Campbell River Project Water Use Plan

JHTMON-6 Campbell Watershed Riverine Fish Production

Implementation Year 1

Reference: JHTMON-6

JHTMON-6 Component 1: Flow Habitat Relationships in Diversion Streams Year 1 Report

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

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

January 5, 2017

JHTMON-6 Campbell Watershed Riverine Fish Production

Component 1: Flow Habitat Relationships in Diversion Streams Year 1 Report




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EXECUTIVE SUMMARY

As the Campbell River Water Use Plan (WUP) 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 Year 1 Report relates to the first of these studies: *Flow-Habitat Relationships in Diversion Streams*. 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 habitat-flow component of JHTMON-6 after Year 1.

Study Objective	Management Questions	Management Hypotheses	Year 1 (2015/2016) status
Reduce uncertainty about habitat-flow relationships in diversion donor streams.	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. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?	H_0*1: Over the range controlled by the diversion, flow does not affect the quantity and quality of fish habitat.* H_0*2: The empirically derived flow-habitat relationships for each diversion stream do not differ significantly from the predictions made by the Bruce and Hatfield (in progress) meta-analysis model.* H_0*3: The frequency and duration of flow events outside the range considered to be optimal or near optimal for maximum habitat availability are not sufficient to cause measurable long term population impacts as indicated by fish abundance assessments.*	Year 1 of this three-year study has been completed. Year 1 involved developing a recommended approach to complete the remainder of this component of JHTMON-6. A review was completed of instream flow assessment methods that identified appropriate methods to resolve uncertainty regarding flow-habitat relationships. Reconnaissance site visits were completed to identify study sites and confirm that proposed methods are appropriate. A recommended approach is presented to complete further fieldwork and analysis during Year 2 and 3 to address the management questions.

This Year 1 Report provides context and details for work that will be undertaken during the remaining two years of the study to collect and analyze data from the two study streams: Miller Creek and Salmon River. Miller Creek flows into Lower Campbell Lake reservoir and conveys diverted water from the Quinsam River when sufficient flow is available. The study section of the Salmon River is downstream of the Salmon River Diversion Dam and therefore experiences reduced flows when flow diversion occurs.

This study will develop species and life stage specific flow-habitat relationships for the two study streams and then compare them with relationships used during WUP development. Specifically, the study will address the following two Management Questions:

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?

The study design is based on recommendations of an earlier review of instream flow assessment methods (Healey and Hatfield 2015; Appendix A). For both rivers, we propose to collect data to calibrate hydraulic habitat models to simulate depth and velocity in the study reaches over a range of flows.

For Miller Creek, we will conduct monitoring at 15 transects during three flow conditions to configure a 1-dimensional hydraulic habitat model (PHABSIM). In addition, two hydrometric gauges will be installed to monitor discharge during the monitoring period to address uncertainty regarding flow conditions downstream of Gooseneck Lake. Additional fish habitat information will be obtained from results of a Level 1 Fish Habitat Assessment that was previously completed (AMEC 2004).

For the Salmon River, we will conduct monitoring at 20 transects during three flow conditions to configure a 1-dimensional hydraulic habitat model that will be applied to the ~18 km section downstream of the dam where the river is predominantly confined to a single channel. In addition, we will collect detailed microhabitat data from a representative 1 km section on the ~6 km reach between Kay Creek and Memekay River confluences where the river is braided. These data will be used to configure a 2-dimensional hydraulic habitat model (e.g., River-2D). Data will be primarily collected using an unmanned aerial vehicle (UAV), with additional field data collected to augment and validate data collected with the UAV.

Hydraulic habitat models will then be used to simulate depth and velocity for a range of flow conditions. These predictions will be combined with established fish habitat suitability criteria to derive species and life stage specific flow-habitat relationships for each stream (Management Question 1). These relationships will then be quantitatively compared to the meta-analysis curves that were used in the WUP to evaluate any differences (Management Question 2). The effects of any differences on the WUP fish habitat performance measure will be assessed by simulating habitat time series under the WUP flow scenarios and comparing the results with the earlier results from WUP development. Finally, the results from this study will be used to support analysis that will be undertaken as part of JHTMON-8 to examine whether habitat limits juvenile fish abundance in the Salmon and Quinsam rivers, and therefore assess the biological significance of uncertainty in the meta-analysis curves that were used in the WUP.

Interim results will be presented in an annual data report submitted at the end of Year 2. A final report will then be submitted at the end of Year 3 that includes the outcomes of analysis to address the management questions.

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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. Flow-Habitat Relationships for Diversion Rivers

Three independent studies have been designed to separately address the three areas of uncertainty listed above. This report represents the Year 1 annual report that is part of a three-year study designed to resolve the first area of uncertainty: *flow-habitat relationships for Miller Creek and Salmon River*. Specifically, there is uncertainty regarding the potential for diversion of water at the Quinsam River Diversion Dam to affect fish habitats in Miller Creek (which conveys diverted water) and in the Salmon River mainstem, downstream of the Salmon River Diversion Dam (Map 1). Plans for the other two studies have been, or will be, presented in separate documents.

This study will primarily address Management Questions 1 and 2. Three of the six null hypotheses relate to these management questions (BC Hydro 2013); these are:

> *$H_0$1: Over the range controlled by the diversion, flow does not affect the quantity and quality of fish habitat.*
>
> *$H_0$2: The empirically derived flow-habitat relationships for each diversion stream do not differ significantly from the predictions made by the Bruce and Hatfield (in progress) meta-analysis model.*
>
> *$H_0$3: The frequency and duration of flow events outside the range considered to be optimal or near optimal for maximum habitat availability are not sufficient to cause measurable long term population impacts as indicated by fish abundance assessments.*

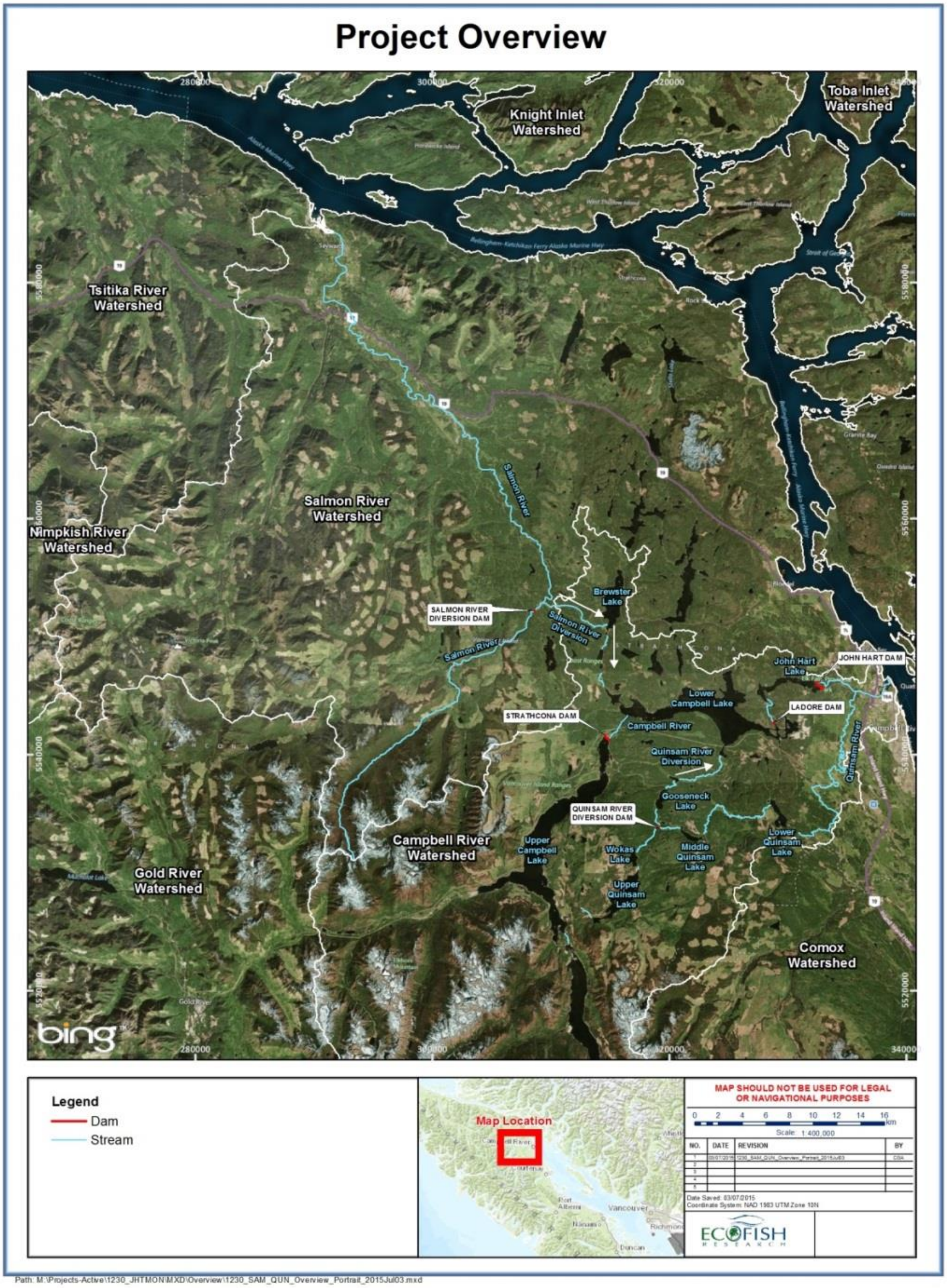
1.3. Objectives

The objectives of this Year 1 report are to:

1. Summarize the work completed during the WUP to quantify flow-habitat relationships;
2. Identify outstanding data needs;
3. Summarize the outcomes of reconnaissance site visits undertaken to select transect locations;
4. Present a recommended approach for fieldwork activities, including rationale for selection of transect locations; and
5. Describe proposed data analysis methods.

A separate memo was completed during Year 1 that provides a review of alternative instream flow assessment methods that could be applied during JHTMON-6 to resolve uncertainty regarding flow-habitat relationships (Healey and Hatfield 2015). This memo is presented in Appendix A and outcomes of the review are summarized in Section 2.

Map 1. Locations of Quinsam River and Salmon River diversion facilities.



2. OVERVIEW OF WORK COMPLETED DURING WUP DEVELOPMENT

During WUP development, several difficulties arose during collection and analyses of stream transect data for the Quinsam and Salmon rivers. These prevented analysis of flow–habitat relationships using stream-specific data to be completed within the timeframe of WUP development. To proceed with the WUP, assessments of flow-related effects on fish habitat instead relied on meta-analysis of other instream flow studies in the Pacific Northwest (Hatfield and Bruce 2000, and Bruce and Hatfield, in progress), supported by professional judgment to reflect site-specific considerations.

