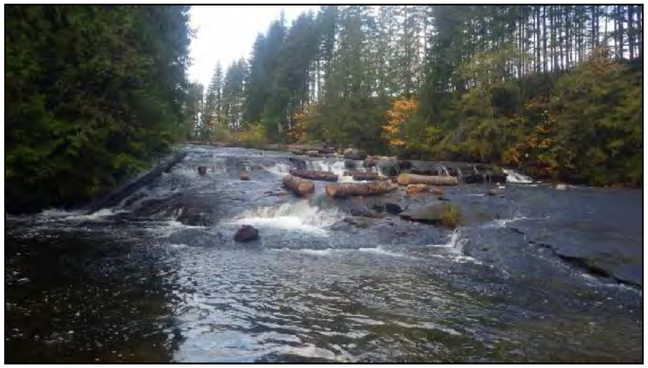
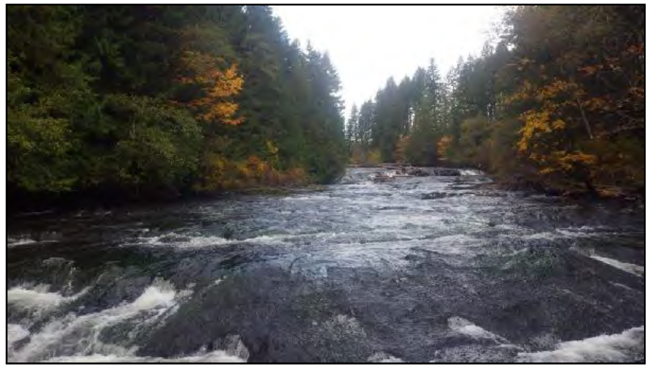
# APPENDICES

# Appendix A. Quisam River Preliminary Barrier Assessment Summaries


Looking upstream at a section retrofitted with logs


Looking downstream from the upstream end of the site.


Looking upstream from the downstream end of the site.

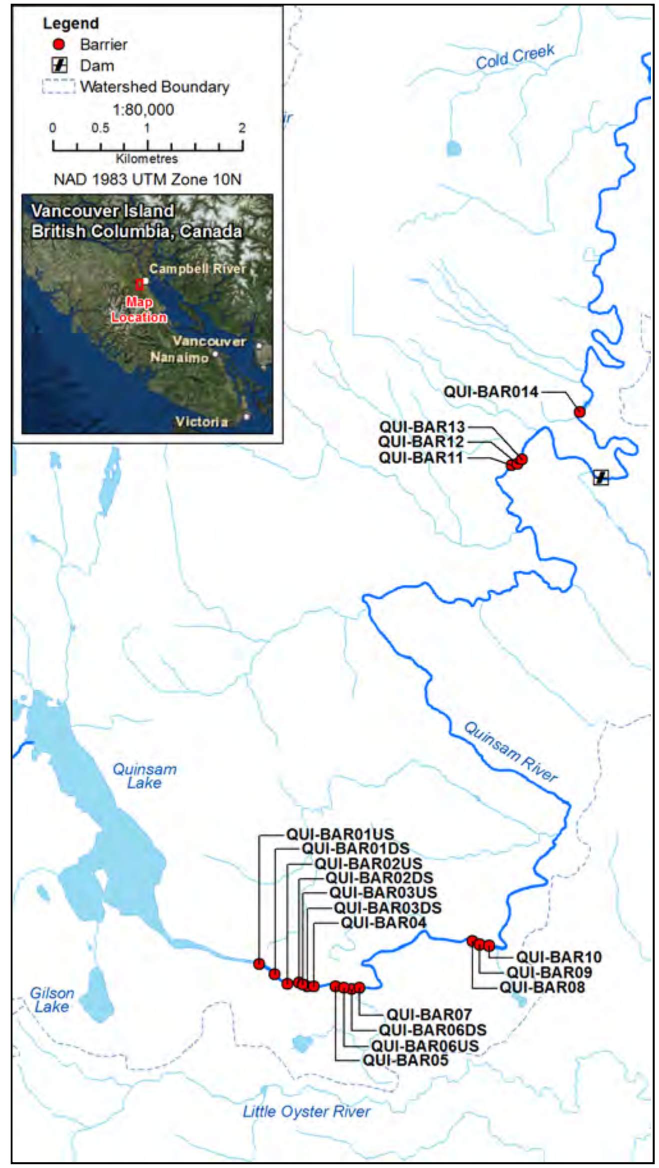

Looking upstream at the center of the site.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR01 (DS - US) |
| River: | Quinsam River |
| River Kilometer: | 27.12 km |
| Barrier Type: | Chute, Falls |
| Passable: | Low |

**Comments**

- Uppermost barrier downstream of Quinsam Lake.
- The barrier has been modified with rock cuts to deepen channels, and LWD to constrict flow.
- The total length is approximately 100 m with a series of cascades over bedrock.
- Passability was ranked low.

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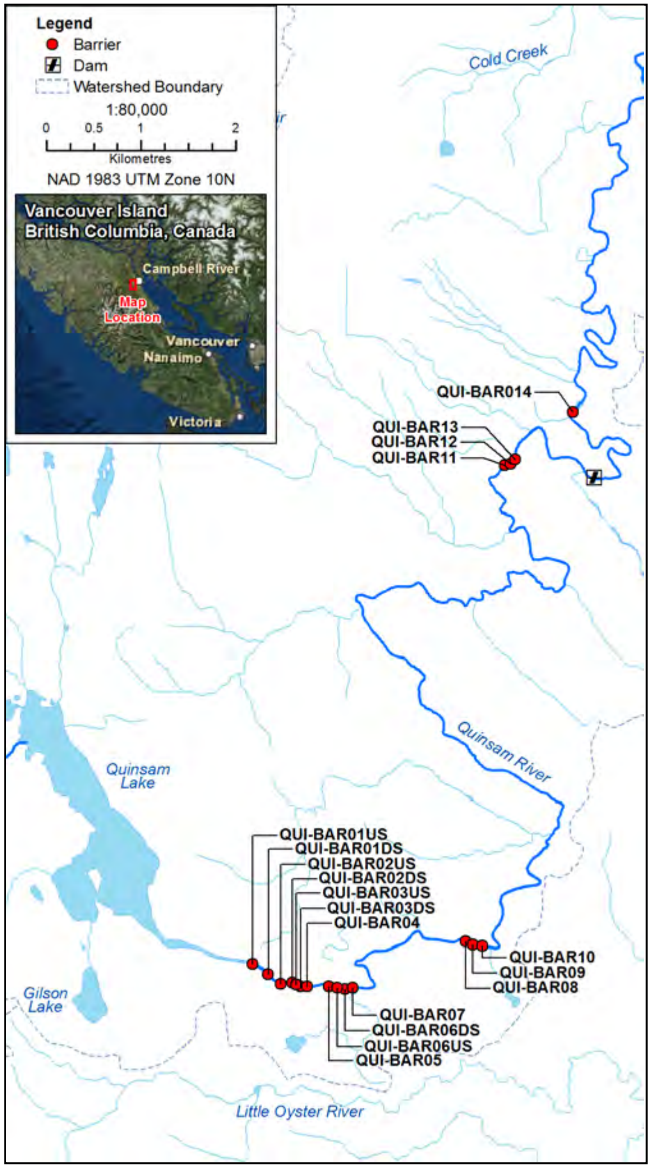
**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking upstream from downstream end of site.

Looking upstream from middle of site.





**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR02 (DS - US) |
| River: | Quinsam River |
| River Kilometer: | 26.82 km |
| Barrier Type: | Chute |
| Passable: | Low |

**Comments**

- Second barrier downstream of Quinsam Lake.
- There is a wide shallow bedrock sill near the downstream end of the barrier that would likely block passage for most species during low flows.
- At higher flows it might become more passable.
- Overall passability was ranked low.

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**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

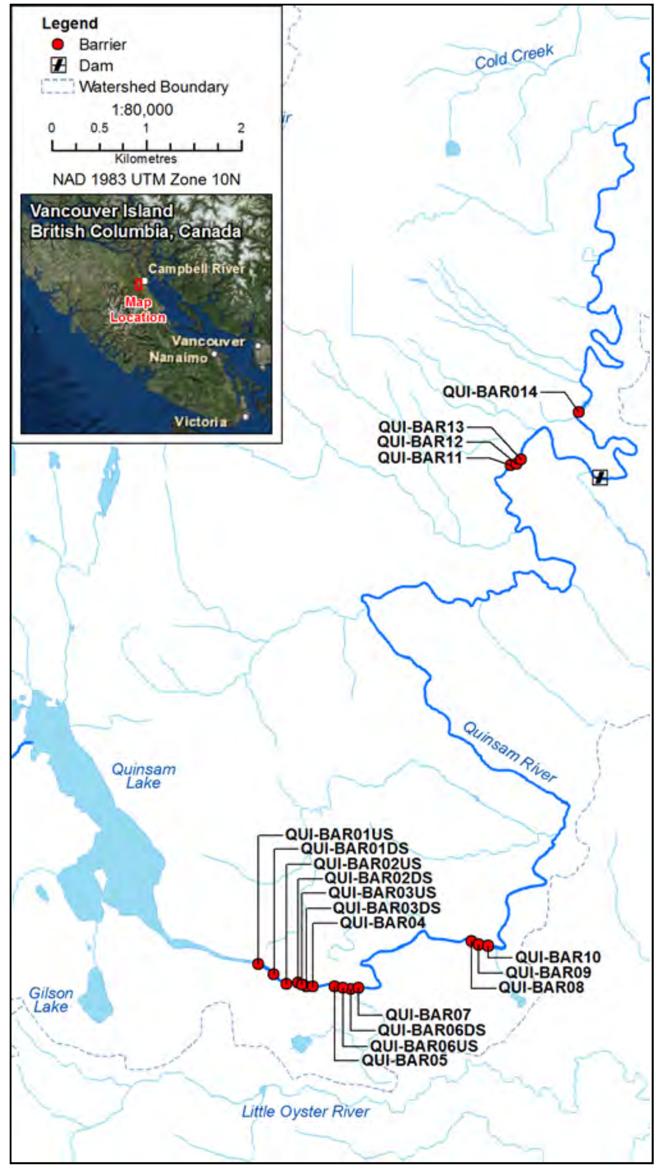
**Crew:** BAM, HMW, SPP

Looking Upstream - River Left focus.

Looking Upstream - River Right focus.

Looking River Right - River Left

Looking upstream at the full barrier.




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR03 (DS - US) |
| River: | Quinsam River |
| River Kilometer: | 26.73 km |
| Barrier Type: | Chute |
| Passable: | Low |

**Comments**

- Third barrier downstream of Quinsam Lake.
- Perhaps slightly more passable than QUI-BAR02, but still ranked low.
- Fish would likely pass up through the left channel.

