Bridge River Water Use Plan

Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed

Implementation Year 2

Reference: BRGMON#14

Study Period: 2013 Annual Data Report

University of British Columbia
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March 2014

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BRGMON-14

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Annual Report - 2013

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Cover photo: Seton Dam.

EXECUTIVE SUMMARY

Adult salmon migration in the Seton-Anderson watershed was studied for a second year as part of the BRGMON-14 monitoring program. The key objective of this five year program is to determine the effectiveness of BC Hydro's current mitigation measures for ensuring the successful migration of salmon past the Seton Generating Station and upstream of Seton Dam to spawning grounds. Current mitigation measures include dilution ratio targets during the Gates Creek and Portage Creek sockeye salmon migration periods and managing Seton Dam discharge for fish passage.

In 2013, adult salmon migration was monitored using radio, acoustic, and PIT telemetry and a fish counter at Seton Dam. Related water preference experiments tested the behavioural response of Gates Creek sockeye salmon and pink salmon to different dilution ratios. Water quality parameters important to migration were monitored and Acoustic Doppler Current Profiler (ADCP) measurements were used to characterize flow patterns in the Seton Dam tailrace. The acoustic telemetry, fish counter, and water quality programs continued from the previous year whereas all other programs were new for 2013. A fish fence in the lower Seton River was used to collect fish downstream of Seton Dam, although a portion of Gates Creek sockeye were captured from the Seton Dam fishway as in the previous year.

Analyses of Gates Creek sockeye salmon migration delay were confounded by elevated water temperatures. Migration rates and survival to Seton Dam were reduced with increased dilution ratio, but the highest dilution ratios coincided with near-lethal water temperatures for Gates Creek sockeye. Elevated temperatures were driven by environmental conditions, but exacerbated by Seton Generating Station shutdowns. In water preference experiments, Gates Creek sockeye avoided high dilution ratios and preferred pure Seton River water.

Passage success of Gates Creek sockeye salmon at Seton Dam was the highest yet observed with a 83% attraction efficiency and 98% passage efficiency for acoustic-tagged fish. Both fishway and fence-caught PIT-tagged fish had equally high passage success. Elevated temperatures at Seton Dam reduced both passage success and abundance. Consistent with 2012 results, females required increased swimming effort to enter the fishway, delayed longer, and had a lower attraction efficiency than males. A minimum 54,800 Gates Creek sockeye and 2,344 coho salmon passed Seton Dam, although these estimates are highly uncertain.

Pink salmon did not avoid high dilution ratios in water preference experiments and the high abundance of pink salmon limited the extent of Portage Creek sockeye and coho salmon migration monitoring. Survival of tagged Gates Creek sockeye salmon to spawning grounds was low, but survival was likely influenced by high temperatures during migration.

Challenges in 2013 included fish capture early in the Gates Creek sockeye salmon migration and estimating fish passage at Seton Dam due to incorrect fish counter wiring by BC Hydro. Future program years will require a fish fence downstream of Seton Dam to properly assess salmon migration success. Seton Dam passage studies would benefit from an experimental approach where conveyance structure use is manipulated while total Seton Dam discharge remains constant. Discharge manipulations could be combined with fish swimming activity and tailrace flow patterns, that were successfully characterized with ADCP in 2013.

BRGMON-14 STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES after Year 2

Objectives	Management Questions	Management Hypotheses	Year 2 (2013) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations? *And* How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?	H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 20%.	Gates Creek sockeye displayed a preference for Seton River water at a dilution ratio of 50% but not at 20% or 5%. Migration data did not indicate delay but further analysis and data collection are required. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.6, 3.9. Discussion: 4.1.2.
		H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 10%.	Migration of Portage Creek sockeye was studied in Year 2 but only during target dilution ratios. Water preference will be tested in the future. Hypothesis cannot be rejected at this time. Methods: 2.4. Results: 3.6. Discussion: 4.1.2.
		H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.	Gates Creek sockeye migration was studied across a range of dilution ratios in Year 2 but high water temperatures may have confounded results. Additional data are required. Hypothesis cannot be rejected at this time. Methods: 2.4. Results: 3.6. Discussion: 4.1.2, 4.1.3.
		H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.	Portage Creek sockeye migration could only be studied over a narrow range of dilution ratios. Additional data are required. Hypothesis cannot be rejected at this time. Methods: 2.4. Results: 3.6. Discussion: 4.1.2.

Objectives	Management Questions	Management Hypotheses	Year 2 (2013) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?	H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.	Pink salmon did not show a preference for Seton River water. Migration data suggests pink salmon did not delay but further data analysis is required. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.6, 3.9. Discussion: 4.1.2.
		H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.	Hypothesis could not be tested in Year 2 because no Chinook salmon were collected for study. Methods: 2.4.
		H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.	Coho were only captured in limited numbers in Year 2. Delay will be assessed with fish counter data and radio telemetry studies in future years. Methods: 2.3, 2.4. Results: 3.3, 3.6.
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.	Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam? *And* What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?	H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.	Attraction efficiency of acoustic-tagged Gates Creek sockeye was 69% in Year 1 and 83% in Year 2. High temperatures due to dam operations likely reduced attraction efficiency in Year 2. Additional data for all species under alternate operating conditions are required. Hypothesis cannot be rejected at this time. Methods: 2.2, 2.4. Results: 3.1.2, 3.2, 3.7. Discussion: 4.1.4, 4.1.5.
		H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.	Passage efficiency of Gates Creek sockeye was 89% in Year 1 and 98% in Year 2. Portage Creek passage was 94% in Year 2. Additional data for other species are required and will be collected in future years. Hypothesis cannot be rejected at this time. Methods: 2.2, 2.4. Results: 3.1.2, 3.2, 3.7. Discussion: 4.1.4, 4.1.5.

Keywords: Pacific salmon, *Oncorhynchus* spp., Seton River, Seton Dam, migration, fish passage, olfaction, telemetry.

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1.0 INTRODUCTION

The Bridge River Power Development Water Use Plan (WUP) was developed for BC Hydro`s operations in the Bridge River Basin and includes the Seton Dam and associated infrastructure in the Seton-Anderson watershed (BC Hydro 2011). Five Pacific salmon species migrate through the Seton-Anderson watershed including two genetically-distinct populations of sockeye salmon (*Oncorhynchus nerka*), coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and steelhead trout (*O. mykiss*) (BC Hydro 2000). The primary spawning grounds for salmon, with the exception of pink salmon, are upstream of the Seton Dam. To access spawning areas, adult salmon migrating up the Fraser River must pass the Seton Generating Station tailrace, enter the Seton River, negotiate the Seton Dam tailrace, and locate and ascend the Seton Dam fishway. Recommendations within the WUP by the Consultative Committee included the implementation of an adult fish passage monitoring program in the Seton-Anderson watershed to identify factors impeding the successful upstream migration of salmon through this migration route. Specifically, the Consultative Committee recommended the monitoring program address uncertainties in the effects of current Seton Dam and fishway operations on salmon passage and uncertainties in the effects of Seton River dilution by Cayoosh Creek on salmon migration.

Sockeye salmon passage through the Seton Dam fishway was recently examined in 2005 (Pon et al. 2006; Pon et al. 2009a, Pon et al. 2009b). A follow-up investigation in 2007 also monitored sockeye fishway passage as well as migration from the Seton Generating Station tailrace to spawning grounds above Seton Dam (Roscoe and Hinch 2008; Roscoe et al. 2010; Roscoe et al. 2011). Several impediments to salmon migration were identified in these studies including high discharge in the Seton River that hindered upstream migration and complex flow patterns in the Seton Dam tailrace that delayed migration and reduced fishway attraction efficiency. These impediments resulted in the majority of observed sockeye salmon migration failure downstream of Seton Dam (Roscoe and Hinch 2008). Upstream migratory failure was also observed as post-passage mortality in Seton Lake and Anderson Lake with physiological indicators in failed migrants suggestive of increased stress. Post-passage mortality was also significantly higher for females than males. Fishway passage efficiency was high in both study years.

Absent from previous investigations was a comprehensive analysis of the influence of discharge and tailrace flow patterns on salmon passage success at Seton Dam. Although a fish counter has historically been operated at the exit of the Seton Dam fishway, the low efficiency of the counter has not allowed Seton Dam operating conditions to be correlated with fish passage success. The studies in 2005 and 2007 provided some insight, but salmon passage could only be examined under five operating conditions and detailed information on Seton Dam water release patterns and associated flow conditions was not collected. In addition, the 2005 and 2007 investigations also primarily focused on sockeye salmon. Needed is a multi-year investigation of Seton River and Seton Dam fish passage to capture a range of discharge and flow conditions associated with Seton Dam operations. In addition, fish counter enumeration efficiency must be improved and a thorough assessment of how discharge and flow patterns at Seton Dam influence delay and fishway attraction for all salmon species is required. Operating conditions at Seton Dam can then be correlated with migratory success, post-passage survival, and environmental variables to identify factors impeding salmon migration and formulate mitigation measures.

Target dilution ratios for Cayoosh Creek discharge to total Seton River discharge are a component of the current WUP. Current targets were adopted from findings of the International Pacific Salmon Fisheries Commission (IPSFC) on population-specific water preference behaviour exhibited by migratory Gates Creek and Portage Creek sockeye salmon (Fretwell 1989). Dilution targets for the Seton River are <20% Cayoosh Creek flow from 20 July to 31 August for Gates sockeye and <10% Cayoosh Creek flow from 28 September to 15 November for Portage sockeye (BC Hydro 2011). Maintaining target dilutions during sockeye migration is intended to reduce sockeye delay in the Seton Generating Station tailrace and encourage upstream migration to the Seton River-Fraser River confluence. The target dilution ratios and the apparent reduction in migratory delay are based on behavioural experiments and telemetry performed in the early 1980's. Neither the water preference behaviour of sockeye salmon nor the effectiveness of current dilution targets have been fully evaluated since the adoption and implementation of the target ratios. Recent studies have shown a high level of sockeye migration failure can still occur at target dilution levels (Hinch and Roscoe 2008). Further, it is not fully known how target dilution ratios influence the migratory behaviour of other salmon species, although pink salmon appear less sensitive to changes in the dilution ratio (Fretwell 1989). The target dilution ratios and their effect on salmon migration will be assessed in this monitoring program.

The current BRGMON-14 monitoring program is a 5-year investigation that will provide a comprehensive assessment of how Seton River dilution, Seton Dam operations, and environmental variables interact with the behaviour and physiology of salmon to affect upstream migration in the Seton-Anderson watershed. Data collected in this program will build upon previous studies while incorporating new technologies to enhance monitoring. The University of British Columbia (UBC) will carry out physical parameter monitoring, use telemetry to assess fish migration, conduct behavioural experiments, and collaborate with the University of Alberta to measure Seton Dam tailrace flow patterns. Instream Fisheries Research Inc. will conduct fish passage enumeration at the Seton Dam fishway using an electronic fish counter and video monitoring. Ultimately, this program will make recommendations to St'át'imc Government Services and BC Hydro on operational modifications to the hydroelectric facilities within the Seton-Anderson watershed to improve salmon passage. This report summarizes Year 2 of the BRGMON-14 monitoring program that continued program components started in Year 1 and implemented several new components including radio and PIT telemetry and water preference experiments.

1.1 Scope and Objectives

The objectives of the BRGMON-14 monitoring program are:

1. To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.
2. To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh dilution in Seton River.
3. To identify operating strategies that will mitigate delays in upstream migration without conflicting with other water use goals for environmental protection, flood risk, and power production in the Bridge Seton generating system.

1.2 Management Questions

The management questions of this monitoring program will achieve the program objectives by addressing specific uncertainties in the current operational requirements at Seton Dam and how these operations impact all salmon species migrating in the Seton-Anderson watershed. Uncertainty within the WUP operational requirements exist because Seton River dilution ratios were derived from studies that were limited to sockeye salmon and have not been re-evaluated. Further, fish passage at Seton Dam requires more detailed investigation. Therefore, the management questions of this monitoring program are:

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

1.3 Management Hypotheses

Although previous investigations indicate that the target dilution ratios are necessary to mitigate delay of upstream migrating Gates Creek and Portage Creek sockeye salmon populations, confirming this operation requirement is central to the BRGMON-14 monitoring program and will address Management Question 1.1. The null (no effect) hypotheses to be tested for the effect of Cayoosh Creek dilution on the two sockeye salmon populations are:

H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 20%.

H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 10%.

Testing these hypotheses will require monitoring sockeye salmon migration at different dilution ratios. Operating conditions during the 5-year monitoring program period should provide sufficient variation in dilution levels to accept or reject these hypotheses.

Variations in the dilution ratio necessitate a secondary set of hypotheses to test the sensitivity of Gates Creek and Portage Creek sockeye migration behaviour and address Management Question 1.2. The null hypotheses are:

H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.

H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.

To date, investigations have focused on sockeye salmon because of their abundance in the Seton-Anderson watershed and high cultural and economic value. It has not been determined if discharge at the Seton Generating Station delay pink, Chinook, or coho salmon migrating to the Seton River. Management Question 2.1 will be addressed by testing the following hypotheses:

H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.

H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.

H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.

The following hypotheses are related to Seton Dam and fishway operations and will address Management Questions 3.1 and 3.2:

H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.

H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.

Year 2 of the BRGMON-14 monitoring program investigated each of the management hypotheses.

1.4 Study Area

The study area for Year 2 of the BRGMON-14 monitoring program encompassed the entire salmon migration route within the Seton-Anderson watershed from downstream of the Seton Generating Station on the Fraser River to Gates Creek and the Gates Creek spawning channel upstream of Anderson Lake (Figure 1-1). Detailed study of salmon migration was carried out in the Seton River study area that included the Seton Generating Station, the Fraser River, Seton River, Cayoosh Creek, and Seton Dam (Figure 1-2). In addition, the migratory success of salmon to the Gates Creek and Portage Creek spawning grounds was quantified. Migration within Seton Lake and Anderson Lake was not studied.

Detailed examination of migration was also carried out at Seton Dam located 4.4 km upstream from the Fraser River (Figure 1-3). Seton Dam is a 76.5 m long by 13.7 m high concrete structure consisting of a radial gate, five siphons, a fish water release gate (FWRG), and fishway. In order to access Seton Lake and spawning grounds, migrating salmon must navigate the radial gate spillway and entrance area (together the Seton Dam tailrace), locate the fishway entrance adjacent to the FWRG, and ascend the fishway. The fishway has a total length of 107 m, contains 32 pools separated by vertical baffles, and has an overall grade of 6.9%. The Seton Dam fish counter is located at the upstream end of the fishway at the exit to Seton Lake. Migrating salmon must pass through the fish counter to exit the fishway.

Water preference experiments were carried out at Seton Dam using a Y-Maze apparatus installed in the compound on the northern bank of the Seton River.

Figure 1-1: **Overview of the Seton-Anderson watershed and study area for the BRGMON-14 monitoring program**

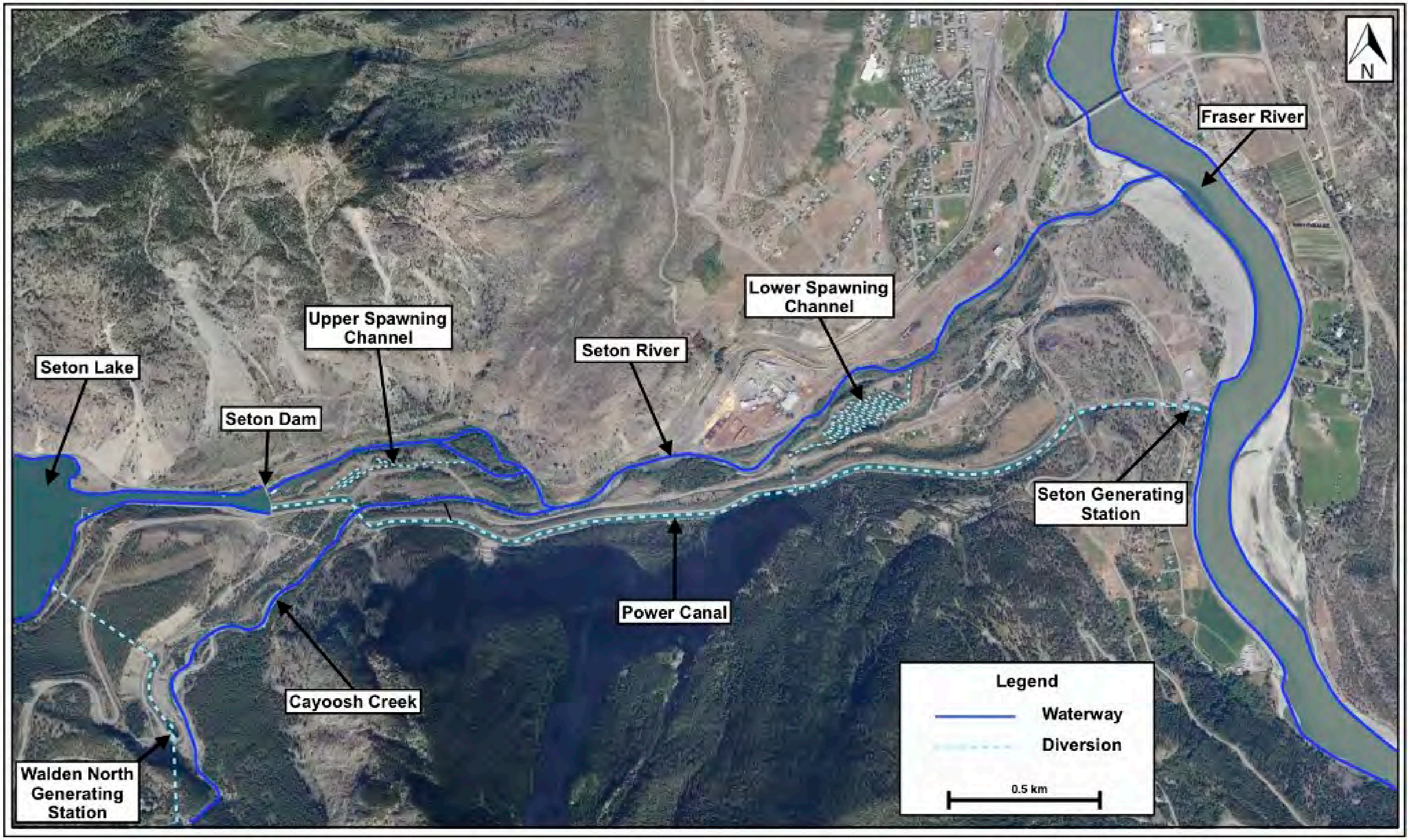

Figure 1-2: Waterways and diversion infrastructure within the Seton River study area

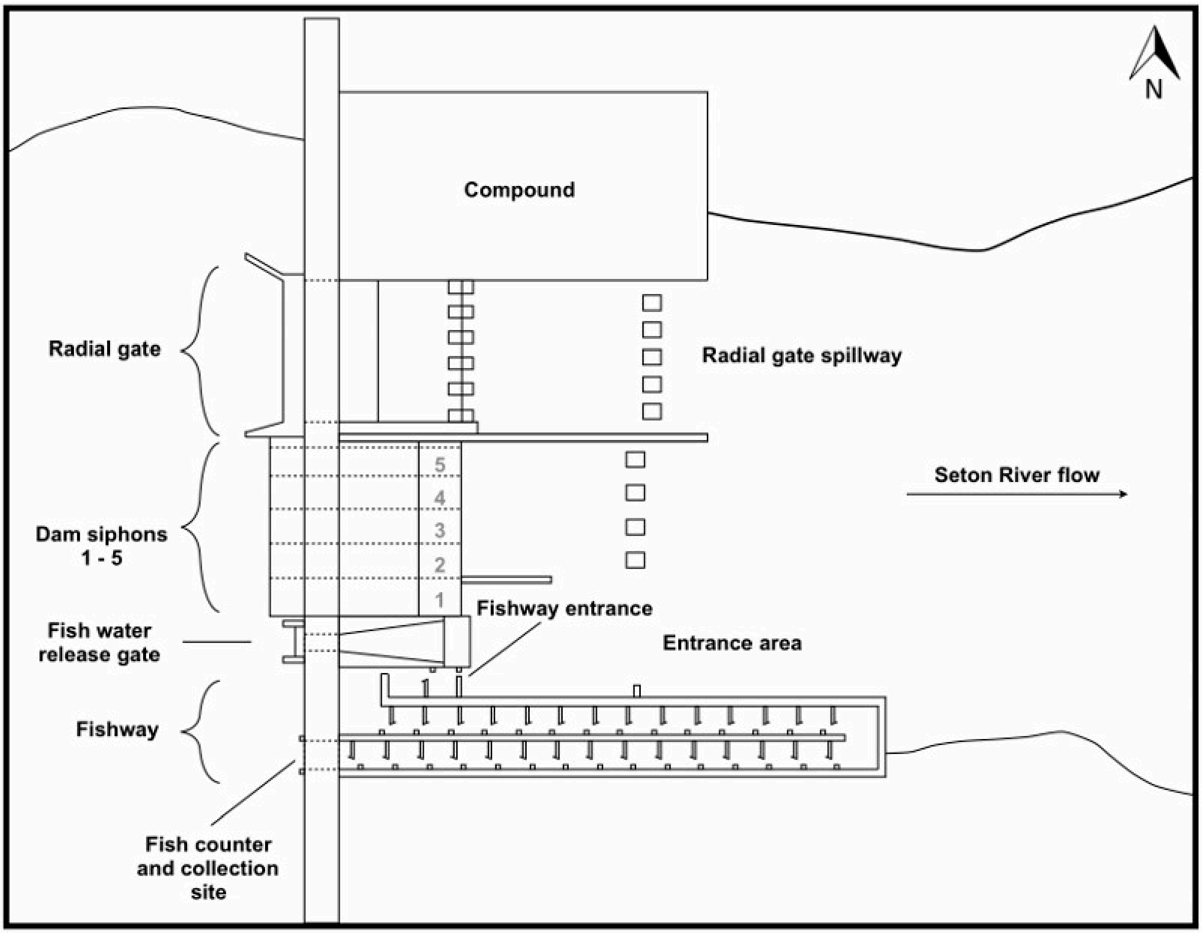

Figure 1-3: Schematic of Seton Dam showing conveyance structures (left), fishway (bottom), Seton Dam tailrace (middle) and the dam compound (top)

2.0 METHODS

All methods involving animals were approved by the University of British Columbia Animal Care Committee.

2.1 Physical Parameters

Physical parameters important for salmon migration in the Seton-Anderson watershed were monitored throughout the 2013 study period. Temperature and dilution ratio parameters were analyzed with Year 2 telemetry data to determine their effect on migration.

2.1.1 Discharge and Dilution Ratio

Discharge data for the Seton River, Cayoosh Creek, Seton Dam, and Seton Generating Station were obtained from BC Hydro Power Records. Daily discharge data were based on the average daily discharges recorded by Water Survey of Canada (WSC) gauging stations on Cayoosh Creek (No. 08ME002) and Seton River above Cayoosh Creek (No. 08ME003) (Figure 2-1). Hourly discharge data were obtained for each conveyance structure at Seton Dam and spawning channels.

The daily dilution ratio for the Seton River was obtained from BC Hydro Power Records. Dilution was calculated by BC Hydro using the daily average discharge of each location in the following equation:

$$\text{Dilution Ratio (\%)} = \frac{\text{Cayoosh Creek}}{(\text{Cayoosh Creek} + \text{Seton River} + \text{Spawning Channels})}$$

2.1.2 Water Temperature

Water temperature data were collected at the water quality sites established in 2012 (Figure 2-1; Table 2-1). Temperature monitoring at four sites (W06-SSC, W08-SLK, W09-UCC, W11-UPC) was identified as redundant and discontinued in 2013. At the remaining sites, TidbiT v2 water temperature loggers (± 0.2°C accuracy) (Onset Computer Corporation Inc., Bourne, Massachusetts, USA) were installed between 12 and 15 July and set to record temperature hourly. Duplicate temperature loggers were installed at select sites to ensure data security. A logger was not installed at the W02-UFR site due to lack of a suitable installation location in the Fraser River.

Table 2-1: Geographic locations of water quality sites and serial numbers for installed temperature loggers

Site	Description	UTM Coordinates	Serial #1	Serial #2
W01-LFR	Seton Generating Station	10 U 0576019 5613952	10206555	10170913
W02-UFR	Upper Fraser River	10 U 0575582 5615178	NA	NA
W03-LSR	Lower Seton River	10 U 0574397 5613831	10170909	10219612
W04-LCC	Lower Cayoosh Creek	10 U 0573069 5613554	10206558	10206556
W05-USR*	Upper Seton River	10 U 0572419 5613636	10219610	10170912
W07-SFW	Seton Dam Fishway	10 U 0572246 5613558	10206557	NA
W10-LPC	Lower Portage Creek	10 U 0550573 5617636	10219613	NA
W12-GSC	Gates Creek Channel	10 U 0536685 5599754	-	NA

*W05-USR logger was installed 17 August 2013

Additional water temperature data were obtained for the Fraser River to estimate the thermal experience of salmon prior to entering the Seton River. Water temperature data were obtained from Fisheries and Oceans Canada from the monitoring station at Qualark Creek (UTM 10 U 613935 5488072) and from the WSC station 08MF040 Fraser River above Texas Creek (Environment Canada – Water Survey Canada, 2013). The Qualark Creek monitoring station was used because it is located approximately equal distance from the mouth of the Fraser River and Seton River. Temperature at Qualark Creek was judged to be representative of the average thermal regime encountered by sockeye salmon during their upstream migration. Entry dates and run duration for Gates Creek and Portage Creek sockeye were determined using migration data from Hague and Patterson (2009). Temperature data from the Fraser River above Texas Creek was used in place of a temperature logger in the Fraser River.