These meta-analysis approaches are described in Healey and Hatfield (2015; Appendix A). In summary, Hatfield and Bruce (2000) examined habitat-flow relationships from 127 hydraulic habitat modelling studies in western North America to derive a relationship between mean annual discharge (MAD) and the optimum discharge that corresponded to maximum fish habitat availability. Separate relationships were derived for four life stages and four salmonid species, plus an "all salmonid species" category. This work was then extended by Bruce and Hatfield (*in preparation*) to generalize whole habitat-flow relationships. For each of the habitat-flow relationships used in the study, they extracted the flows corresponding to 50%, 60%, 75%, and 90% of the optimal habitat (on both ascending and descending portions of the habitat-flow relationship). Statistical analysis of these data points revealed that the habitat-flow relationships follow a log-normal relationship. A risk function was defined as the inverse of the habitat-flow relationship and the optimal flows in Hatfield and Bruce (2000) were also revised. The results of Bruce and Hatfield (*in preparation*) were incorporated into a computer tool to generate habitat-flow relationships based on user-defined stream information. The purposes of this tool are to aid in project scoping (e.g., determine if a detailed study is necessary), assist in design of detailed studies (e.g., determine flow rates for sampling), and aid decisions in adaptive management (e.g., flow rates for testing). This tool was used to calculate the rearing habitat performance measure in the Campbell River WUP.

Healey and Hatfield (2015; Appendix A) also reviewed six alternative approaches, with the relative advantages and disadvantages of each approach reviewed in the context of their applicability to resolving uncertainties surrounding habitat-flow relationships in the JHTMON-6 study streams. This review concluded that application of either a 1-dimensional (1D) or 2-dimensional (2D; budget permitting) physical habitat model is recommended to address the applicable management questions. Data analysis methods are discussed further in Section 6.2.

3. BACKGROUND TO STUDY STREAMS

3.1. Miller Creek

3.1.1. Watershed Description

The Quinsam River diversion route conveys diverted water from the Quinsam River to Lower Campbell Lake reservoir, where the diverted water is then used for hydroelectricity generation at the Ladore and John Hart facilities. The diversion dam is located 47.4 km from the mouth of the

Quinsam River and was constructed in 1957. The diversion route flows from the point of diversion at the Quinsam River Diversion Dam, through Gooseneck Lake (0.78 km^2) and Snakehead Lake (0.20 km^2), and into Miller Bay in the southern side of Lower Campbell Lake reservoir (Map 2).

Consistent with the terms of reference (TOR; BC Hydro 2013), we refer here to the entire diversion route as 'Miller Creek'. This therefore includes the ~1.8 km canal that conveys water from the diversion dam to Gooseneck Lake (Burt 2003), as well as the natural channels downstream that convey water to Lower Campbell Lake reservoir via Snakehead Lake.

3.1.2. Hydrology and Diversions

3.1.2.1. 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 minimum flows (when naturally available; Table) and maximum down-ramping rates (Table) in the Quinsam River downstream of the diversion dam.

Table 1. 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

Table 2. 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

3.1.2.2. Historic Discharge Data

The Water Survey of Canada (WSC) maintains a hydrometric gauge at one site in the Quinsam River diversion route, immediately downstream of the diversion dam (Map 2; WSC 2015). 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 3).

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

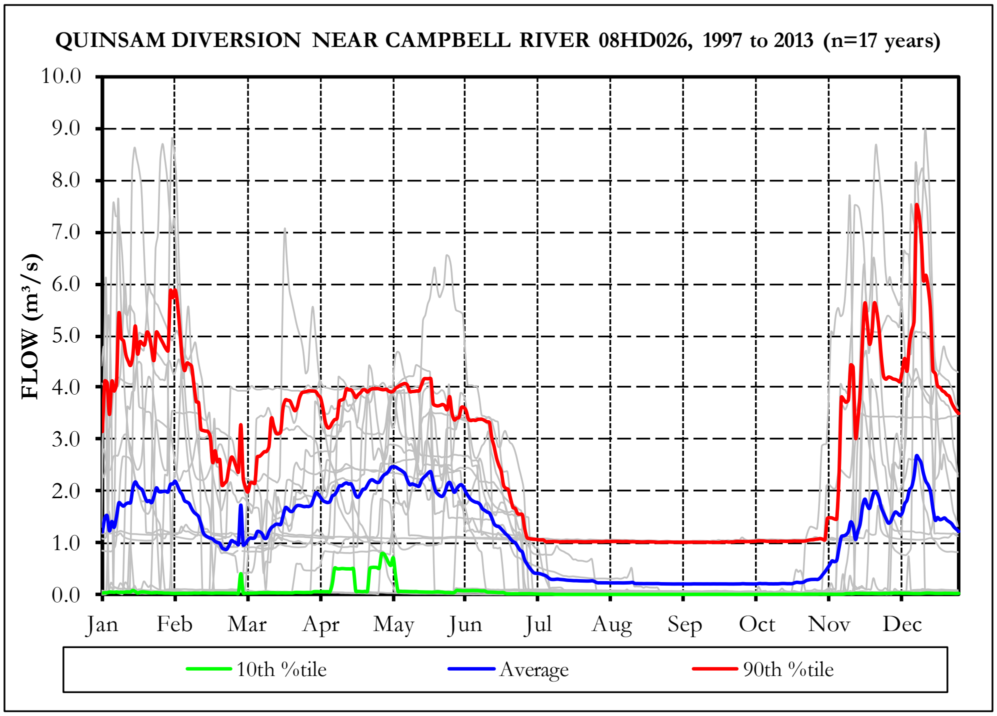


Table 3. Monthly flow statistics for the Quinsam River Diversion near Campbell River 1997–2013, *n* = 13 years (WSC gauge 08HD026; WSC 2015).

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

3.1.3. Fish Species and Periodicity

Fish species present in Miller Creek include Cutthroat Trout (*Oncorhychus clarkii*) and resident Rainbow Trout (*O. mykiss*) (Lough 2000, Hatfield *et al.* 2016). Dolly Varden (*Salvelinus malma*) are present in Lower Campbell Lake reservoir (Michalski 2014) and therefore this species may also use habitats in Miller Creek in the reach upstream of Lower Campbell Lake reservoir, e.g. during spawning. Coastrange Sculpin (*Cottus aleuticus*) and Threespine Stickleback (*Gasterosteus aculeatus*) are also present in Miller Creek (AMEC 2004).

Miller Creek is inaccessible to anadromous salmonids: the Quinsam River Diversion Dam lies upstream of the upstream limit to anadromous salmonid distribution on the Quinsam River (Burt 2003), while anadromous salmonids are impeded from migrating upstream to Lower Campbell Lake reservoir by John Hart and Ladore dams.

Periodicity information for Cutthroat Trout, Rainbow Trout and Dolly Varden is presented in Table 4.

Table 4. Spawning and incubation periods for salmonids present/potentially present in Miller Creek. Based on Effective Spawning Habitat model applied to Lower Campbell Lake reservoir (Hatfield *et al.* 2016).

Species	Period	Start	End	Peak
Cutthroat Trout	Spawning	01-Mar	30-Apr	22-Mar
	Incubation	01-Mar	15-Jul	
Rainbow Trout	Spawning	15-May	31-Jul	08-Jun
	Incubation	15-May	15-Aug	
Dolly Varden	Spawning	08-Oct	08-Dec	01-Nov
	Incubation	08-Oct	15-Apr	

3.1.4. Fish Habitat

Habitat data pertaining to Miller Creek were collected in 2000 by AMEC (2004), based on a Level 1 Fish Habitat Assessment procedure (Johnson and Slaney 1996). The reach breaks defined in that study are broadly consistent with those defined during the reconnaissance site visit (Section 4), shown on (Map 4).

Miller Creek is 9.7 km long, comprising 2.1 km lake habitat, 1.5 km wetland and 6.1 km stream habitat. Upstream of Lower Campbell Lake reservoir, there is a 400 m section of creek consisting of slow flowing pool habitat that flows through a wetland. Upstream, there is a 5.3 km section that comprises three reaches downstream of Snakehead Lake. This section predominantly consists of riffle habitats and includes a high gradient (9.0%) section located 1.2–1.7 km upstream of the reservoir. Small falls (0.5 m) present a partial barrier in this section and it is unlikely that fish in Lower Campbell Lake reservoir migrate through this reach to spawn upstream, while habitat downstream is used for spawning by adfluvial populations of Cutthroat Trout and Rainbow Trout (Lough and Hay 2001). There are four defined reaches between Gooseneck Lake and Snakehead

Lake; these include low gradient pool habitats, a pond, and a 600 m reach that predominantly includes riffle and glide habitats. Upstream of Gooseneck Lake, there is a 200 m reach that has mainly gravel substrate. This provides spawning habitat for resident salmonids in the lake (Lough and Hay 2001). There are cascades ~200 m upstream of Gooseneck Lake that are a barrier to upstream fish migration. The diversion canal extends for ~1.6 km upstream of these cascades. The canal conveys diverted water from the diversion dam to Gooseneck Lake, and primarily consists of uniform glide habitat with limited cover for fish.

3.2. Salmon River

3.2.1. Watershed Description

The Salmon River is located in central Vancouver Island with headwaters originating in the Vancouver Island Ranges in the north end of Strathcona Park (Map 3). 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).

3.2.2. Hydrology and Diversions

3.2.2.1. 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 5), maximum diversion flows to enhance fish screen efficiency (Table 6), 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 5. 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 6. 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

3.2.2.2. Historic Discharge Data

The WSC 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 7). Monthly mean discharge is highest in April (8.7 m^3/s) and May (10.3 m^3/s; Table 7).

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 3; Table 8). 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 4; Table 9). 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 2. Historic discharge data for the Salmon River Diversion (WSC gauge 08HD020; WSC 2015).