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BChydro

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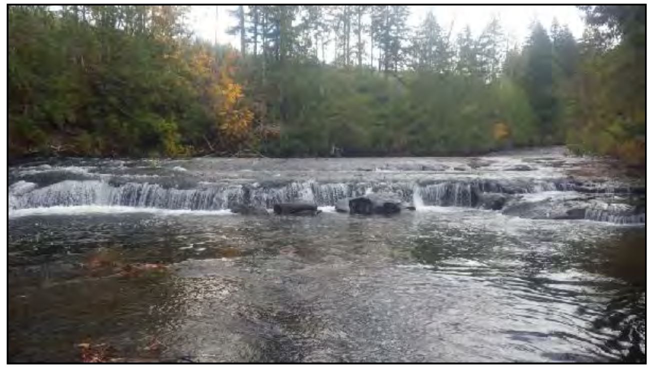
**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**

**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking River Right to River Left.



Looking Upstream

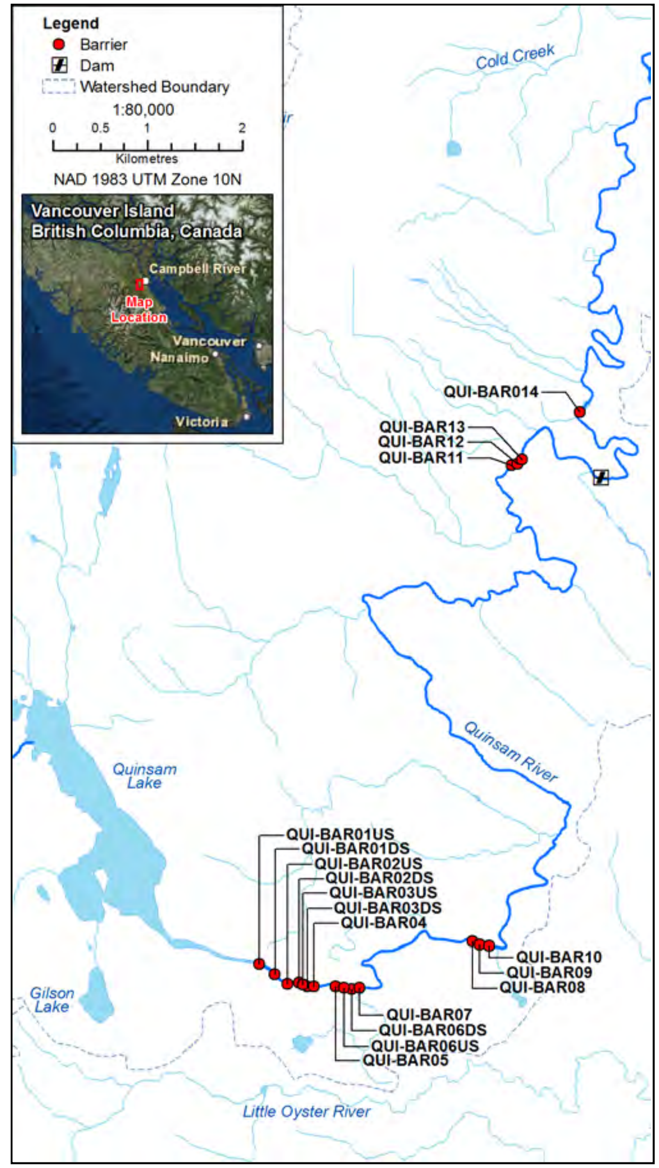
Looking River Left to River Right.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR04 |
| River: | Quinsam River |
| River Kilometer: | 26.65 km |
| Barrier Type: | Chute, Falls |
| Passable: | Low |

**Comments**

- Small falls/chute over wide bedrock sill.
- May be a barrier to Pink Salmon at a wide range of flows.
- Likely passable for Coho and Steelhead at higher flows.
- Passability was ranked low.





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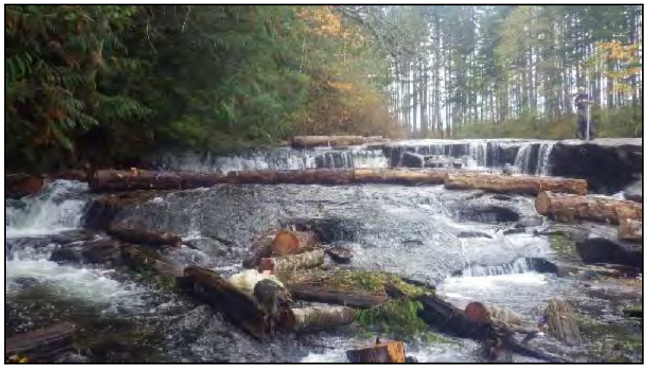
**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

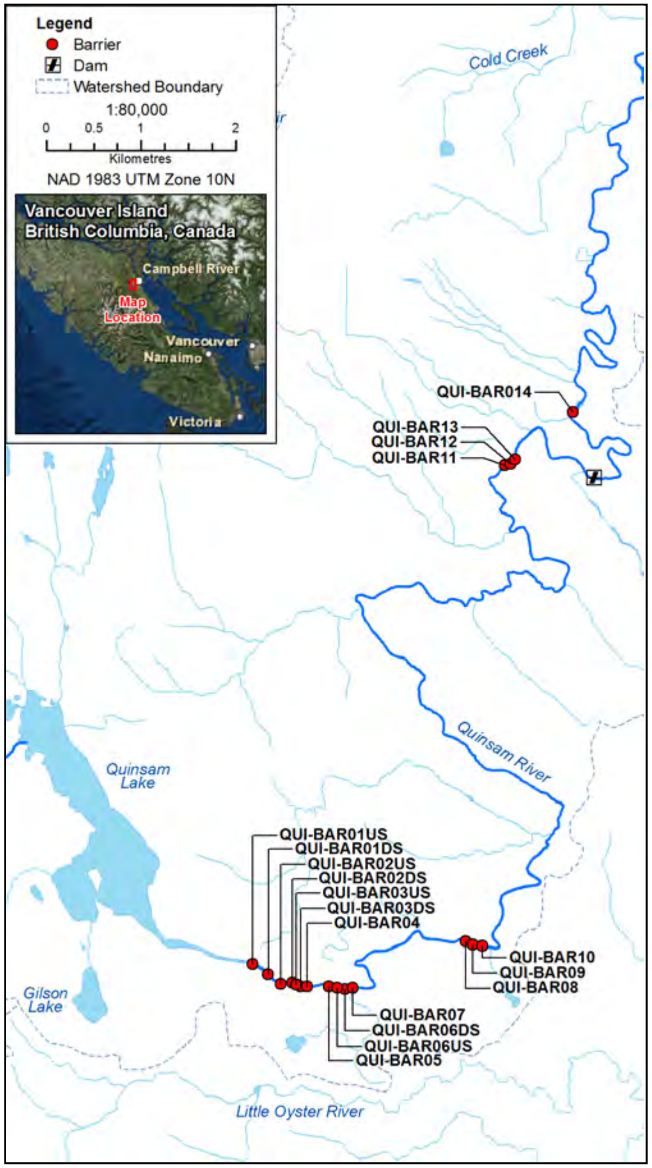
River Left Falls.



Looking Upstream at Upper River Right Falls.

Looking Upstream at River Right Falls.

Looking UPstream at River Left Falls.




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR05 |
| River: | Quinsam River |
| River Kilometer: | 26.42 km |
| Barrier Type: | Chute, Falls |
| Passable: | Low |

**Comments**

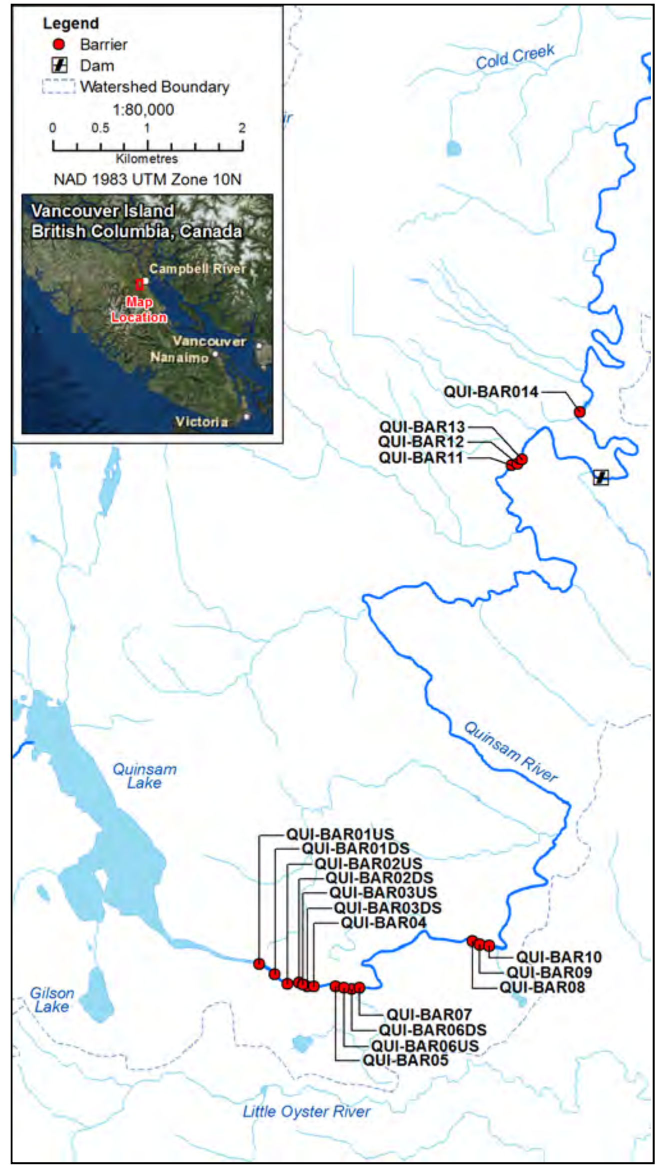
- Chute/falls that may be a barrier to Pink Salmon. Coho and Pink salmon observed immediately downstream.
- During low flows fish would have to leap approximately 1.5 m from a 0.8 m deep pool.
- LWD placement and rock cutting has improved passability.
- Passability was ranked low.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking Upstream.