2.1.3 Water Chemistry

Measurements of specific conductivity (SC) and water samples for dissolved free amino acid (DFAA) analysis were collected to compare the water chemistry of the Seton-Anderson and Cayoosh Creek watersheds. Specific conductivity can be used as a general indicator of water chemistry (Fretwell 1989) and is an important consideration given that dilution ratio targets are fixed during the Gates Creek and Portage Creek sockeye salmon migration periods. Amino acids are known to be an important migratory cue for salmon (Udea 2011).

Water chemistry monitoring at five previously monitored and sampled sites (W06-SSC, W08-SLK, W09-UCC, W10-LPC, W11-UPC) was identified as redundant and discontinued in 2013. Specific conductivity ($\mu S \cdot cm^{-1}$) was monitored at the remaining sites (Figure 2-1; Table 2-2) from 15 July to 20 October using a hand-held YSI Pro30 conductivity meter (YSI Inc., Yellow Springs, Ohio, USA). Measurements were taken daily so long as personnel were available. Water samples for DFAA analysis were collected on 31 July (Table 2-2). Samples were filtered through a 0.45 µm polyethersulfone membrane filter into 1 L acid-washed Nalgene high-density polyethylene bottles and frozen at -20ºC within 1 h of sampling.

Laboratory analyses of DFAA samples from 2012 and 2013 are still in progress. Analysis will follow the methods outlined in Hawkins et al. (2006).

Table 2-2: Locations of specific conductivity (SC) measurements and amino acid (AA) water sampling in 2012 and 2013

Site	Parameters Measured (2012)	Parameters Measured (2013)
W01-LFR	SC	SC; AA (31 July)
W02-UFR	SC; AA (Aug 4)	SC; AA (31 July)
W03-LSR	SC; AA (Aug 4 & 20)	SC; AA (31 July)
W04-LCC	SC; AA (Aug 4 & 20)	SC; AA (31 July)
W05-USR	SC; AA (Aug 4 & 20)	SC; AA (31 July)

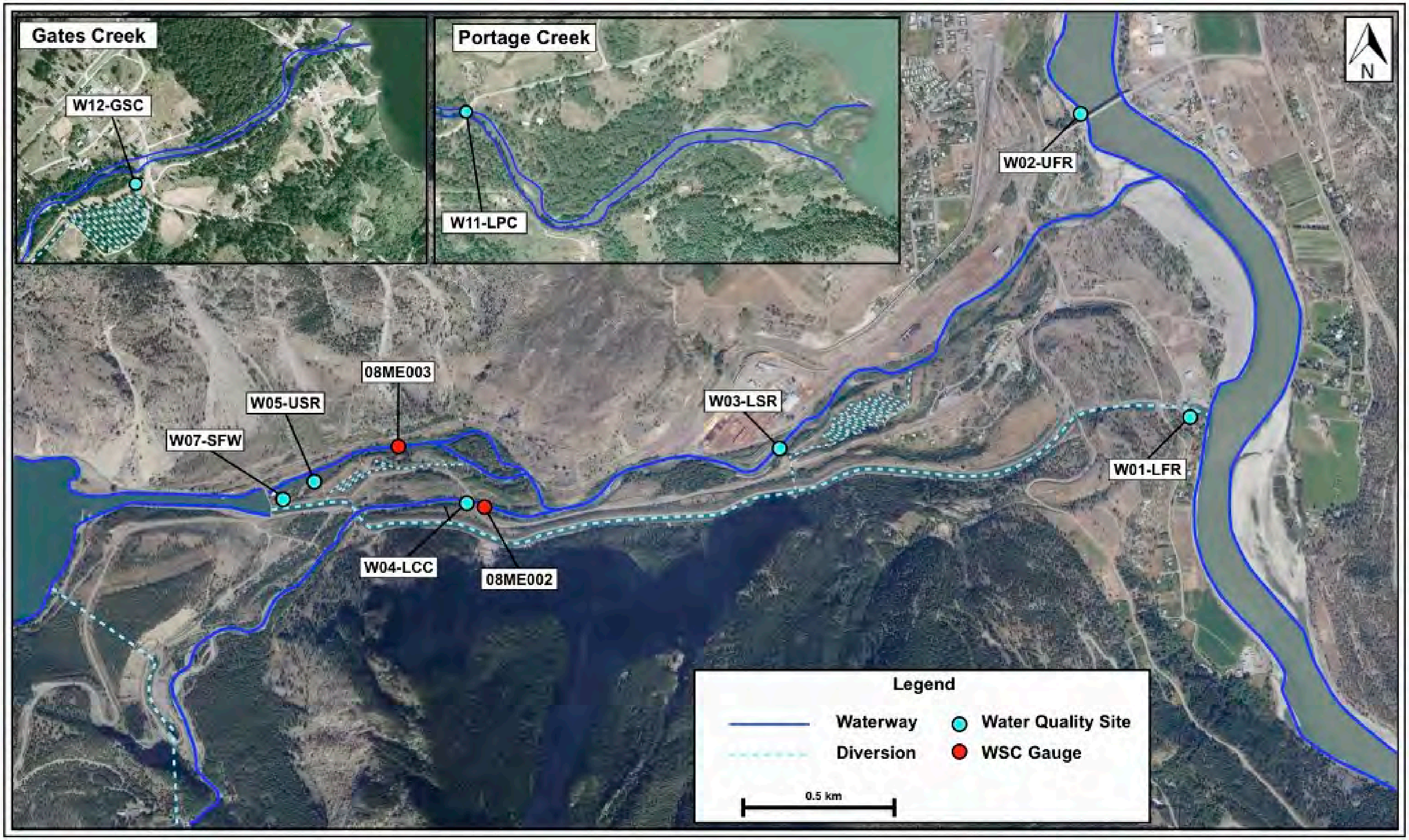

Figure 2-1: **Water quality sites in the Seton River (main map), Gates Creek spawning channel (insert upper left), and Portage Creek (insert upper centre)**

2.2 Seton Dam Tailrace Flow Patterns

Flow patterns in the Seton Dam tailrace were investigated because of their potential to cause salmon migration delay and failure (Pon et al. 2006; Roscoe and Hinch 2008). As part of a pilot study, the University of Alberta was contracted to use Acoustic Doppler Current Profiler (ADCP) technology to measure flow velocities (magnitude and direction) in the tailrace during one discharge condition in late-August. Data were used to identify the subsurface flow features in the Seton Dam tailrace and measure flow velocities near the fishway entrance. Future analyses will integrate flow patterns with the swimming behaviour and activity of salmon in the Seton Dam tailrace as measured with acoustic accelerometry.

2.2.1 Acoustic Doppler Current Profiler

An Acoustic Doppler Current Profiler measures water velocity using the Doppler Effect whereby high frequency sounds pulses transmitted by the ADCP reflect off water particles and back to the ADCP unit (Nortek 2005). Changes in frequency of the reflected sound pulses are proportional to water velocity and these changes are recorded by the ADCP unit. Water velocity measurements can be made over a range of distances from the ADCP unit, however, turbulent water that is aerated can disrupt the sound pulses and reduce both the range and accuracy of ADCP measurements.

2.2.2 Field Measurements

Water velocity measurements were taken in the Seton Dam tailrace between 23 and 27 August. Total Seton Dam discharge during this time was approximately 22.8 $m^3 \cdot s^{-1}$ with water primarily released through Siphon 1.

Two ADCP units were used to measure water velocity in the tailrace. A 2-dimensional ChannelMaster H-ADCP (Teledyne RD Instruments, Poway, California, USA) was manually positioned in the Seton Dam tailrace while a frame-mounted 3-dimensional Aquadopp Current Profiler (NortekUSA, Boston, Massachusetts, USA) was positioned near the fishway entrance. A total of 34 horizontal transects were measured in the tailrace up to 110 m downstream of Seton Dam using the ChannelMaster H-ADCP (Figure 2-2). The measurement range of each ChannelMaster H-ADCP transect was approximately 20 m with velocity measurements taken at 0.20 m to 0.25 m segments along the transect. Measurements were taken for a minimum of 5 min with a 5.5 s sampling interval. At the fishway entrance, three measurements were taken at 1.25 m, 2.25 m, and 3.25 m downstream of the entrance using the Aquadopp Current Profiler. In contrast to the horizontal transects in the tailrace, measurements at the fishway entrance were taken vertically by positioning the Aquadopp Current Profiler on a frame in an upwards-facing position. Measurements were taken for a minimum of 15 min with a 1 s sampling interval across 0.1 m segments. Additional details on measurements can be found in Appendix I.

2.2.3 Data Analysis

Measured flow velocities were indirectly validated using visual and calculated flow velocity estimates based on river discharge and total wetted width. Recorded data were post-processed using the software packages supplied by the ADCP manufacturers and imported to Microsoft Excel and Matlab for further analysis. See Appendix I for further information.

Figure 2-2: **Acoustic Doppler Current Profiler measurement transects in the Seton Dam tailrace (T1-T34) and at the fishway entrance (P1-P3)**

2.3 Fish Passage Enumeration

Fish passage abundance past Seton Dam was estimated using a resistivity fish counter installed at the exit of the Seton Dam fishway. Data from the counter was used to estimate the migration timing of Gates Creek sockeye, Portage Creek sockeye, pink, and coho salmon passing Seton Dam.

Abundance estimates for 2013 were complicated by problems with the wiring provided by BC Hydro to connect the fish counter sensors with recording equipment (see Section 4.2.3). Due to these technical issues, abundance estimates for Gates Creek sockeye and coho salmon are highly uncertain. Estimates for Portage Creek sockeye and pink salmon are ongoing and will be provided in future reports.

2.3.1 Resistivity Counter

In July, the Seton Dam fish counter was reinstalled with all eight sensor tubes relocated to the bottom of the sensor unit with the separation grid located at the water surface (Figure 2-3). A second Logie 2100c resistivity electronic fish counter (Aquantic Ltd., Scotland, UK) was installed and allowed for each of the sensor tubes to be monitored by a single sensor channel on one of the two counters.

Detailed fish counter operation is summarized in the Year 1 report. Briefly, the counter operates by detecting a change in electrical resistance when fish swim through a sensor tube (Figure 2-4). The change in resistance is measured by the counter and an algorithm is used to determine if a fish passed through the counter in the up (up count) or down (down count) direction or if the fish failed to pass. For detections exceeding a minimum threshold, the date and time, conductivity, channel, direction (upstream or downstream), and peak signal size (PSS) are recorded. The PSS is a function of fish size, fish swimming distance from the sensors, electrode sensitivity, river conductivity, and bulk resistance (background resistance caused by flowing water). Minimum thresholds for detection were set (PSS of 40 out of 127) to eliminate resistance noise caused by air bubbles from the lake surface or debris passing through the sensor tubes. Automatic re-calibrations of the sensor were programmed to occur every 30 min to compensate for changes in environmental conductivity. Detections were saved to one of eight channels on one of the two fish counters. Detection data was downloaded every 2-3 d during the study period.

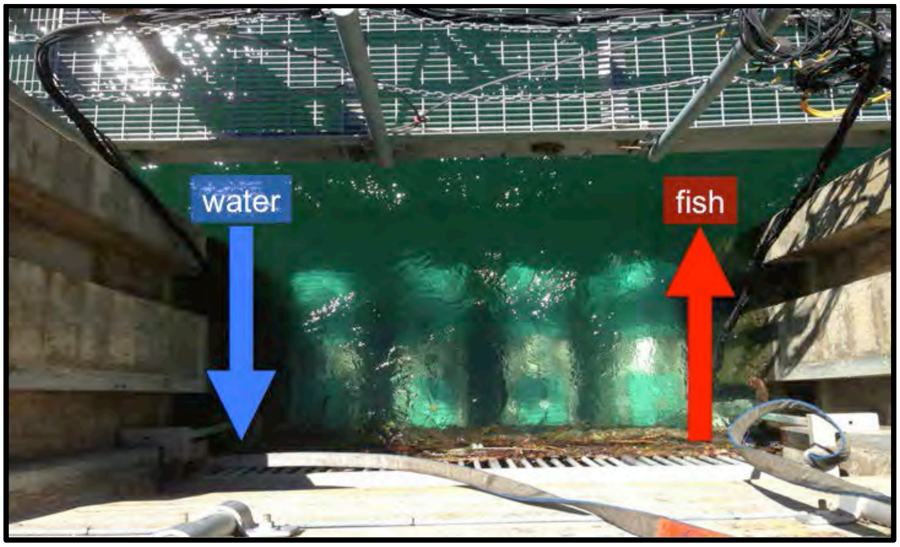

Figure 2-3: Overhead view of the resistivity counter sensor tubes installed at the exit of the Seton Dam fishway. Water flow and fish migration directions are indicated

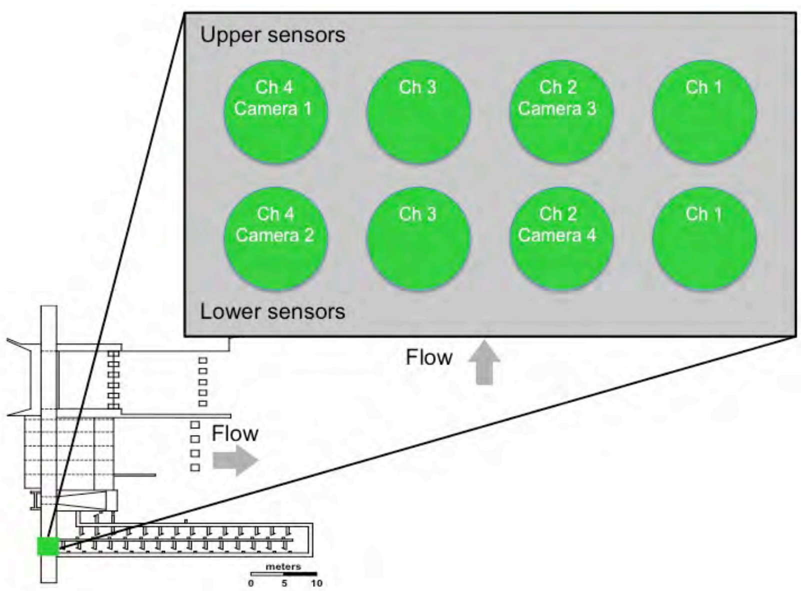

Figure 2-4: Schematic of the fish counter located at the exit of the Seton Dam fishway. The upper and lower sensors were monitored by two, four channel resistivity counters. Cameras were fitted to the upstream end of sensor tubes

2.3.2 Video Monitoring

Digital underwater video cameras (VCULED, Visiontech) were attached to the upstream ends of four sensor tubes to record fish movements and evaluate counter efficiency on the lower channels 2 and 4 and the upper channels 2 and 4. Video was recorded from 16 August to 05 October and was saved to a digital-video recorder (Capture DVR400) at 15 frames per second. Although cameras had more-powerful infrared lights than in 2012, nighttime species identification was not possible.

2.3.3 Data Analysis

Video recording data were used to estimate the efficiency of the fish counter. Video recording of fish passing through the counter was matched with the counter output to determine the proportion of detections that were correctly recorded. Video validation was carried out on a single camera-channel combination (lower sensors, channel 2, camera 4) with six, randomly–selected 20 min segments of video data reviewed from every second day between 16 August and 30 August. Additional video validation will be required to produce efficiency estimates for the three remaining camera-channel combinations. Estimates from the four validated camera-channel combinations will be used to estimate the overall efficiency of the fish counter.

Abundance estimates were complicated by incorrect wiring that caused misdetections on five of the eight fish counter sensor channels. This technical issue posed many challenges during analysis and limited the accuracy of abundance estimates because up counts were only counted on three channels. This problem was identified and rectified on 25 September. As a result of these technical issues, abundance estimates for Portage Creek sockeye and pink salmon are not yet available. Raw up count data from all counter channels were used to estimate the migration timing for each species.

Abundance estimates for Gates Creek sockeye and coho salmon were calculated using limited video validation and correction factors that attempted to deal with the fish counter wiring issues and overlapping migration timing. Further work is required to correct for the wiring issues. Therefore, the abundance estimates of Gates Creek sockeye salmon and coho salmon passage at Seton Dam are highly uncertain and both estimates are subject to change once validation is complete.

2.4 Telemetry

Salmon migration behaviour in the Seton-Anderson watershed was monitored in 2013 using acoustic, radio, and passive integrated transponder (PIT) telemetry programs. Fish were collected from either the top of the Seton Dam fishway or from a fish fence downstream of Seton Dam. Acoustic accelerometer transmitters were used for a second year to assess the swimming activity and behaviour of Gates Creek sockeye salmon during Seton Dam passage. Radio transmitters were used on Gates Creek sockeye, pink, and Portage Creek sockeye salmon to monitor the migration of these species through the watershed. All acoustic and radio-tagged fish received a PIT tag with additional Gates Creek sockeye, pink, Portage Creek sockeye, coho, and Chinook salmon receiving only PIT tags.

2.4.1 Fish Collection

Fish were collected by dip-net from the exit basin of the Seton Dam fishway or trapped using a fully-spanning fish fence installed in the Seton River approximately 200 m downstream of Seton Dam (Figure 2-5). Gates Creek sockeye salmon were collected at both the fishway and the fence while pink, Portage Creek sockeye, coho and Chinook salmon were only captured at the fish fence. The exception was a sub-set of coho salmon that was collected during a BC Hydro fish salvage operation in the Power Canal.

Originally, all fish capture was to take place using a fish fence installed in the lower Seton River downstream of Cayoosh Creek. In July, a partial spanning fish fence was constructed 500 m upstream from the Seton River-Fraser River confluence. Unfortunately, high discharge prevented the fence from being positioned in the main channel of the Seton River and no fish were collected at this location. On 02 August, during the Gates Creek sockeye salmon migration, the fence was relocated downstream of Seton Dam. Initially, fish capture success at the fence was limited and the number of Gates Creek sockeye collected was insufficient for tagging programs. To meet tagging targets, fish were captured via dip-net from the Seton Dam fishway while the fence was modified to improve fish capture. On 16 August, the fish fence was expanded across the Seton River and capture success improved. Collection of Gates Creek sockeye salmon from the fishway continued past 16 August to compare the migration success of fishway and fence-caught fish.

Fish captured from the fishway were truck-transported in a 1,000 L oxygenated tank to an in-river holding pen at the fish fence site or to a holding tank at the Seton Dam compound. Fish captured at the fence were moved directly from the fence trapbox into the holding pen.

Fence operation varied according to fish abundance and migration timing. During the Gates Creek and Portage Creek sockeye salmon migration, the fence was closed (actively fishing) at approximately 0600 for five to eight daylight hours each tagging day. Since sockeye were observed to primarily migrate at night, daytime closures minimized the likelihood of fence operations altering the migration behaviour of tagged and untagged sockeye salmon. During the pink salmon migration, closures were as short as 0.5 h and at the peak of pink salmon spawning, the fence was temporarily removed (22 September to 02 October) due to high spawner abundance. Overnight closures were required to capture coho salmon, however, this did not overlap with the migration of other species. When the fence was not in operation, sections were removed to allow salmon migration to continue unimpeded (Figure 2-5).

Figure 2-5: Full-spanning fish fence in the Seton River. Note open panels mid- and left-channel to allow upstream fish migration

2.4.2 Tagging Protocol

All fish were tagged and sampled using standardized protocols and received either an acoustic accelerometer transmitter, radio transmitter, or PIT tag as a primary tag (Table 2-3). The samples collected from fish varied with primary tag type. Tagging was performed at the Seton Dam compound or at the Seton River fence site.

Fish were transferred from holding to a V-shaped trough supplied with fresh water and manually restrained. Anaesthesia was not used to minimize handling and the duration of the tagging procedure. An estimate of somatic lipid concentration was made using a fish Fatmeter (FM 692 Fish Fatmeter, Distell, West Lothian, Scotland, UK) and the methods of Crossin and Hinch (2005). Based on findings from Year 1, any sockeye salmon that were collected during the Gates Creek migration period with an average Fatmeter reading greater than 2.7-3.0% were rejected as strays and not tagged. This screening procedure was not applied during the Portage Creek sockeye salmon migration.

Table 2-3: Tags applied to fish and parameters sampled for each of the primary tags used to monitor adult salmon migration

Primary Tag	Transmitter	Thermal Logger	PIT Tag	Spaghetti Tag	Parameters Sampled
Acoustic	V13A-1x[1]	-	X	X	Sex, fork length, fat, injuries, blood, DNA.
Radio	Pisces 5[2]	iButton	X	X	Sex, fork length, fat, injuries, blood, DNA.
PIT	-	-	X	X	Sex, fork length, fat, injuries, DNA.

[1]Vemco, Bedford, Nova Scotia, Canada. [2]Sigma Eight Inc., Newmarket, Ontario, Canada.

Following screening, all fish were measured for fork length to the nearest 0.5 cm, sex estimated using secondary sexual characteristics, and external injuries assessed according to the parameters outlined in Table 2-4. Fish without any injuries were recorded as uninjured while fish with injuries were ranked as having either minimal injuries (would not be expected to impair migration), moderate injuries (could be expected to impair migration), or severe injuries (expected to impair/prevent migration). The location and type of injury was recorded and the origin of the injury was estimated. Fish with severe external injuries generally received a PIT tag only.

Table 2-4: External injury monitoring protocol preformed on fish tagged in Year 2

Injured?	Injury Severity	Injury Location	Injury Type	Injury Origin
Yes or No	Minor Moderate Severe	Head Injury Eye Injury Body Injury Fin Injury Gills	Fin Fray Fungus Sea Lice Scars Lesions Abrasion Gillnet Wound Hook Wound Bruising	Fisheries Encounter Disease/Parasite Migration Barrier Predator Unknown

For acoustic and radio-tagged fish, a 3-5 mL blood sample was withdrawn into heparinized Vacutainers using a caudal puncture with a 22G needle (Houston 1990). Vacutainers were then centrifuged to separate blood plasma and the plasma samples frozen in liquid nitrogen for 1-3 weeks. Plasma samples were later transferred to a -80°C freezer for storage until laboratory analysis. Following blood sampling, acoustic accelerometers and radio transmitters (see Table 2-3 for specifications) were implanted gastrically by placing the tag in the mouth of the fish and inserting the tag into the stomach using a plastic plunger. An iButton DS1921Z temperature logger (Maxim Integrated, San Jose, California, USA) programmed to record temperature at 15 min intervals was secured to each radio tag to record the thermal profile of fish during migration.

All fish received a 32 mm HDX PIT tag (Oregon RFID, Portland, Oregon, USA) implanted in the dorsal musculature and a 12” spaghetti tag (Floy Tag & Mfg., Inc., Seattle, Washington, USA) tied behind the dorsal fin. A DNA sample was taken from the adipose fin of all fish using a hole punch and the sample stored in 95% ethanol. The exception was PIT-tagged pink salmon, where a DNA sample was taken from the adipose fin but not retained. Where possible, photographs of each tagged fish were taken along with detailed photographs of any notable injuries. The total time to sample and tag each acoustic- and radio-tagged fish was approximately 5 min while the sampling and tagging of PIT-tagged fish was completed in 2-3 min.

Fish tagged at Seton Dam were temporarily held in a 1,000 L transport tank for a maximum of 45 min prior to transport to release sites while fish tagged at the Seton River fence site were either temporarily returned to the in-river holding pen for later transport or immediately released.

2.4.3 Fish Releases

Four release sites were established to study different aspects of salmon migration in the Seton-Anderson watershed (Figure 2-6; Table 2-5).

Table 2-5: Location of the four release sites for acoustic, radio, and passive integrated transponder (PIT) tagged salmon

Release Site	UTM Coordinates	Tags Types Released at Site
Fraser River West	10 U 0576422 5612849	Radio
Fraser River East	10 U 0576781 5612685	Radio
Lower Seton River	10 U 0575385 5614966	Acoustic, Radio, PIT
Upper Seton River	10 U 0572423 5613637	Acoustic, PIT

Two Fraser River release sites downstream of the Seton Generating Station were used to examine the behaviour of fish migrating past the Seton Generating Station to the Seton River-Fraser River confluence. West and east bank release sites were 1.2 km and 1.6 km downstream of Seton Generating Station, respectively. Two sites on opposite banks of the river were established to recreate the natural upstream migration of salmon that could occur on either side of the Fraser River. A third release site 3.9 km downstream of Seton Dam in the lower Seton River, downstream of the Cayoosh Creek-Seton River confluence, was established to study the influence of dilution and discharge on fish migrating in the Seton River. Finally, a fourth release site was established in the upper Seton River at the Seton River fish fence, to study migration within the Seton Dam tailrace.

The number, timing, and type of tags deployed at each location (Table 2-6) depended upon the suitability of each tag type for monitoring the migration of fish upstream of the release location, the number of tags available, conditions present, and the abundance of each fish species. Dilution was monitored from BC Hydro reports and releases strategically timed to coincide with a range of dilution levels.