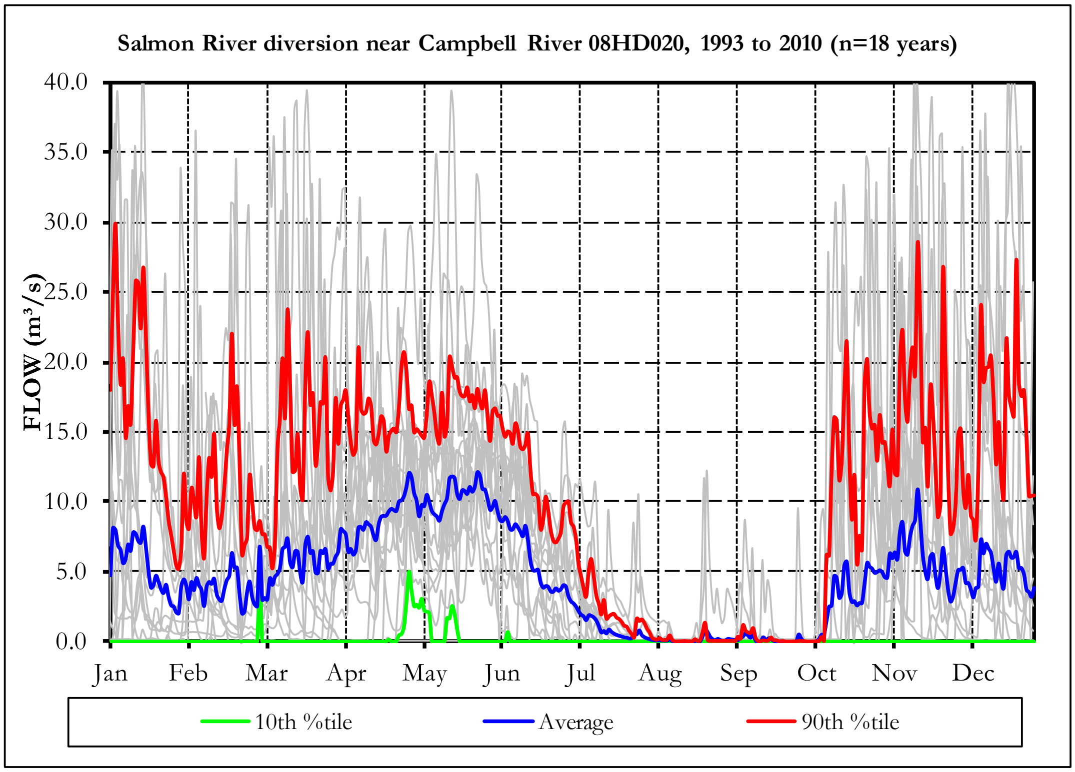


Table 7. Monthly flow statistics for the Salmon River Diversion 1993–2010, *n* = 18 years (WSC gauge 08HD020; WSC 2015).

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

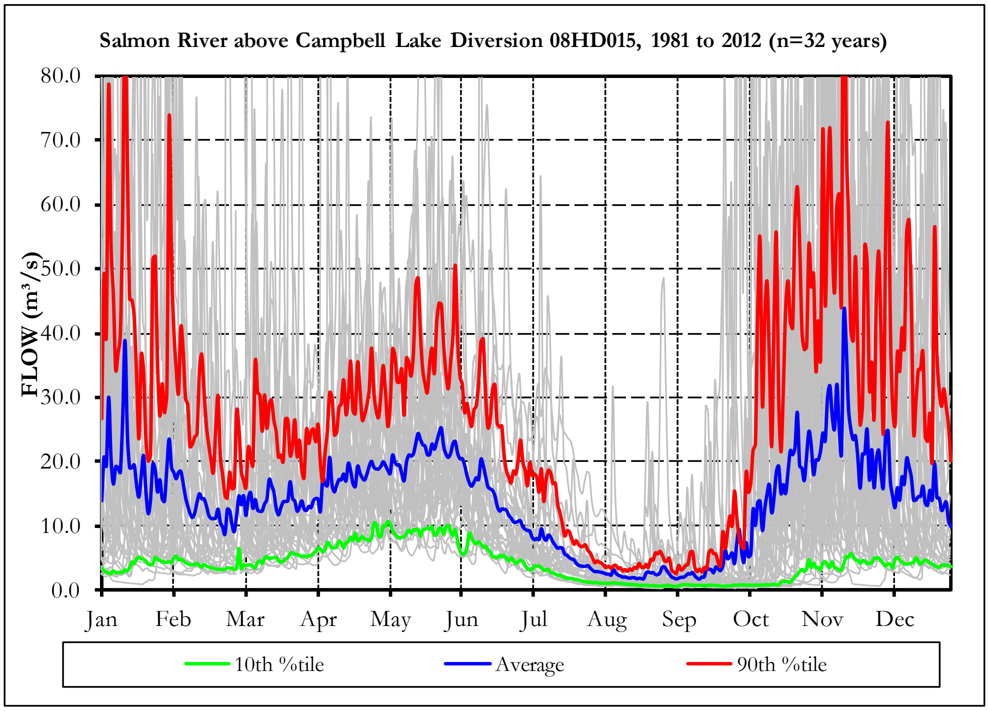


Table 8. **Monthly flow statistics for the Salmon River, above the Salmon River Diversion 1981–2012, *n* = 32 years (WSC gauge 08HD015; WSC 2015).**

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

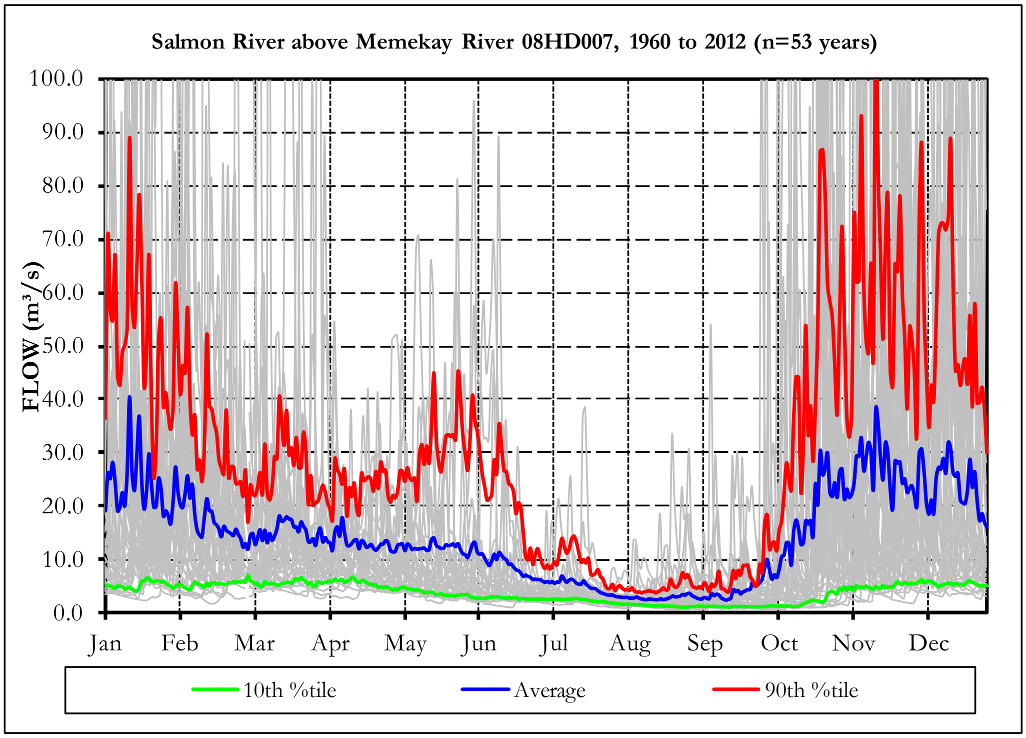


Table 9. **Monthly flow statistics for the Salmon River, upstream of the Memekay River confluence 1960–2012, n = 53 years (WSC gauge 08HD007; WSC 2015).**

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

3.2.3. Fish Species and Periodicity

The Salmon River supports a variety of anadromous and resident fish. Fish species known to inhabit the Salmon River include: Pink Salmon (*O. gorbuscha*), Coho Salmon (*O. kisutch*), Chum Salmon (*O. keta*), Chinook Salmon (*O. tshawytscha*), Sockeye Salmon (*O. nerk;* low abundance), steelhead (*O. mykiss*), Kokanee (*O. nerka*), Rainbow Trout, Cutthroat Trout (anadromous and resident), Dolly Varden, Coastrange Sculpin, Slimy Sculpin (*C. cognatus*), Threespine Stickleback and lamprey (*Lampetra spp.*) (Burt and Robert 2001, Burt 2010). Atlantic Salmon (*Salmo salar*; non indigenous) has also been noted in the Salmon River (Burt and Robert 2001, Burt 2010). A summary of the life history periodicity for fish species in the Salmon River is provided in Table 10.

The JHTMON-6 assessment of flow-habitat relationships focuses on the Salmon River mainstem from the diversion dam to the confluence with the Memekay River (Map 3). Based on information presented in Burt (2010), this reach is upstream of the limits to distribution for Chum Salmon and Pink Salmon, while Coho Salmon, steelhead and anadromous Dolly Varden are distributed throughout the reach. The upstream limit to distribution for Chinook Salmon reported by Burt (2010) is the Memekay River confluence, although work proposed in fall 2016 and 2017 as part of the JHTMON-6 fish passage assessment will seek to confirm this.

Table 10. 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.

3.2.4. Fish Habitat

A detailed review of fish habitats in the Salmon River is provided by Burt (2010), which provides an update to a review conducted by Burt and Robert (2001). This updated review summarizes the findings of numerous studies, including detailed field assessments undertaken in 1975–1976 by

Ptolemy *et al*. (1977), and data collection undertaken in 2006 and 2007 by Silvestri and Gaboury (2008), based on Level 1 and 2 Fish Habitat Assessment procedures (Johnson and Slaney 1996).

The JHTMON-6 assessment of flow-habitat relationships focuses on the Salmon River mainstem from the diversion dam to the confluence with the Memekay River (Map 3). Based on Burt (2010), this section predominantly comprises two reaches. The first extends upstream for 6.0 km from the Memekay River confluence to the confluence with Kay Creek (Reach 3, Map 5). The channel is unconfined and braided, with an average width of 130 m. The average gradient is 0.4% and habitats consist of pool-riffle sequences with medium complexity and substrates dominated by cobble and gravel. The second reach (Reach 4, Map 5) extends 16.6 km upstream from the Kay Creek confluence to Paterson Creek, which joins the mainstem ~1.5 km downstream of the diversion dam. In this reach, the channel is meandering with point bars, has an average width of 52 m, and an average gradient of 0.8%. This reach includes a canyon situated 2 km upstream from the Kay Creek confluence; blasting was undertaken here in the late 1970s to improve fish passage. Based on Ptolemy *et al*. (1977) dominant habitats are riffles and pools downstream of the canyon, riffles and rapids in the canyon, and riffles and glides upstream of the canyon. Substrates in this reach are dominated by cobbles and gravels, except in the canyon where boulders and bedrock dominate.

The mid reaches of the Salmon River provide valuable rearing habitat for juvenile Coho Salmon (Anderson 2009) and steelhead (Pellett 2012, 2014). Sampling of juvenile Coho Salmon and steelhead is currently being undertaken as part of JHTMON-8; this program includes multiple sites in this section of the river and continues sampling that was historically undertaken by DFO and BCCF, respectively.