### Barrier Assessment Summary

| | |
|---|---|
| Name: | QUI-BAR06 (DS - US) |
| River: | Quinsam River |
| River Kilometer: | 26.25 km |
| Barrier Type: | Chute |
| Passable: | Medium |

### Comments

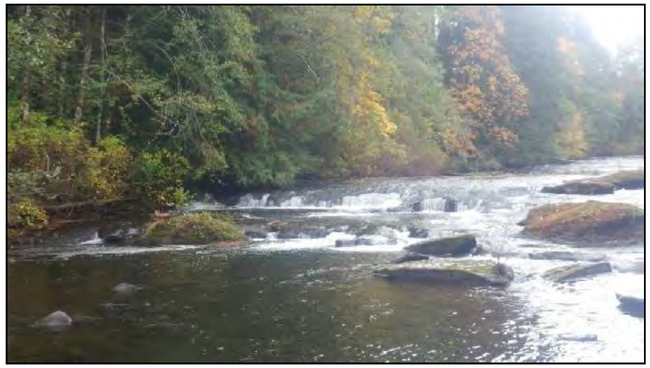
- Long, shallow bedrock chute.
- No evidence of delayed migration during field visit.
- Passability ranked medium.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

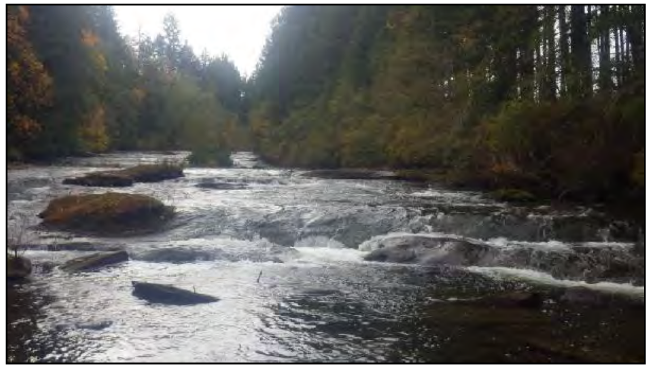
**Crew:** BAM, HMW, SPP

Looking River Right - River Left.



Looking Upstream at River Right.

Looking River Left - River Right.



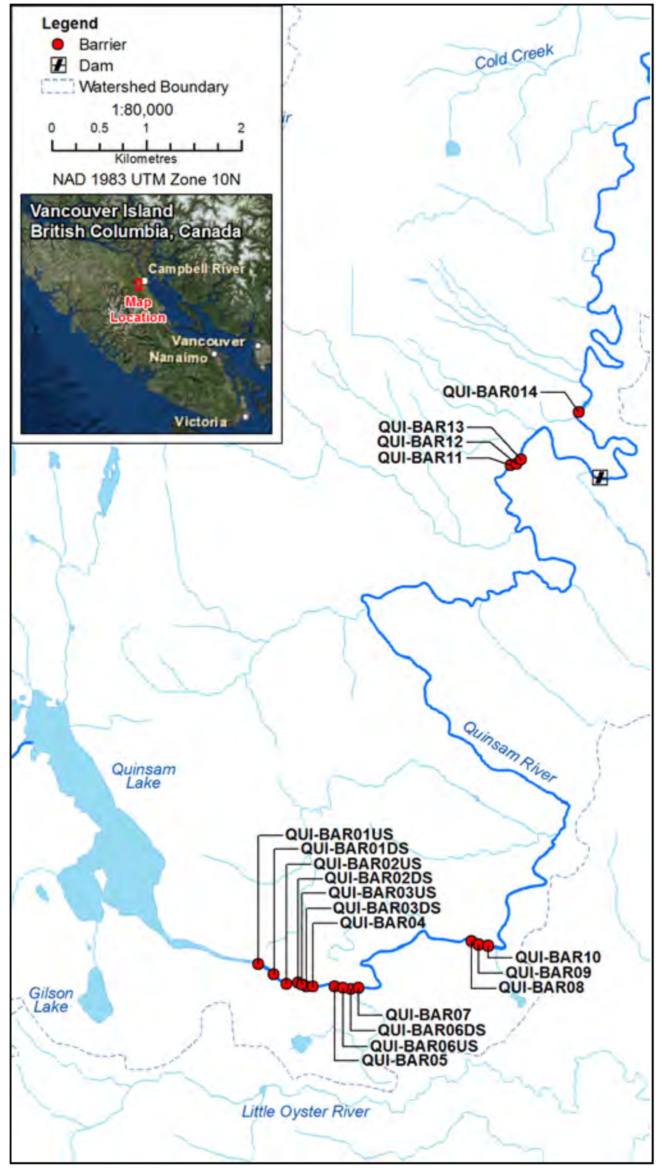
Looking upstream at River Left.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR07 |
| River: | Quinsam River |
| River Kilometer: | 26.17 km |
| Barrier Type: | Chute, Falls |
| Passable: | Medium |

**Comments**

- Bedrock chute/falls that was passable by Pink Salmon at low flows.
- High numbers of live and dead Pink Salmon were observed downstream.
- Passability ranked medium.
- Good site for assessing suitable passage flows.





**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

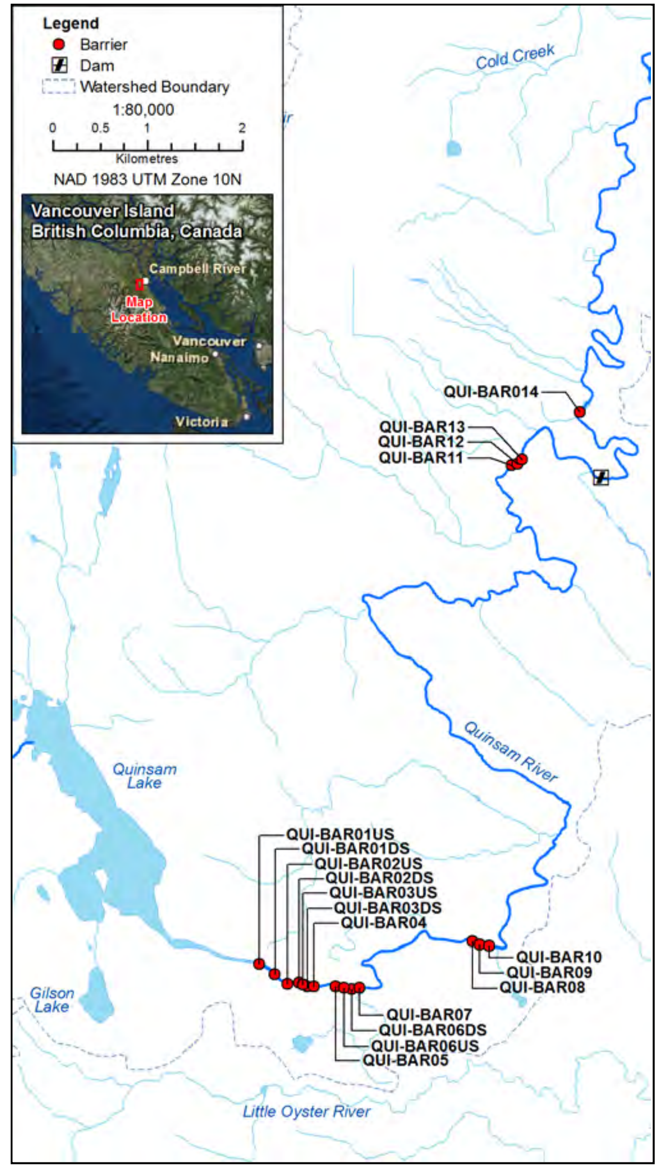
**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking Upstream.

Looking River Left - River Right.

Looking River Right - River Left.




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR08 |
| River: | Quinsam River |
| River Kilometer: | 24.25 km |
| Barrier Type: | Chute |
| Passable: | High |

**Comments**

- Shallow bedrock chute that may be a barrier under very low flows.
- Pink Salmon observed upstream.
- Passability was ranked high.

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**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

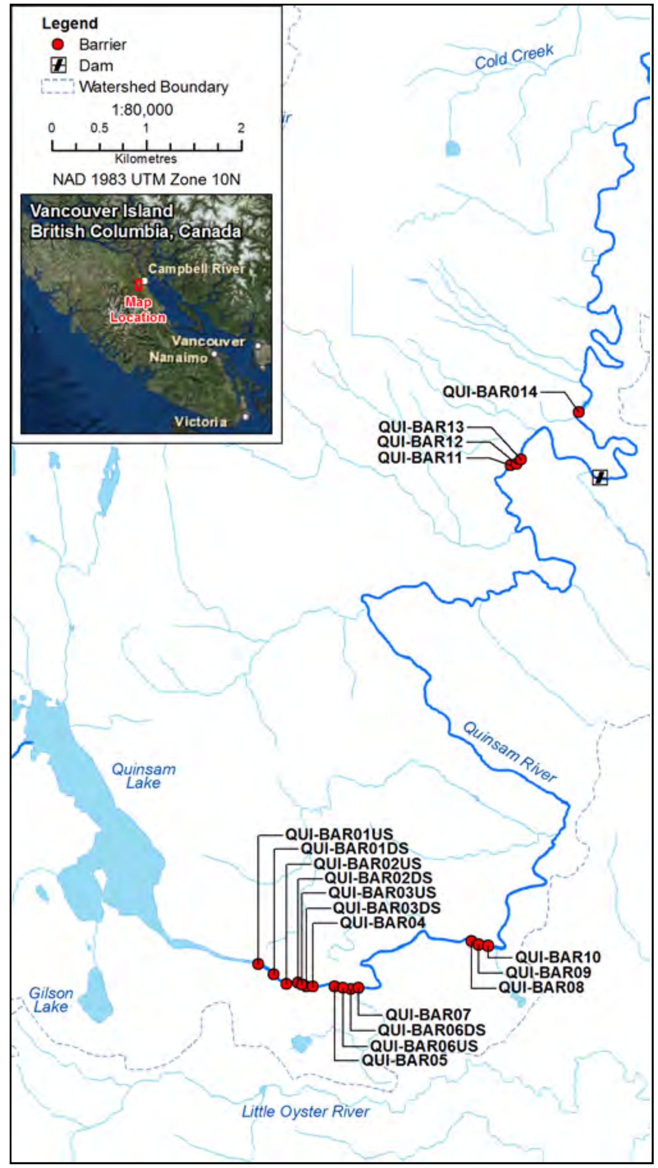
**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking at River Left Falls.

Looking Upstream.

Looking at River Left Falls




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR09 |
| River: | Quinsam River |
| River Kilometer: | 24.17 km |
| Barrier Type: | Falls |
| Passable: | Medium |

**Comments**

- Falls that required a 1.0 m leap.
- Passable by Pink Salmon, although multiple leap attempts required.
- Overall passability ranked medium.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

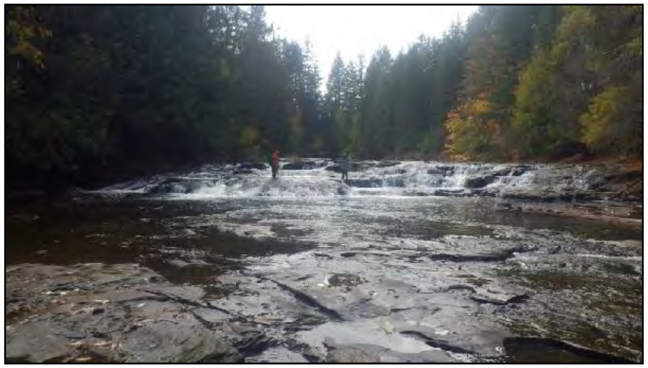
**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking Upstream at River Left.

Looking Upstream at River Right.

Looking Upstream at Channel Center.