Radio tags were exclusively deployed at the Fraser River sites with a total of 168 Gates Creek sockeye salmon, 58 pink salmon, and 24 Portage Creek sockeye salmon released at these sites. Originally, PIT-tagged fish were to be released at the Fraser River sites to increase the sample size of fish migrating through the entire watershed. However, transport limitations, fish abundance, and temperature conditions only allowed radio-tagged fish to be released in the Fraser River in Year 2.

Within the Seton River, a combination of acoustic, radio, and PIT tags were deployed with a total of 91 Gates Creek sockeye salmon released at the Lower Seton River release site. No other species were released at the Lower Seton River release site. Both acoustic and PIT tags were deployed at the Upper Seton River release site. Acoustic tags were only applied to Gates Creek sockeye salmon while PIT tags were applied to all salmon species.

A total of 625 PIT-tagged salmon, including coho and Chinook, were release from the Upper Seton River site. Releases at the Upper Seton River site included 200 Gates Creek sockeye salmon released between 20 and 29 August that were used to assess differences in passage success and survival to spawning grounds of fishway (n=107) and fence-caught (n=93) fish. Gates Creek sockeye used in this comparison were collected and released on the same day, ensuring fish from each capture location experienced identical migration conditions.

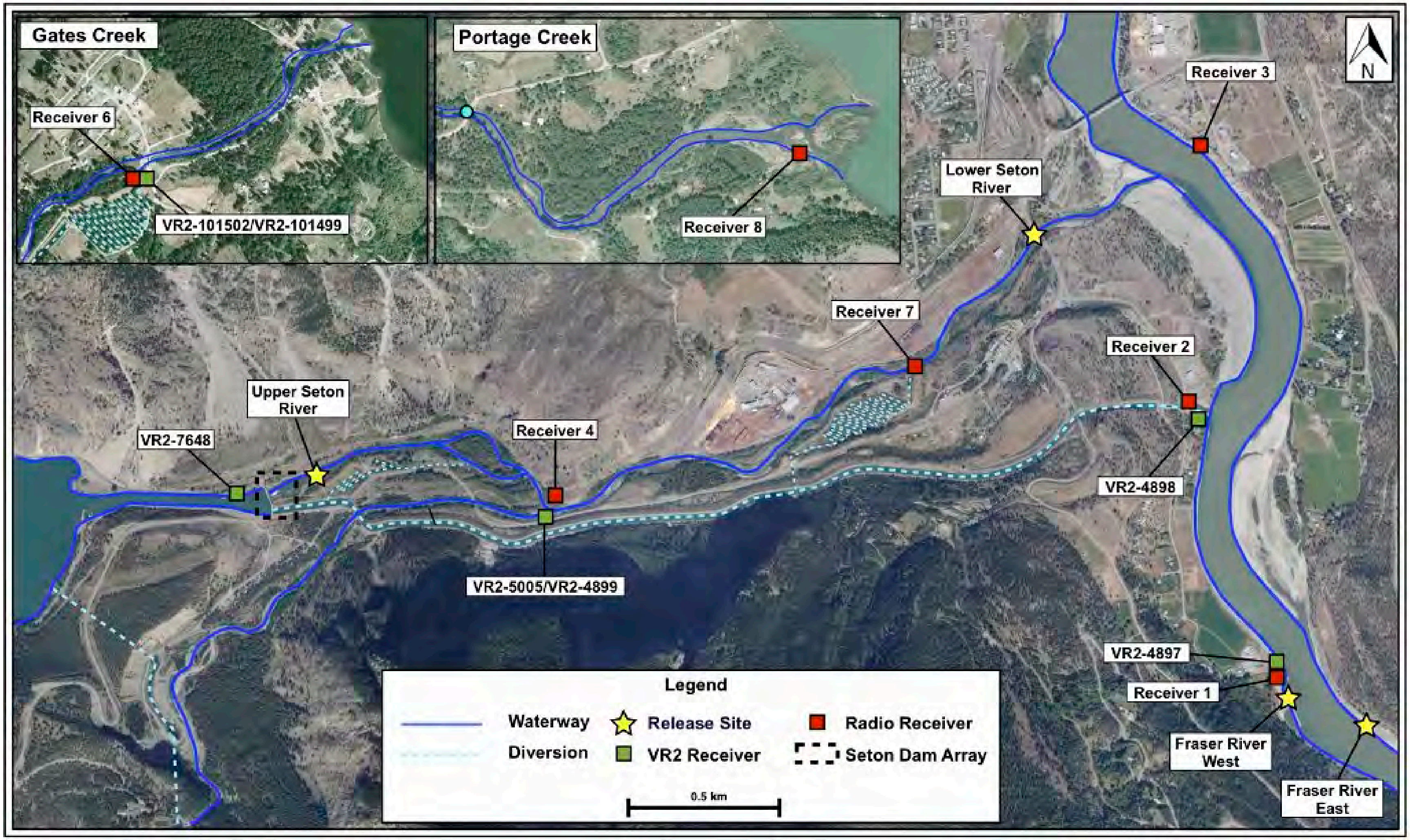

Figure 2-6: Release sites, acoustic receiver installations, and radio receiver installations in the Fraser River, lower Seton River, Gates Creek, and Portage Creek

Table 2-6: Summary of 2013 tagged fish releases by location and tag type and population

Tag Type/ Population	Total Releases by Location (Release Date Range)			
	Fraser River West	Fraser River East	Lower Seton River	Upper Seton River
Acoustic				
Gates Creek Sockeye	-	-	30 (02 Aug – 10 Aug)	30 (15 Aug – 26 Aug)
Radio				
Gates Creek Sockeye	81 (05 Aug – 31 Aug)	87 (10 Aug –02 Sept)	37 (7 Aug – 23 Aug)	-
Pink	30 (09 Sept – 21 Sept)	28 (09 Sept – 21 Sept)	-	-
Portage Creek Sockeye	12 (04 Oct to 09 Oct)	12 (04 Oct to 09 Oct)	-	-
PIT				
Gates Creek Sockeye	-	-	24 (31 Jul – 11 Aug)	300 (17 Aug – 13 Sept)
Pink	-	-	-	280 (20 Aug – 21 Sept)
Portage Creek Sockeye	-	-	-	14 (17 Sept – 08 Oct)
Coho	-	-	-	30 (03 Oct – 20 Oct)
Chinook	-	-	-	1 (18 Oct)

2.4.4 Telemetry Arrays

Radio and acoustic receivers were installed in strategic locations on the Fraser River, Seton River, and in the Seton Dam tailrace and fishway (Figure 2-6; Figure 2-7). Additional receivers were installed at Gates Creek and Portage Creek to detect fish at spawning grounds.

Five stationary radio receivers were installed downstream of the Seton Dam from 04 August to 29 October to detect fish as they entered and exited the study area and moved past key migration locations. Each receiver station consisted of either an Orion receiver (Sigma Eight Inc.) or SRX-400 receiver (Lotek Wireless Inc.) connected to a Yagi 3- or 5-element antenna and powered by two to four deep cycle batteries. A receiver immediately upstream of the Fraser River West and Fraser River East release sites (Receiver 1) detected fish entering the study area. Movements within the study area were recorded as fish moved past or held at the Seton Generating Station (Receiver 2), the Seton River-Fraser River confluence (Receiver 3), the Cayoosh Creek-Seton River confluence (Receiver 4), and the Seton Dam (Receiver 5). A sixth receiver was temporarily installed (07 to 25 September) at the outflow of the lower spawning channel (Receiver 7) to detect pink salmon spawning in the lower Seton River. Data on the radio receivers were downloaded approximately every two weeks and batteries changed as required.

Acoustic VR2 receivers (Vemco, Bedford, Nova Scotia, Canada) were also installed in the lower Seton River as well as the Fraser River. Two acoustic receivers were installed at Cayoosh Creek-Seton River confluence with a detection range that overlapped with the radio receiver installed at this location. As a result, the upstream migration of acoustic and radio-tagged fish released in the Seton River could be compared. Additional acoustic receivers were installed in the Fraser River at the Seton Generating Station and upstream of the Fraser River West release site. The purpose of the two Fraser River acoustic receivers was to detect any fish that failed to migrate past Seton Dam and fell out of the Seton River.

At Seton Dam, acoustic receivers were installed as an array to detect detailed swimming behavior and activity data from acoustic-tagged fish navigating the tailrace and fishway (Figure 2-7). Receivers were secured to concrete bases, lowered into the tailrace, and secured to the dam or river bank with rope. A total of 17 acoustic receivers were installed in the Seton Dam tailrace with four receivers installed in the radial gate spillway, one installed in the siphon spillway, eight installed in the fishway entrance area, and four installed in the fishway. One acoustic receiver was installed upstream of Seton Dam to detect fish that successfully located, entered, and ascended the fishway (Figure 2-6). Overall, the Seton Dam acoustic receiver array installed in 2013 had eleven more receivers than the array used in 2012 with five additional receivers installed in the entrance area.

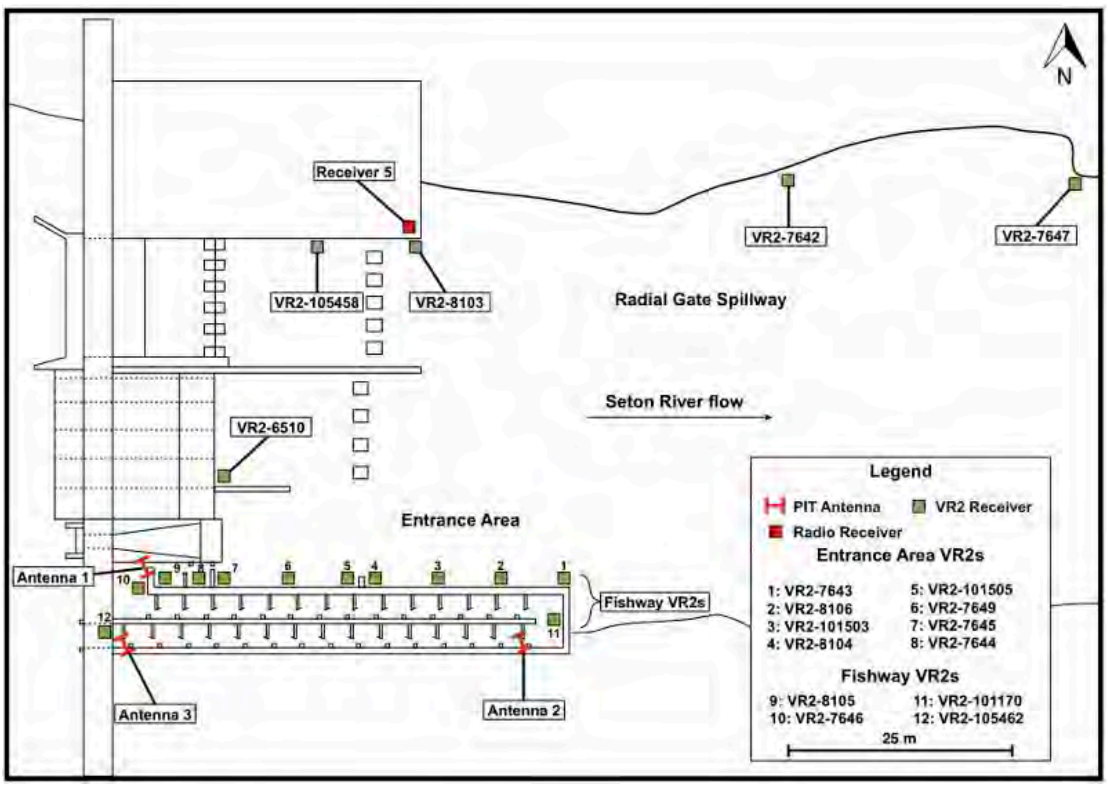

Figure 2-7: Location of acoustic receivers, radio receivers, and Passive Integrated Transponder (PIT) antennas in the Seton Dam tailrace and fishway

Migration of tagged fish through the fishway was also recorded by three pass-through PIT antennas located in the entrance, second turning, and exit basin of the fishway. (Figure 2-7). PIT antennas were constructed out of 1.5" polyvinyl chloride (PVC) pipe with 12-gauge stranded electrical wire. Each antenna was connected to a remote tuner box (Oregon RFID) and all three antennas connected to a multi-antenna HDX reader (Oregon RFID) via twin-axial cable. Antennas were tuned and tested daily prior to tagging to ensure optimal read range (0.5 m) and tag-reading performance.

Acoustic and radio receivers were installed on Gates Creek and Portage Creek to detect fish that successfully migrated to spawning grounds (Figure 2-6). A PIT array was also installed at the Gates Creek spawning channel diversion, however, a PIT antenna was not installed in Portage Creek due to lack of a suitable installation site. At Gates Creek, two acoustic receivers, one radio receiver (Receiver 6), and two PIT antennas were installed at the Gates Creek spawning diversion located approximately 800 m upstream from Anderson Lake. During the Gates Creek sockeye salmon migration a Fisheries and Oceans Canada fish fence was installed on Gates Creek from early-August to mid-September. The fence blocked upstream fish passage on Gates Creek requiring fish migrate through the diversion to access the spawning channel or upper Gates Creek. Therefore, any fish accessing the spawning channel or upper Gates Creek were required to swim within range of the receivers and PIT antennas. It should be noted, however, that removal of the fish fence in September resulted in fish being able to freely migrate up Gates Creek without passing through the Gates Creek diversion. Consequently, no fish were detected on the Gates Creek PIT array following fence removal.

2.4.5 Tag Recoveries

Tags were recovered to obtain the iButtons attached to radio tags, assess the spawning success of fish, or estimate the cause of migratory failure.

Tag recovery efforts focused primarily on Gates Creek sockeye salmon that were spawning at the Gates Creek spawning channel and in Gates Creek. Radio tags were located using a portable SRX-400 receiver while acoustic and PIT-tagged fish were located visually via the external spaghetti tag. Fisheries and Oceans Canada stock assessment personnel carrying out escapement estimates for Gates Creek also assisted in tag recoveries. Where possible for recovered tags, fish condition was assessed using the same sampling protocols established for tagging but including spawning percent (0%, 50%, 100%) and egg mass for unspawned females. Similar efforts were applied to Portage Creek sockeye salmon radio tag recovery, however, the overall number of tagged Portage Creek sockeye salmon was much lower than Gates Creek sockeye salmon and the spawning fish distributed over a broader area.

Mobile radio tracking was performed throughout the Seton River study area to locate tags from sockeye salmon that did not migrate past Seton Dam or tags from pink salmon that spawned below Seton Dam. Additional mobile tracking was carried out downstream of the Fraser River West and Fraser River East release sites in order to detect any tags from fish that either failed to enter the Seton River or were lost downstream of the study area. Tracking was performed along the Fraser River for approximately 20 km south of Lillooet. Radio transmitters that were repeatedly tracked to the same location were classified as mortalities.

2.4.6 Data Analysis

Gross somatic energy density estimates and DNA stock identification were all carried out using the methods outlined in Year 1. Due to budget limitations, DNA analysis has yet to be carried out on samples from PIT-tagged fish. In addition, due to laboratory limitations, the analysis of blood plasma has yet to be completed.

All radio, acoustic and PIT detection data were filtered to remove detection errors and the detection efficiency calculated for the acoustic array at Seton Dam. As in 2012, multiple acoustic receivers within the Seton Dam tailrace were considered as an array because of the low detection range of individual receivers. Due to the size of the radio and PIT telemetry data set, the detection efficiency of the radio receivers and PIT arrays has yet to be calculated.

Detection data from the PIT arrays was used to compare the migratory behaviour and passage success of Gates Creek sockeye salmon captured from the Seton Dam fishway versus those captured from the fish fence in the upper Seton River. However, given the preliminary nature of this report, PIT detection data was not incorporated with radio and acoustic migration data.

Radio telemetry data were used to calculate migration rate and survival of fish through the Seton River study area. Migration rates were calculated from the time between release and the first detection at Seton Dam and the distance between these two sites. Survival rates were calculated by determining the proportion of released fish that were subsequently detected at either the Seton River-Fraser River confluence (pink salmon), Seton Dam (pink salmon, Gates Creek and Portage Creek sockeye) or spawning grounds (Gates Creek and Portage Creek sockeye). Stray radio-tagged (n=8) were excluded from all analyses as were fish where sampling data was lost (n=4) or where inconsistences were observed in the radio telemetry data (n=1).

Acoustic accelerometer data from Seton Dam were used to examine fish passage success at Seton Dam. The following passage parameters were calculated according to the definitions outlined in Year 1: entrance delay (h), attraction efficiency (%), fallback delay (h), passage efficiency (%), overall delay (h), and overall success (%). Swimming speeds in body lengths per second ($BL\ s^{-1}$) were calculated according to the methods in Year 1. For swimming speed calculations, optimal swimming speed was 1 $BL \cdot s^{-1}$ and critical swimming speed was 2.10 $BL \cdot s^{-1}$. Stray acoustic-tagged (n=3) sockeye salmon were excluded from analysis. Additional analyses were performed as part of a peer-reviewed paper that was prepared from data in this report (see Appendix II).

Telemetry and acceleration data management and analysis was carried out in Excel. Fish passage metrics were compared amongst tagging groups and discharges using the statistical methods stated in text. Statistical analyses were considered significant at $p<0.05$ and were performed using SigmaPlot 11 (San Jose, California, USA) and R Version 3.0.2 (R Core Team 2013). All data are presented as mean ± S.D. unless otherwise noted.

2.5 Water Preference Experiments

Year 2 olfaction studies examined the behavioural response of Gates Creek sockeye salmon and pink salmon to different Seton River to Cayoosh Creek dilution ratios. Water preference experiments were carried out in a Y-Maze using methods similar to Fretwell (1989). Additional experiments tested the influence of co-migrating salmon (conspecifics) on water preference. The goals of Year 2 experiments were to verify that salmon migrating in the Seton-Anderson watershed display a preference for Seton River over Cayoosh Creek, to approximate the threshold dilution ratio at which a preference for Seton River water is displayed, and determine whether conspecifics influence the water preference of salmon.

2.5.1 Fish Collection and Holding

Gates Creek sockeye salmon (*n*=174) and pink salmon (*n*=163) were collected between 03 and 24 August and 09 and 23 September, respectively. Fish were either individually captured via dip net from the exit basin of the Seton Dam fishway or collected from the Seton River fish fence (see Section 2.4.1). Upon collection, sockeye salmon were screened using the Fatmeter to identify and remove potential strays. A small number of fish were not screened because one of the two Fatmeters used in the program malfunctioned. Groups of up to 12 fish per day were transported in a 1,000 L oxygenated transport tank to a holding tank at the Seton Dam compound. Fish were held in the holding tank in individual flow-through isolation chambers made from PVC pipe measuring 8” in diameter and 28” in length. Fish were held in the isolation chambers for one to eight hours prior to experiments.

2.5.2 Test Apparatus

Water preference experiments were carried out at the Seton Dam compound in a custom-built Y-Maze apparatus (Figure 2-8; Figure 2-9).

Water supply for the Y-Maze was stored in two 11,365 L polyethylene supply tanks (Premier Plastics Inc., Delta, BC, Canada) containing either Seton River water or the test mixture (Figure 2-8). One supply tank was used exclusively for Seton River water while the other contained the test mixture of either Seton River water or Seton River water diluted with Cayoosh Creek water. Seton River water was pumped directly into the supply tanks using a submersible pump installed on the upstream side of Seton Dam. Cayoosh Creek water was transported from Cayoosh Creek to the supply tanks using a 2,000 L truck-transport tank. Prior to water transport, the transport tank was disinfected with Ovadine (Syndel Laboratories, Qualicum Beach, BC, Canada) to eliminate any residual odours. Each supply tank was filled with fresh water at the start of each day and the dilution ratio of the test mixture was pre-mixed in the supply tank. Tanks were refilled during the day as required and drained at the end of each experiment day. Water from the tanks was gravity-fed to two 1,135 L mixing tanks before draining into the Y-Maze.

The Y-Maze was a custom-built plywood test chamber measuring 4.9 m x 1.2 m (Figure 2-9) and sealed with fiberglass and an odorless waterproof gel-coat. During dilution ratio experiments, water from each mixing tank gravity-fed into one of two test arms at a rate of 40 $L \cdot min^{-1}$. For experiments with conspecifics, flow was increased to 80 $L \cdot min^{-1}$. Dye-testing was used to confirm that water flow was unidirectional and there was no exchange of water between the two arms. Water depth in the Y-Maze was 0.6 m. For trials with Gates Creek sockeye salmon, water supplied to the left arm was always from Seton River. To test for a potential preference bias, a control experiment was carried out where Seton River water was supplied to both arms. For trials with pink salmon, the test mixture was alternated daily between arms to control to any bias. During experiments, the test chamber was covered to prevent external visual cues from altering salmon behaviour. Behaviour of salmon was monitored remotely using a video camera installed at the rear of the test chamber.

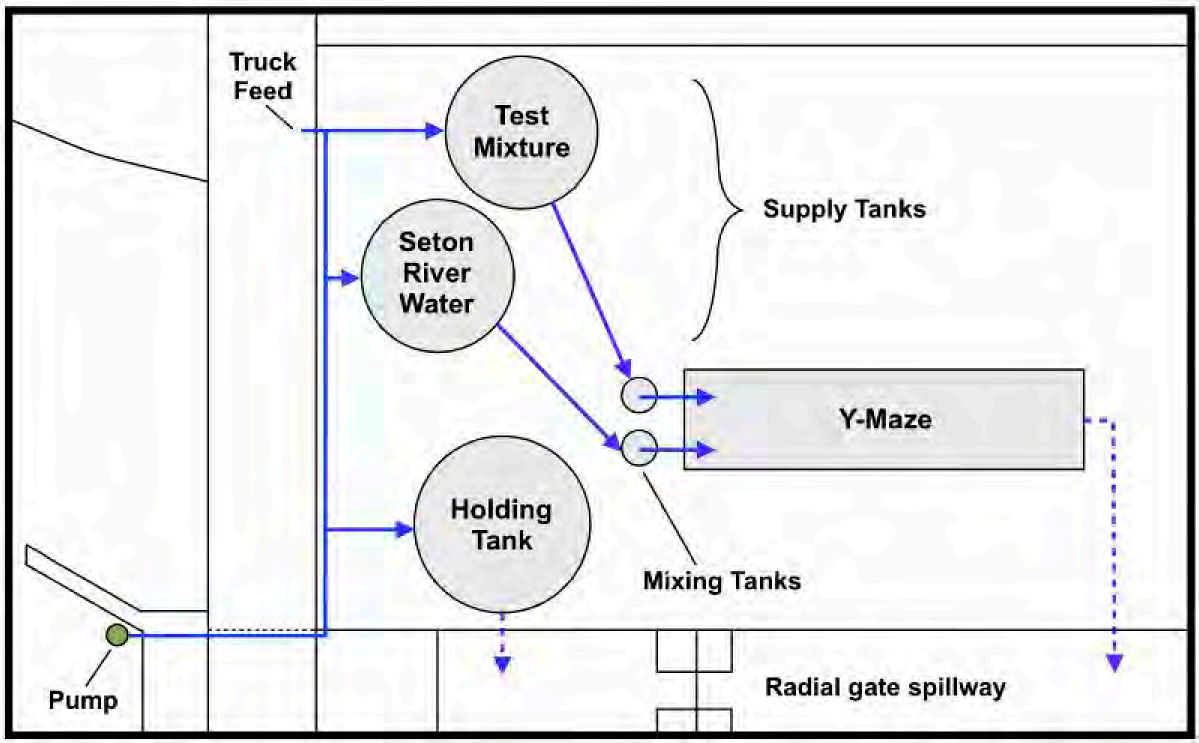

Figure 2-8: Overview of the Y-Maze test apparatus installed at the Seton Dam compound. Supply tanks were filled with water pumped from the Seton River or truck-transported from Cayoosh Creek and drained into supply tanks (truck feed)

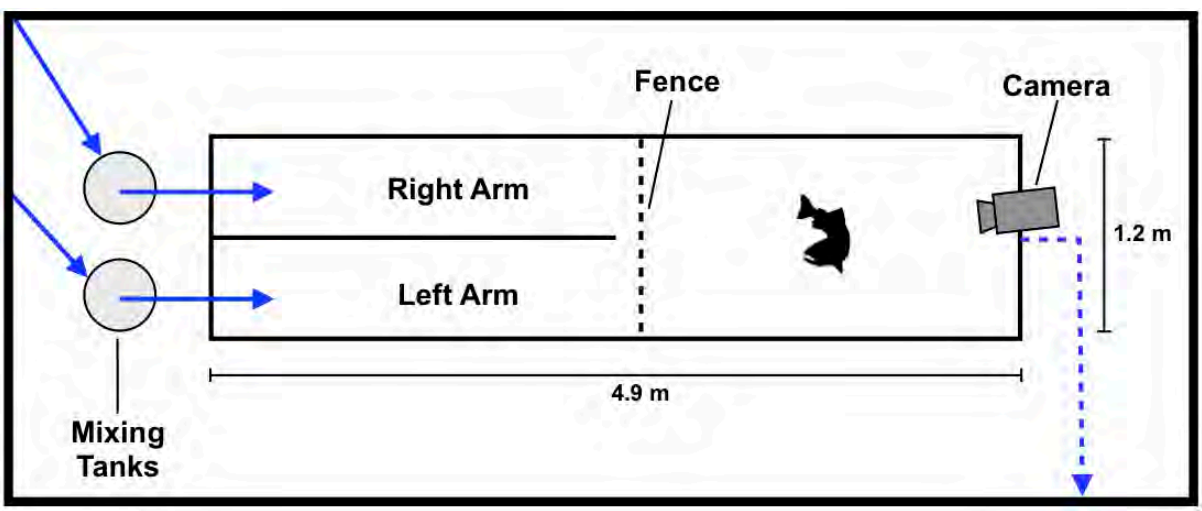

Figure 2-9: Detailed view of the Y-Maze used for water preference experiments

2.5.3 Experimental Protocol

Gates Creek sockeye salmon water preference experiments were carried out at three dilution ratios of Cayoosh Creek to Seton River water: 0% (Seton River water in both arms), 5%, 20% (current dilution target for Gates Creek sockeye salmon), and 50%. Pink salmon were only tested at a 50% dilution ratio. The effect of conspecifics on the water preference of Gates Creek sockeye and pink salmon was tested by supplying both Y-Maze arms with Seton River water and adding three salmon to one of the mixing tanks during experiments. It was hypothesized that adding fish to a mixing tank would increase the olfactory cues in the associated Y-Maze arm.