4. RECONNAISSANCE SITE VISITS

4.1. Purpose

Reconnaissance site visits were conducted to each of the two study streams to collect data to assist with developing the recommended approach. The purpose of the site visits was to select study sites and confirm that study reaches were suitable for proposed methods. This was primarily based on evaluating stream habitat characteristics such as mesohabitat type, channel width, and channel braiding. Any access limitations were also considered.

4.2. Reconnaissance Site Visit Methods

Prior to conducting the field site visits, a desktop review was undertaken to identify reach breaks and identify suitable areas for conducting an instream flow study (IFS). This involved reviewing previous fish habitat assessments (AMEC 2004; Silvestri and Gaboury 2008), maps, hydrological data maintained by WSC (2015), and additional studies (e.g., Burt 2010).

One to three sites were visited within each of the target reaches on Miller Creek and the Salmon River. At each site, information collected included: site photos, GPS coordinates, meso-habitat type, gradient, fish cover, bank full width, channel type (multiple/single), IFS suitability (high, medium, low), and access details.

4.3. Reconnaissance Site Visit Outcomes

A total of 14 sites within 7 reaches of Miller Creek and 13 sites within 3 reaches of the Salmon River were visited from February 9 to 11, 2016. The locations of the sites visited and previously established reach breaks (AMEC 2004, Silvestri and Gaboury 2008) are shown on Map 4 and Map 5.

4.3.1. Miller Creek

A summary of information collected during site visits to Miller Creek is provided in Table 11. Representative photos of each site visited are provided in Appendix B. The following descriptions summarize additional information for each reach that is relevant to IFS design.

Table 11. Summary of habitat data collected during reconnaissance site visits to Miller Creek, February 9–11, 2016.

Date	Site Name	UTM Zone	Easting (m)	Northing (m)	Habitat	Gradient (%)	Cover[1] (D/SD)[2]	Bankfull Width (m)	Channel	Suitabilty for IFS Transects	Access
9-Feb-2016	MIL-RE02B	10U	324376	5539060	Riffle	1.5-2.0	CO/OV	9.0	Single	High	Moderate
9-Feb-2016	MIL-RE02A	10U	324339	5539367	Riffle	1.5	OV/LWD	11.0	Mulitple	Moderate	Moderate
9-Feb-2016	MLR-RE03A	10U	324122	5538633	Cascade/Riffle	5.0	BO/OV	11.0	Single	Low	Good
9-Feb-2016	MLR-RE04A	10U	323017	5538185	Riffle	1.5	OV/BO	8.5	Single	High	Good
9-Feb-2016	MLR-RE04B	10U	322415	5538120	Riffle	1.0	DP/LWD	12.0	Single	Low	Good
9-Feb-2016	MLR-RE04C	10U	322191	5537857	Glide	0.5	OV/LWD	-	Single	High	Good
11-Feb-2016	MLR-RE04D	10U	320870	5537910	Glide	0.5	DP/ IV	20.0	Single	High	Good
9-Feb-2016	MLR-RE07A	10U	320242	5537361	Riffle	1.5	BO/LWD	10.3	Single	High	Good
9-Feb-2016	MLR-RE09A	10U	319913	5537362	Glide	-	OV/IV	-	Multiple	Low	Moderate
11-Feb-2016	MLR-RE09C	10U	319630	5537202	Riffle/Glide	0.5	OV/IV	-	Multiple	Low	Moderate
11-Feb-2016	MLR-RE09D	10U	319604	5537129	Riffle	0.5	OV/LWD	5.0	Multiple	Low	Moderate
11-Feb-2016	MLR-RE09B	10U	319721	5537156	Riffle/Glide	1.5	CO/OV	8.0	Multiple	Moderate	Moderate
9-Feb-2016	MLR-RE11A	10U	318876	5535356	Riffle	2.0	SWD/CO	11.5	Single	Moderate	Good
9-Feb-2016	MLR-RE12A	10U	318930	5534768	Ditch-Run	-	OV/IV	7.2	Single	Moderate	Good
9-Feb-2016	MLR-RE12B	10U	318919	5534724	Flume-Run	-	NO	-	Single	-	Good

[1] Cover type: BO-boulder; CO-cobble; DP-deep pool; IV-instream vegetation; LWD-large woody debris; NO-none; OV-overhanging vegetation; SWD-small woody debris
[2] D-Dominant; SD-Subdominant

Reach 1 is a 400 m-long section immediately upstream of Lower Campbell Lake. The reach primarily comprises low velocity glide and pool habitat (AMEC 2004). This reach was not investigated during the site visits because water levels in the reach are affected by reservoir elevation and therefore habitats exhibit limited sensitivity to changes in flow related to diversion operations.

Reach 2 is a 800 m-long section of riffle habitat that is accessible to adfluvial salmonids from Upper Campbell Lake. Multiple channels are present in some sections, which may require additional field effort to collect IFS data relative to sections where the stream is confined to a single channel. Access was rated as moderate, with a single egress point at the forest service road bridge crossing near the top of the reach.

Reach 3 is a 500 m-long section comprising steep gradient riffles and cascades. The substrate is primarily bedrock. The reach was considered to be poor quality fish habitat and less susceptible to flow change due to narrow channel width. There is a series of cascades and small falls (0.5 m) located 500 m from the downstream end of this reach. AMEC (2004) concluded that it is unlikely that adfluvial trout from Lower Campbell Lake migrate upstream past this barrier.

Reach 4 is a 4 km-long section downstream of Snakehead Lake. The habitat largely comprises single channel riffle, with occasional braided sections. Access is good as Highway 28 is located within 500 m throughout the reach. This reach contains good quality fish habitat, as substantiated by high catches of Cutthroat Trout during minnow trap sampling in 2004 (AMEC 2004).

Reach 5 consists of Snakehead Lake. It was excluded from the reconnaissance site visits due to its poor suitability for IFS (habitat is largely invariant with flow).

Reach 6 is a 500 m-long section of deep pool habitat that meanders through a wetland immediately upstream of Snakehead Lake (AMEC 2004). It was not considered to be highly sensitive to flow changes, and was therefore not inspected during the site reconnaissance visits.

Reach 7 is a 600 m-long moderate gradient, single channel reach between Snakehead and Gooseneck lakes. The reach has a high abundance of riffle habitat and seems to have good quality fish habitat, as supported by high catches of Cutthroat Trout by AMEC (2004).

Reach 8 is a short, 100 m-long section of wetland located about 500 m downstream of Gooseneck Lake. This reach was excluded from the reconnaissance site visits due to poor suitability for IFS (habitat is largely invariant with flow).

Reach 9 is a 400 m-long section at the outlet of Gooseneck Lake. The upper portion of this reach contains a high abundance of riffle habitat, and contains good quality fish habitat, as supported by fish sampling by AMEC (2004). The majority of the flow is in a single channel, although there are smaller braids at the outlet of Gooseneck Lake that appear to offer some fish habitat during higher flow periods. Access to this section is moderate with road access within 400 m of the stream.

Reach 10 is Gooseneck Lake, and was excluded from the reconnaissance site visits due to poor suitability for IFS (habitat is largely invariant with flow).

Reach 11 is a 200 m-long accessible length of stream upstream of Gooseneck Lake, and downstream of an impassable falls. This section contains a high abundance of riffle habitat, but it is highly braided and appears unstable. It appeared to offer moderate quality fish habitat, and low catches were recorded by AMEC (2004).

Reach 12 consists of a diversion canal and concrete flume downstream of the diversion dam. It contains homogenous habitat and is considered to be poor quality fish habitat.

4.3.2. Salmon River

A summary of information collected during site visits to the Salmon River is provided in Table 12. Representative photos of each site visited are provided in Appendix B. The following descriptions summarize additional information for each reach that is relevant to IFS design. Information is presented for reaches 3–5 (based on Silvestri and Gaboury 2008), which encompass the JHTMON-6 study section.

Table 12. Summary of habitat data collected during reconnaissance site visits to the Salmon River, February 10–11, 2016.

Date	Site Name	UTM Zone	Easting (m)	Northing (m)	Habitat	Gradient (%)	Cover[1] (D/SD)[2]	Bankfull Width (m)	Channel	Suitabilty for IFS Transects	Access
10-Feb-2016	SAM-RE03A	10U	302609	5567494	Riffle/Glide	1.0	CO/LWD	79.0	Multiple	Moderate	Good
11-Feb-2016	SAM-RE03B	10U	303054	5566708	Riffle/Glide/Pool	1.0	CO/DP	140.0	Single	High	Moderate
11-Feb-2016	SAM-RE03D	10U	304110	5564194	Riffle/Glide	1.0	CO/BO	45.0	Single	High	Good
11-Feb-2016	SAM-RE03C	10U	303725	5564989	Riffle/Glide	1.3	CO/LWD	75.0	Multiple	Moderate	Good
10-Feb-2016	SAM-RE04D	10U	309300	5556583	Riffle/Glide	1.0	BO/CO	23.3	Single	High	Good
10-Feb-2016	SAM-RE04C	10U	306869	5559680	Riffle/Pool	1.5	BO/CO	78.7	Multiple	Moderate	Good
10-Feb-2016	SAM-RE04B	10U	306758	5559738	Glide/Riffle	1.0	BO/CO	37.0	Single	High	Good
10-Feb-2016	SAM-RE04CYN	10U	305777	5562294	Riffle/Glide	2.0	CO/DP	34.0	Single	High	Poor
11-Feb-2016	SAM-RE04A	10U	304341	5564139	Riffle/Glide	1.3	CO/BO	45.0	Single	High	Good
10-Feb-2016	SAM-RE05D	10U	308923	5552475	Riffle/Glide	1.5	BO/DP	24.2	Single	High	Good
10-Feb-2016	SAM-RE05C	10U	309061	5552559	Riffle/Pool	1.0	DP/BO	25.0	Single	High	Good
10-Feb-2016	SAM-RE05B	10U	309484	5553022	Riffle/Glide	1.5	BO/CO	42.0	Single	High	Moderate
10-Feb-2016	SAM-RE05A	10U	309691	5553221	Riffle/Glide	1.0	BO/DP	40.0	Multiple	Moderate	Moderate

[1] Cover type: BO-boulder; CO-cobble; DP-deep pool; IV-instream vegetation; LWD-large woody debris; NO-none; OV-overhanging vegetation; SWD-small woody debris
[2] D-Dominant; SD-Subdominant

Reach 3 is a 6 km section that extends from the Memekey River confluence upstream to the confluence with Kay Creek. Based on Burt (2010), this reach is accessible to adult steelhead and Coho Salmon, which access the upper watershed upstream of the diversion dam. The upstream limit of distribution for Chinook Salmon is recorded by Burt (2010) as the downstream end of this reach, although it is possible that adult individuals of this species migrate into the reach during some years, depending on flow conditions. This section largely comprises riffle and glide habitat. The channel width is typically >50 m, with extensive alluvial bars and channel braids. There is evidence of recent channel erosion and bank destabilization. Fish habitat quality is variable, with some areas offering suitable depth and velocity with instream cover, and other areas of over-widened, shallow habitat with minimal cover. Access to this reach is generally good, with one bridge crossing (Big Tree Mainline), and logging road spurs that provide access to within 200 m in a few locations.