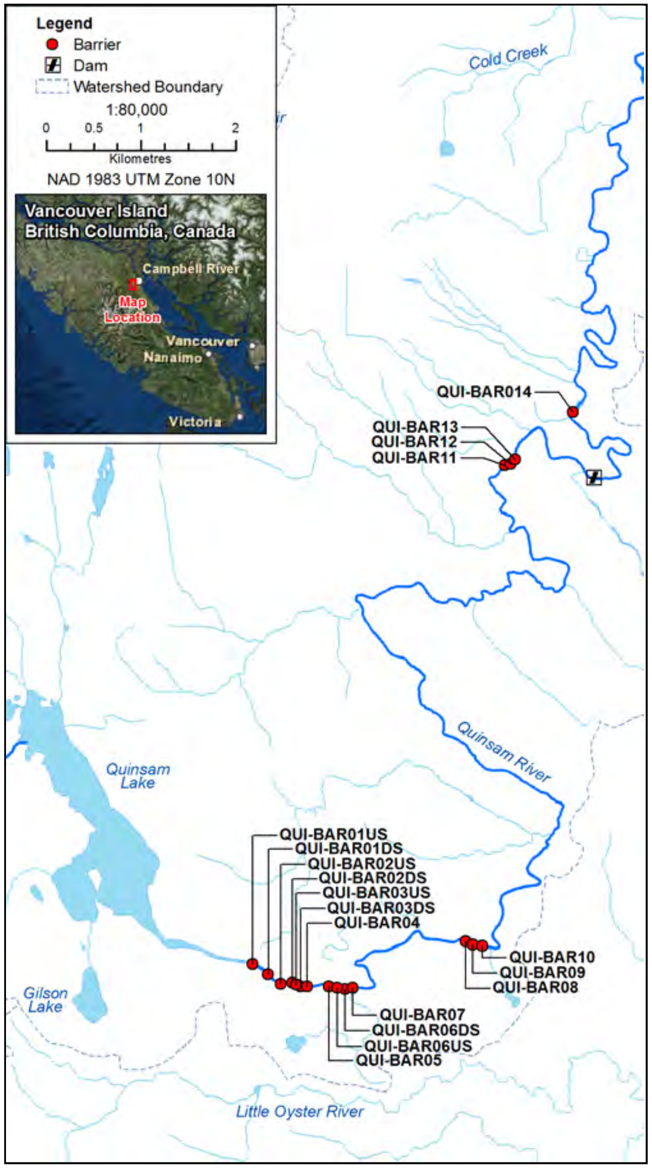
Looking Upstream.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR10 |
| River: | Quinsam River |
| River Kilometer: | 24.06 km |
| Barrier Type: | Chute, Falls |
| Passable: | Medium |

**Comments**

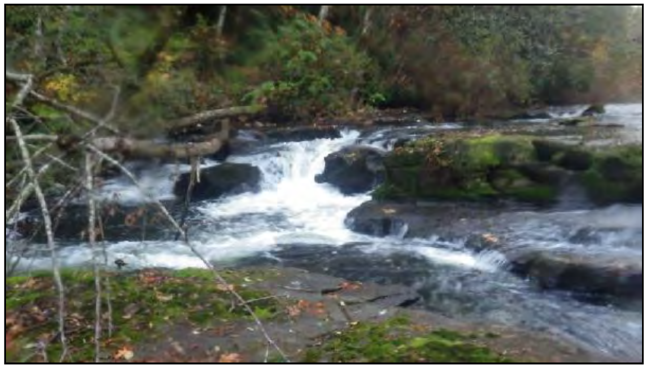
- Chute/falls that is passable, but delays Pink migration.
- Upstream passage for Steelhead, Coho, and Chinook may not be delayed.
- Overall passability ranked medium.




**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

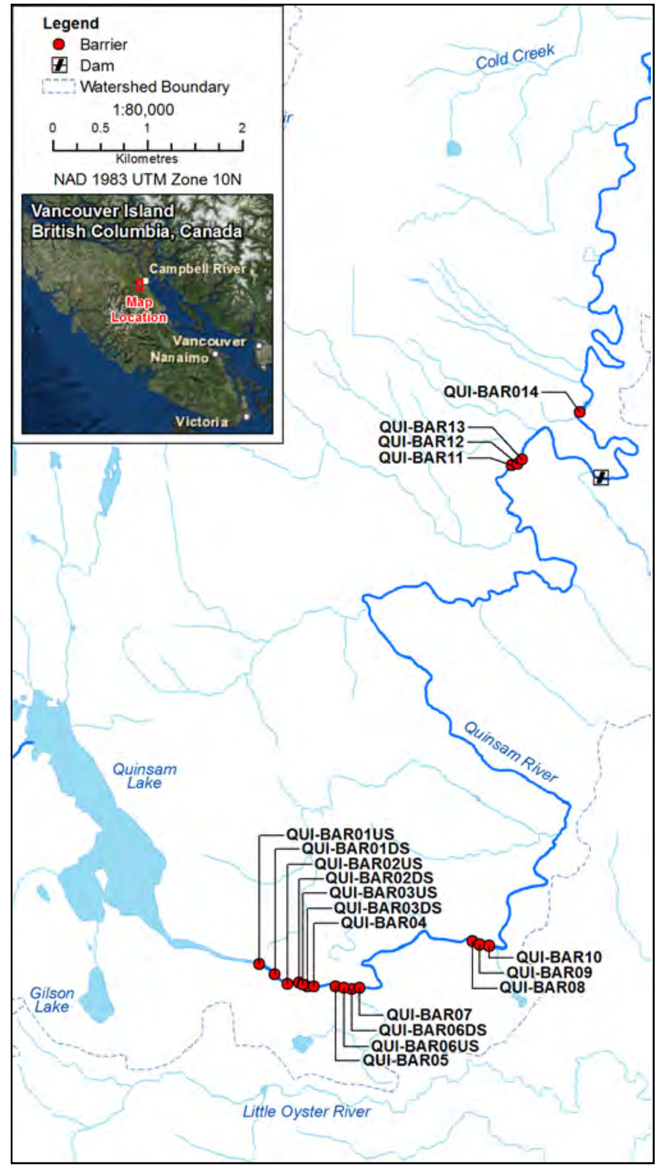


Looking Upstream at River Right.

Looking Upstream at River Left.

Set Description

Looking Upstream at Channel Center.




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR11 |
| River: | Quinsam River |
| River Kilometer: | 13.39 km |
| Barrier Type: | Chute, Falls |
| Passable: | Medium-High |

**Comments**

- Chute/falls with defined passage routes.
- Possible hindrance to Pink Salmon migration. Likely would not delay Steelhead or Coho migration.
- Passability ranged med-high.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**

**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM

Looking Upstream at River Left.

Looking Upstream at River Right.

Looking Upstream at Channel Center.

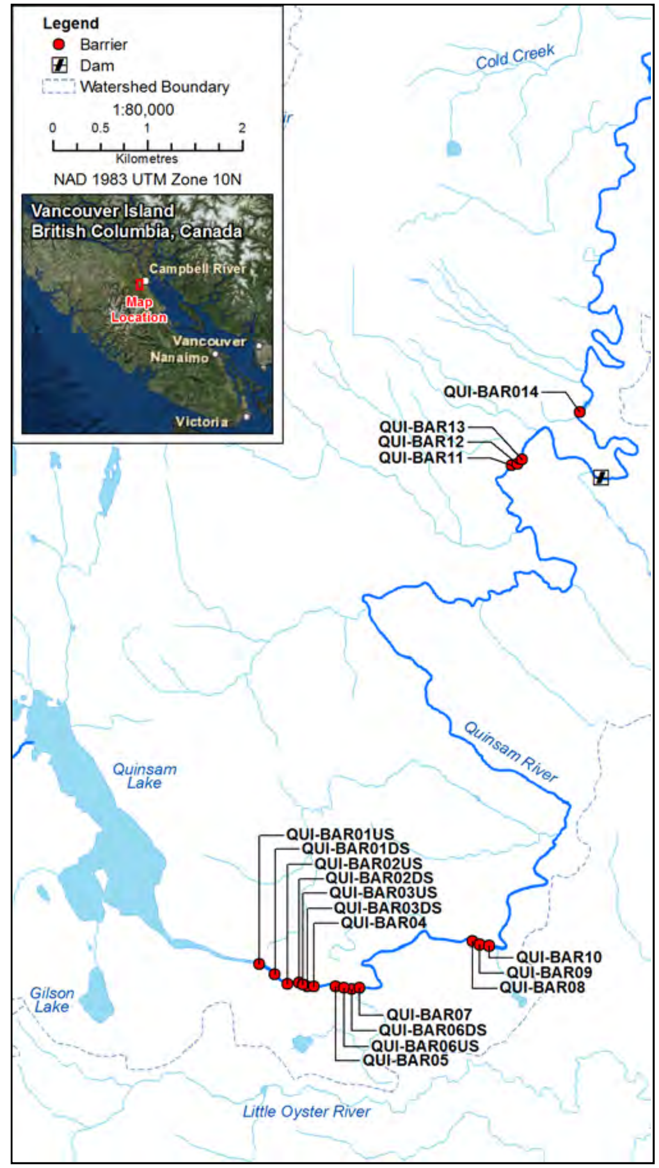
Looking Upstream.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR12 |
| River: | Quinsam River |
| River Kilometer: | 13.32 km |
| Barrier Type: | Chute |
| Passable: | High |

**Comments**

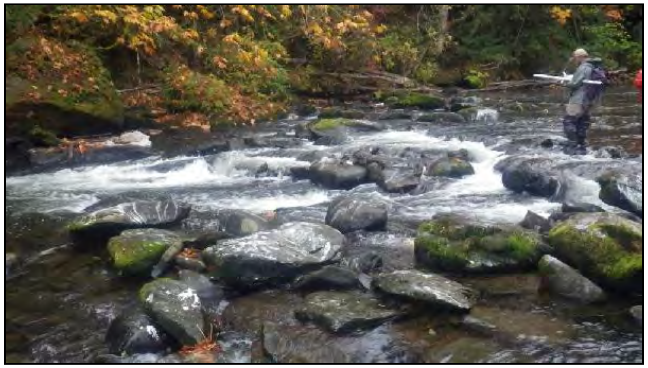
- Chute over bedrock.
- Fish travel up the center and river right channels.
- Highly passable by Coho, Steelhead, and Chinook.
- Moderately passable by Pink Salmon.




## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

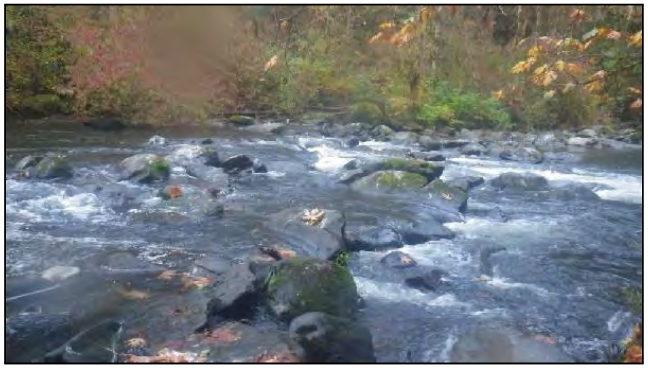
**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP



Looking River Left - River Right.