Test fish were transferred from isolation chambers to the Y-Maze and released. Each fish was allowed 10 min to acclimate to the Y-Maze prior to experiments. During the acclimation period, a temporary mesh fence was placed at the entrance to the Y-Maze arms to prevent fish from accessing the arms but still allowed water to flow from each arm into the rear section of the Y-Maze. At the end of the acclimation period, the fence was removed and behaviour of the fish observed for 20 min. All trials were recorded using a digital video recorder and real-time measurements of fish behaviour were recorded during the experiments. Behaviour was observe once for each fish.

2.5.4 Fish Sampling

Fish were sampled at the end of the water preference experiment using the same protocol as tagged fish (see Section 2.4.2). All fish were sampled for fork length, sex, blood, and DNA for stock identification. Fat content was only measured for a portion of fish because one Fatmeter malfunctioned during experiments and the remaining Fatmeter was used on tagged fish. A subset of fish were sacrificed via cerebral concussion and the olfactory rosette excised for analysis of olfactory gene expression. Rosette samples were stored in RNA Later® (Life Technologies Inc., Burlington, Ontario, Canada) and frozen at -20ºC before being transferred to -80ºC for storage until analysis. Non-scarified fish were released into the Seton Dam forebay.

2.5.5 Data Analysis

Fish behaviour during water preference experiments was analyzed to determine the number of times a fish entered each arm of the Y-Maze as well as the amount of time spent in each arm. Time in each arm was selected for the present behavioural analysis but entrance frequency or other measures may be analyzed in the future. The time in each arm for all individuals within a treatment group was tested for normality using the Shapiro-Wilk normality test. If normally distributed, a student's t-test was used to compare the time spent in each arm. If not normally distributed, a Wilcox signed rank-test was used instead. Individuals that did not enter either arm of the Y-Maze were removed from analysis as were individuals that spent less than 5 min in the two arm combined. Stray sockeye were also removed from analysis (n=10).

Due to laboratory limitations, blood plasma analysis from Year 1 and Year 2 has yet to be completed. Olfactory rosette gene expression analysis was performed following the methods outlined in the Year 1 report. Analysis of gene expression data is ongoing and will be presented in future reports.

3.0 RESULTS

3.1 Physical Parameters

3.1.1 Discharge and Dilution

Seton River discharge and dilution data is only presented for 2013 because salmon migration in the Seton River was not studied in 2012. In 2013, temporary increases in Cayoosh Creek discharge occurred in mid-July and mid-August (Figure 3-1), the latter of which was the result of Walden North Generating Station maintenance. As a result, the target dilution ratio for Gates Creek sockeye was exceeded for 17 of 43 days during the Gates Creek sockeye migration period. Dilution target ratios were exceeded from 20 to 26 July (21-27%), on 04 August (21%), and from 07 to 16 August (27-41%) (Figure 3-2). From 28 September to 15 November, the target dilution ratio for Portage Creek sockeye was exceeded for 4 days but by less than 1% each day.

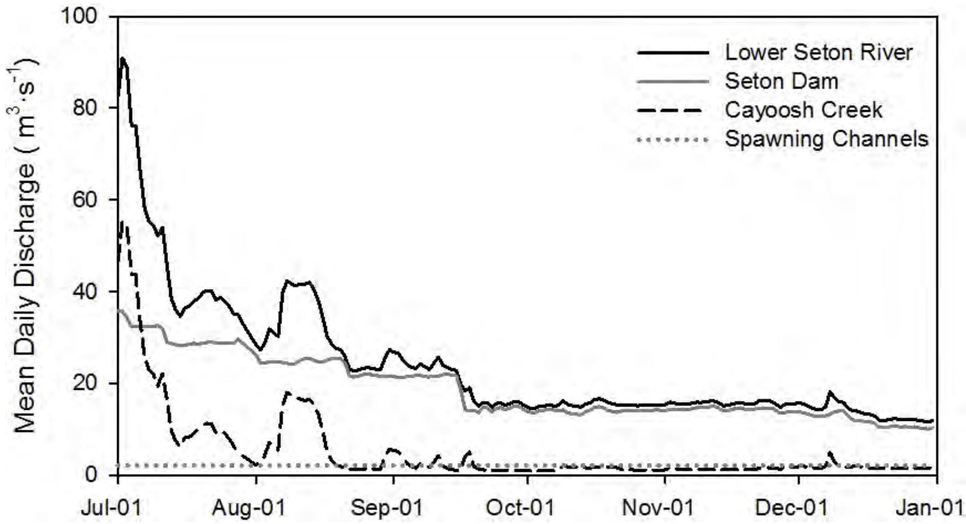

Figure 3-1: Total discharge of the lower Seton River in 2013 from the Seton Dam, Cayoosh Creek, and spawning channels (BC Hydro data)

Figure 3-2: Daily dilution ratio of the Seton River in 2013 (BC Hydro data). Target dilution ratios for sockeye salmon migration periods are shown in red (BC Hydro 2011)

Seton Dam discharge remained within the Water Use Plan target flow schedule throughout most of the study period (Figure 3-3). During telemetry studies (02 August to 29 October) adjustments to conveyance structure use decreased total Seton Dam discharge from 26.2 $m^3 \cdot s^{-1}$ to 22.8 $m^3 \cdot s^{-1}$ on 21 August (FWRG reduced from 4.9 $m^3 \cdot s^{-1}$ to 1.5 $m^3 \cdot s^{-1}$) and from 22.8 $m^3 \cdot s^{-1}$ to 16.0 $m^3 \cdot s^{-1}$ on 16 September (FWRG increased from 1.5 $m^3 \cdot s^{-1}$ to 13.9 $m^3 \cdot s^{-1}$; Siphon 1 turned off). A radial gate opening during the 16 September adjustment temporarily increased Seton Dam discharge by 18.6 $m^3 \cdot s^{-1}$ to 70.5 $m^3 \cdot s^{-1}$ over a 7 h period with a maximum total Seton Dam discharge of 89.0 $m^3 \cdot s^{-1}$ occurring during this time (Figure 3-4).

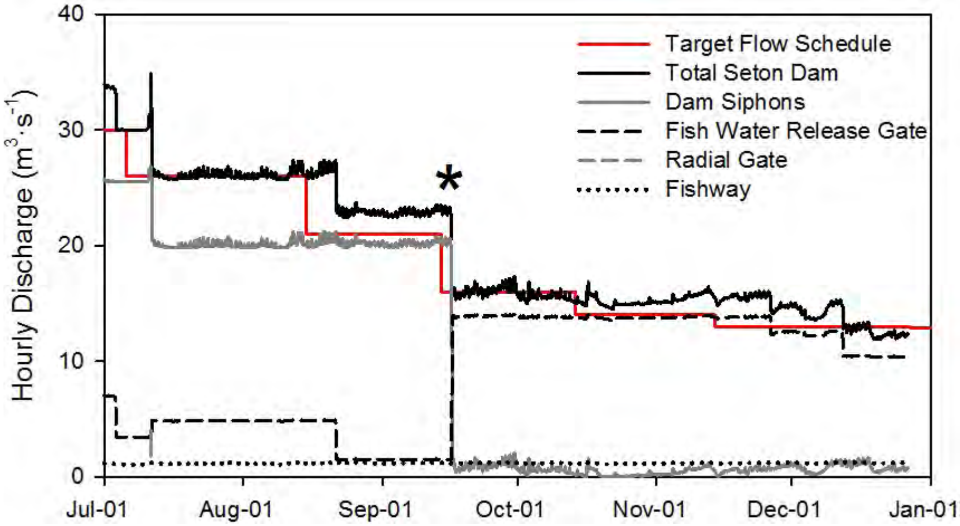

Figure 3-3: Hourly discharge for Seton Dam conveyance structures in 2013 (BC Hydro data). A radial gate opening on 16 September (*) is omitted. The target flow schedule for Seton Dam is shown in red (BC Hydro 2011)

Total Seton Dam discharge was considerably lower in 2013 than in 2012 (Figure 3-4). Discharge at the start of the Gates Creek sockeye salmon migration period (18 July) was approximately 87 $m^3 \cdot s^{-1}$ lower in 2013 than in 2012. However, discharges in both years were approximately equal by late-September during the migration period for pink, Portage Creek sockeye, and coho salmon.

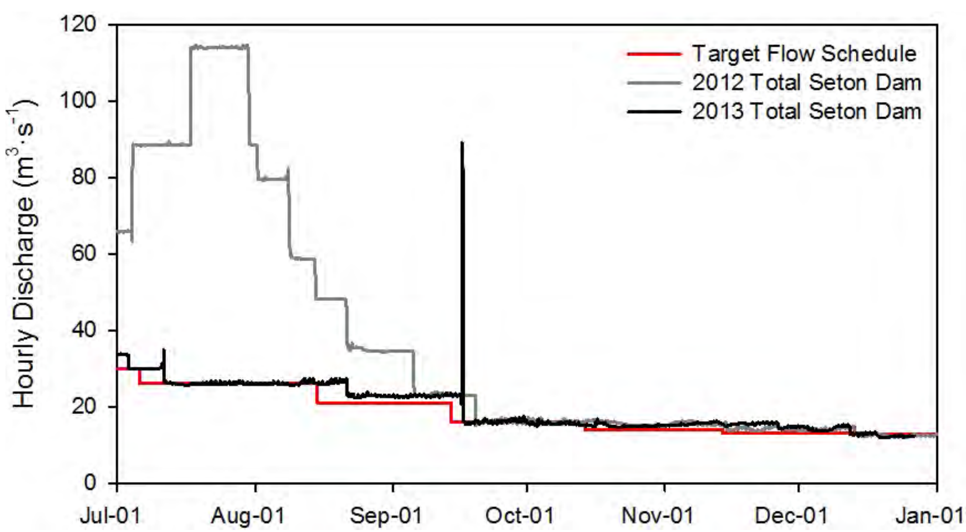

Figure 3-4: Total Seton Dam discharge in 2012 and 2013 (BC Hydro data)

3.1.2 Water Temperature

The thermal experience of Gates Creek and Portage Creek sockeye salmon prior to entering the Seton-Anderson watershed was estimated using the temperature of the Fraser River at Qualark Creek (Figure 3-5). Run timing past Qualark Creek was estimated using the methods presented in Year 1. Mean daily temperature of the Fraser River ranged from 16.3-21.6°C during the Gates Creek sockeye salmon migration and 13.5-21.4°C during the Portage Creek sockeye salmon migration. Fraser River temperatures during the Gates Creek migration were up to 2.2°C warmer than in 2012, with peak temperatures at Qualark Creek exceeding 20°C between 05 and 18 August, coinciding with the migration of Gates Creek sockeye salmon past this location. Therefore, given the 17.5ºC optimal temperature for this population (Lee et al. 2003), Gates Creek sockeye salmon experienced elevated temperatures and stressful thermal conditions within the Fraser River during their migration. Portage Creek sockeye may have also experienced elevated Fraser River temperatures in early-August. However, temperatures decreased in late-August during the migration period for this population.

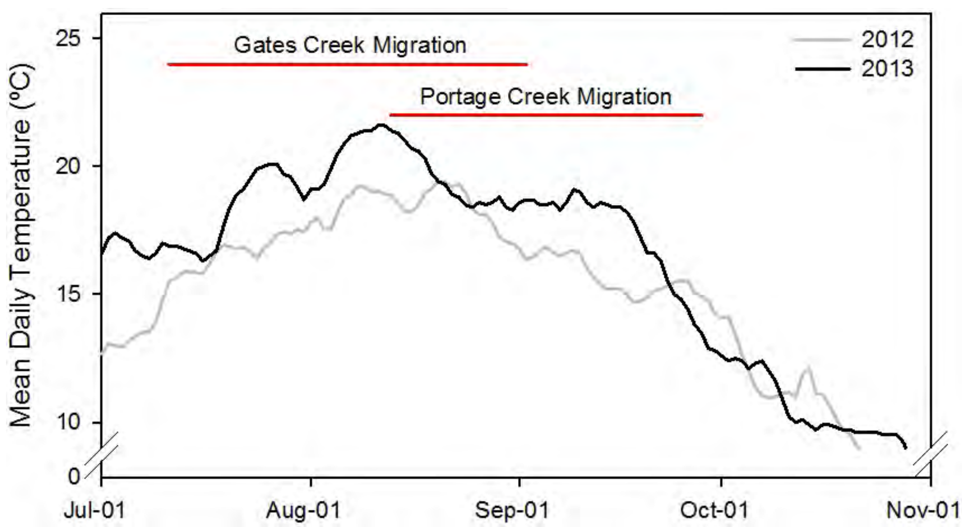

Figure 3-5: Mean daily temperature of the Fraser River at Qualark Creek in 2012 and 2013. The timing of Gates Creek and Portage Creek sockeye migration past Qualark Creek is shown in red (Hague and Patterson 2009)

Water temperatures at sites within the Seton River study area in August likely caused stressful conditions for migrating salmon and were unlikely to have offered significant opportunity for thermal refuge. Mean daily temperatures in the study area reached a maximum on 11 August with peak temperatures in the lower Seton River (19.7°C), Cayoosh Creek (15.9°C), and Seton Dam fishway (23.0°C) coinciding with peak temperatures in the Fraser River (21.3°C) (Figure 3-6). Temperature in the Seton Generating Station tailrace, a potential thermal refuge for salmon, was 2.9ºC cooler than the Fraser River on 05 August and 3.0ºC cooler 06 August. However, water temperature in the Seton Generating Station tailrace was typically within 1ºC of the temperature of the Seton Dam fishway and rapid fishway warming after 07 August eliminated any temperature differences between the Seton Generating Station and the Fraser River. Cayoosh Creek was cooler than both the lower Seton River and Seton Dam fishway throughout the study period and may have offered thermal refuge for Gates Creek sockeye migrating in August.

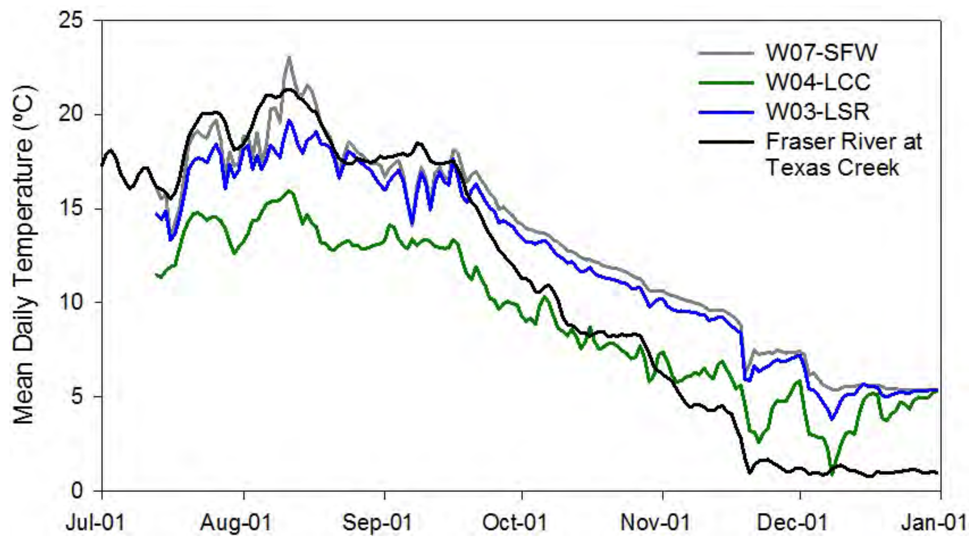

Figure 3-6: Mean daily temperature of the Fraser River, Lower Seton River, Cayoosh Creek, and Seton Dam fishway during the 2013 study period

Seton River temperatures in August were exacerbated by Seton Generating Station shutdowns (Figure 3-7). Intermittent shutdowns of the Seton Generating Station were associated with immediate and rapid temperature increases at the Seton Dam fishway. For example, an overnight shutdown on 10 August caused temperature with the fishway to increase from 19.0ºC to 22.7ºC in 4 h. The peak temperature in the Seton Dam fishway was 23.7ºC on 11 August. Rapid increases in temperature were likely the result of the 90-100 $m^3 \cdot s^{-1}$ reductions in Seton Lake outflow associated with station shutdowns that may have reduced the withdrawal of colder hypolimnetic water from Seton Lake. In addition, the Walden North diversion to Seton Lake was not operating from 07 to 15 August and likely contributed to elevated Seton Lake temperatures. Seton Generating Station shutdowns continued until 25 August, however, water temperatures began to naturally decrease on 12 August and after 18 August remained below 20ºC for the remainder of the study period.

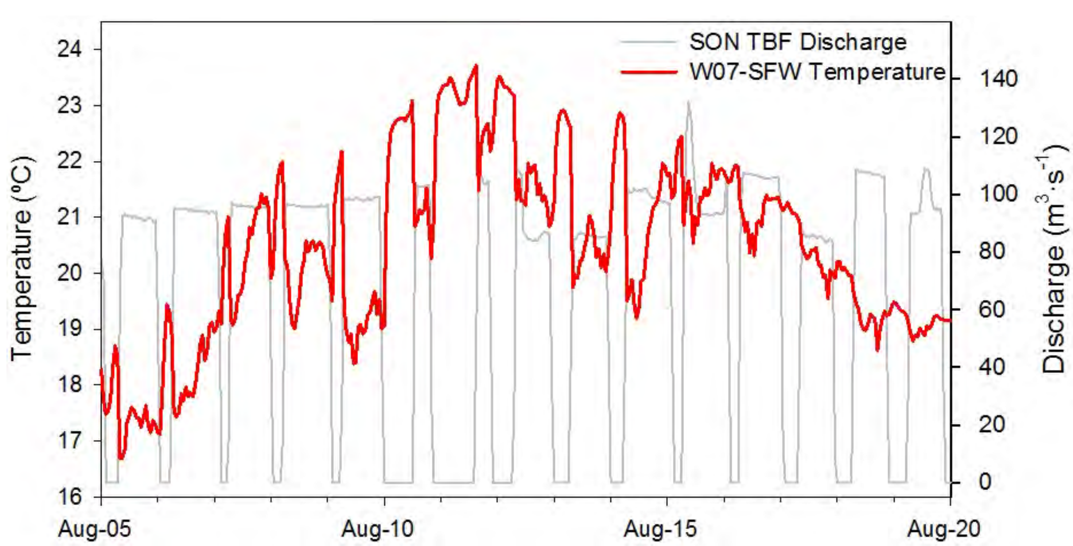

Figure 3-7: Seton Dam fishway (W07-SFW) temperature and Seton Generating Station turbine release flow (SON TBF) discharge from 05 August to 20 August 2013

3.1.3 Water Chemistry

Specific conductivity measurements in 2013 (Figure 3-8) were consistent with those measured in 2012. Specific conductivity in Cayoosh Creek gradually increased throughout the study period whereas conductivity decreased in the upper and lower Seton River. Differences in specific conductivity between the upper Seton River and Seton Generating Station were only observed on three occasions (17 July, 21 August, 16 October) when conductivity measurements coincided with Seton Generating Station shutdowns and Fraser River water filled the station tailrace.

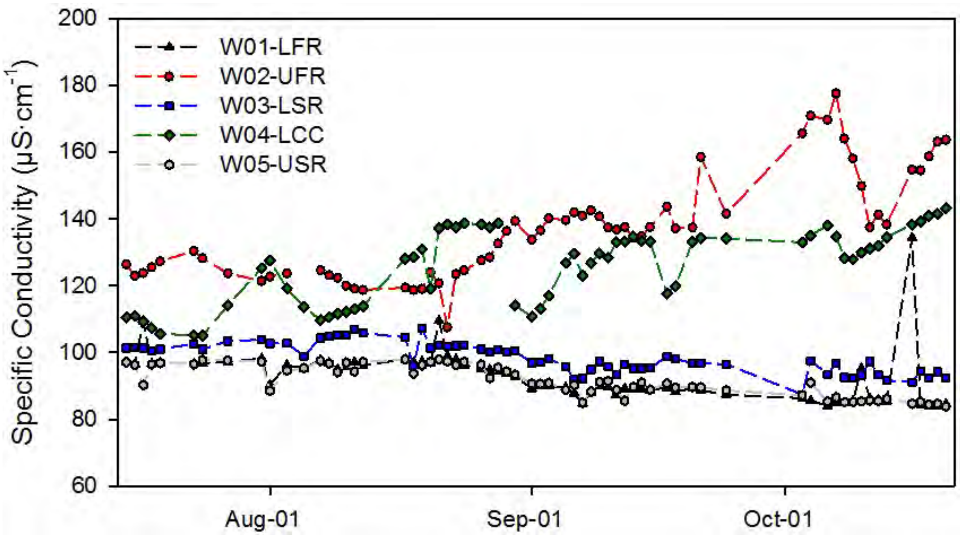

Figure 3-8: Specific conductivity at the Seton River study area water quality sites from 05 July to 20 October 2013

In 2013, differences in the specific conductivity between Cayoosh Creek and the upper Seton River matched the changes observed in 2012 (Figure 3-9). Differences in conductivity increased during the study period, resulting in the greatest differences in water chemistry during the Portage Creek sockeye migration period.

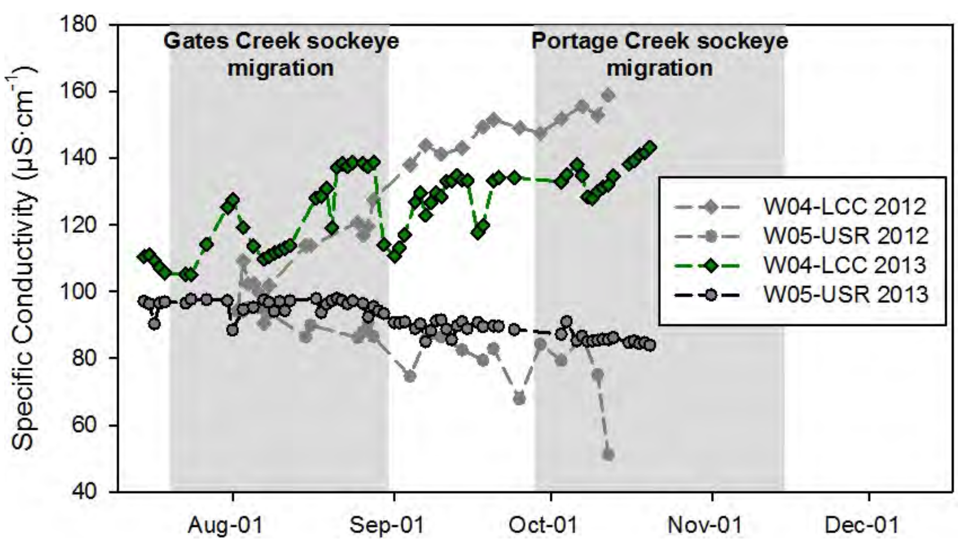

Figure 3-9: Specific conductivity readings from Cayoosh Creek (W04-LCC) and the upper Seton River (W05-USR) during the target dilution periods for Gates Creek and Portage Creek sockeye salmon in 2012 and 2013

3.2 Seton Dam Tailrace Flow Patterns

Flow velocities were characterized in the Seton Dam tailrace and at the fishway entrance. Highly aerated water from Siphon 1 attenuated the measurement range of the ADCP units and prevented the characterization of subsurface flows in the turbulent areas of the tailrace. However, flow velocities were measured in non-turbulent areas of the tailrace and at the fishway entrance. Detailed results of ADCP flow velocity measurements can be found in Appendix I.

3.2.1 Seton Dam Tailrace and Seton River Flows

ADCP measurement transects were integrated to describe flow patterns in the Seton Dam tailrace to the downstream-most measurement transect (T18) (Figure 3-10). The transects closest to Seton Dam (T19-T26 south bank; T1-T11 north bank) were attenuated at the edge of the turbulent water caused by discharge from Siphon 1. As a result, the loss of signal range (end of blue transect lines) outlines the extent of the turbulent water during the measurement period. Visual estimates of flow direction (red arrows) indicated that flow in this area was predominantly downstream.