Reach 4 is a 16.6 km section that extends from the Kay Creek confluence upstream to the confluence with Paterson Creek. This section of stream is primarily single channel, with bankfull widths typically of 30–40 m. There is one 2.5 km-long section that is heavily braided with an over-widened channel, located near Norberg Creek confluence (SAM-RE04C). This section is more typical of Reach 3. Fish habitat appears to be of moderate quality, with a high abundance of riffle and glide habitat. The channel appears generally more confined and stable than in Reach 3; consequently, it may offer better rearing habitat for juvenile salmonids under low flow conditions. Access is limited in large sections of this reach, with good access at two locations: Memekey Mainline Bridge crossing, and from the Memekey Mainline logging road downstream of Norberg Creek. Good access to the lower portion of Reach 5 and the upper portion of Reach 4 could also be obtained by drifting in a raft from Menzies Mainline down to Memekey Mainline. This would only be advisable under moderate flow conditions, as the boat would have to be pulled over shallow riffle areas when flows < ~5 m^3/s.

Reach 5 is a 2.5 km-long section that extends from the Paterson Creek confluence upstream to the Diversion Dam. Reach 5 is predominantly single channel riffle/glide habitat, and has similar characteristics to Reach 4. Fish habitat is moderate quality, and is fairly similar to Reach 4, although there is more bedrock substrate, particularly in the upper 1 km. Access is good in the 1 km section between the diversion dam and the Menzies Mainline Bridge crossing. Below the Menzies Mainline, there is moderate access adjacent to the diversion canal, which is located within ~100 m of the Salmon River for ~500 m before it flows to the east, away from the river. Access to areas from this point downstream to Patterson Creek confluence requires a hike of up to 500 m through mature second growth forest. Good access to the lower portion of Reach 5 could also be obtained by drifting in a raft down from the Menzies Mainline Bridge (see Reach 4 above).

5. RECOMMENDED APPROACH – DATA COLLECTION

5.1. Overview

Based on recommendations from our review of potential methods (Healey and Hatfield 2015; Appendix A), we propose to use habitat-rating methods to address the management questions. We will collect data to calibrate hydraulic habitat models to simulate depth and velocity over a range of flows. Model predictions will then be analyzed in association with species-specific information about habitat suitability to predict how flow changes affect the area of fish habitat in each stream. Further details about data analysis are provided in Section 6.2.

The following data for each stream are required for our analysis:

- depth, velocity and substrate data collected at transects during a range of flow conditions;
- stream discharge estimates for the study period; and
- area estimates of mesohabitats, e.g., riffle, glide, pool.

For both Miller Creek and Salmon River, transect surveys will be conducted at sites identified during the reconnaissance site visits (Section 4) using standard methods consistent with the BC Instream Flow Methodology (Lewis *et al.* 2004). Consistent with the TOR (BC Hydro 2013), surveys will be conducted at a minimum of 15 transects on Miler Creek and 20 transects on the Salmon River. We propose to measure each transect at three flow conditions. The proposed number of target flow conditions is less than that specified in the TOR (a minimum of five; BC Hydro 2013), but the method described in the TOR to derive flow-habitat relationships is based on a statistical method to fit an empirical relationship between flow (m^3/s) and habitat (e.g., weighted usable area), whereas we have proposed to use 1D or 2D physical habitat models to simulate velocity and depth characteristics for a range of flows (see Section 6.2). Such models use hydraulic principles to derive these relationships and can be configured based on fewer measurements than empirical approaches; further discussion of IFS methodologies is presented in Healey and Hatfield (2015; Appendix A). The adoption of this approach was reviewed and accepted by BC Hydro (Alf Leake) in 2015.

For Miller Creek, discharge is currently only monitored in the diversion canal, upstream of Gooseneck Lake (Map 2). Therefore, there is uncertainty about flow conditions in Miller Creek in the section between Gooseneck and Snakehead lakes, and downstream of Snakehead Lake, especially when the diversion is not operating. Accordingly, we propose to install two hydrometric gauges in these sections of the stream to improve understanding of how discharge varies spatially in the stream. For the Salmon River, we expect that sufficient information about flow conditions in the study section will be available from existing WSC gauges (Map 3).

For Miller Creek, mesohabitat information will be obtained from results of the Level 1 Fish Habitat Assessment that was previously completed (AMEC 2004). For the Salmon River, mesohabitat information for the braided section will be obtained primarily from analysis of aerial imagery, which will be validated with field measurements. Mesohabitat information for the shorter unbraided section will be obtained from a Level 1 Fish Habitat Assessment (Silvestri and Gaboury 2008) previously completed upstream of Kay Creek (Map 3).

5.2. Miller Creek

Consistent with the TOR (BC Hydro 2013), we propose to conduct monitoring at 15 transects in Miller Creek (Table 13). Data will be collected to apply a 1D hydraulic habitat model, which is appropriate for this channel morphology. Transects will be sited in four reaches that contain good quality fish habitats that are relatively sensitive to flow changes. These four reaches comprise a total length of 6.2 km, ~55% of the length of Miller Creek. We propose to measure each transect at three flow conditions: 1) summer baseflow (diversion flow <0.5 m^3/s); 2) moderate flow (diversion flow ~1.0 m^3/s); 3) high flow (diversion flow ~5.0 m^3/s). Flow ranges are approximate and the actual flows sampled will depend on the hydrologic characteristics of the study period. This is particularly the case for the highest target flow: this value has been selected to be representative of high diversion flows yet not be too high to prohibit safe collection of transect measurements.

Transect surveys will be conducted based on guidelines (Lewis *et al*. 2004), which prescribe methods in detail. Briefly, 14 transect locations will be selected using a stratified-random approach by randomly selecting sites within predetermined reaches that have been identified based on biological (good fish habitat) and physical (sensitivity to flow change) criteria (Table 13). One additional transect (for a total of 15) will be selected to represent the best available spawning habitat in Reach 2, as this reach is accessible to adfluvial trout from Lower Campbell Lake. Transects will be named, marked and georeferenced. Pins will be installed at the end of each transect and the elevation of the pins will be recorded relative to a benchmark. Water level sensors (Solinst Leveloggers) will be installed at each transect location to monitor how stage changes relative to discharge over the course of the study. Streambed topography data will be collected during the first sampling trip by using a rod and level to take measurements at a minimum of 20 verticals at each transect. Water depth and velocity will be measured during each survey, while substrate size and instream cover will be recorded for each vertical on one sampling date. Depth and velocity measurements will be collected at a minimum of 15 verticals at each transect, using equipment and procedures described in RISC

(2009). Specifically, velocity measurements will be collected using a Price-type velocity meter at 60% depth from the water surface to estimate average water column velocity if depth < 0.75 m; if depth ≥ 0.75 m, additional measurements will be made at 20% and 80% of the water column depth to obtain more precise estimates of average water column velocity. Water velocity will also be recorded at multiple depths (i.e., 20%, 60%, and 80% of column depth) if the velocity profile is irregular due to instream obstructions. Complete depth and velocity surveys will be collected at each transect during the two lowest target flows. We expect that it will be necessary to only collect depth measurements during the highest target flow, although this will be confirmed following initial analysis of the distribution of velocity data collected at lower flows. Substrate and cover data will be recorded based on classifications defined in RISC (2001). Coverage of substrate classes (e.g., gravel) will be estimated and recorded as a percentage; fish cover (e.g., overhanging vegetation) within each cell will be recorded. For braided channels, data will be collected for a maximum of two transects per site. The bed elevation, water surface elevation, and sensor elevation will be surveyed at each transect location.

Depth and velocity measurements at transects will be used to estimate discharge in each reach on each sample date. In addition, two hydrometric gauges (Solinst Leveloggers) will be installed at sites in Reach 4 (downstream of both diversion lakes) and in Reach 7 (in between Gooseneck and Snakehead lakes) to monitor discharge during the monitoring period (Table 13). Four discharge measurements will be required at each hydrometric gauge site to develop a stage-discharge rating curve. The discharge transects will be conducted in the most suitable location to obtain an accurate estimate of stream flow, and therefore they may be situated in a different location to IFS transects. The discharge time series from each reach will provide information on spatial distribution of flow conditions in Miller Creek downstream of the diversion canal and how conditions vary with flow diversion at the dam, including during periods when no diversion occurs. In addition, two water level loggers will be installed at side channels near the outlet of Gooseneck Lake. During the reconnaissance site visits (Section 4), these were identified as areas of moderate–high quality fish habitat that are particularly sensitive to dewatering. Installing water level loggers will help to understand how the extent of these habitats changes with flow.

Table 13. Proposed distribution of transects in Miller Creek by reach (Map 4).

Reach	River km Downstream	River km Upstream	Habitat	# of Transects	Rationale	Comments
1	0.0	0.4	Pool and glide	0	Excluded because habitat is highly dependent on reservoir stage, rather than flow conditions	-
2	0.4	1.2	Pool-riffle-glide sequence	4	Good quality fish habitat including spawning habitats for adfluvial fish populations; flow sensitive	-
3	1.2	1.7	Cascades and small falls	0	Narrow channel; insensitive to flow; poor fish habitat.	-
4	1.7	5.7	Pool-riffle-glide sequence	5	Good quality fish habitat; primary reach d/s of diversion lakes; flow sensitive	Hydrometric gauge to be installed
5	5.7	5.9	Snakehead Lake	0	Not suitable for transect surveys	-
6	5.9	6.4	Slow meandering pool habitat in wetland	0	Insensitive to flow; not suitable for transect surveys	-
7	6.4	7.0	Pool-riffle-glide sequence	3	Good quality fish habitat; flow sensitive	Hydrometric gauge to be installed
8	7.0	7.1	Low velocity marshy habitat	0	Insensitive to flow; not suitable for transect surveys	-
9	7.1	7.9	Short braided reach below Gooseneck Lake; majority of flow conveyed through one channel at outlet; transitions into glide habitat upstream of Reach 7	3	Good quality fish habitat, potentially including spawning habitat; flow sensitive; abundant fish observed	Two water level loggers to be installed at side channels near outlet to measure change in habitat area
10	7.9	9.5	Gooseneck Lake	0	Not suitable for transect surveys	-
11	9.5	9.7	Short reach d/s of falls and u/s of lake	0	Short reach; fish habitat value uncertain	-
12	9.7	11.3	Diversion canal; relatively uniform glide habitat	0	Poor quality fish habitat	-

5.3. Salmon River

5.3.1. Overview

We propose to collect data to configure both 1D and 2D hydraulic habitat models (see Healey and Hatfield 2015; Appendix A) to derive flow–habitat relationships for the JHTMON-6 study section, which extends downstream from the diversion dam to the confluence with the Memekay River (Map 3). One-dimensional hydraulic habitat modelling will be used to derive a flow–habitat relationship for the upper ~18 km of this study section where the river is meandering and predominantly comprises a single channel. Two-dimensional hydraulic habitat modelling will be used to derive a flow–habitat relationship for the lower ~6 km of this study section where the river is braided, downstream of the Kay Creek confluence. Our proposed study design extends the scope of data collection outlined in the TOR, which specifies that a minimum of 20 transects should be surveyed throughout the study section. Instead, we propose to collect data at 20 transects in the upper area of the study section where the river is unbraided. In the braided section, we propose to collect detailed information throughout a 1 km survey reach using an unmanned aerial vehicle (UAV). This will be supplemented by additional fieldwork to address data gaps and validate data collected using the UAV, to support development of a digital surface model (DSM) of the stream channel.