Looking Upstream.



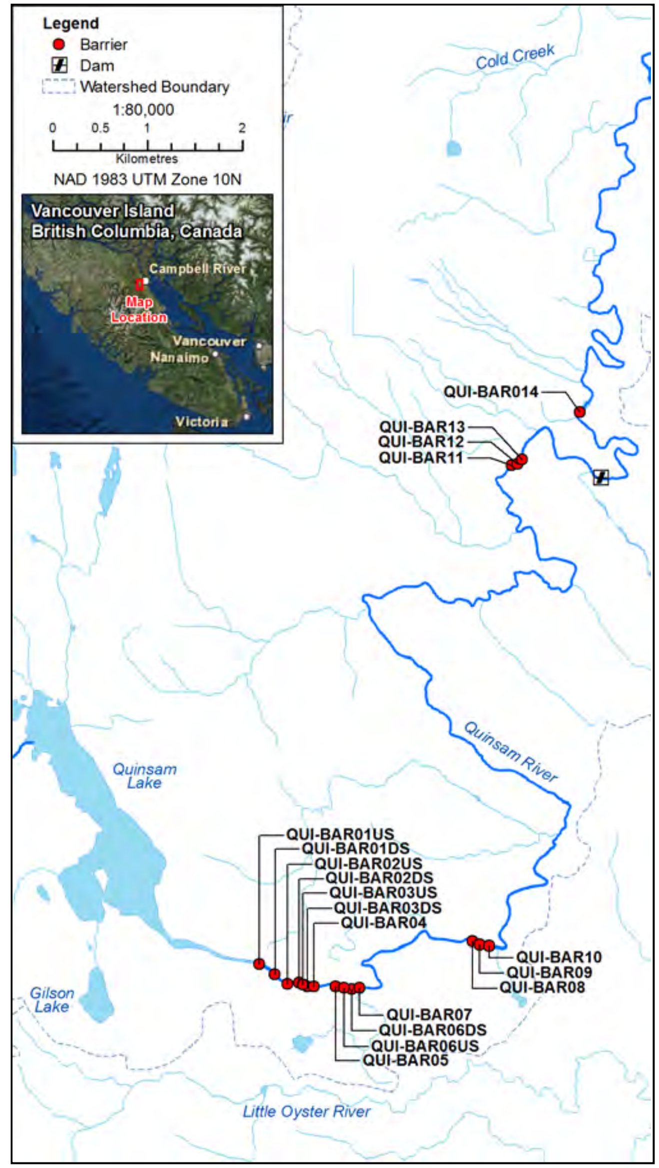
Looking River Right - River Left.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR13 |
| River: | Quinsam River |
| River Kilometer: | 13.26 km |
| Barrier Type: | Chute |
| Passable: | High |

**Comments**

- Small boulder cascade/chute.
- Highly passable.





**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-06

**Crew:** BAM, HMW, SPP

Looking Upstream at River Right.

Looking Upstream at River Left.

Looking Upstream at Channel Center.

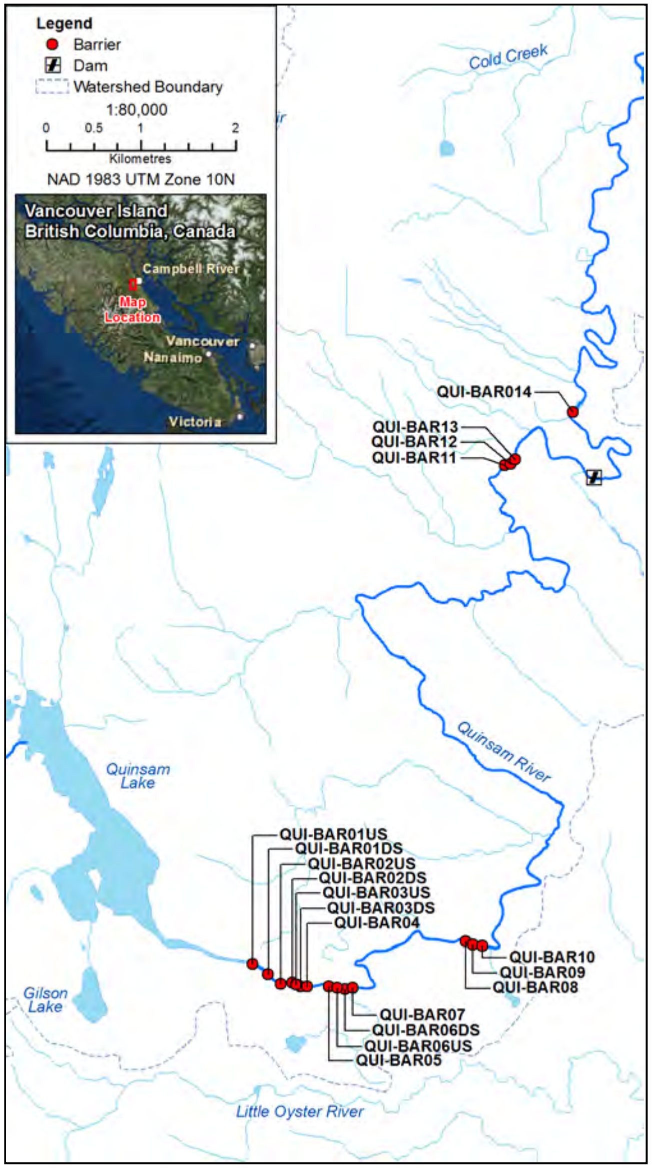
Looking Upstream at Fish Pass.

**Barrier Assessment Summary**

| | |
|---|---|
| Name: | QUI-BAR014 |
| River: | Quinsam River |
| River Kilometer: | 10.01 km |
| Barrier Type: | Chute |
| Passable: | High |

**Comments**

- Bedrock chute with a fishway on river right.
- Highly passable.

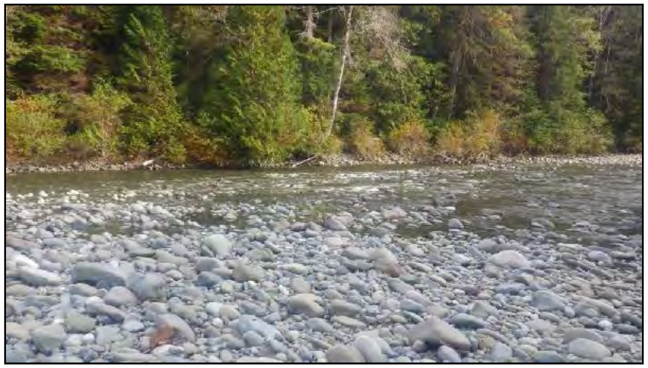



**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-07

**Crew:** BAM, SPP

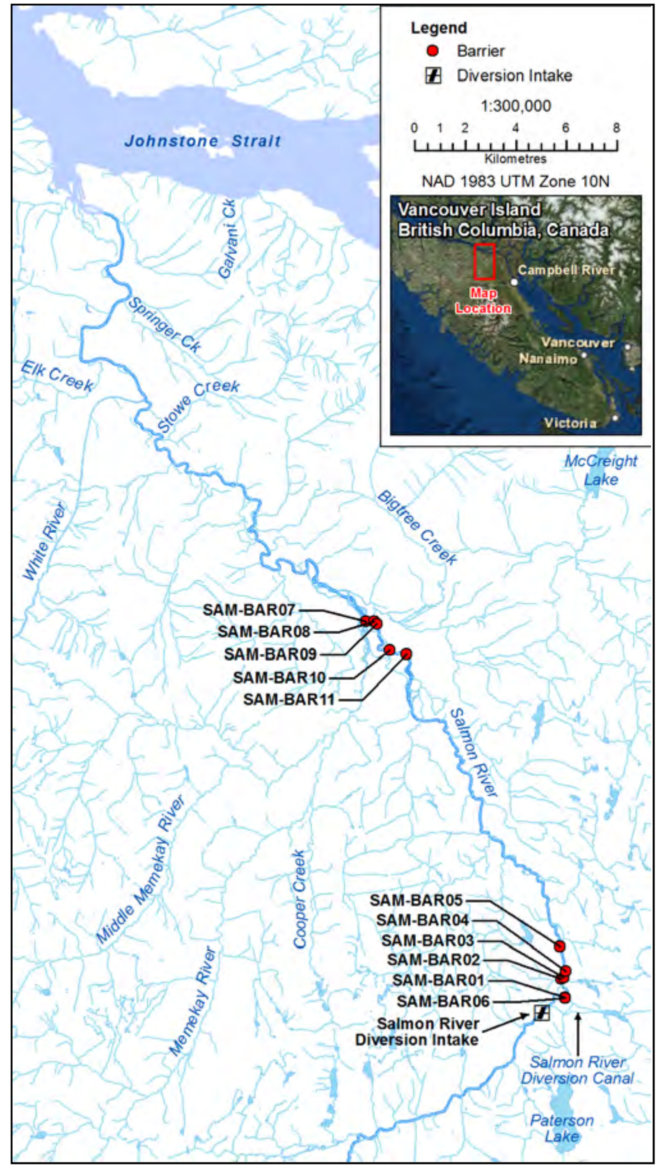
# Appendix B. Salmon River Preliminary Barrier Assessment Summaries



Looking River Left - River Right

Looking Downstream

Looking Upstream




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | SAM-BAR01 |
| River: | Salmon River |
| River Kilometer: | 52 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 55 m |
| Length: | 14 m |
| Maximum Riffle Depth: | 0.08 m |

**Comments**

- Shallow diagonal riffle, with a wide cross section.
- The maximum depth at the shallowest cross-section was 0.08 m.
- There was still a fairly well defined thalweg, and the longitudinal distance was fairly short (14 m), therefore it was rated as highly passable.