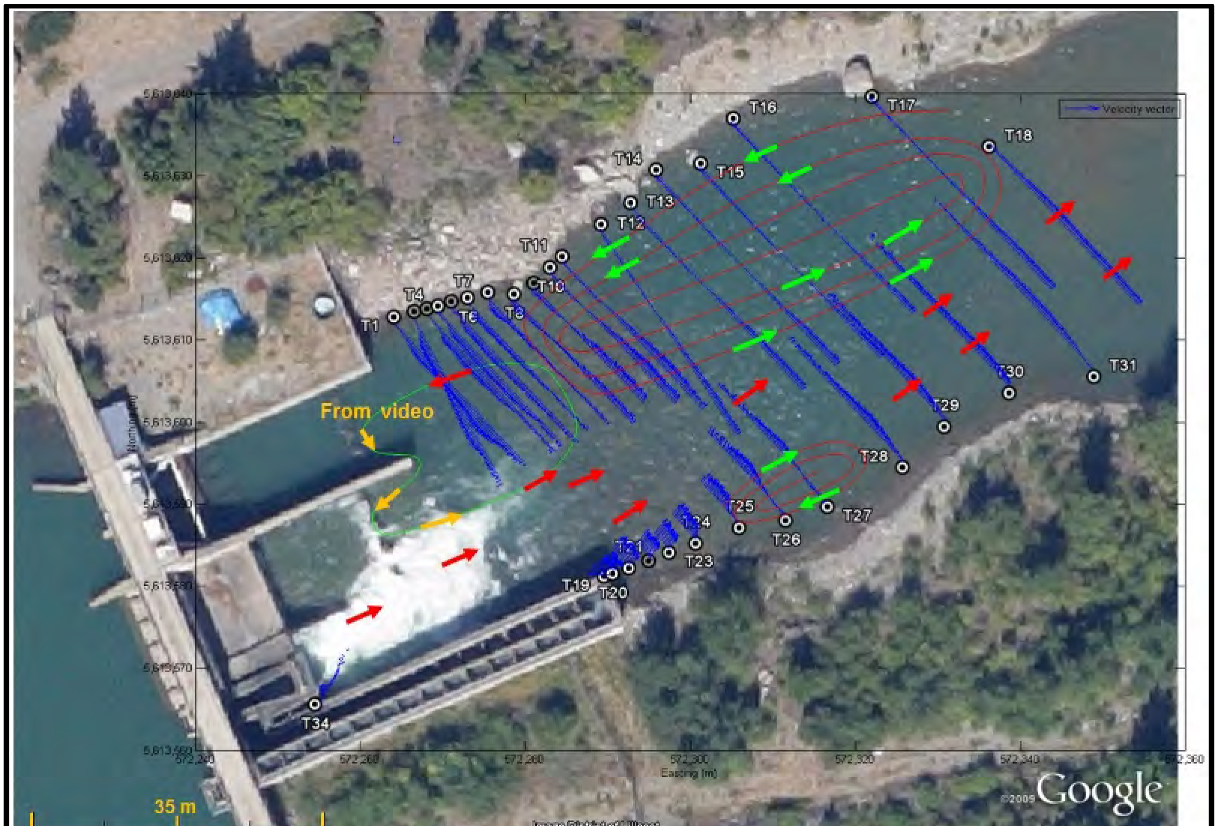

Figure 3-10: ADCP measurement transects (blue lines), calculated flow velocities (green arrows, red lines) and visually estimated flow direction (red and yellow arrows) in the Seton Dam tailrace

ADCP measurement transects revealed three subsurface vortices in the Seton Dam tailrace. The largest vortex, measuring approximately 60 m by 20 m, was located off the northern bank of the tailrace in the radial gate spillway. Flow velocities up to approximately 1 $m \cdot s^{-1}$ occurred in each direction in this vortex. A second, smaller vortex was present on the southern bank of the tailrace and measured approximately 15 m by 6 m. The third, visually-identified vortex was located near Seton Dam and was approximately 25 m by 15 m. Vortices in the tailrace were likely created by the high downstream velocities from Siphon 1 interacting with the bathymetry of Seton River. Both vortices on the northern bank are upstream of shallow gravel bars, located near transects T8-T10 and T18, that likely create subsurface obstructions leading to reverse flows and the formation of the vortices in the Seton Dam tailrace.

3.2.2 Fishway Entrance Flows

Substantial variation in both flow magnitude and direction were found to occur near the fishway entrance. Time-averaged measurements from the upward-facing Aquadopp Current Profiler positioned 1.25 m to 3.25 m downstream of the fishway entrance, revealed downstream flows up to 0.6 $m \cdot s^{-1}$ in the upper 2 m of the water column but upstream flows of 0.3 $m \cdot s^{-1}$ at depths greater than 2 m (Figure 3-11). This flow pattern was consistent at Aquadopp sites downstream of the fishway entrance (P1-P3). Further downstream, the 2-dimensional ChannelMaster transect (T34) measured >1 $m \cdot s^{-1}$ flows (0.1 and 0.6 m depth) perpendicular to the fishway entrance that emanated from the fishway wall (Appendix I, Figure 19). However, these flows dissipated at depths greater than 1 m. Unfortunately, the ChannelMaster transect signal could not effectively characterize flows further than 5-7 m into the tailrace due to the high turbulence from Siphon 1. However, where flows velocities could be detected, velocities were up to 4 $m \cdot s^{-1}$ with highly varied direction.

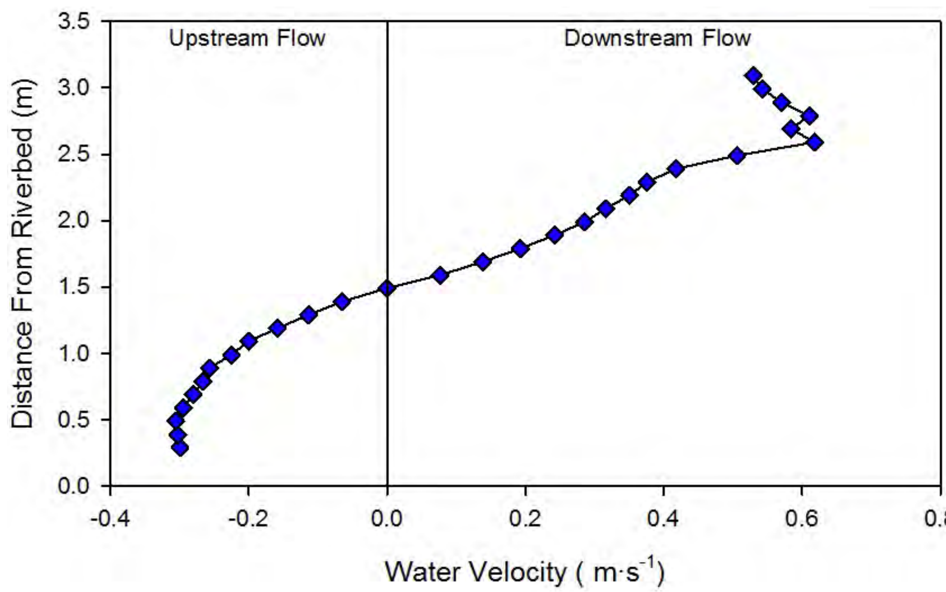

Figure 3-11: Aquadopp Current Profiler flow velocities as measured at the Seton Dam fishway entrance (P1). Velocity measurements were taken the in the upstream-downstream direction

3.3 Fish Passage Enumeration

Due to technical issues with the Seton Dam fish counter (see Section 4.2.3) passage abundance estimates were only calculated for Gates Creek sockeye and coho salmon. Passage estimates are highly uncertain for these species and are subject to change. No Chinook salmon were observed on video data and peak signal size data could not be used to differentiate Chinook from other species.

3.3.1 Video Validation

The detection efficiency of the Seton Dam fish counter was lower in 2013 than 2012. Review of 16 h of video data between 16 August and 30 August recorded 371 Gates Creek sockeye salmon migrating upstream through a single sensor tube on the fish counter. The detection efficiency of the fish counter for these fish was 83% (308/371 fish detected correctly) compared with an estimated 99% detection efficiency in 2012. A reduced detection efficiency in 2013 was likely due to the high abundance of Gates Creek sockeye salmon that led to multiple fish migrating through sensor tubes at the same time.

3.3.2 Gates Creek Sockeye Salmon Migration Timing and Abundance

Gates Creek sockeye salmon were observed migrating through the fish counter from 18 July to mid-September (Figure 3-12). An exact date for the end of Gates Creek sockeye migration could not be determined with the fish counter because Gates Creek sockeye cannot be visually discriminated from Portage Creek population. However, stock identification DNA analysis of sockeye salmon sampled up to 02 September showed only Gates Creek sockeye were migration at this time (see Section 3.4.1). Further, Gates Creek sockeye were observed arriving at Gates Creek up to 27 September, suggesting migration continued until at least mid-September. DNA analysis of PIT-tagged sockeye salmon sampled throughout September should provide an estimate of when Gates Creek sockeye salmon migration ended.

A minimum of 54,800 Gates Creek sockeye salmon passed through the Seton Dam between 18 July and 30 September. This is likely an underestimate of the abundance of sockeye due to fish counter wiring issues.

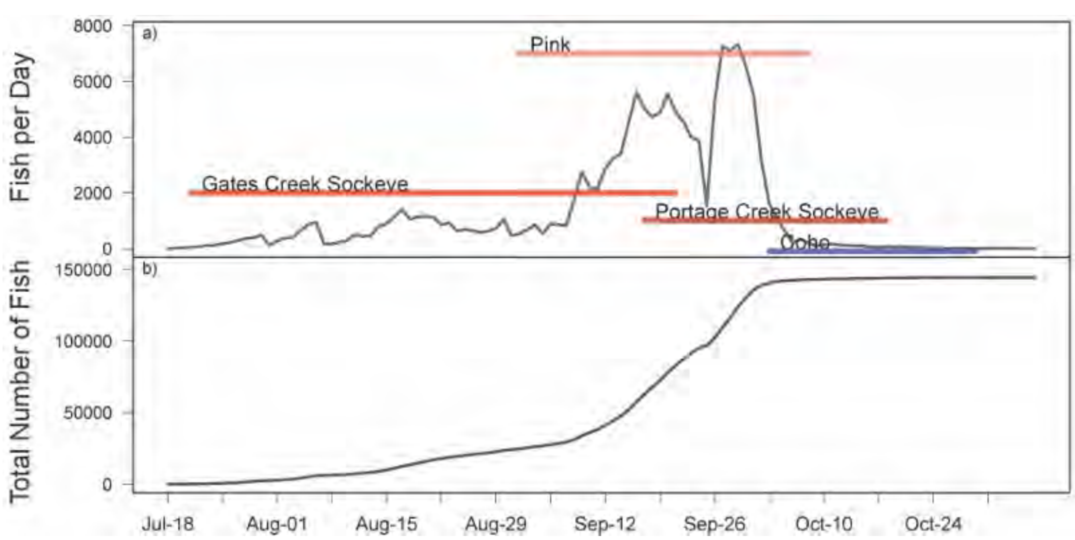

Figure 3-12: Plots of a) daily abundance and b) cumulative abundance of fish migrating through the Seton Dam fishway between 18 July and 05 November 2013

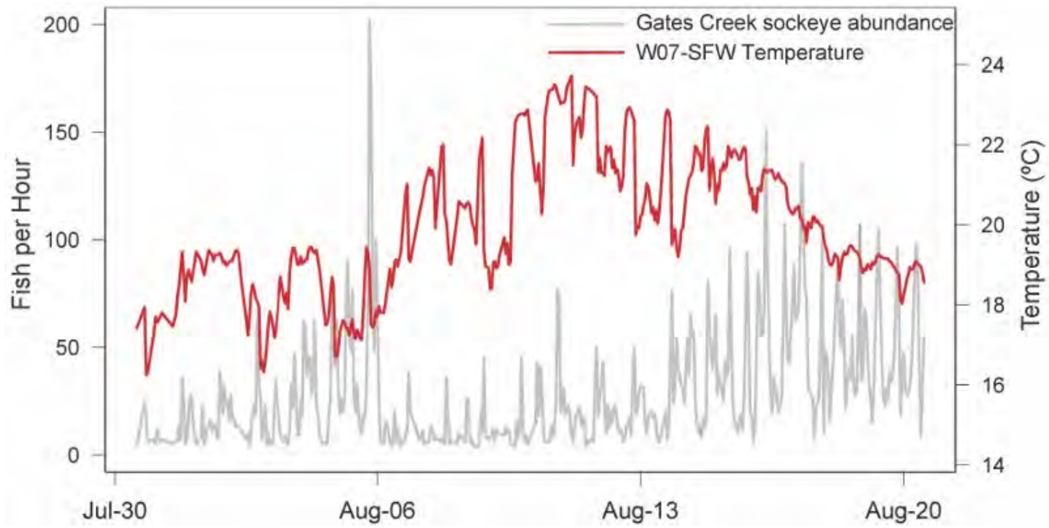

Figure 3-13: Plots of hourly water temperature in the Seton Dam fishway and hourly abundance (up counts) of Gates Creek sockeye exiting the fishway

Two distinct peaks in Gates Creek sockeye salmon migration were observed in August (Figure 3-13). The first peak occurred on 06 August and the second peak occurred between 17 August and 23 August. Decreased migration between these peaks coincided with high water temperatures in the Seton Dam fishway. Daily peaks in migration were due to Gates Creek sockeye primarily migrating during the early morning (05:00-07:00 h) with lower migration during the day (07:00-20:00 h) and the lowest migration at night (20:00-05:00 h).

3.3.3 Pink Salmon Migration Timing

Migration of a high number of pink salmon through the Seton Dam fishway began 09 September and continued to 03 October (Figure 3-12). Pink salmon migration overlapped with the migration of all other salmon populations. Migration of pink salmon was consistent throughout daytime hours but there was relatively little migration during nighttime hours. At the peak of pink salmon migration, over 700 up counts per hour were detected on the Seton Dam fish counter.

3.3.4 Portage Creek Sockeye Salmon Migration Timing

Sockeye salmon migrated continuously from September to October making it difficult to estimate the start of Portage Creek sockeye salmon migration. Stock identification results will aid in determining the run timing of Portage Creek sockeye salmon.

3.3.5 Coho Salmon Migration Timing and Abundance

Coho salmon were observed migrating through the fish counter from 02 October to 05 November (Figure 3-12). Although fish migrated in late-October and early-November, the number of coho salmon migrating per day decreased after 25 October. Coho migrated during day and nighttime hours and at the peak of the migration up to 16 fish per hour were migrating through Seton Dam.

An estimated 2,334 coho salmon passed through Seton Dam between 02 October and 05 November. Uncertainty in this estimate is due to migration overlap with Portage Creek sockeye early in the migration and limited video validation of fish counter efficiency.

3.4 Fish Sampling

3.4.1 Gates Creek Sockeye Salmon

Stock identification DNA analyses were performed on a total of 458 sockeye salmon identified in the field as part of the Gates Creek population. DNA results indicated that 95% (*n*=437) of fish collected were from the Gates Creek population with the remaining fish either strays from other systems (*n*=19) or from the Portage Creek population (*n*=1). Stray sockeye salmon were collected between 08 and 20 August and the single Portage Creek sockeye salmon was collected on 20 August.

Consistent with 2012 results, 2013 estimates of GSE density were significantly higher in stray sockeye salmon (7.3 ± 2.2 $MJ \cdot Kg^{-1}$) than Gates Creek sockeye salmon (6.0 ± 1.4 $MJ \cdot Kg^{-1}$) (Mann-Whitney rank-sum test: $U=874.5$, $p<0.001$) with minimal overlap of individual GSE estimates between the two groups (Figure 3-14). Using GSE to screen for stray sockeye salmon in 2013 may have introduced a bias in the GSE estimate for Gates Creek sockeye because screening rejected sockeye with a GSE greater than 7.2-7.4% and these fish were not sampled for stock identification. As a result, the GSE for Gates Creek sockeye in 2013 may be underestimated. However, the range of GSE estimates for Gates Creek sockeye in 2013 (1.5-8.3 $MJ \cdot Kg^{-1}$) was similar to that of 2012 (2.9-8.4 $MJ \cdot Kg^{-1}$) where no screening took place. In addition, the implementation of GSE screening reduced the proportion of sockeye salmon removed from analyses from 37% in 2012 to 5% in 2013.

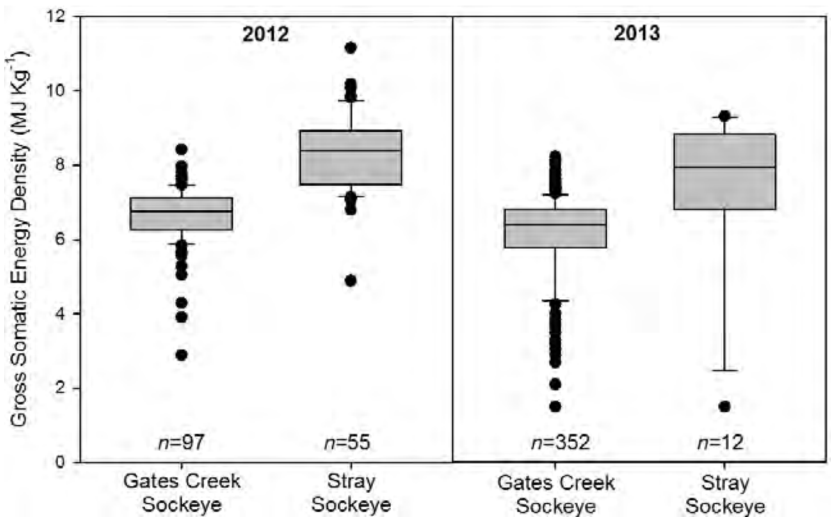

Figure 3-14: Estimated gross somatic energy density of Gates Creek and stray sockeye salmon in 2012 and 2013. Upper and lower whiskers show the 90th and 10th percentiles. Upper, lower and middle box boundaries show the 75th and 25th percentiles and median

Sampling results were calculated for positivity-identified Gates Creek sockeye salmon (Table 3-1). Males and females made up 51% and 49% of sampled Gates Creek sockeye salmon, respectively. Sex was not estimated for 122 Gates Creek sockeye salmon with poorly-defined secondary sexual characteristics. Nearly all unsexed Gates Creek sockeye salmon (*n*=118) were used in water preference tests. Plasma analyses will be used to determine the sex of these remaining fish. As in 2012, males had a greater fork length than females (Mann-Whitney rank-sum test: $U=5121.5$, $p<0.001$) while females had a higher estimated GSE (Mann-Whitney rank-sum test: $U=9668$, $p=0.018$).

Table 3-1: Mean fork length and estimated gross somatic energy (GSE) of Gates Creek sockeye salmon sampled in 2013

	Fish Sampled (*n*)	Fork Length (cm)	GSE ($MJ \cdot kg^{-1}$)
All	437	58.1 ± 3.1	6.0 ± 1.4
Male	161	59.4 ± 3.1*	5.8 ± 1.4
Female	154	56.8 ± 2.4	6.0 ± 1.5*

All value are presented as mean ± S.D. A (*) indicates a significant difference from the opposite sex.

3.4.2 Other Salmon Species

Sampling results for pink, Portage Creek, Chinook and coho salmon are presented in Table 3-2. Results are for all pink, coho, and Chinook salmon collected in 2013 whereas results for Portage Creek sockeye salmon are only for those positivity identified as Portage Creek sockeye. Stock identification DNA analyses were performed on all radio-tagged Portage Creek sockeye salmon (*n*=24) and no strays were identified. Additional Portage Creek sockeye salmon may have been collected for PIT-tagging in September and October, however, stock identification has yet to be performed on these individuals. The single Portage Creek sockeye collected on 20 August is excluded from sampling results because the sex and fat content of this fish were not estimated.

The mean estimated GSE of Portage Creek sockeye salmon fell below the threshold for rejecting sockeye salmon as strays. Therefore, it is unlikely that Portage Creek sockeye salmon co-migrating with Gates Creek sockeye were identified as strays during collection.

Table 3-2: Mean fork length and estimated gross somatic energy (GSE) of pink, Portage Creek sockeye, coho, and Chinook salmon sampled in 2013

	Fish Sampled (*n*)	Fork Length (cm)	GSE ($MJ \cdot kg^{-1}$)
Pink salmon			
Male	272	53.5 ± 3.5*	3.3 ± 1.8
Female	154	51.4 ± 2.2	3.0 ± 1.8
Portage Creek			
Male	9	57.8 ± 2.0	3.2 ± 2.0*
Female	15	56.3 ± 1.6	5.9 ± 0.7
Coho salmon			
Male	24	61.1 ± 5.6	7.8 ± 0.7
Female	6	59.3 ± 2.9	6.2 ± 2.9
Chinook salmon			
Female	1	71.0	8.3

All value are presented as mean ± S.D. A (*) indicates a significant difference from the opposite sex.

3.4.3 Injury Monitoring

Results of monitoring for external injuries are only presented for fish that were PIT-tagged in 2013 because injury prevalence on PIT-tagged fish was judged to be the most representative sample of the population. Injury analysis was based on the presence or absence of an injury and the severity of any injuries that were present.

Gates Creek sockeye salmon showed the highest prevalence of injuries of all salmon species sampled in the Seton River while pink salmon displayed the lowest prevalence of injuries in 2013 (Table 3-3).

Table 3-3: Injury prevalence amongst PIT-tagged salmon in 2013

Species/Population	Injured (*n*)	Uninjured (*n*)	Proportion Injured (%)
Gates Creek sockeye	78	248	24%
Pink	10	268	4%
Portage Creek sockeye	1	13	7%
Coho	4	30	13%

Of the injured Gates Creek sockeye, 60% had minor injuries (*n*=47), 21% moderate injuries (*n*=16), and 19% had severe injuries (*n*=15). Severe injuries were most commonly associated with either eye injuries (judged to severely impair vision) or abrasions due to gill net entanglement (Figure 3-15). Head injuries that may have been the result of attempted migration at the Seton Generating Station were not observed in high frequency although further review of tagging data is required.

Analysis of injury location, injury type, and the estimated origin of the injury has yet to be completed for all PIT-tagged fish and will presented in future reports. Injury assessments of acoustic and radio-tagged fish will be integrated with migration data to determine if fish condition influenced migration success.

Figure 3-15: Example of a severe external injury on a Gates Creek sockeye salmon. Note dorso-ventral scars indicating gillnet entanglement and the severe abrasion on the ventral surface

3.5 Capture Location

Challenges during the installation and operation of the Seton River fish fence necessitated the capture of Gates Creek sockeye salmon from the Seton Dam fishway in early-August. Prior to the 16 August installation of the fence, a total of 68 radio-tagged, 28 acoustic-tagged, and 64 PIT-tagged Gates Creek sockeye salmon were captured from the fishway and released. However, only a limited number of fence-caught fish (*n*=9) were released during this time and after 16 August, all acoustic and radio-tagged Gates Creek sockeye were captured from the fence.

In order to determine the possible effect of capture location on migration, a group of Gates Creek sockeye salmon were captured from the fishway, PIT-tagged, and co-released at the Upper Seton River site with fence-caught PIT-tagged fish. Due to transport capacity limitations, no PIT-tagged fish were released at the Lower Seton River or Fraser River sites. Therefore, determining if capture location influences lower Seton River migration success is limited to a comparison of the fishway and fence-caught acoustic and radio-tagged fish released at the Lower Seton River and Fraser River sites. However, comparing lower Seton River migration success with capture location was complicated by large differences in temperature, dilution, and discharge before and after 16 August, resulting in markedly different migration conditions for fishway and fence-caught fish. As a result, data to assess the relationship between capture location and migration success is primarily limited to the group of fishway and fence-caught PIT-tagged Gates Creek sockeye salmon released at the Upper Seton River site. These results were used to perform a preliminary assessment of the effect of capture location on Seton Dam passage and survival to spawning grounds. Some analysis of the effect of capture location on Seton Dam passage has also been performed (see Section 3.7).

Passage success at Seton Dam was not significantly different for fence and fishway-caught Gates Creek sockeye salmon release at the Upper Seton River site (Chi-squared test: x^2=2.55, d.f.=1, p=0.11) (Table 3-4). However, survival to spawning grounds was significantly (30%) lower for fishway-caught fish (Chi-squared test: x^2=18.70, d.f.=1, p<0.001) with overall survival from release to spawning grounds being 33% lower. Therefore, this preliminary analysis suggests that fish captured from the fishway have reduced long-term survival but short-term effects may be limited. Further analysis is required to determine the effect of different capture locations on 2013 migration results. From these preliminary analyses, capture location will be a factor considered in all future analyses.

Table 3-4: Seton Dam passage success and survival to spawning grounds of fishway-caught and fence-caught Gates Creek sockeye salmon PIT-tagged and released at the Upper Seton River site 20 August to 29 August 2013

Measure	Fence-Caught	Fishway-Caught
Seton Dam Passage Success	93% (86 of 93)	84% (90 of 107)
Survival to Spawning Grounds	87% (75 of 86)	57% (51 of 90)
Overall Survival	81% (75 of 93)	48% (51 of 107)

Paired releases of fence and fishway caught fish occurred on the following dates in August 2013: 20, 22, 26, 27, 28, 29.

3.6 Migration in the Lower Seton River

The effect of dilution and temperature on the migration rate and survival of salmon migrating to Seton Dam was examined using radio-tagged Gates Creek sockeye, pink, and Portage Creek sockeye salmon released in the Fraser and Seton River. Given the scope of the tagging program, only preliminary analyses of the effect of dilution and temperature are available for Year 2. Although the effects of capture location were not considered in the present analysis, it has been noted where capture location was a potential factor in the observed results.