In both sections, water level and velocity data will be collected in the field at three target flow conditions: summer base flow (< 4.0 m^3/s), 4.0 m^3/s (the minimum discharge that must be maintained during diversion; Section 3.2.2) and at high flow (>10 m^3/s).

5.3.2. Data Collection for 1D Model

Microhabitat data to support 1D modelling will be collected downstream of the diversion dam in Reach 4 and 5 (Map 5). Reach 4 extends 16.6 km upstream from the Kay Creek confluence to the Paterson Creek confluence. Reach 5 extends ~1.5 km upstream from the Paterson Creek confluence to the diversion dam. Together, these two reaches comprise the upper ~18 km of the study section where the river predominantly consists of a single channel.

Ten transects will be established throughout Reach 4 and a further 10 transects will be established throughout Reach 5, with sites selected randomly within representative mesohabitat types. Although Reach 4 (16.6 km) is much longer than Reach 5 (~1.5 km), we plan to sample the same number of transects in each reach because access is easier to Reach 4 and habitat characteristics are broadly consistent between reaches.

Water level sensors (Solinst Leveloggers) will be installed at each transect site to provide near-continuous records of stage for the study period. The existing hydrometric gauge (Salmon River below Campbell Lake Diversion, 08HD032; Map 3) will be used to determine discharge during field sampling and to derive relationships between discharge and stage measured at each transect. Transect surveys will be completed during the three target flow conditions described above. At the two lower flow conditions, transect surveys will be undertaken in accordance with guidelines (Lewis *et al.* 2004), as described above for Miller Creek (Section 5.2). During high flows, depth and velocity data will be collected during transect surveys using an acoustic Doppler current profiler (ADCP), as flow conditions are expected to be unsuitable to collect data safely by wading across the full width of the channel. Additional fish habitat information, including measurements of the relative distribution of mesohabitat types, will be obtained from a previous fish habitat assessment conducted in part of this reach by Silvestri and Gaboury (2008). In addition, we will review orthorectified aerial photographs, to estimate areas of mesohabitats in areas that were not previously sampled. These images have already been compiled; preliminary analysis has been completed, which will be extended during Year 2. These data will be validated by conducting a field-based fish habitat assessment of a ~4 km section that was not previously assessed by Silvestri and Gaboury (2008).

5.3.3. Data Collection for 2D Model

Microhabitat data to support 2D modelling will be collected within a section of Reach 3, which consists of braided habitat that extends ~6.0 km downstream of the Kay Creek confluence to the Memekay River confluence (Map 5). Within Reach 3, detailed data will be collected from a representative 1 km section. Detailed habitat data will be collected primarily by analyzing high resolution aerial imagery collected using a UAV. Additional field data will be collected to resolve gaps in survey coverage and validate measurements.

The UAV will be deployed over a two-day period to produce high-resolution orthorectified images of the 1 km survey reach. The UAV will be deployed when discharge is ~4.0 m^3/s. Multiple ground control points (GCPs) will be established along the survey reach and coordinates will be recorded for each GCP using a GPS. This information will be used with photogrammetry methods to derive a

DSM of the survey reach that includes the channel bed and bankfull width. The maximum depth that can be surveyed using the UAV will depend on water clarity; uncertainty regarding deeper areas will be addressed by collecting additional field measurements (see below). The UAV will also be used to collect detailed imagery to classify substrate composition; this will be accomplished by flying at low elevation, close to the streambed.

Further measurements of elevation will be collected in the field using a total station. These will be used to collect data for areas not surveyed by the UAV and to validate data derived from imagery. Specifically, total station surveys will be conducted to survey the elevation of: GCPs; water surface along the shoreline; the thalweg; bed surface beneath overhanging vegetation, and; deep and/or fast areas of the river that cannot be surveyed using the UAV. The elevation of wetted areas will be surveyed during each of the three target flow conditions

Water level sensors (Solinst Leveloggers) will be installed at the upstream and downstream ends of the 1 km survey reach. In addition, sensors will be deployed upstream, downstream and in the centre of sections where the channel bifurcates. Based on the reconnaissance site visits (Section 4) and inspection of aerial imagery, we anticipate that the survey reach will consist of a single channel that bifurcates at the upstream end then converges at the downstream end. Depending on the specific location within Reach 3, it is possible that the braided channels may join and then bifurcate once within the reach. Accordingly, we expect that it will be necessary to deploy 4–7 water level sensors to provide near-continuous records of stage throughout the study period.

Current velocity and depth measurements will be collected at sites throughout the survey reach to validate velocity predictions derived using the 2D model, and to determine stage/discharge relationships for individual channel braids. Depth and velocity measurements will be collected at each of the three target flow conditions. Data will be collected using a Price-type velocity meter deployed along transects that are perpendicular to braided channels to measure lateral differences in current velocity across the river, and to calculate stream discharge. Depth and velocity measurements will be also collected in the thalweg; we anticipate that this will require deploying an ADCP during the highest flow condition.

Coverage of substrate classes (e.g., gravel) will be estimated and recorded as a percentage at six sites close to GCPs. These data will be used to validate estimates of dominant substrate classes derived from analysis of imagery collected using the UAV.

5.4. Fieldwork Summary Table

Table 14. Summary of proposed fieldwork. Reach locations are shown in Map 4 and Map 5.

Stream	Target Flows	Reach	Methods	Data Requirements
Miller Creek	1. Summer baseflow (diversion flow <0.5 m^3/s) 2. Moderate flow (diversion flow ~1.0 m^3/s) 3. High flow (diversion flow ~5.0 m^3/s)	2	Transect (*n* =4) surveys; Leveloggers (temporary)	Mesohabitat type; depth and velocity at ≥ 20 points across channel; substrate size; spawning habitat presence; instream cover; near-continuous stage data collected using Levelogger; 4 discharge measurements to develop stage/discharge relationship
		4	Transect (*n* =5) surveys; Leveloggers (temporary)	
		7	Transect (*n* =3) surveys; Leveloggers (temporary)	
		9	Transect (*n* =3) surveys; Leveloggers (temporary)	
Salmon River	1. Summer base flow (< 4.0 m^3/s) 2. ~4.0 m^3/s 3. High flow (>10 m^3/s)	3	Deploy UAV to collect aerial photography; collect field data to augment/validate photography; Leveloggers (temporary)	Orthorectified images; digital surface model (based on images); substrate composition; elevation; velocity profiles; near-continuous stage records; stage/discharge relationships for bifurcated channels
		4	Transect (*n* =10) surveys; Leveloggers (temporary)	Mesohabitat type; depth and velocity at ≥ 20 points across channel; substrate size, spawning habitat presence; instream cover; near-continuous stage data collected using Leveloggers
		5	Transect (*n* =10) surveys; Leveloggers (temporary)	

6. RECOMMENDED APPROACH – DATA ANALYSIS AND REPORTING

6.1. 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. Hydrological time series data will be managed through the AQUARIUS Time-Series software and database.

6.2. Data Analysis

6.2.1. Development of Habitat-Flow Relationships ($H_0$1)

6.2.1.1. One-Dimensional Hydraulic Habitat Model

A 1-D model will be used to simulate physical habitat variables throughout study reaches that predominantly comprise a single (i.e., unbraided) channel; these are Miller Creek and Reach 4 and 5 of the Salmon River, downstream of the diversion dam (Map 5). A 1D hydraulic habitat model will be calibrated to simulate water depth and velocity at each transect across a range of flow conditions. The flow rates that can be reasonably simulated will depend on the flow rates sampled in the field, which are targeted to capture the range of flows expected in each diversion donor stream.

First, transect elevation, velocity, and substrate data will be screened for quality and imported into a 1D physical habitat simulation (PHABSIM) model (Healey and Hatfield 2015).

Second, a water surface model will be developed for each transect by deriving relationships between water surface elevation and discharge. These relationships will consider both discrete water surface elevation/discharge measurements and continuous water surface elevation/discharge data that are recorded using data loggers. These relationships will be fitted in the AQUARIUS rating curve toolkit or using nonlinear regression in a statistical software package and entered into the PHABSIM model. Relationships between transect wetted width, average depth, and average velocity will be simulated and compared to the discrete field measurements to ensure that the model reasonably reproduces the measured transect hydraulics.

Third, the PHABSIM software will be used to configure velocity models for each transect using the velocity measurements collected at each transect. One velocity model will be configured for each of the three sets of velocity data measured.

Finally, habitat simulations (depth and velocity) will be conducted over the range of flow conditions that are expected in each of the diversion donor streams. Flows will be selected for modelling such that the shape of the habitat-flow relationship can be well resolved, i.e., resolution will be finer at low flows (where the rate of habitat change with flow is typically high) and will be coarser at higher flows (where the rate of habitat change with flow is typically less). This resolution will minimize the likelihood that $H_0$1 will be erroneously retained as a result of a poorly-defined habitat-flow relationship.

6.2.1.2. Two-Dimensional Hydraulic Habitat Model

Two-dimensional modelling will be used to simulate physical habitat variables in the braided section of the Salmon River that extends ~6.0 km downstream of the Kay Creek confluence to the Memekay River confluence (Map 5). Within this section, a 2-D model hydraulic habitat model (e.g., using River2D) will be completed for a 1 km long representative reach. First, a DSM for this reach will be constructed by processing the UAV aerial photographs with photogrammetry software (Pix4Dmapper Pro) following the methodology of Tamminga *et al.* (2015). Elevation data collected using the total station will be used to supplement the DSM in locations where the aerial photography cannot adequately resolve the bed topography (e.g., undercut banks, sections of deep or rough water, stream thalweg).

Second, a 2D hydrodynamic model will be developed using the DSM-derived stream channel topography. The model will be calibrated for surveyed flow conditions to reproduce the observed longitudinal water surface profile, wetted extents, and flow distribution in the multiple-channel sections of the study reach.