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**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-05

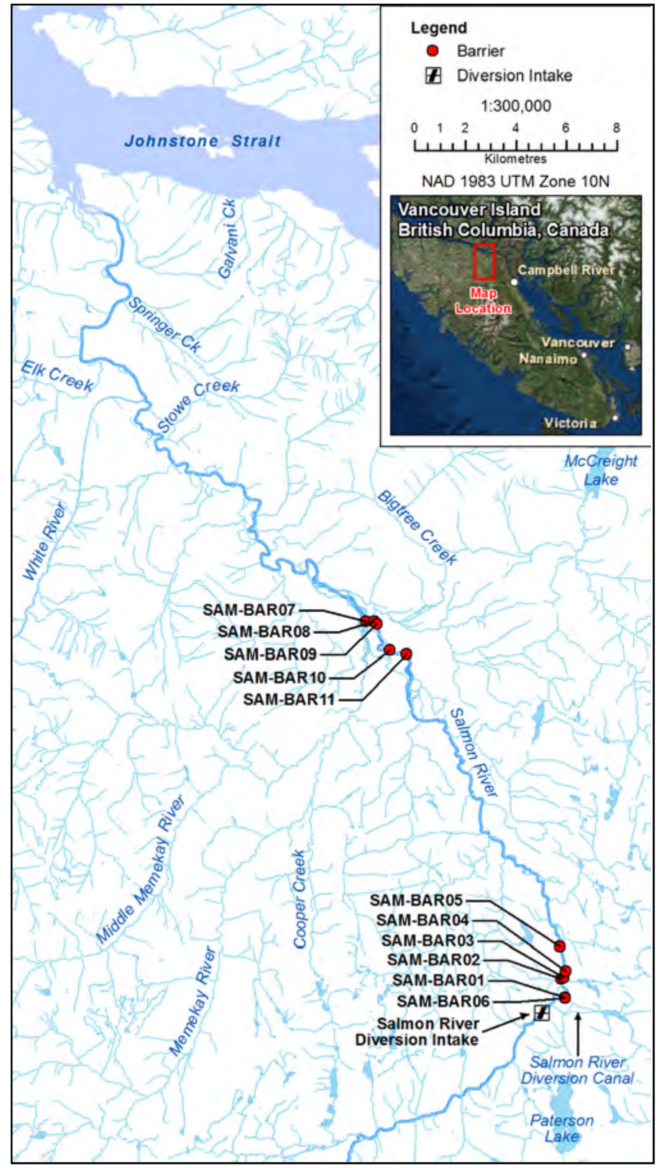
**Crew:** BAM, HMW, SPP

River Right Channel Looking Downstream

River Right Channel Looking River Left - River Right

River Left Channel Looking River Right - River Left

River Left Channel Looking Upstream




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR02 |
| River: | Salmon River |
| River Kilometer: | 51 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 10.2 m |
| Length: | 43 m |
| Maximum Riffle Depth: | 0.1 m |

### Comments

- Multi-channel riffle, with fairly steep gradient.
- The maximum depth at the shallowest cross-section was 0.10 m.
- The overall length was 43 m for the right channel, and 13 m for the left channel.
- The left channel contained the majority of flow.

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BChydro

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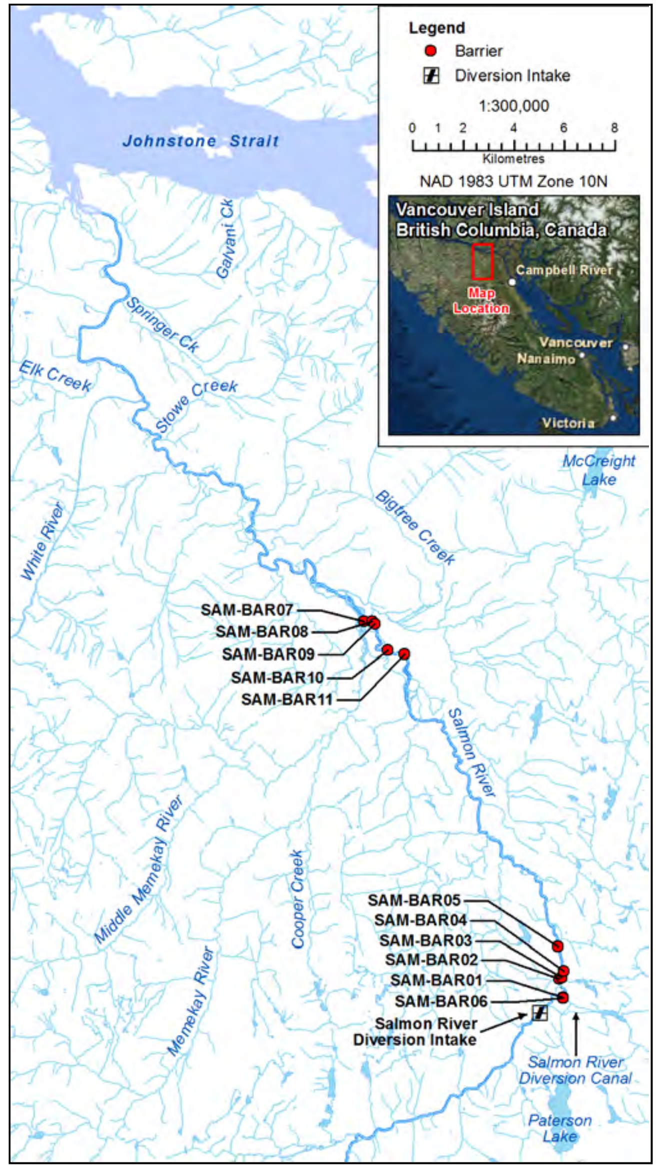
**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-05

**Crew:** BAM, HMW, SPP

Looking River Right - River Left

Looking Upstream from River Right




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR03 |
| River: | Salmon River |
| River Kilometer: | 51 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 35 m |
| Length: | 40 m |
| Maximum Riffle Depth: | 0.2 m |

### Comments

- Maximum depth of 0.2 m would allow for passage at low flows.
- The site was long (40 m) with no well defined thalweg, therefore it could potentially cause migration delays.

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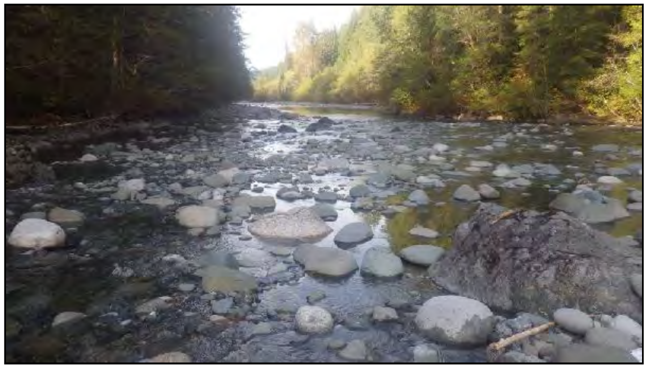
BChydro

ECOFISH RESEARCH

## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

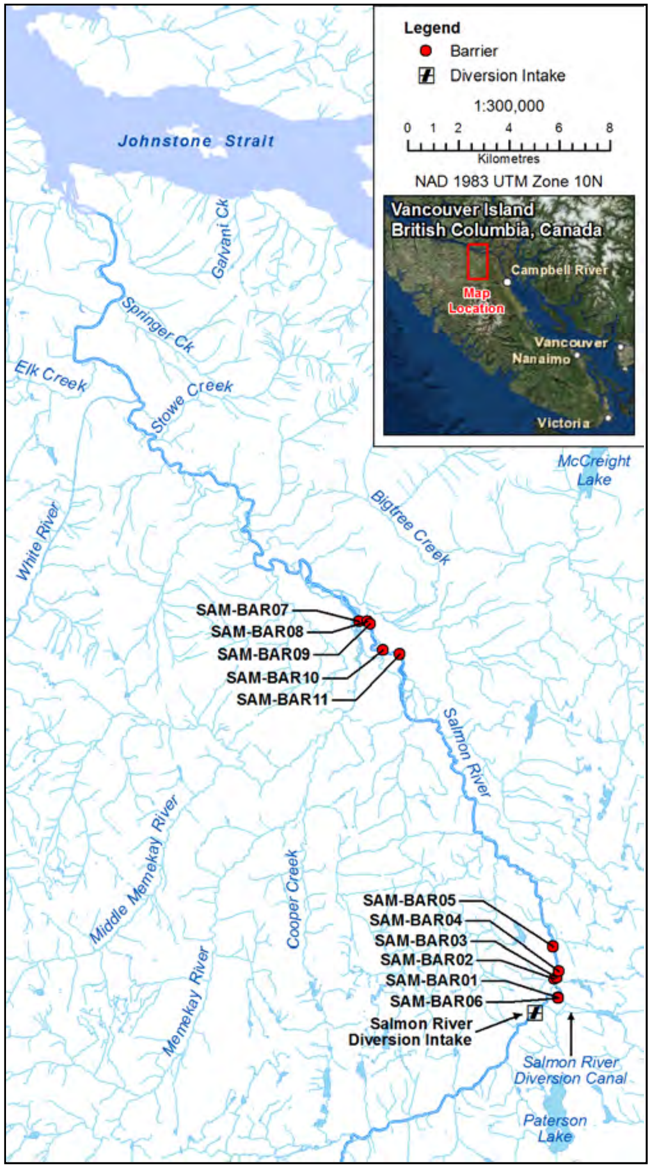
**Date:** 2015-10-05

**Crew:** BAM, HMW, SPP



Looking Downstream

Looking River Left - River Right




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | SAM-BAR04 |
| River: | Salmon River |
| River Kilometer: | 51 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 40 m |
| Length: | 25 m |
| Maximum Riffle Depth: | 0.2 m |

**Comments**

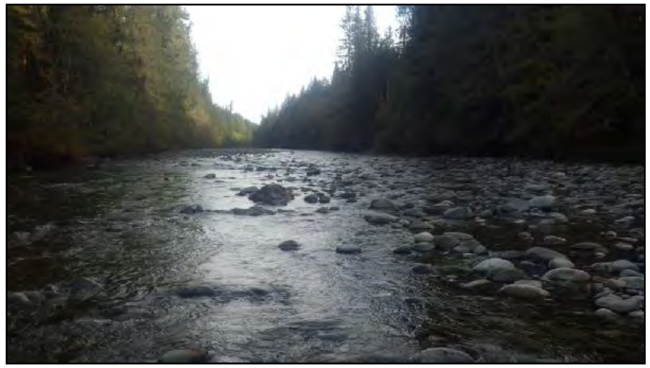
- Moderately wide riffle.
- The maximum depth at the shallowest cross section was 0.2 m.
- This riffle is likely highly passable at flows below 2 $m^3/s$.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-05

**Crew:** BAM, HMW, SPP

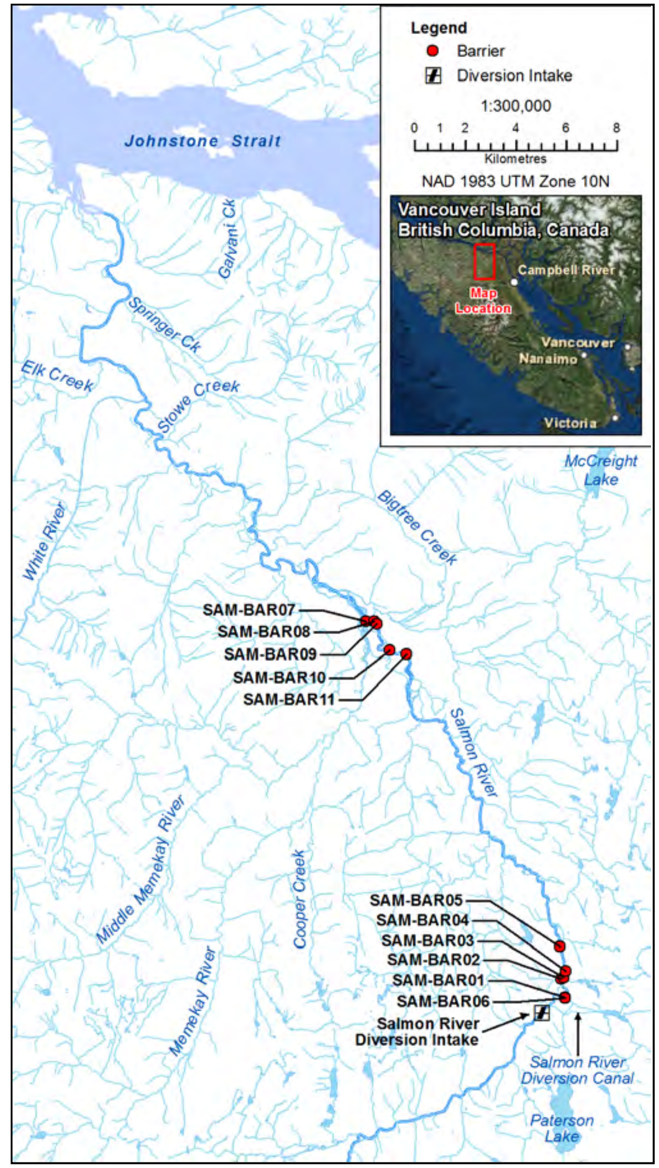
Looking River Right - River Left



Looking Upstream

Looking River Left - River Right

Looking Downstream




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR05 |
| River: | Salmon River |
| River Kilometer: | 50 km |
| Barrier Type: | Riffle |
| Passable: | Low-Medium |
| Wetted Width: | 60 m |
| Length: | 80 m |
| Maximum Riffle Depth: | 0.2 m |

### Comments

- Large, shallow uniform riffle located at the downstream end of the upper sampling reach.
- The shallow portion of the riffle was 80 m long, and the width was 60 m.
- The passibility of this site was ranked low-medium due to the overall length and width, and lack of a defined channel.