3.6.1 Migration Conditions

Conditions in the Seton River during releases of radio-tagged Gates Creek sockeye, pink, and Portage Creek sockeye salmon are summarized in Figure 3-16. Operational adjustments at the Seton Generating Station, Walden North Generating Station, and Seton Dam caused rapid fluctuations in dilution, discharge, and temperature in the lower Seton River and at the Seton Generating Station (see Section 3.1). It is likely that migrating salmon, in particular Gates Creek sockeye, encountered highly variable conditions while migrating to Seton Dam. Temperature, dilution, and discharge profiles for individual fish will be used to account for variable conditions during migration. However, for the purposes of this report, analyses of the effects of physical parameters on the migration of radio-tagged fish were based on the conditions present at the time of release. Conditions in the lower Seton River below Cayoosh Creek were used as they were intermediary to conditions in the Fraser River and the upper Seton River.

Gates Creek sockeye salmon experienced the greatest range of conditions while migrating in the lower Seton River. Fish were released while the dilution ratio in the lower Seton River ranged from 5.2-40.5%, the discharge ranged from 24.9-44.5 $m^3 \cdot s^{-1}$ and the temperature ranged from 16.0-19.7ºC. Fish were released across the entire range of dilution ratios (Table 3-5) with 80 fish released when the dilution ratio exceeded the <20% Gates Creek target dilution ratio.

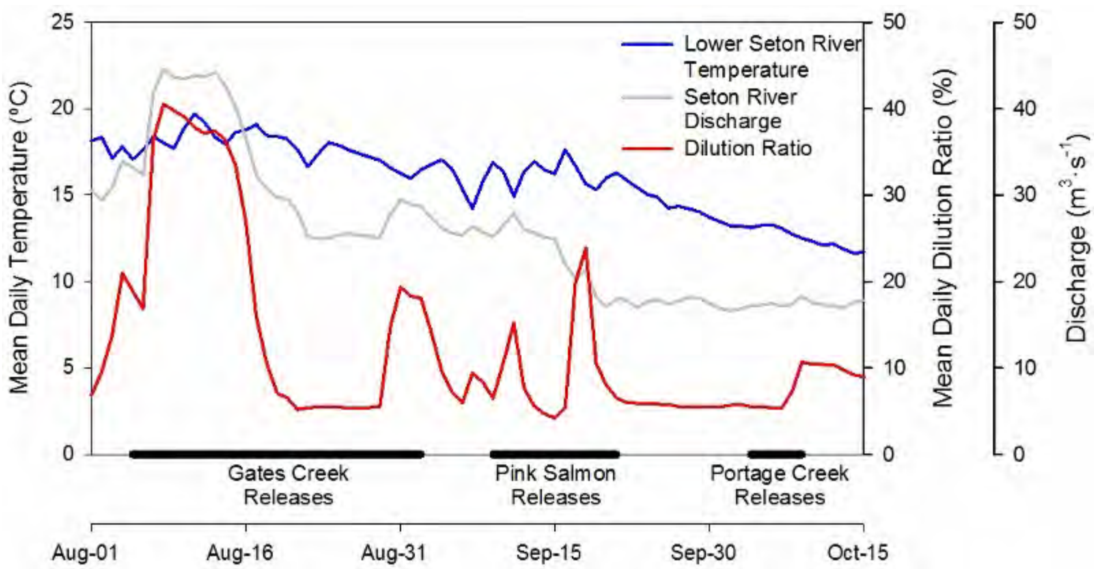

Figure 3-16: Discharge, dilution, and temperature conditions in the Lower Seton River during 2013 releases of radio-tagged Gates Creek sockeye salmon (Gates Creek), pink salmon, and Portage Creek sockeye salmon (Portage Creek)

Table 3-5: The number of radio-tagged Gates Creek sockeye, pink, and Portage Creek sockeye salmon released at different dilution ratios

Release Site/Population	Dilution Ratio				
	<10%	10-20%	20-30%	30-40%	>40%
Lower Seton River					
Gates Creek sockeye salmon	13	8	-	14	1
Fraser River West and East					
Gates Creek sockeye salmon	72	32	12	41	12
Pink salmon	38	20	-	-	-
Portage Creek sockeye salmon	19	5	-	-	-

Dilution ratio experienced is based upon the dilution at the time of release.

The conditions experienced by pink salmon and Portage Creek sockeye salmon were less varied than that of Gates Creek sockeye salmon. Pink salmon were released when the dilution ratio in the lower Seton River ranged from 4.2-19.8%, the discharge ranged from 17.1-27.9 $m^3 \cdot s^{-1}$, and the temperature ranged from 15.3-17.6ºC. During Portage Creek sockeye salmon releases, the dilution ratio in the lower Seton River ranged from 5.5-10.7%, the discharge ranged from 17.2-18.3 $m^3 \cdot s^{-1}$, and the temperature ranged from 12.5-13.3ºC. A total of five Portage Creek sockeye were released when the dilution ratio exceeded the <10% target dilution ratio (Table 3-5). However, the dilution ratio was exceeded by <1%. In 2013, preliminary analysis showed that lower Seton River discharge below Cayoosh Creek did not have a strong effect on migration rates or survival for any species and was not included in analyses.

3.6.2 Comparison of Release Sites

No differences were observed in the migration rates or survival of Gates Creek (migration rate: Mann-Whitney rank sum test: T=2966, p=0.195; survival: Chi-squared test: x2=0.83, d.f.=2, p=0.661) or Portage Creek (migration rate: Mann-Whitney rank sum test: T=124, p=0.342; survival: Fisher exact test: p=1.0) sockeye salmon released from opposite banks (west and east) of the Fraser River. Pink salmon migration rates and survival to spawning grounds in the lower Seton River were also found to not differ between sites (migration rate: Mann-Whitney rank sum test: T=198, p=0.275; survival: Chi-squared test: x^2=1.087, d.f.=1, p=0.297). Therefore, releases from either the Fraser River West or Fraser River East release sites were combined and treated as a single release site for all species.

Migration rates to Seton Dam for Gates Creek sockeye salmon were compared for fish released at the Fraser River and Lower Seton River. Migration rates were significantly greater for fish released in the Fraser River (5.4 ± 2.4 $km \cdot d^{-1}$) than fish released in the lower Seton River (4.2 ± 2.5 $km \cdot d^{-1}$) (Mann-Whitney rank sum test: T=1442, p=0.005) (Figure 3-17). Therefore, analyses for the effects of dilution and temperature on Gates Creek sockeye salmon migration rate were analyzed separately for Fraser River and Lower Seton River releases.

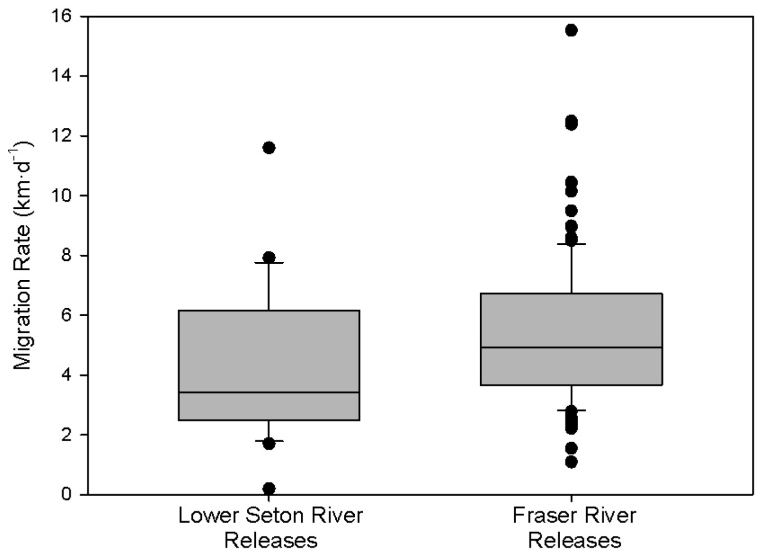

Figure 3-17: Migration rates to Seton Dam for Gates Creek sockeye salmon released at the Lower Seton River and the Fraser River release sites

3.6.3 Dilution and Sockeye Salmon Migration

The effects of dilution on Gates Creek and Portage Creek sockeye salmon was examined by comparing the relationship between dilution ratio and migration rate.

Gates Creek sockeye salmon did not appear to delay at higher dilution ratios. Migration rates of fish released in the Fraser River at >20% dilution (5.2 ± 2.1 $km \cdot d^{-1}$) was not significantly different than fish released at <20% (5.5 ± 2.5 $km \cdot d^{-1}$) (Mann-Whitney rank sum test: T=1667, p=0.782). Lower Seton River migration rates also did not differ at higher dilution ratios (>20%: 4.0 ± 2.5 $km \cdot d^{-1}$; <20%: 4.4 ± 2.6 $km \cdot d^{-1}$; Mann-Whitney rank sum test: T=155, p=0.65). Linear regressions showed no relationship between dilution and migration rates at either release site (Fraser River: F=0.18, p=0.67, r^2=0.002; Lower Seton River: F=0.00, p=0.99, r^2=0) (Figure 3-18).

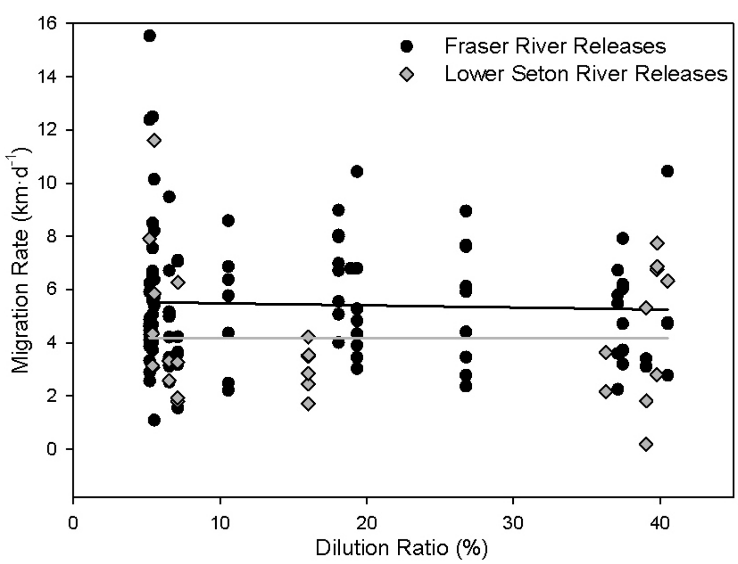

Figure 3-18: Linear regressions of dilution ratio and migration rate to Seton Dam for Gates Creek sockeye salmon released in the Fraser River and lower Seton River

Portage Creek sockeye salmon migration rates also did not vary with dilution (Linear Regression: F=4.04, p=0.059, r^2=0.18) or differ above or below the 10% target dilution ratio (Mann-Whitney rank sum test: T=63, p=0.098). However, the sample size for Portage Creek sockeye was low (*n*=21) and the dilution ratio exceeded the 10% target ratio by less than 1%. Portage Creek sockeye salmon survival was high at all dilution ratios experienced (Table 3-6). Overall, Portage Creek sockeye salmon survival to Seton Dam was 92% (22/24).

Gates Creek sockeye salmon survival to Seton Dam decreased with increasing dilution ratio. Survival of fish released at dilution ratios <30% (86%) was twice that of fish released at dilution ratios >30% (43%) (Table 3-6). However, given that changes in the dilution ratio did not affect migration rates of Gates Creek sockeye, reduced survival at dilution ratios >30% may have been due to a combination of capture location and temperature. Both capture location and temperature at the time of release differed for fish that experienced dilution ratios greater or less than 30%. All 68 Gates Creek sockeye that experienced dilution ratios >30% were captured from the fishway and were released at temperatures above the 17.5ºC optimal temperature for this population (Lee et al. 2003). In comparison, all 137 Gates Creek sockeye salmon that were released at a dilution ratio <30% were captured at the fence and only 76 of 137 were released at above-optimal temperatures. Therefore, both temperature and capture location are factors that may have reduced the survival of fish released at dilution ratios >30%. However, determining the relative influence of each factor on survival may be difficult with the present data since only fishway-caught fish were released at high dilution ratios and fence-caught fish at low dilution ratios (see Section 3.5). Further, any effect of dilution on survival was likely masked by the effects of capture location and temperature.

Table 3-6: Survival of radio-tagged Gates Creek and Portage Creek sockeye salmon from release to Seton Dam at different release dilution ratios

Sockeye Salmon Population	Dilution Ratio				
	<10%	**10-20%**	**20-30%**	**30-40%**	**>40%**
Gates Creek	88% (75 of 85)	80% (32 of 40)	92% (11 of 12)	42% (23 of 55)	46% (6 of 13)
Portage Creek	90% (17 of 19)	80% (4 of 5)	-	-	-

3.6.4 Temperature and Sockeye Salmon Migration

The effect of temperature on the migration rate and survival of Gates Creek sockeye salmon were considered without capture location as a factor. However, as noted in Section 3.6.3, high temperatures during the Gates Creek sockeye salmon migration were studied with fish captured from the fishway whereas migration during low temperatures was studied with fish captured at the fence. Therefore, the observed temperature effects could, in part, be due to capture location. Future analyses will attempt to isolate the effect of temperature from the effect of capture location.

The migration rate of fish released in the lower Seton River was significantly reduced with increasing Seton River temperature (Figure 3-19) (Linear regression: F=4.64, p=0.041 r^2=0.15). High temperature in the lower Seton River also reduced the migration rate of Gates Creek sockeye released in the Fraser River, although not significantly (Linear regression: F=3.47, p=0.065, r^2=0.03).

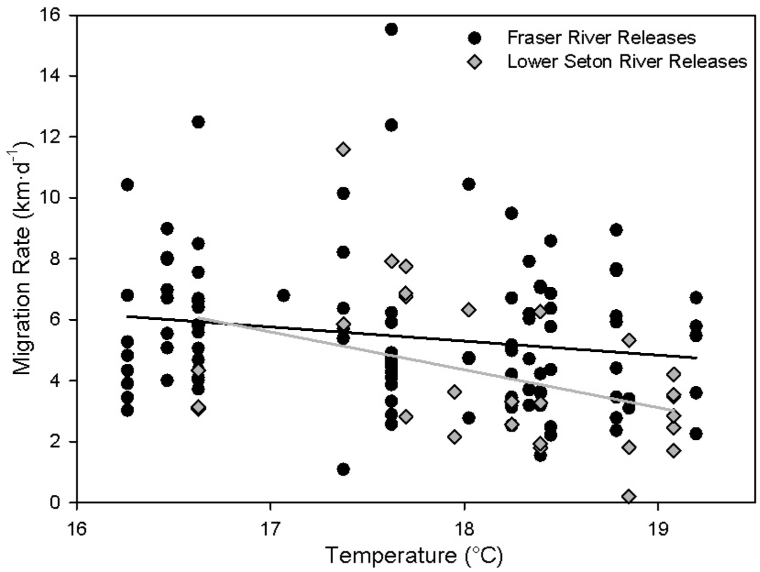

Figure 3-19: Linear regressions of temperature and migration rate to Seton Dam for Gates Creek sockeye salmon released in the Fraser River and the lower Seton River

High temperature reduced the likelihood of Gates Creek sockeye salmon reaching Seton Dam. For Gates Creek sockeye salmon released at temperatures of 16-17ºC, the survival to Seton Dam from all release sites was 97% (36 of 37 fish). Above 17ºC, however, survival to Seton Dam decreased to 75% (39/52) at 17-18ºC, 67% (61/91) at 18-19ºC, and 44% (11/25) at 19-20ºC. As a result, the probability of Gates Creek sockeye reaching Seton Dam steadily decreased with increasing temperature (Figure 3-20).

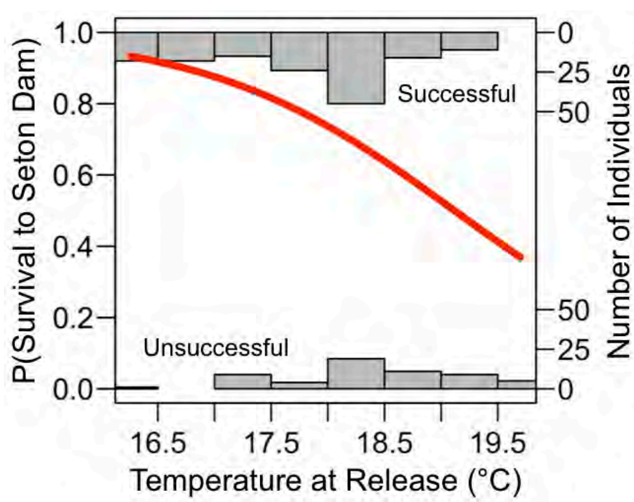

Figure 3-20: Logistic regression of the predicted probability (red line) of Gates Creek sockeye salmon surviving to Seton Dam after release at different lower Seton River water temperatures

Temperature during releases of Portage Creek sockeye salmon varied by <1ºC. The migration rates of Portage Creek sockeye salmon migration rate was not significantly related to temperature (Linear regression: F=4.19, p=0.055, r^2=0.18). Additional migration data over a greater temperature range is needed to determine the effect of temperature on Portage Creek sockeye migration rate and survival.

3.6.5 Sex-specific Difference in Sockeye Migration

Sex-specific differences in the migration rate and survival of sockeye salmon were only compared for Gates Creek sockeye because the sample size of Portage Creek sockeye (*n*=24) was judged as too small to compare differences between sexes. Although dilution did not appear to affect migration rates (see Section 3.6.3), sex-specific differences were still examined to determine if males and females responded differently to changes in the dilution ratio. Sex-specific differences in survival were only examined with temperature. The effect of capture location was not considered but it is probable that any sex-specific effects of capture location mirrored the effects of temperature.

Migration rates of Gates Creek sockeye salmon released in the Fraser River were significantly greater for males (6.2 ± 2.6 $km \cdot d^{-1}$, *n*=61) than females (4.6 ± 1.8 $km \cdot d^{-1}$, *n*=52) (Mann-Whitney rank sum test: T=2337, p<0.001). For releases from the Lower Seton River site, migration rates of males (4.4 ± 2.7 $km \cdot d^{-1}$, *n*=19) and females (3.6 ± 1.9 $km \cdot d^{-1}$, *n*=9) were not significantly different (Student's t-test: t=-0.799, d.f.=26, p=0.43), although this was likely due to low statistical power.

Survival from release to Seton Dam was greater for males than females at both release sites. Survival from the Fraser River to Seton Dam was 13% greater for males (77%, 65/84) than females (64%, 54/83), although this difference was not significant (Chi-squared test: x^2=2.52, d.f.=1, p=0.112). Greater differences in survival between sexes occurred at the Lower Seton River release site, with male survival significantly greater than female survival (males: 19/20; females: 9/16; Fisher Exact test: p=0.012). For all releases, male survival was 81% (84/104) and significantly greater than the overall female survival of 61% (62/101) (Chi-squared test: x^2=7.66, d.f.=1, p=0.006).

Differences in the migration rate of males and females could not be attributed to sex-specific responses to dilution. Dilution ratios >20% did not significantly affect the migration rates of either male or female Gates Creek sockeye (2-way ANOVA: F=1.90, p=0.17) (Table 3-7) and there was no relationship between dilution and migration rate for either sex when released in the Fraser River (Linear regression; males: F=1.81, p=0.18, r^2=0.03; females: F=0.84, p=0.36, r^2=0.02) or in the Lower Seton River (Linear regression; males: F=1.44, p=0.27, r^2=0.17; females: F=0.21, p=0.65, r^2=0.01).

Table 3-7: Migration rates of male and female Gates Creek sockeye salmon to Seton Dam at dilution ratios greater than or less than the 20% target dilution ratio

Release Site	Males		Females	
	<20%	>20%	<20%	>20%
Fraser River Release Migration Rate ($km \cdot d^{-1}$)	6.5 ± 2.8 (*n*=42)	5.4 ± 2.2 (*n*=19)	4.5 ± 1.7 (*n*=41)	4.9 ± 2.1 (*n*=11)
Lower Seton River Release Migration Rate ($km \cdot d^{-1}$)	4.5 ± 2.8 (*n*=13)	4.3 ± 2.8 (*n*=6)	2.9 ± 1.1 (*n*=5)	4.5 ± 2.6 (*n*=4)

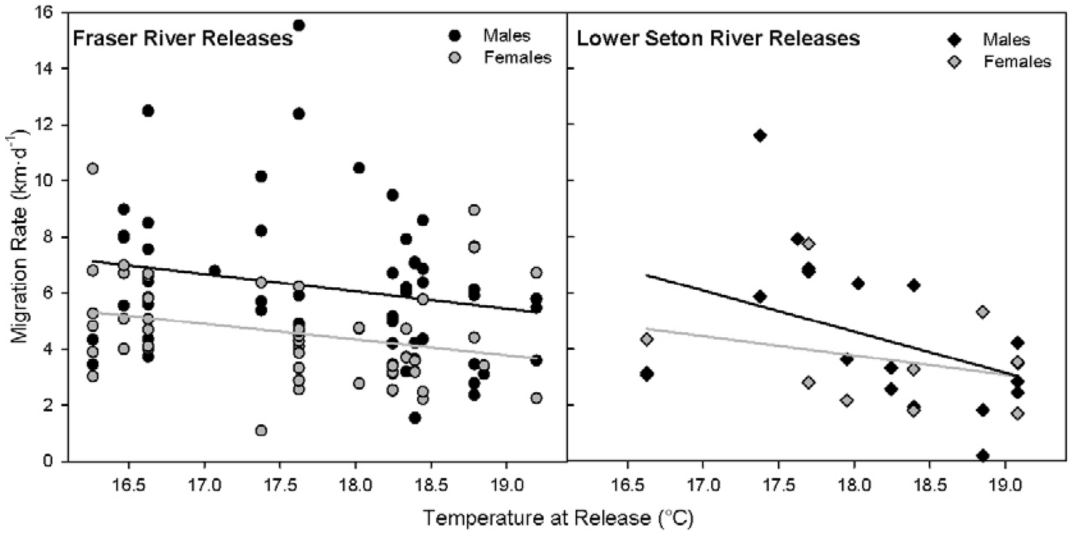

Figure 3-21: Linear regressions of the relationship between temperature at release and male (black) and female (grey) Gates Creek sockeye salmon migration rates

Increased temperature decreased the migration rate of male and female Gates Creek sockeye salmon although effects were only significant for females. The migration rates of females released in the Fraser River decreased significantly with increasing temperature (Figure 3-21) (Linear regression: F=4.69, p=0.035, r^2=0.09). Male sockeye released in the Fraser River had a similar decrease in migration rate in response to temperature, however, the decrease was not significant (Linear Regression: F=3.22, p=0.078, r^2=0.05). For releases at the Lower Seton River site, temperature had a greater effect on males than females but the decrease in migration rate was not significant (Linear Regression: males: F=3.8, p=0.068, r^2=0.18; females: F=0.60, p=0.46, r^2=0.08). Greater variation in the migration rate of males (Table 3-7) likely contributed to a non-significant result.

Survival of female Gates Creek sockeye salmon was more sensitive to increased temperature than males (Table 3-8). Fish released from both the Fraser River and Lower Seton River were combined to assess the effect of temperature on survival to Seton Dam. At the lowest release temperature range (16-17ºC), males and female survival was equally high (≥95%). However, with increasing release temperature the survival of female sockeye decreased faster than males. As a result, female survival at the highest release temperatures (19-20ºC) was approximately half that of males, explaining, in part, the 20% lower overall survival of female Gates Creek sockeye salmon to Seton Dam.

Table 3-8: Sex-specific survival of radio-tagged Gates Creek sockeye salmon from release to Seton Dam at different temperatures

Sex	Temperature at Release			
	16-17ºC	**17-18ºC**	**18-19ºC**	**19-20ºC**
Male Survival to Seton Dam	100% (18 of 18)	87% (20 of 23)	77% (39 of 51)	58% (7 of 12)
Female Survival to Seton Dam	95% (18 of 19)	66% (19 of 29)	55% (22 of 40)	31% (4 of 13)

Dilution ratio experienced is based upon the dilution at the time of release.

3.6.6 Pink Salmon Migration to Spawning Grounds

Pink salmon were considered to have reached spawning grounds if they were detected on either the lower Seton River receiver (Receiver 7) or the Seton Dam receiver (Receiver 5). A small number of pink salmon were either detected only at Seton Dam (*n*=4) or detected at Seton Dam prior to detection in the lower Seton River (*n*=1), suggesting the lower Seton River receiver may have had a reduced detection efficiency. Detection efficiencies will be taken into account in future analyses. For the present analysis, the migration rates of pink salmon was estimated based on first detection in the Seton River. A number of radio-tagged pink salmon (*n*=9) were observed to migrate upstream of Seton Dam. Although the fate of these fish was unknown, all fish were considered to have reached spawning grounds.

The mean migration rate of pink salmon to spawning grounds was 4.1 ± 5.3 $km \cdot d^{-1}$ with no differences in migration rates between males (4.0 ± 5.3 km d^{-1}, *n*=17) and females (4.1 ± 5.6 $km \cdot d^{-1}$, *n*=15) (Student's t test: t=-0.27, d.f.=30, p=0.79). Of the 58 pink salmon released in the Fraser River, a total of 32 were detected in the Seton River (55%). The migration rate of fish was not related to dilution (Linear regression: F=0.09, p=0.76, r^2=0) or temperature (Linear regression: F=1.8, p=.8, r^2=0.06) but this was likely the result of the low dilution ratio range (4.2-19.8%) and temperature range (15.3-16.8ºC) experienced by radio-tagged pink salmon in 2013.