Third, the model will be used to simulate the two other flow conditions for which water surface and flow distribution data were collected. The purpose of these simulations is to validate the model; however, if large departures from observed conditions are noted, the model will be adjusted to better reproduce the field measurements at all flow conditions sampled. At the locations where discrete transect measurements were taken, the measured transect depth and velocity data will be compared to the simulated depth and velocity data to ensure that the model hydraulics are reasonable.

Finally, hydrodynamic simulations will be run for a minimum of 10 flow conditions spanning the range of rearing and spawning flows that are expected in the Salmon River. Where possible, these simulations will be validated by comparing the water surface elevation at specific model points to water surface data collected by the corresponding water level recorders under similar flow conditions.

6.2.1.3. Habitat-flow Relationships

Habitat suitability criteria (HSC) for each fish species and life stage will be applied to the water depth and velocity data that are predicted by the hydraulic habitat models. We expect to model relationships for Rainbow Trout and Cutthroat Trout in Miller Creek; and Coho, Chinook, and Rainbow Trout/steelhead in the Salmon River. The selection of species and life stages will depend on the availability of approved or agreed-upon HSC. Where possible, HSC developed for WUP projects using the Delphi process will be applied; WUP Delphi criteria are available for Coho Salmon, Chinook Salmon, and steelhead rearing and spawning life stages. Habitat suitability at each station will be calculated as the product of the water depth, velocity, and substrate/cover suitability per Lewis *et al.* (2004). As described above, the habitat-flow relationship will be interpolated to flow conditions between and outside of the sampled flows using a mechanistic, rather than empirical, model, i.e., interpolation will be based on a hydraulic habitat model that is developed based on physical principles, rather than fitting a statistical function to the measured habitat quantities.

For the 1D model, the combined habitat suitability values will be weighted by station width to derive weighted usable width (WUW) versus flow relationships for each transect. For each habitat stratum, an average WUW versus flow relationship will be derived, and these relationships will be multiplied by the length of each stratum and summed across all strata to derive a weighted usable area (WUA) versus flow relationship. Bootstrap analysis will be performed using 1000 replicates to estimate 80%, 90%, and 95% confidence intervals for the flow-WUA curves.

For the 2D model, flow-WUA curves will be derived for the model reach via interpolation of habitat suitability between model nodes. This relationship will be assumed representative of the reach between the Kay Creek and Memekay River confluences, and scaled by a multiplier to account for the stream length that was not included in the model. The 1D and 2D flow-WUA curves for the Salmon River will be added together to obtain an overall flow-WUA curve for this stream.

The flow-WUA relationships will be used to evaluate $H_0 1$ by comparing the 95% confidence intervals across flow values. If the confidence intervals do not overlap to some extent at all flow levels, then WUA is concluded to be significantly different between at least two flow conditions and $H_0 1$ is rejected.

6.2.2. Comparison to Meta-Analysis Results ($H_0 2$)

To test $H_0 2$, the flow-WUA curves derived from the hydraulic habitat modelling will be compared to the meta-analysis curves that were used in the WUP, which we assume will be provided by BC Hydro. Each curve will be rescaled by dividing by the maximum value to obtain habitat values between 0 and 1.0, which will be directly comparable to the meta-analysis curves. Statistical analysis will be completed to examine similarities and differences between the two sets of curves, including a regression analysis and a calculation of difference statistics. Key statistics for each will be summarized to facilitate further comparison between the curves; these include the discharge of peak habitat area ("optimum flow"), rates of habitat change with flow, and range of flows where highly suitable habitat is present (e.g., curve value > 0.75). The meta-analysis curves will also be overlain on the bootstrapped confidence intervals described above to determine if differences between the meta-analysis curves and hydraulic habitat curves may be explained by heterogeneity of habitat. The effect of these differences on the WUP fish habitat PM will be quantified using a habitat time series analysis. The two sets of flow-WUA curves will be used to simulate habitat time series under the WUP flow scenarios, WUP PM calculations will be repeated, and the WUP flow scenarios will be ranked based on the PMs. The rankings obtained under the two sets of flow-WUA curves will be compared to determine whether application of a site-specific flow-WUA curve would change the fish habitat PM rankings of alternatives considered in the WUP. Our approach assumes that BC Hydro will provide the flow time series for the alternatives considered in the WUP.

6.2.3. Comparison to Fish Productivity Results ($H_0$3)

$H_0$3 will be tested within the scope of JHTMON-8 *Salmon River and Quinsam River Smolt and Spawner Abundance Assessments*. Specifically, this null hypothesis will be tested in concert with testing $H_0$2 of JHTMON-8:

> *Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA)*

Juvenile fish population abundance data to test this hypothesis are being collected annually as part of JHTMON-8. Fieldwork for this monitor commenced in 2014 and will continue to 2023 (JHTMON-8 Year 10). The fish sampling continues programs that were historically undertaken by other parties. Analysis to test this hypothesis will initially examine data collected as part of JHTMON-8, although, depending on resources, we will consider incorporating earlier data into the analysis to increase statistical power. For both streams, the analysis will consider Coho Salmon and steelhead, which are priority species of interest for JHTMON-6. For the Quinsam River, the analysis will also consider juvenile Chinook Salmon. The analysis will focus on spawning and rearing life stages.

For the Quinsam River, the hypothesis will be tested using data collected in the river mainstem. Population abundance data for juvenile fish will be obtained by sampling at the salmon counting fence at the Quinsam River Hatchery. Habitat data will be derived using flow-habitat relationships that have already been derived for the mainstem of the Quinsam River during the WUP planning process (BC Hydro 2013). The hypothesis will not be examined for Miller Creek because juvenile fish abundance data are not being collected for that stream.

For the Salmon River, juvenile Coho Salmon abundance will be estimated at six individual sites, based on sampling conducted in the early fall with beach and pole seine nets. Juvenile steelhead abundance will be estimated at ten sites based on electrofishing sampling. Habitat data will be derived using flow-habitat relationships developed in this study.

Analysis will initially involve using scatterplots and correlation analysis to examine relationships for each stream between habitat and fish abundance. Annual habitat availability will be quantified based on WUA, calculated using mean daily discharge and averaged over each period that is applicable to the species and life stage of interest, based on periodicity information for each river. Where appropriate, the use of additional metrics will be considered in the analysis, e.g., calculation of 7-day minimum WUA to examine the potential influence of short periods of poor quality habitat, which may be more directly related to fish abundance than WUA based on mean discharge. Abundance of individual species will be estimated based on JHTMON-8 sampling. For the Quinsam River, this will be based on the abundance of downstream migrating juveniles of each species estimated at the salmon counting fence, i.e., a single value per species, per year. For the Salmon River, this will be based on the abundance of rearing juveniles measured each year at multiple sampling sites distributed throughout the watershed. For each year, the geometric mean abundance measured across multiple sites on the Salmon River will be calculated to provide an overall annual metric of abundance for each species. The Salmon River sampling sites are not all located in the JHTMON-6 study reach and therefore the primary metric of abundance used for this analysis will be the geometric mean of abundance measured at sites within the JHTMON-6 study reach[1]. However, comparisons will be made between the geometric mean abundance at sites upstream and downstream of the diversion dam to examine any potential differences associated with the location of sampling sites relative to the diversion.

For each stream, fish abundance metrics will be calculated for separate age classes to reflect that the temporal focus of the analysis will vary depending on fish age, e.g., the abundance of 0+ fish is potentially dependent on the availability of spawning habitat during the most recent spawning period, whereas the abundance of 1+ fish is potentially dependent on the availability of spawning habitat during the year prior to that. We will attempt to extend the analysis by standardizing juvenile abundance based on the abundance of adult spawning fish (estimated using DFO escapement data). This will help to remove the potential influence of variability in adult escapement on juvenile abundance; however, this will be dependent on successfully deriving robust spawner-recruitment relationships. This task is scheduled for JHTMON-8 but it is yet to be determined whether data quality is sufficient.

If initial correlation analysis indicates that there is a relationship between juvenile fish abundance and habitat (i.e., evidence that JHTMON-6 $H_0 3$ can be rejected), then further analysis will be undertaken to quantify the influence of habitat availability on fish abundance relative to other potential limiting factors that are being considered in JHTMON-8 (e.g., food availability). This analysis will involve using general linear models to quantify the statistical power of different metrics to predict fish abundance that reflect individual JHTMON-8 hypothesises; see Abell *et al*. 2015 for further details. Results of this analysis will be used to evaluate the biological significance of any differences are between the flow-habitat predictions from this study and the meta-analysis curves that were used in the WUP.

The results of this analysis will be presented in JHTMON-8 reports; note that Year 3 (final year) of the flow-habitat component of JHTMON-6 aligns with only Year 4 of JHTMON-8, i.e., JHTMON-8 (ten year study) will be less than 50% complete when the final report for this study is submitted. The results of preliminary analysis to test this hypothesis will be presented during the interim JHTMON-8 presented at the end of JHTMON-8 Year 5. The final results will be presented at the end of JHTMON-8 Year 10.

6.3. Reporting and Deliverables

A Year 2 Annual Data Report will be submitted by March 31, 2017. This report will:

- describe the data collection methods;

[1] Of the ten JHTMON-8 juvenile steelhead sampling sites, three are in the JHTMON-6 study reach. Of the six JHTMON-8 juvenile Coho Salmon sampling sites, three are located in tributaries that flow into the JHTMON-6 study reach.

- summarize the data collected in each of the diversion streams;
- summarize progress with hydraulic habitat model development; and
- identify any outstanding data needs for collection in the following year.

A final report will then be submitted by March 31, 2017, at the end of Year 3. This report will:

- summarize all data collected to date;
- describe the hydraulic habitat model calibration and validation
- present all flow habitat relationships;
- report the outcomes of hypothesis testing and use these outcomes to address the management questions; and
- discuss how results relate to the current BC Hydro operations.