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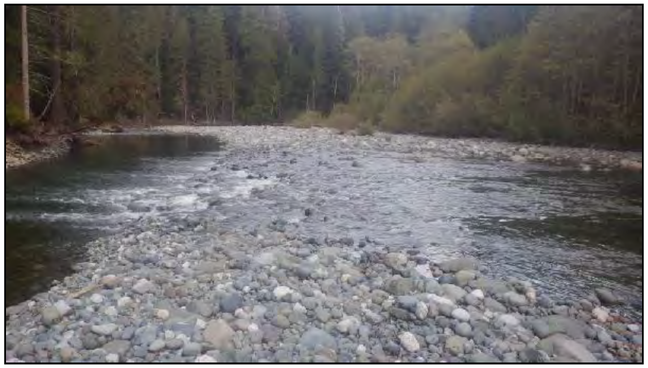
## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

**Date:** 2015-10-05

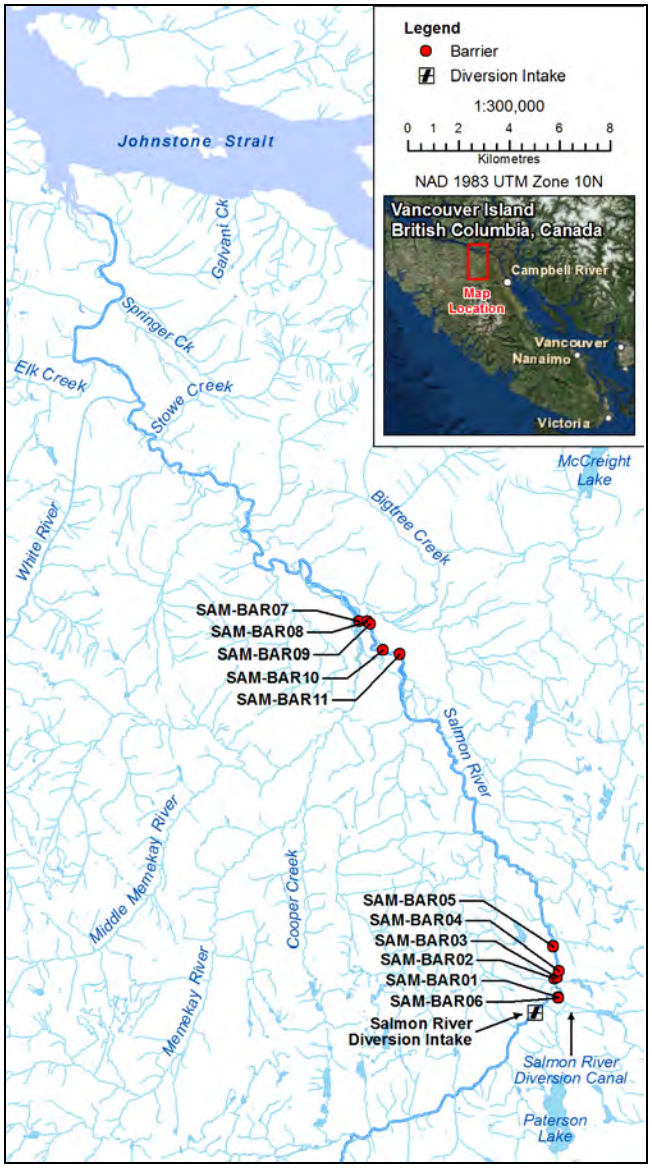
**Crew:** BAM, HMW, SPP

Looking Upstream



Looking River Left - River Right

Looking River Right - River Left




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR06 |
| River: | Salmon River |
| River Kilometer: | 52 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 40 m |
| Length: | 15 m |
| Maximum Riffle Depth: | 0.25 m |

### Comments

- Wide diagonal riffle.
- This site was wide (40 m wetted width), but was only 15 m long.
- The site was rated highly passable, due to depth of 0.25 m, and short length.

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**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

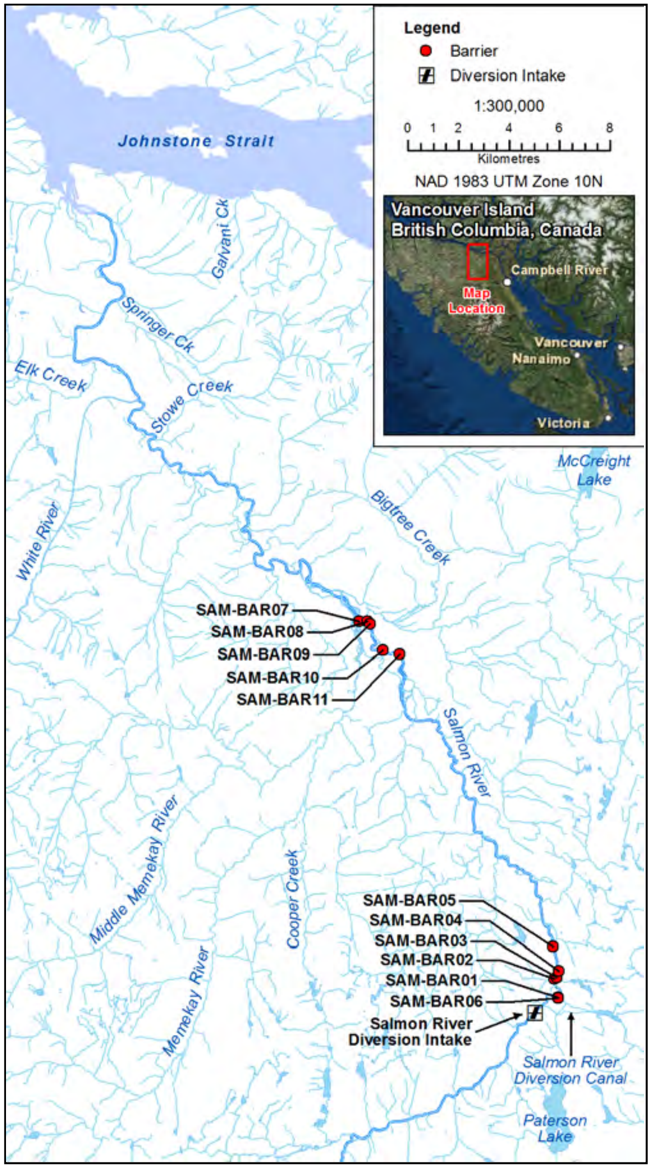
**Date:** 2015-10-05

**Crew:** BAM, HMW, SPP

Looking River Right - River Left

Looking River Left - River Right

Looking Upstream




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR07 |
| River: | Salmon River |
| River Kilometer: | 31 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 70 m |
| Length: | 18 m |
| Maximum Riffle Depth: | |

### Comments

- Wide, diagonal riffle.
- The riffle is 70 m wide, and some areas are very shallow and impassable by adult fish at low flow, but there is a defined thalweg which likely offers adequate depth for upstream migration.
- Passibility was ranked high, although this site and SAM-BAR011, may be the most limiting barriers in the section from Big Tree Creek confluence to Big Tree Mainline Bridge crossing.

## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

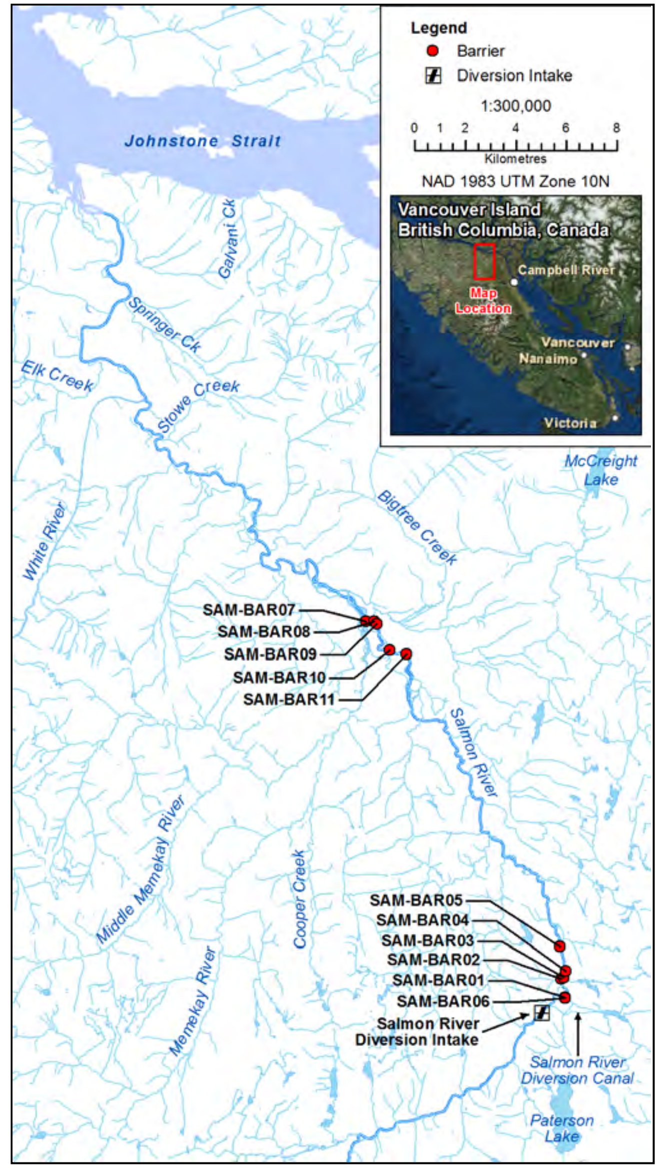
**Date:** 2015-10-07

**Crew:** BAM, HMW, SPP

Looking River Left - River Right

Looking Upstream

Looking River Right - River Left




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR08 |
| River: | Salmon River |
| River Kilometer: | 31 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 52 m |
| Length: | 25 m |
| Maximum Riffle Depth: | |

### Comments

- Wide, diagonal riffle.
- The riffle is braided, and some areas are very shallow, but there is a well defined thalweg at low flows that provide adequate depth for upstream passage.