Survival of pink salmon also did not appear to be related to dilution or temperature. Survival rates for pink salmon released at dilution ratios of 0%-10% and 10-20% were 53% (20/38) and 65% (13/20), respectively. The survival of pink salmon that experienced the highest dilution ratio (19.8%) had a survival of 70% (7/10). Temperature was unlikely to be a factor affecting pink salmon survival to spawning grounds given the temperature tolerance of pink salmon (Clark et al. 2011) and relatively low temperatures during the pink salmon migration in 2013. However, five recovered iButtons will provide insight into the thermal history of pink salmon.

Discharge may have been a factor in the survival of pink salmon (Table 3-9). The survival of fish released at lower Seton River discharges of <25 $m^3 \cdot s^{-1}$ was 70% (21/30) whereas survival at discharges >25 $m^3 \cdot s^{-1}$ was 43% (12/28). However, it is important to note that discharge steadily decreased during pink salmon releases and large differences in survival occurred when the difference in discharge was relatively small (e.g. 12 September *versus* 15 September). Pink salmon were increasingly more likely to survive to the Seton River later in the migration with survival lowest in the two earliest release groups. Therefore, it is unclear if the observed increase in survival was due to decreased discharge or a possible increase in site fidelity as pink salmon reached a more advanced maturation state later in the migration.

Table 3-9: Survival of radio-tagged pink salmon released in the Fraser River according to release group and conditions in the lower Seton River at the time of release

Variable	Release Date					
	09 Sept	12 Sept	15 Sept	17 Sept	19 Sept	21 Sept
Dilution	6.5%	7.7%	4.2%	19.8%	10.5%	6.5%
Discharge ($m^3 \cdot s^{-1}$)	25.2	26.1	25.0	20.4	18.2	18.0
Temperature	16.9ºC	16.4ºC	16.3ºC	16.7ºC	15.3ºC	16.3ºC
Survival to Seton River	25% (2 of 8)	20% (2 of 10)	80% (8 of 10)	70% (7 of 10)	60% (6 of 10)	80% (8 of 10)

3.7 Passage Success at Seton Dam

Detailed study of Gates Creek sockeye salmon passage at Seton Dam was carried out using acoustic accelerometers. The detection efficiency of the acoustic array in the Seton Dam tailrace was examined and the passage success of Gates Creek sockeye salmon was compared with previous years and during different migration conditions. Radio and PIT telemetry was used to estimate the passage success of Portage Creek sockeye salmon. The overall passage success of pink and coho salmon was also estimated.

3.7.1 Acoustic Array Detection Efficiency

The detection efficiency of the Seton Dam acoustic array in 2013 was considered to be high in all areas of the Seton Dam tailrace (Table 3-10). Of the acoustic-tagged Gates Creek sockeye salmon that were detected at Seton Dam (*n*=54) all were detected in the radial gate spillway. In the fishway entrance area, detection efficiency was lower, with 20% of fish that were detected in the fishway not detected in the entrance area. Reduced detection efficiency in the entrance area was likely due to the decreased detection range of the acoustic receivers in the highly turbulent flows from Siphon 1 and the FWRG. Regardless, the detection efficiency of the entrance area array in 2013 was 17% greater than the array installed in 2012 (63%).

Table 3-10: Seton Dam acoustic array detection efficiency based on the proportion of Gates Creek sockeye salmon detected

Seton Dam Area	Detection Efficiency
Radial Gate Spillway	100% (54 of 54 fish detected)
Entrance Area	80% (36 of 45 fish detected)
Fishway	100% (45 of 45 fish detected)
Seton Dam Forebay	100% (44 of 44 fish detected)

Despite the increased detection efficiency of the Seton Dam array in 2013, the proportion of fish activity detected while fish were in the tailrace was slightly lower than in 2012 (Table 3-11). However, the higher proportion of activity detected in 2012 was likely due to a smaller sample size (*n*=16) and because the proportion of activity recorded exceeded 20% for some fish (*n*=3). Changes to the array in 2013 doubled the proportion of all detections that occurred in the entrance area (2012: 0.9%; 2013: 2.0%). Therefore, data from the acoustic array in 2013 likely represent a better overall estimate of swimming behaviour and activity in the Seton Dam tailrace.

Table 3-11: Proportion of Gates Creek sockeye salmon swimming activity captured by the Seton Dam acoustic array while fish were present in the tailrace

Variable	2012 Overall	2013 Discharge @ 26.1 $m^3 \cdot s^{-1}$	2013 Discharge @ 22.8 $m^3 \cdot s^{-1}$
Time in Tailrace (Range)	23.2 ± 33.8 h (0.8 – 116.8 h)	8.3 ± 1.2 h (0.1 – 24.8 h)	15.3 ± 3.0 h (0.9 – 58.4 h)
Detections per Fish (Range)	618 ± 1342 (6 – 5,429)	209 ± 54 (5 – 1811)	283 ± 52 (21 – 907)
% Activity Recorded (Range)	10.3 ± 10.3% (1.1 – 34.0%)	7.0 ± 1.0% (0.6 – 31.7%)	7.2 ± 1.6% (2.4 – 27.1%)

All value are presented as mean ± S.E.

3.7.2 Migration Conditions

Conditions in the tailrace varied throughout study period for Gates Creek sockeye salmon migration at Seton Dam (Figure 3-22). While acoustic-tagged fish were present in the tailrace, temperature ranged from 15.6-23.7ºC. Given such large variation in temperature, the maximum temperature encountered while in the Seton Dam tailrace was used to estimate effect of temperature on passage success. Maximum temperature was used rather than release temperature because fish did not migrate through different thermal environments. Discharge experiences were determined for individual fish to account for daily variations in discharge. For simplicity, passage success is presented according to operation regime.

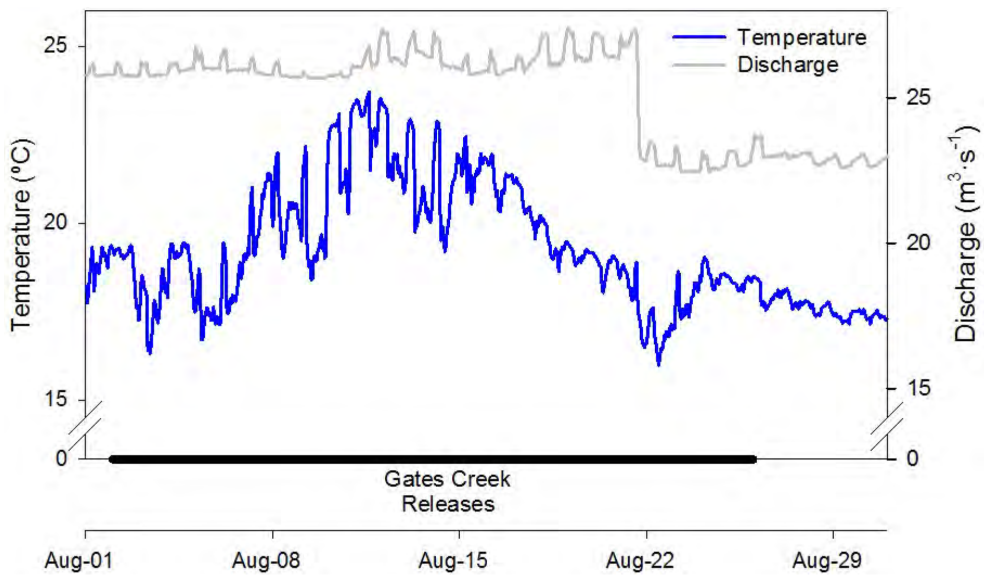

Figure 3-22: Discharge and temperature conditions at Seton Dam during 2013 releases of acoustic-tagged Gates Creek sockeye salmon (Gates Creek)

3.7.3 Gates Creek Sockeye Salmon

Gates Creek sockeye salmon passage success in 2013 was estimated with acoustic telemetry results and is presented in Table 3-12 along with previous estimates of passage success.

Direct comparison of passage success across years is complicated by differences in annual discharge conditions. Compared to previous study years, total Seton Dam discharge in 2013 was the second lowest observed. The maximum discharge experienced by fish in 2013 (26.1 $m^3 \cdot s^{-1}$) was substantially lower than that experienced in 2007 (60.0 $m^3 \cdot s^{-1}$) and 2012 (48.0 $m^3 \cdot s^{-1}$). However, total Seton Dam discharge in 2013 fell within the Water Use Plan target flow schedule (BC Hydro 2011) whereas all previous years had all been outside of target flow schedule. Annual differences in discharge will be an important variable in future fish passage analyses but have not been integrated into the present comparison.

Attraction and passage efficiency in 2013 fell within the range of previously observed values while entrance delay was the lowest observed to date (Table 3-12). Passage success of fish in 2013 was the highest observed to date. Passage efficiency was nearly 100% in 2013 with only one fish failing to ascend the fishway after locating the fishway entrance.

Table 3-12: Comparison of Gates Creek sockeye salmon passage at Seton Dam in 2005, 2007, 2012, and 2013

Variable	2005[a]	2007[b]	2012	2013
Attraction Efficiency	77% (23 of 30)	86% (44 of 51)	69% (18 of 26)	83% (45 of 54)
Mean Entrance Delay	18.0 ± 4.7 h	16.3 ± 3.1 h (0.5 – 92.6 h)	18.8 ± 6.8 h (0.5 – 114.7 h)	10.8 ± 1.4 h (0.1 – 58.4 h)
Passage Efficiency	100% (23 of 23)	93% (41 of 44)	89% (16 of 18)	98% (44 of 45)
Overall Success	77% (23 of 30)	80% (41 of 51)	62% (16 of 26)	81% (44 of 54)

Entrance delay is mean ± S.E. Data from [a]Pon et al. (2006) and [b]Roscoe and Hinch (2008). Assessed discharges ($m^3 \cdot s^{-1}$) were 15.8, 12.7, and 11.0 (2005); 60.0 and 35.0 (2007); 48.0, 35.0 and a radial gate opening (2012); and 26.1 and 22.8 (2013)

High attraction efficiency and low entrance delay occurred at different discharges in 2013 (Table 3-13). Discharge at Seton Dam was reduced following partial closure of the FWRG on 21 August. Reduced FWRG discharge resulted in a 22% increase in attraction efficiency but also a significant increase in entrance delay (Student's t-test: t=-2.821, d.f.=43, p=0.007). These results suggest that higher FWRG discharges may reduce the ability of fish to enter the fishway but might provide better fishway attraction flows that reduced entrance delay.

Table 3-13: Summary of Gates Creek sockeye salmon passage at Seton Dam for each discharge condition in 2013

Variable	26.1 $m^3 \cdot s^{-1}$	22.8 $m^3 \cdot s^{-1}$
Attraction Efficiency	77% (27 of 35)	95% (18 of 19)
Mean Entrance Delay	7.3 ± 1.4 h	15.9 ± 3.1 h*
Median Entrance Delay	4.4 ± 7.3 h	15.7 ± 13.2 h
Entrance Delay Range	0.1 – 22.3 h	0.9 – 58.4 h
Fallback Rate	26% (9 of 35)	5% (1 of 19)
Mean Fallback Delay	11.4 ± 2.1 h	4.3 h
Median Fallback Delay	11.6 ± 6.2 h	4.3 h
Fallback Delay Range	3.1 – 24.8 h	-
Passage Efficiency	96% (26 of 27)	100% (18 of 18)
Overall Success	74% (26 of 35)	95% (18 of 19)
Mean Overall Delay	8.3 ± 1.2 h	15.3 ± 3.0 h
Median Overall Delay	6.0 ± 7.2 h	15.5 ± 13.1 h
Overall Delay Range	0.1 – 24.8 h	0.9 – 58.4 h

Mean delay times are mean ± S.E. Median delay times are median ± S.D.

3.7.4 Temperature and Sockeye Passage Success

Gates Creek sockeye salmon migrating at Seton Dam in early August encountered near-lethal water temperatures that reduced passage success. Fish that encountered water temperatures above approximately 21ºC had a reduced likelihood of passing Seton Dam (Figure 3-23). Capture location may have been a factor in the reduced passage success observed at high temperatures because 25 fishway-caught fish released on or before 11 August would have experienced high water temperatures. Analyses to separate capture location and temperature effects showed that fence-caught fish were 16% more likely to pass Seton Dam (Appendix II). Therefore, the probability of Gates Creek salmon passing Seton Dam after encountering high water temperature may be under-estimated. Regardless, temperature was an important factor for Seton Dam passage in 2013 and 21ºC may be an important temperature threshold above which the passage success of Gates Creek sockeye salmon is greatly reduced. Further work is required to incorporate temperature into passage analyses and the iButtons recovered from radio-tagged fish will provide insight on the temperatures encountered by fish that failed to migrate past Seton Dam.

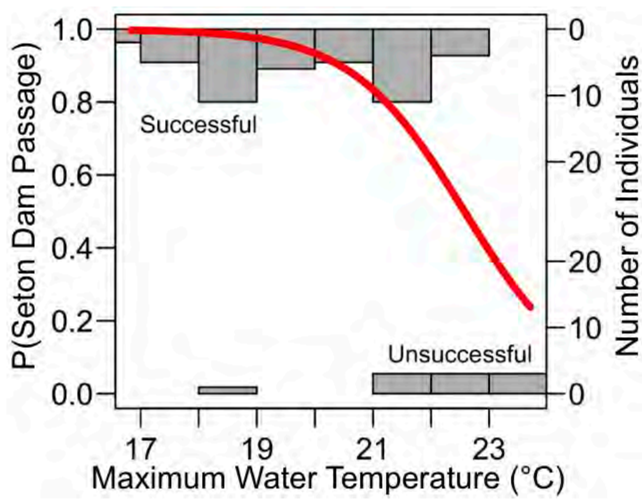

Figure 3-23: Logistic regression of the predicted probability (red line) of Gates Creek sockeye salmon passing Seton Dam after encountering different maximum water temperatures downstream of the dam

3.7.5 Sex-specific Differences in Sockeye Passage Success

Dam passage success differed between male and female Gates Creek sockeye salmon in 2013 (Table 3-14). Compared to males, females had 25% lower attraction efficiency (Fisher exact test: $p=0.165$) and delayed 37% longer, although the differences were not significant (Student's t-test: $t=-1.076$, d.f.=43, $p=0.288$). Overall, female passage success at Seton Dam was 12% less than males.

Sex differences in passage success in 2013 showed similar trends to 2012, where females had lower attraction efficiency and longer delays below Seton Dam. In 2012, lower female passage efficiency was possibly due to only females experiencing the radial gate opening (0% attraction efficiency). In 2013, however, both sexes experienced the same conditions and in approximately equal numbers for each sex. Therefore, 2013 results suggest that there are differences in the ability of male and female Gates Creek sockeye salmon to migrate past Seton Dam.

Table 3-14: Summary of conditions experienced and passage success for male and female Gates Creek sockeye salmon at Seton Dam in 2012 and 2013

	2012		2013	
Variable	**Male**	**Female**	**Male**	**Female**
Discharges Experienced (*n*)	Radial Gate (1) 35.0 $m^3 \cdot s^{-1}$(6)	48.0 $m^3 \cdot s^{-1}$ (4) Radial Gate (4) 35.0 $m^3 \cdot s^{-1}$ (11)	26.1 $m^3 \cdot s^{-1}$ (9) 22.8 $m^3 \cdot s^{-1}$ (21)	26.1 $m^3 \cdot s^{-1}$ (10) 22.8 $m^3 \cdot s^{-1}$ (14)
Attraction Efficiency	86% (6 of 7)	63% (12 of 19)	90% (27 of 30)	75% (18 of 24)
Mean Entrance Delay	9.0 ± 3.6 h	23.7 ± 7.8 h	9.4 ± 1.5 h	12.9 ± 3.3 h
Median Entrance Delay	5.4 ± 9.5 h	6.9 ± 34.1 h	6.5 ± 7.9 h	9.8 ± 14.2 h
Entrance Delay Range	1.9 – 21.9 h	0.5 – 114.7 h	0.1 – 25.9 h	0.1 – 58.4 h
Passage Efficiency	83% (5 of 6)	92% (11 of 12)	96% (26 of 27)	100% (18 of 18)
Overall Success	71% (5 of 7)	58% (11 of 19)	87% (26 of 30)	75% (18 of 24)
Mean Overall Delay	10.9 ± 4.2 h	16.4 ± 5.8 h	10.1 ± 1.4 h	11.7 ± 2.6 h
Median Overall Delay	9.2 ± 9.5 h	6.5 ± 19.1 h	8.3 ± 7.9 h	7.3 ± 12.5 h

Mean entrance delay is mean ± S.E. Median entrance delay is median ± S.D.

3.7.6 Swimming Activity at Seton Dam

Given the observed trends in male and female Gates Creek sockeye salmon passage success, and the differences in the attraction efficiency of males and females in 2013, swimming activity data from different discharges were pooled to compare male and female activity in the Seton Dam tailrace in 2012 and 2013.

For both sexes, the fastest swimming speeds were observed in the fishway entrance area (Figure 3-24). In 2013, swimming speeds in the entrance area were significantly greater than other areas of the tailrace (one-way ANOVA: F=70.94, d.f.=3, $p<2e^{-16}$). The slowest swimming speeds were observed in the radial gate spillway, with both sexes swimming near the optimal (most energetically efficient) swimming speed (1 BL s^{-1}). In all areas of the Seton Dam tailrace, females were found to swim at higher speeds than males (Figure 3-24). Although the differences in swimming speed within each area were not significant, the swimming speed of females within the fishway entrance area (2.12 ± 0.08 $BL \cdot s^{-1}$) exceeded the critical swimming speed for sockeye (2.10 $BL \cdot s^{-1}$). The mean swimming speed for males did not exceed this threshold, suggesting that females must reply on burst swimming to access the fishway. This difference could contribute to the observed differences in the attraction efficiency between males and females in 2013.

3.7.7 Portage Creek Sockeye Salmon Passage Success

Attraction efficiency, delay, and passage efficiency of Portage Creek sockeye was estimated using radio and PIT telemetry data. Twenty-two of the 24 radio-tagged Portage Creek sockeye were detected in the Seton Dam tailrace and 21 of these fish entered the Seton Dam fishway (96% attraction efficiency) The attraction efficiency of PIT-tagged fish was 100% (13/13). Delay for radio-tagged fish was 9.4 ± 10.9 h (*n*=18) with a range of 0.1-33.2 h. One radio-tagged fish failed to ascend the fishway for an overall passage efficiency of 95% (20/21). Passage efficiency of PIT-tagged fish was 100% (13/13). The overall passage success of tagged Portage Creek sockeye salmon was 94% (33/35) in 2013.

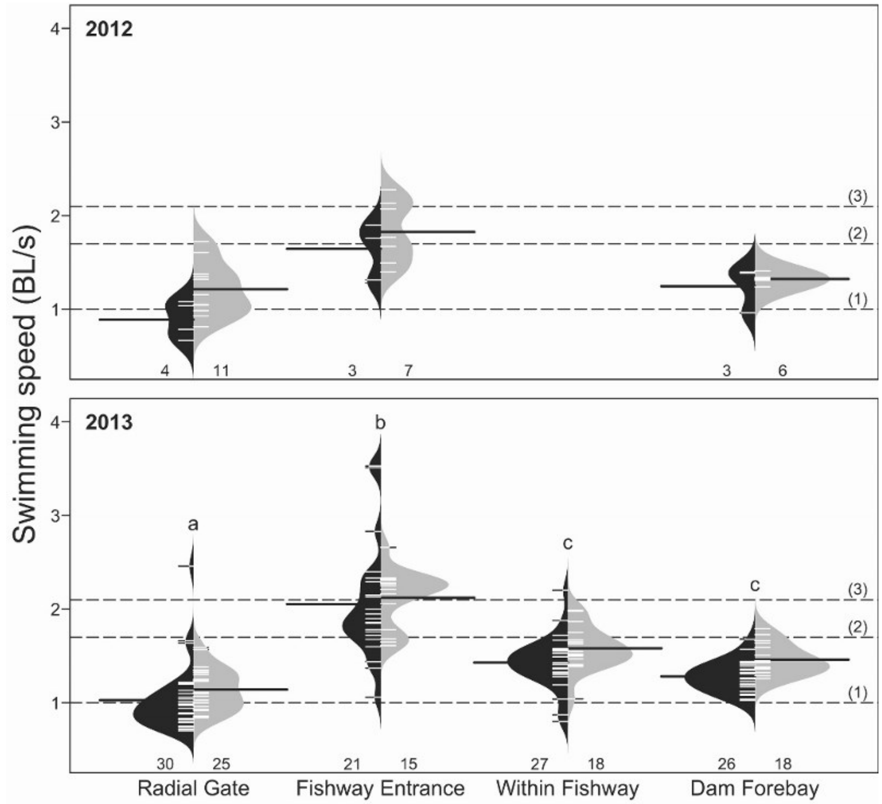

Figure 3-24: Bean-plot comparing the swimming speeds of male (black) and female (grey) Gates Creek sockeye salmon in different areas of the Seton Dam tailrace in 2012 and 2013. Shaded curves represent estimated distribution of swimming speeds for each sex. Mean (black horizontal lines) and individual (white horizontal lines) values are shown. Different letters indicate a significant difference between swimming speed in the tailrace areas for both sexes. Dashed horizontal lines indicate the optimal (1), 80% critical (2), and critical (3) swimming speeds for Gates Creek sockeye salmon

3.7.8 Pink and Coho Salmon Passage Success

Estimating the passage success of pink and coho salmon was complicated by spawning grounds downstream of Seton Dam. Pink and coho salmon released in the lower Seton River may not have attempted to ascend the Seton Dam fishway. In 2013, pink salmon were observed spawning in the lower Seton River, the upper and lower Seton River spawning channels, and Cayoosh Creek. No coho salmon were observed spawning in the lower Seton River but are known to spawn in the lower Seton River and spawning channels. Therefore, low number of pink and coho salmon detected at Seton Dam may be due to fish spawning downstream.

In 2013, 30% (101/335) of all tagged pink salmon were detected in the Seton Dam fishway. Prior to 06 September, the proportion of pink salmon detected in the fishway was low with only 5% (4/72) of tagged fish detected. After 06 September, however, detections increased considerably, and 37% (97/259) of tagged pink salmon were detected in the fishway after this date. Pink salmon tagging was discontinued on 21 September due to high spawner mortality in the lower Seton River, but the highest proportion of fish detected in the fishway (51%) was observed on this date, suggesting an upward trend in the proportion of pink salmon attempting migration upstream of Seton Dam in late-September. Of the 101 pink salmon detected in the fishway, 78 were detected on the PIT antenna in the fishway exit basin (77% passage efficiency). This passage efficiency is lower than that observed for sockeye salmon. However, pink salmon passage of Seton Dam could not be verified at upstream spawning grounds and the detection efficiency of the PIT array has not been verified. Therefore, pink salmon passage efficiency could be underestimated.

Coho salmon passage success at Seton Dam was 40% (12/30). All coho salmon tagged prior to 16 October (*n*=12) were detected in the Seton Dam fishway. However, none of the coho salmon tagged after 16 October (*n*=18) were detected. It is possible that the lack of detections after 16 October was due to a low detection efficiency of the PIT array as debris was beginning to accumulate on the PIT antennas in October.

3.8 Migration to Spawning Grounds

Radio and PIT telemetry data was used to perform a preliminary assessment of the survival of Gates Creek and Portage Creek sockeye salmon to spawning grounds. Pink salmon migration to spawning grounds is summarized in Section 3.6.6. Survival to spawning grounds could not be assessed for coho and Chinook salmon in 2013.

3.8.1 Gates Creek Sockeye Salmon

Overall survival of acoustic, radio, and PIT-tagged Gates Creek sockeye salmon from release to spawning grounds was 41% (244/590) in 2013. For fish that successfully passed Seton Dam (*n*=405), survival from Seton Dam to spawning grounds was 60% (244/405). Capture location (Section 3.5) as well as temperature conditions in the lower Seton River (see Section 3.1) likely contributed to the low overall survival of tagged Gates Creek sockeye salmon. The relationship between survival to spawning grounds and lower Seton River migration conditions, capture location, delay at Seton Dam and other factors will be considered in future analyses. Survival estimates using combined telemetry data can also be compared with a population-level survival estimate derived from comparison of fish passage at Seton Dam (via the fish counter) and escapement estimates at Gates Creek (via data from Fisheries and Ocean Canada stock assessment).

Carcass recoveries were used to assess the spawning success of female sockeye salmon that successfully migrated to Gates Creek. Of the 131 tagged Gates Creek sockeye salmon that were recovered on spawning grounds, 62 were female. Spawning success (0,50, or 100% spawn) was estimated for 59 of these fish. Fully-spawned (100% spawn) females accounted for 22% (13/59) of the females recovered at Gates Creek. Partially-spawned (50% spawn) or unspawned (0% spawn) females accounted for 19% (11/59) and 59% (35/59) of females, respectively. Future analyses including a greater number of recovered females will help determining if female spawning success is related to the conditions fish experienced during their upriver migration.

3.8.2 Portage Creek Sockeye Salmon

Radio telemetry data was used to assess the survival of Portage Creek sockeye salmon to spawning grounds. A PIT antenna was not installed at Portage Creek so survival data is not available for PIT-tagged fish. Survival to spawning grounds for Portage Creek sockeye salmon from Seton Dam was 35% (7/20) from Seton Dam and 29% (7/24) from release sites in the Fraser River.