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PROJECT MAPS

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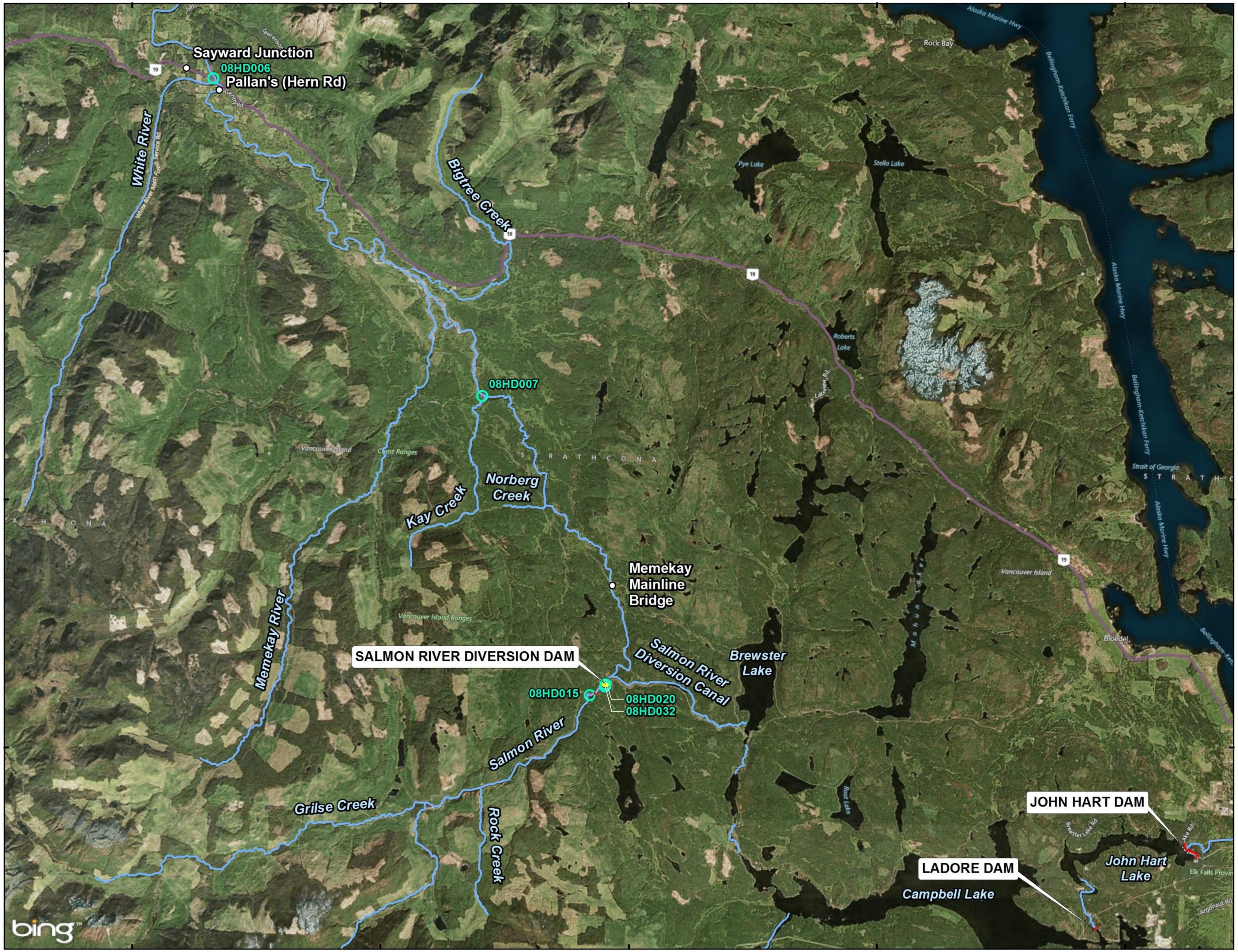

JHTMON Campbell River Water Use Plan

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

ECOFISH RESEARCH

Map 3.

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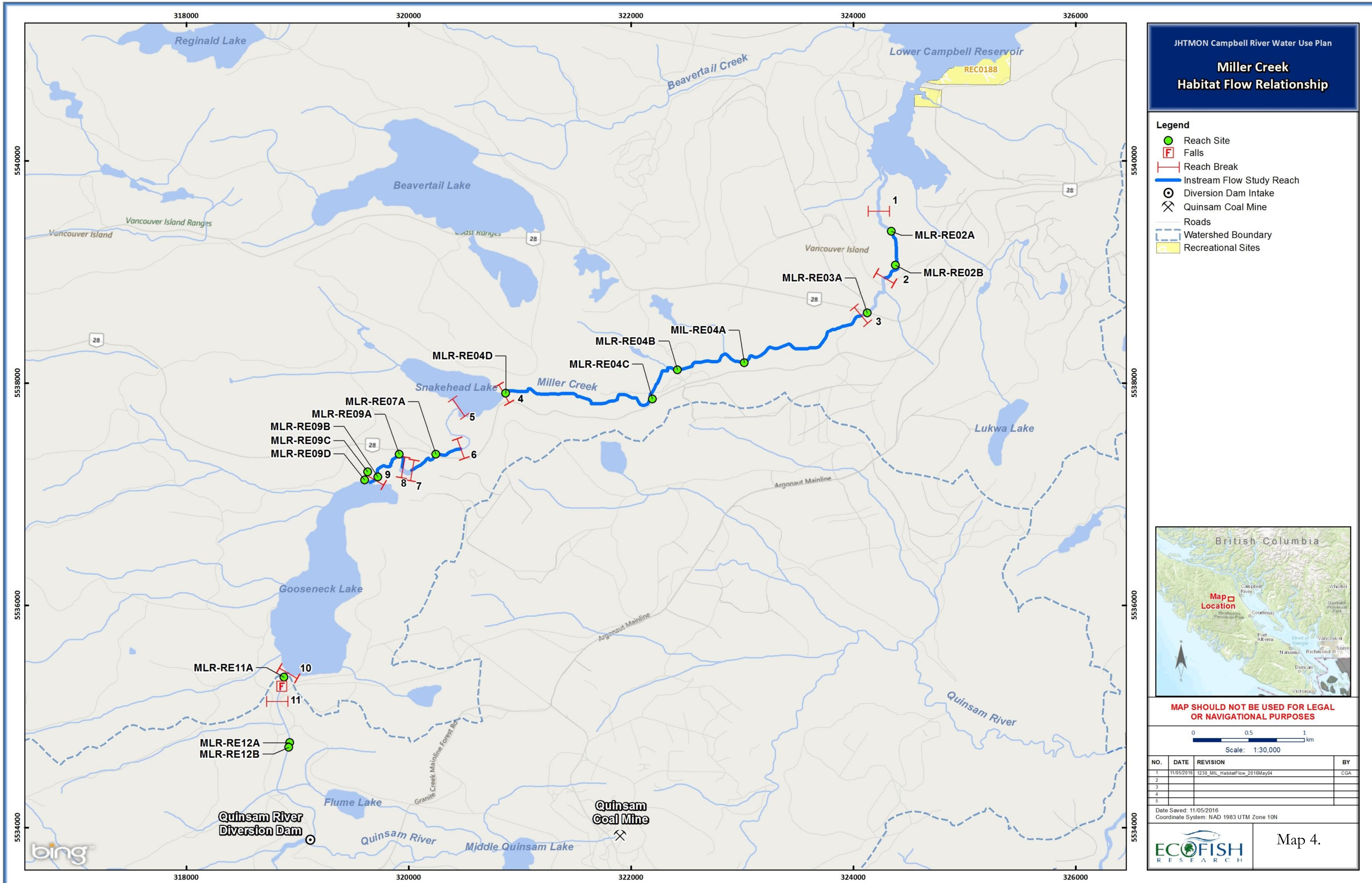

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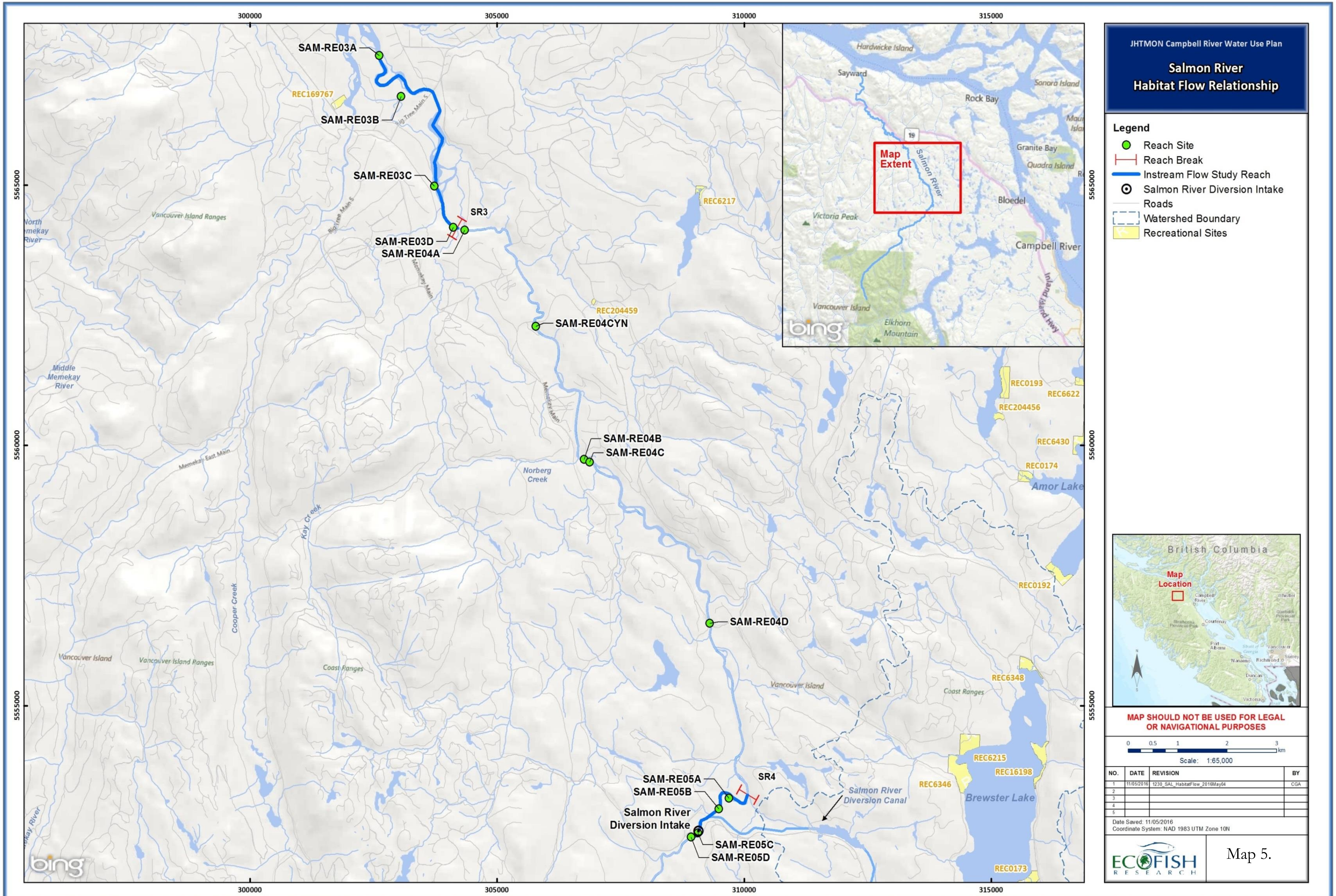

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APPENDICES