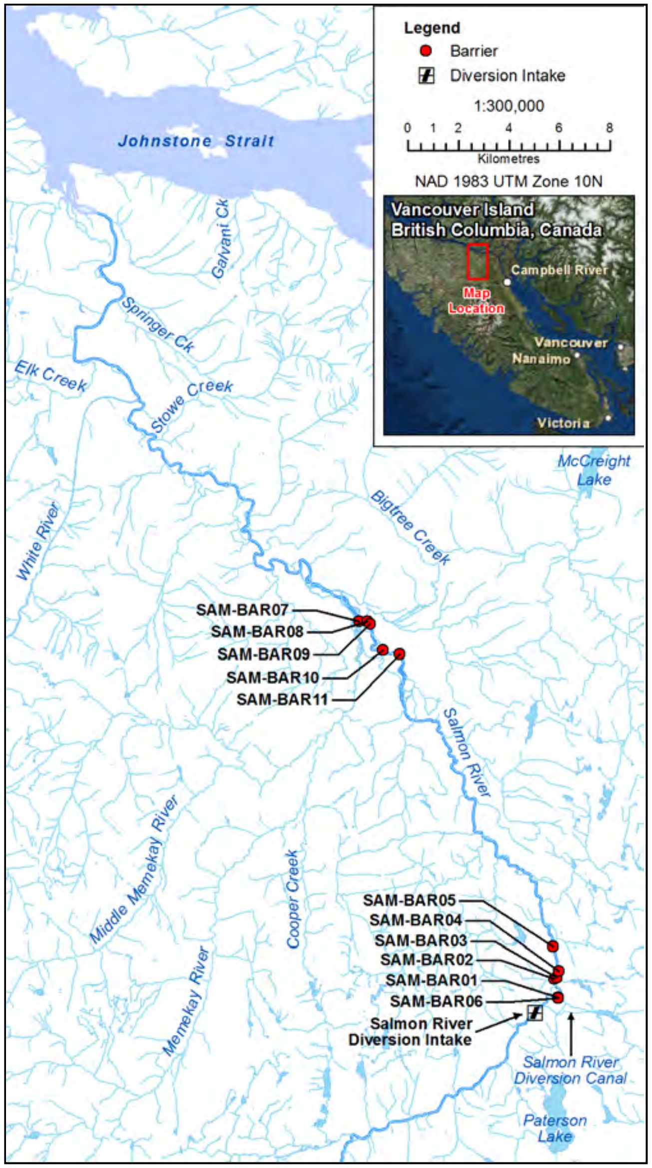
## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

**Date:** 2015-10-07

**Crew:** BAM, HMW, SPP

Looking Upstream

Looking River Right - River Left




### Barrier Assessment Summary

| | |
|---|---|
| Name: | SAM-BAR09 |
| River: | Salmon River |
| River Kilometer: | 31 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 27 m |
| Length: | 24 m |
| Maximum Riffle Depth: | |

### Comments

- Moderately shallow riffle.
- Fairly uniform, with slightly more depth and flow on river right.
- This site was considered highly passable.

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## JHTMON-6 Campbell Watershed Riverine Fish Production Assessment
## Preliminary Barrier Assessment

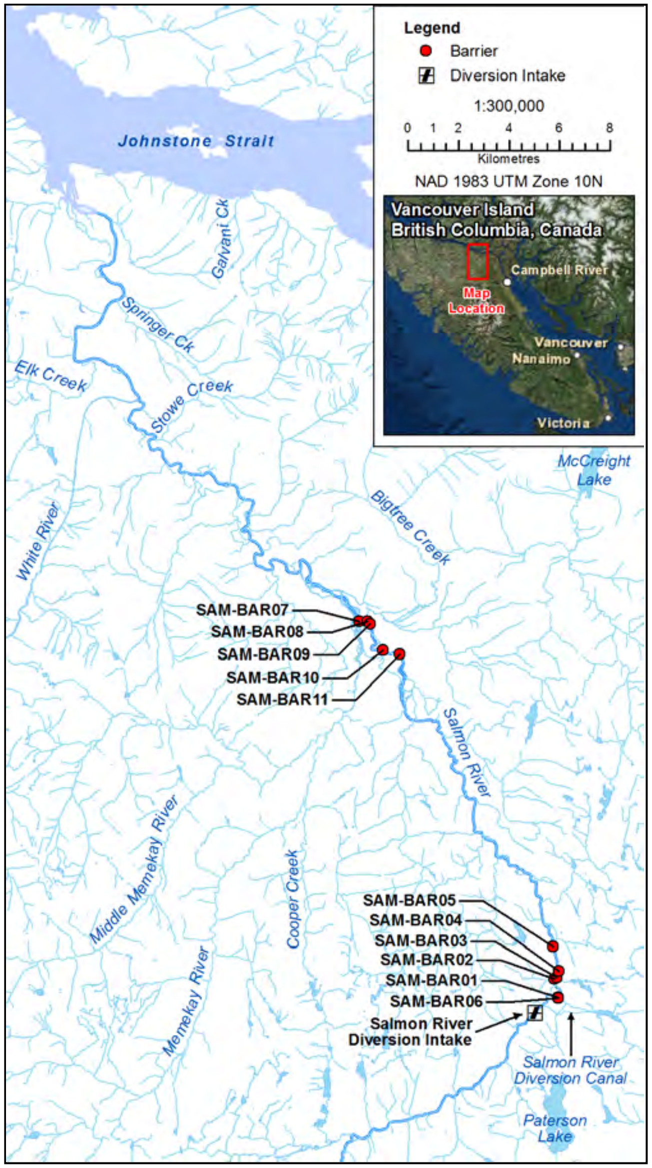
**Date:** 2015-10-07

**Crew:** BAM, HMW, SPP

Looking Upstream at River Left Braid

Looking River Left - River Right

Looking Upstream at River Right Braid




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | SAM-BAR10 |
| River: | Salmon River |
| River Kilometer: | 33 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | 70 m |
| Length: | 30 m |
| Maximum Riffle Depth: | |

**Comments**

- Wide, braided riffle.
- Despite having a wide channel (70 m), the flows were concentrated in distinct channels which would be passable by adult fish at low flows.

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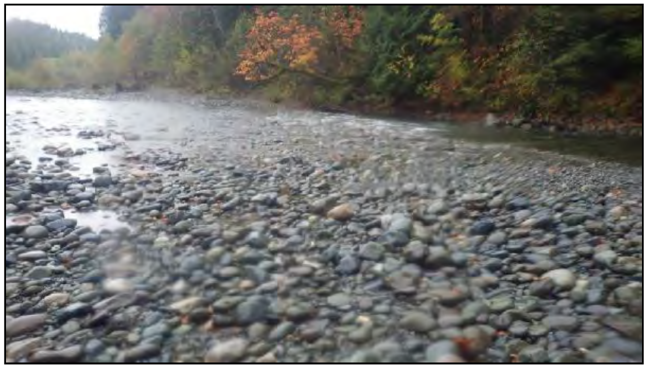
BC hydro

ECOFISH RESEARCH

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-07

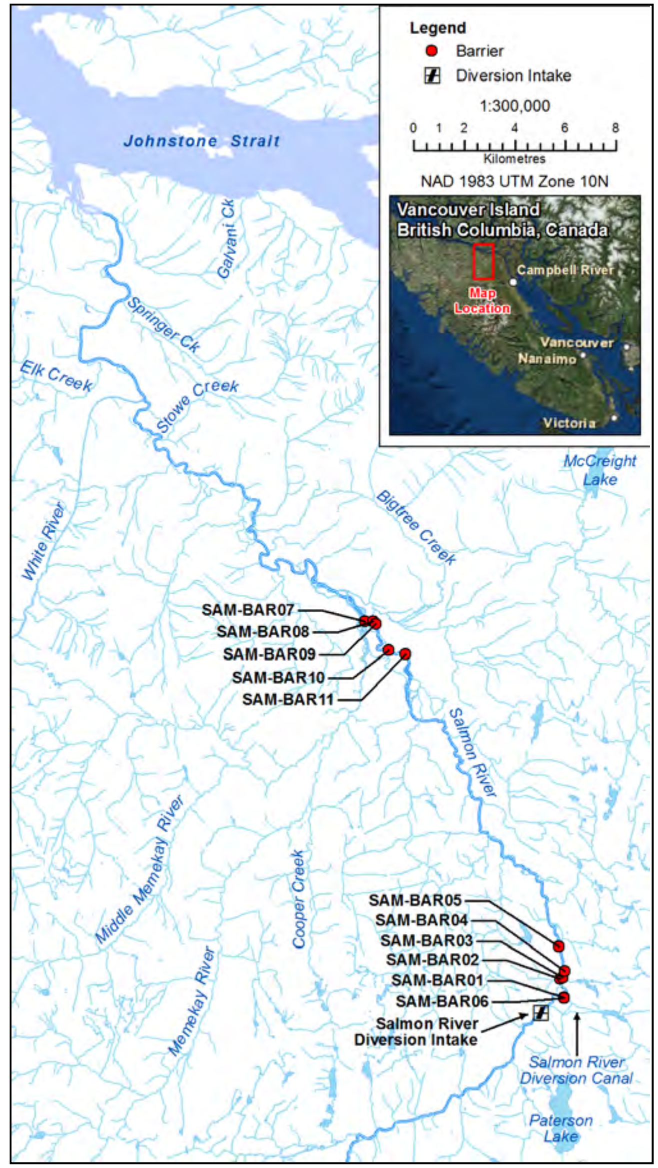
**Crew:** BAM, HMW, SPP



Looking River Right - River Left

Looking River Left - River Right

Aerial View Looking River Right - River Left




**Barrier Assessment Summary**

| | |
|---|---|
| Name: | SAM-BAR11 |
| River: | Salmon River |
| River Kilometer: | 34 km |
| Barrier Type: | Riffle |
| Passable: | High |
| Wetted Width: | |
| Length: | |
| Maximum Riffle Depth: | |

**Comments**

- Wide, shallow, diagonal riffle located at the Big Tree Mainline Bridge Crossing.
- Passibility was ranked high, although this site and SAM-BAR07, may be the most limiting barriers in the section from Big Tree Creek confluence to Big Tree Mainline Bridge crossing.

**JHTMON-6 Campbell Watershed Riverine Fish Production Assessment**
**Preliminary Barrier Assessment**

**Date:** 2015-10-07

**Crew:** BAM, HMW, SPP