3.9 Water Preference Experiments

3.9.1 Gates Creek Sockeye Salmon

Gates Creek sockeye salmon displayed no water preference during control tests (100% Seton River water in both arms) indicating that no arm bias was present in the Y-Maze (Figure 3-25). No significant differences were found in the amount of time fish spent in each arm (Wilcoxon signed rank test: *n*=19, V=66, p=0.25) or in the number of entrances into each arm (Student's t-test: t=-1.1019, p=0.29).

Increasing the dilution ratio of the test mixture to 5% or 20% did not appear to result in a water preference by Gates Creek sockeye salmon. At both 5% and 20%, no significant difference was found in either the amount of time spent in each arm (5%: Student's t-test: *n*=9, t=1.9189, p=0.09; 20%: Student's t-test: n=26, t=-0.5836, p=0.57) or the number of entrances (5%: Student's t-test: t=1.6013, p=0.15; 20%: Student's t-test: t=0.9605, p=0.35).

Gates Creek sockeye showed a preference for Seton River water over Cayoosh Creek water when the dilution ratio was increased to 50%. At a 50% dilution ratio, fish spent significantly more time in the arm containing 100% Seton River water (Student's t-test: *n*=26, t=4.3252, p<0.01), and also entered the arm more frequently (Student's t-test: *n*=26, t=2.1425, p=0.04).

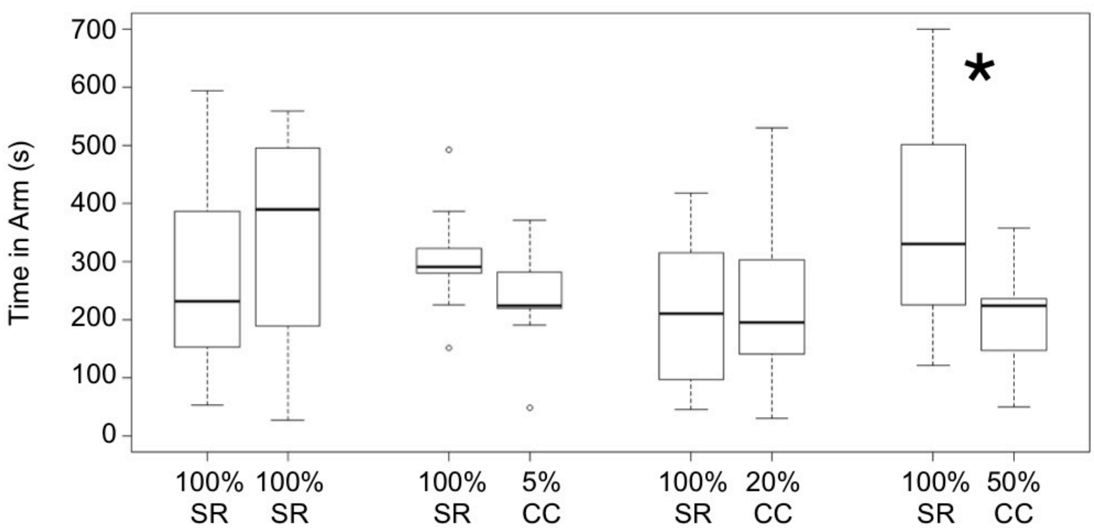

Figure 3-25: Time spent by Gates Creek sockeye salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, and 50% Cayoosh Creek (CC) dilution ratios. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicated a significant difference

The addition of conspecifics to the Y-Maze resulted in an avoidance response by Gates Creek sockeye salmon. When co-migrating sockeye salmon were added to the mixing tank upstream of the Y-Maze, sockeye spent significantly less time in the associated arm (Wilcoxon signed rank test: *n*=50, V=1122, p<0.01). This result is opposite to that observed in Cayoosh Creek in 2012 when sockeye salmon entered Cayoosh Creek, where none were present before, following the installation of isolation chambers containing sockeye salmon.

3.9.2 Pink Salmon

Pink salmon were only tested at a dilution ratio of 50% and showed a preference for the mixture of 50% Seton River water and 50% Cayoosh Creek water over 100% Seton River water (Figure 3-26). Pink salmon spent a significantly longer amount of time in the arm containing the 50% dilution ratio (Wilcoxon signed rank test: *n*=41, V=160, $p<0.01$), however, there was no significant difference in the number of entrances into each arm (Wilcoxon signed rank test: *n*=41, V=271.5, p=0.10).

Pink salmon did not show any preference for water with or without conspecifics present, spending a similar amount of time in each arm (Wilcoxon signed rank test: *n*=73, V=1357, p=0.81) and entering each arm with a similar frequency (Wilcoxon signed rank test: *n*=73, V=1501, p=0.13).

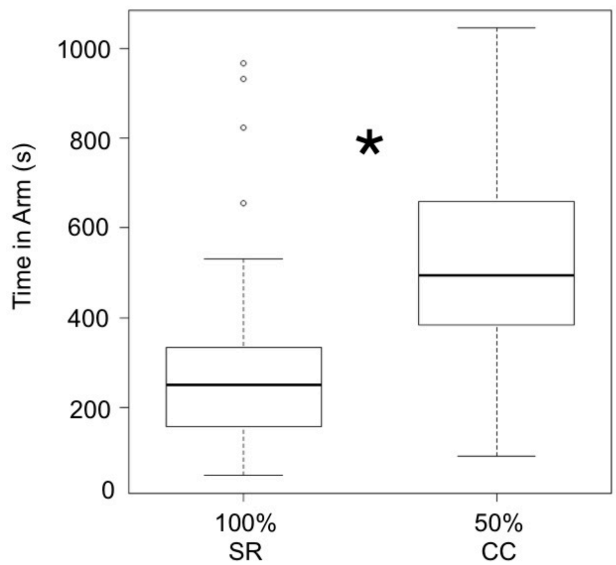

Figure 3-26: The time spent by pink salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicated a significant difference

4.0 DISCUSSION

Work in Year 2 of the BRGMON-14 program greatly expanded on the work completed in Year 1. Several new program components were added in Year 2 including detailed measurement of flow patterns at Seton Dam, refined fish counter validation methods, the use of multiple telemetry technologies in combination to gather migration data on all salmon species, and water preference tests to characterize the migration behaviour of Gates Creek sockeye and pink salmon at various dilution levels.

The discussion below highlights key findings in Year 2, summarizes the challenges faced during the field season, and provides an assessment of the progress made towards answering each of the management questions.

4.1 Key Findings

4.1.1 Capture Location

The effect of capture location on the migratory success of salmon in the Seton-Anderson watershed has not previously been investigated. Recent telemetry studies captured Gates Creek sockeye salmon exclusively from the exit pool of the Seton Dam fishway (Pon et al. 2005; Roscoe and Hinch 2007). These studies speculated that the passage success of fishway-caught fish was greater than that of fishway-naïve fish because fishway-caught fish would be familiar with the Seton Dam tailrace. Year 2 of the BRGMON-14 program was able to test this hypothesis because Gates Creek sockeye were captured from the fishway and the fish fence downstream of Seton Dam, with all fish co-released at the Upper Seton River release site. In addition, Year 2 was able to determine if capture location affected post-passage survival by determining the proportion of fishway and fence-caught Gates Creek sockeye salmon that successfully migrated to spawning grounds.

Gates Creek sockeye salmon captured from the fish fence had comparable passage success at Seton Dam as fish captured from the fishway. Passage success was slightly higher for fence-caught fish, although the difference was not significant. Survival to spawning grounds, however, was significantly lower for fishway-caught fish. Differences in survival to spawning grounds could be due to handling effects during fishway capture and transport (Cooke and Hinch 2013), or the added energetic costs of relocating and re-ascending the fishway (Brown et al. 2006).

Given the reduction in survival to spawning grounds for fishway-caught fish, fish capture downstream of Seton Dam will be required in future study years to accurately assess the effects of BC Hydro operations on the migration and survival of salmon to spawning grounds. High water temperatures in 2013 confounded a comparison of capture location and migratory success for Gates Creek sockeye salmon that were released in the Fraser River and the lower Seton River. The effects of capture location for these fish will be revealed with further analysis of acoustic and radio telemetry data and future studies.

4.1.2 Dilution

Gates Creek sockeye salmon demonstrated a preference for Seton River water over a 50% dilution ratio of Cayoosh Creek to Seton River water. However, no water preference was shown at the current 20% target dilution ratio (BC Hydro 2011). This result differs from that of Fretwell (1989) who found that Gates Creek sockeye salmon displayed a preference for Seton River water compared to a 20% dilution ratio. However, the experiments of Fretwell (1989) tested migration behaviour of multiple fish simultaneously which can influence the behaviour of individuals (Martin 2003). Further water preference tests on Gates Creek sockeye will confirm this result and test dilution ratios in the 20-50% range.

Pink salmon demonstrated a preference for a 50% dilution ratio of Cayoosh Creek to Seton River water over Seton River water. This result differs from Fretwell (1989), who found that pink salmon did not demonstrate any preference for a water source at any dilution level. Both results are similar, however, in that pink salmon behaviour does not appear to be sensitive to high dilution ratios. Pink salmon were also observed to be spawning in Cayoosh Creek in significant abundance in 2013, further suggesting that dilution may not be a factor in pink salmon migration. However, studies in 2015 will help provide a clearer answer of how pink salmon respond to dilution.

A preliminary analysis of Gates Creek and Portage Creek sockeye salmon migration suggested that fish did not delay at the Seton Generating Station in 2013. Migration rates to Seton Dam were examined because it was predicted that if fish delayed at the Seton Generating Station at high dilution ratios, migration rates would be reduced. Conditions in 2013 exposed migrating Gates Creek sockeye salmon to dilution ratios in excess of 40%. However, preliminary analyses performed to date show that these elevated dilution ratios did not appear to have a significant effect on migration rate.

Temperature and dilution effects in this preliminary analysis were confounded because the highest temperatures in the study period coincided with the highest dilution ratios. High temperatures can alter the migration behaviour of sockeye salmon (Crossin et al. 2008) and the present analysis did not attempt to isolate temperature effects from dilution. Further, fine scale analysis of migration patterns in the Fraser River, such as the residency time of fish at the Seton Generating Station or exploratory movements between the station and the Seton River-Fraser River confluence, has yet to be performed. In addition, migration rates of Gates Creek sockeye salmon in the Fraser River are known to be 20-35 $km \cdot d^{-1}$ (Hague and Patterson 2009) and may have masked any delay at the Seton Generating Station.

4.1.3 Temperature and Migration Success

High water temperatures in the Seton-Anderson watershed in August reduced the abundance of Gates Creek sockeye salmon passing through the Seton Dam and reduced the ability of fish to pass Seton Dam. Water temperatures in the Seton River between 07 August and 18 August exceeded the optimal temperature (T_{opt}) of Gates Creek sockeye salmon (17.5ºC; Lee et al. 2003). Temperatures above T_{opt} are known to reduce the aerobic scope, swimming performance and survival of sockeye salmon (Lee et al. 2003; Farrell et al. 2008; Eliason et al. 2011). High temperatures were associated with decreased abundance of fish migrating through the Seton Dam fishway, decreased migration rates from downstream release sites to Seton Dam, and a lower probability of Gates Creek sockeye salmon surviving to and successfully passing Seton Dam. Temperature effects on migration rate and survival were also greater for females than males, a result consistent with Martins et al. (2012). Latent effects of thermal stress likely contributed to the overall poor survival of tagged Gates Creek sockeye salmon to spawning grounds.

Intermittent shutdowns of the Seton Generating Station contributed to the high water temperatures observed in 2013. Seton Generating Station shutdowns were linked to immediate and rapid increases in water temperature in the Seton Dam fishway. Both the magnitude and rate of the temperature increase suggests that Seton Generating Station shutdowns altered the withdrawal of cooler hypolimnetic water from Seton Lake. However, confirming the upstream mechanism for the observed temperature changes is beyond the scope of this program. Acoustic telemetry data suggested that temperatures above 21ºC reduced the probability of Gates Creek sockeye passing Seton Dam.

4.1.4 Tailrace Flow Characterization

Acoustic Doppler Current Profiler technology was used to characterize flow patterns in the Seton Dam tailrace. ADCP units measured flow velocities downstream of Seton Dam and surrounding the fishway entrance. Large vortices downstream of the dam were identified and highly-variable flows were measured around the fishway entrance.

Future analyses will link flow patterns with the swimming activity and behaviour of Gates Creek sockeye salmon in the Seton Dam tailrace. Using ADCP measurements to characterize how tailrace flow patterns change when Seton Dam water releases are adjusted could help explain differences in fish attraction efficiency and delay. Combined with telemetry on spawning grounds, ADCP measurements can help determine water release strategies that improve fish passage and survival to spawning grounds.

4.1.5 Fish Passage at Seton Dam

The passage success of acoustic-tagged Gates Creek sockeye salmon at Seton Dam was 81% in 2013 and was the highest observed at Seton Dam in the previous four years of studies. Mean entrance delay was also the lowest yet observed. Higher passage success was observed for PIT-tagged fish caught in the fishway (84%) or at the fence (93%). For acoustic-tagged Gates Creek sockeye, the overall attraction efficiency was 83% and the overall passage efficiency 98%. Comparable estimates of passage success were observed in 2007 (86% attraction efficiency; 93% passage efficiency; 80% overall passage success).

Deployments of acoustic accelerometers with an improved acoustic telemetry array in the Seton Dam tailrace increased the quantity of data collected on Gates Creek sockeye salmon swimming activity and behaviour. The highest fish swimming speeds were recorded in the turbulent flow surround the fishway entrance and nearly all fish required some degree of burst swimming activity to successfully enter the fishway. Female Gates Creek sockeye salmon required increased swimming effort to navigate the entrance area of the tailrace and locate the fishway entrance. Despite this increased effort, female attraction efficiency was lower than males and females delayed longer downstream of Seton Dam. These findings are consistent with those observed in 2012. Given the two-year trend in reduced female Gates Creek sockeye salmon passage success at Seton Dam, future investigations may benefit by focusing primarily on female success, as males could be assumed to have greater passage success.

4.2 Challenges

4.2.1 Fish Capture

Fish capture was proposed to occur in the lower Seton River downstream of the Cayoosh Creek-Seton River confluence. However, Seton River discharge levels did not permit the installation of a fence in the lower Seton River and a new site was selected in the upper Seton River 200 m downstream of Seton Dam. Installation of the fence in the upper Seton River increased transport time to the downstream Fraser River release sites. Benefits to the upper Seton River fence site included increased security and close proximity to Seton Dam, an important consideration for the transport of fishway-caught fish to the tagging site at the fence.

The capture success of Gates Creek sockeye salmon at the fence was limited from early to mid-August due to a combination of discharge and fence design. To meet program requirements during this period, Gates Creek sockeye were captured from the Seton Dam fishway for telemetry and water preference studies. Capture location was found to affect the migratory success of Gates Creek sockeye to spawning grounds, and will be accounted for in all future analyses and study years. Changes in the fence design greatly improved fish capture success in mid-August. Incidentally, fish counter data suggests that the majority of Gates Creek sockeye salmon migrated past Seton Dam in the latter half of August. Therefore, despite limited fish capture success in the first half of August, tagging at the fence occurred throughout the primary migration period for Gates Creek sockeye salmon in 2013.

4.2.2 Water Temperature

High water temperatures during the Gates Creek sockeye salmon migration in August affected all aspects of the BRGMON-14 program. Water used for fish transport, water preference tests, and fish holding was drawn from the Seton Dam forebay where the highest water temperatures in the Seton River were recorded. To compensate for high water temperatures, program methods were modified and the number of fish collected was reduced. Holding and transport densities were also limited and any fish that displayed abnormal behaviour during water preference tests were removed from analyses. Fortunately, Gates Creek sockeye salmon abundance increased after the high temperature period and both telemetry and water preference tests were able to compensate for reduced program capacity during the high temperature period.

4.2.3 Seton Dam Fish Counter

Seton Dam fish passage estimates were complicated by problems encountered with the fish counter wiring provided by BC Hydro. An in-season data evaluation in August, as a result of unusual patterns in counter records between sensors, identified detection errors on both fish counter units. Two faults were identified in the wiring that ran from the fishway sensors to a junction box on Seton Dam, and then from the junction box to the instrument hut on the northern bank of the Seton River. The first fault was identified in the wiring provided for the lower counter (installed 2012) where a pair of wire terminals had been reversed in the instrument hut. This resulted in two of the four fish counter channels functioning incorrectly with one channel producing events with some up counts and the second channel only recording events. The second fault was identified in the wiring between the junction box and the instrument hut where each of the wires in this segment were incorrectly paired at each terminal. This resulted in three of the four channels on the upper fish counter (installed 2013) functioning incorrectly.

Although these faults were corrected mid-season, analysis of fish passage data recorded prior to correcting these faults has been difficult. Fish passage estimates for all species will eventually be completed but will required additional effort to ensure estimates are accurate.

4.2.4 Factors Influencing Seton Dam Passage

Determining the optimal water release strategy for fish passage at Seton Dam is complicated by changes in total discharge that coincide with changes in conveyance structure use. For instance, in 2013, decreased discharge at Seton Dam during the Gates Creek sockeye salmon migration resulted in increased fish attraction efficiency but with increased entrance delay. These changes were observed following a reduction in FWRG discharge. A similar pattern was observed in 2012, but when discharge from the FWRG was increased.

Manipulating Seton Dam conveyance structure use while total Seton Dam discharge remained constant would better help determine what factors affect attraction efficiency and delay. This controlled approach could also be combined with ADCP measurements and acoustic accelerometry to monitor flow patterns and fish swimming activity during different discharge conditions.

4.3 Management Questions

4.3.1 Question #1

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

Water preference test results, radio telemetry data, and fish counter data collected in Year 2 addressed the two-parts of management question #1. However, with the current sample size and conditions assessed it is not yet possible to determine if the IPSFC-derived dilution ratio targets mitigate migration delay by Gates Creek and Portage Creek sockeye salmon or determine the sensitivity of migration behaviour of each population to variations in the dilution ratio. Statistical models will be used to estimate the effects of physical parameters on sockeye salmon migration and delay once further data are collected in Year 3 and Year 4.

Assessing the validity of the current IPSFC dilution ratio targets is important to determining their effectiveness at mitigating the migration delay of Gates and Portage Creek sockeye salmon. Water preference tests found that Gates Creek sockeye salmon did not display a preference for Seton River water at or below the current dilution target of 20%. Avoidance behaviour at a dilution ratio of 50% confirmed that Gates Creek sockeye are sensitive to increases in the dilution ratio. Determining the sensitivity of Gates Creek sockeye salmon to variation in the dilution ratio will require testing the behavioural response of sockeye across an intermediary range of values in Year 3. Water preference tests were not carried out with Portage Creek sockeye in Year 2 but will be performed in Year 3.

Year 2 radio telemetry captured detailed data on the migration of Gates Creek sockeye salmon at both target and above-target dilution ratios and the migration of Portage Creek sockeye at target dilution ratios. Population–level migration patterns for both populations were recorded at the Seton Dam fish counter. Gates Creek sockeye salmon migration during above-target dilution ratios coincided with both high water temperatures and increased discharge in the lower Seton River. As a result, further analyses are required to separate the interaction of these variables. Portage Creek sockeye salmon migration behaviour was studied in Year 2 but dilution ratios during the Portage Creek migration did not exceed the target dilution ratio. If dilution ratios in future study years do not exceed the target dilution ratios, it will likely not be possible to determine the effectiveness of the current IPSFC-derived targets for mitigating delays in the migration Gates Creek and Portage Creek sockeye salmon.

4.3.2 Question #2

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

Water preference tests and radio telemetry in Year 2 gathered data on the behaviour and migration of pink salmon from downstream of the Seton Generating Station to spawning grounds. However, the current sample size is too small to determine the effects of Seton Generating Station operation on the migration of pink salmon. Chinook and coho salmon migration to the Seton-Anderson watershed could not be studied in Year 2 due to the low abundance of these species.

Water preference tests found that pink salmon did not display a preference for Seton River and showed a preference for water containing a high (50%) dilution ratio of Cayoosh Creek water. This suggests that pink salmon migration to the Seton-Anderson watershed would likely not be affected by the Seton Generating Station. Similar results were found with a preliminary analysis of data from radio-tagged pink salmon. Migration rates of pink salmon to spawning grounds did not differ with dilution but the dilution ratio range experienced by pink salmon was relatively narrow. Additional behavioural tests and continued radio telemetry of pink salmon, combined with statistical modeling of migration with physical parameters, will be needed to determine if pink salmon are affected by operation of the Seton Generating Station.

4.3.3 Question #3

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

For Gates Creek sockeye salmon, Year 1 and Year 2 acoustic telemetry data and Year 2 radio and PIT-telemetry data will help answer the first part of this management question. For Portage Creek sockeye and pink salmon, Year 2 radio and PIT-telemetry data are available. PIT-telemetry data from coho salmon are also available from Year 2. Further data from all species will be collected in Year 3 and Year 4.

Results to date suggest that Seton Dam operations affect salmon passage upstream of Seton Dam by reducing attraction efficiency and increasing delay. However, the effect of Seton Dam operations on salmon passage varies both within and across years. This variation is likely due to differences in Seton Dam discharge and the conveyance structures used for water releases. Other environmental factors, such as water temperature, also affected passage success. Therefore, addressing the second part of the management question may require an experimental approach to control certain factors at Seton Dam (e.g. total discharge) while other factors are manipulated (e.g. conveyance structure use). This approach will advance our understanding of how different water release strategies affect salmon passage upstream of Seton Dam and increase the strength of the statistical models used to determine the factors influencing passage success. Further study is needed before recommendations can be made on how to mitigate fish passage issues at Seton Dam.

4.4 Monitoring Program Schedule

A schedule of activities outlining the tasks completed in Year 2 and the revised schedule of tasks to be completed in Year 3 to Year 5 is presented in Table 4-1. All tasks proposed for Year 2 were completed as scheduled.

Table 4-1: Tasks completed in Year 1 and Year 2 of the BRGMON-14 monitoring program and the tasks proposed for Year 3 to Year 5

Task	Year 1 (2012)	Year 2 (2013)	Year 3 (2014)	Year 4 (2015)	Year 5 (2016)
1) Project Coordination	X	X	X	X	X
2) Physical Parameter Monitoring					
i. Discharge and Dilution Ratio	X	X	X	X	-
ii. Water Temperature	X	X	X	X	-
iii. Water Chemistry	X	X	X	X	-
3) Adult Salmon Telemetry					
i. Radio Transmitters	-	X	X	X	-
ii. PIT Tags	-	X	X	X	-
4) Adult Sockeye Telemetry					
i. Radio Transmitters	X	X	X	X	-
ii. Accelerometer Loggers	X	-	-	-	-
iii. Accelerometer Transmitters	X	X	X	X	-
iv. PIT Tags	-	X	X	X	-
5) Salmon Dilution Sensitivity					
i. Olfactory Sensitivity Trials	X	-	-	-	-
ii. Water Source Preference Tests	-	X	X	X	-
6) Physiology and Injury Monitoring	X	X	X	X	-
7) Fishway Fish Counter	X	X	X	X	X
8) Final Reporting	-	-	-	-	X

5.0 RECOMMENDATIONS

5.1 Status of Year 1 Recommendations

The majority of the recommendations made in Year 1 of the BRGMON-14 monitoring program were implemented in Year 2. However, some Year 2 recommendations could not be completed.

- The fish fence proposed for the lower Seton River downstream of Cayoosh Creek was installed in the upper Seton River downstream of Seton Dam.
- Fish passage at Seton Dam was not monitored during radial gate openings because the fish fence could not function at high discharges.
- Fish counter detection issues were encounter because the initial wiring installation by BC Hydro was incorrect.
- Fish counter video validation was not possible during nighttime hours because species could not be identified.

Installation of a fish fence downstream of the Cayoosh Creek-Seton River confluence was recommended because fish would be captured prior to locating the upper Seton River that is not diluted by Cayoosh Creek. Unfortunately, no fence installation site could be identified in the lower Seton River that was suitable for both in-river fence installation and vehicle access. The upper Seton River fence site used in Year 2 was able to capture fish prior to encountering the Seton Dam tailrace and fishway and permitted easy vehicle access necessary for fish transport. Installing the fence close to Seton Dam did not allow the fence to be actively fishing during radial gate openings due to safety concerns.

Fish counter wiring issues were resolved mid-season and video validation during daytime hours was still possible in Year 2.

5.2 Year 2 Recommendations

Based on findings in Year 1 and Year 2, the following recommendations are made for Year 3 of the BRGMON-14 monitoring program:

- Repeat the installation of a fish fence downstream of Seton Dam
- Continue GSE screening all sockeye salmon to identify strays
- Discontinue conductivity monitoring at the W01-LFR site
- Install additional cameras and infrared lighting on the Seton Dam fish counter
- Discontinue fish releases at the Lower Seton River release site
- Release fishway and fence-caught fish at the Fraser River release sites to determine the effect of capture location on migration in the lower Seton River
- Install telemetry receivers upstream and downstream of Portage Creek throughout the migration period for sockeye salmon
- Install telemetry receivers further downstream in Gates Creek
- Carry out experimental flow manipulations of Seton Dam discharges with BC Hydro while monitoring fish passage and tailrace flow patterns with ADCP
- Test Gates Creek sockeye behaviour at dilution ratios between 20% and 50%

It is also recommended that BC Hydro monitor water temperature at Seton Dam and in the Seton River during periods of high temperature.

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