Bridge River Project 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

Final Report

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Final Program Report (2012 - 2016)

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Cover photo: Left panel - Seton Dam and power canal; Right panel - fish tagging by Wesley Payne (St'át'imc Eco-Resources), Collin Middleton (UBC) and Nich Burnett (UBC). Photos © University of British Columbia.

EXECUTIVE SUMMARY

The Bridge-Seton Water Use Plan requires BC Hydro mitigate impacts to adult salmon upstream migration in the Seton-Anderson Watershed. Currently, Seton Dam discharges limit the dilution of Seton River by Cayoosh Creek to <20% and <10% during the Gates and Portage Creek sockeye migration periods, respectively. The dilution targets are intended to prevent migration delays at the Seton Generating Station. However, it is uncertain if the current dilution targets are effective or if Seton Dam operations or the fishway affect upstream salmon passage. BRGMON-14 objectives were to: 1) evaluate the sensitivity of adult salmon to the dilution of Seton River by Cayoosh Creek and the effectiveness of current dilution targets; 2) assess the effectiveness of current Seton Dam operations and fishway for adult salmon passage; and, 3) identify operational strategies to mitigate delays in upstream migration. Field studies including water preference experiments, physiological and behavioural monitoring with telemetry, and dilution and water release experiments were used to address these objectives.

Monitoring began in 2012 with pilot assessments of telemetry technology and passage success at Seton Dam, followed by major field operations from 2013 to 2016. Water preference Y-maze experiments (2013 - 2014) examined a total of 338 Gates Creek sockeye and 108 Portage Creek sockeye to determine sensitivity to dilution of Seton River. Concurrently, a fish tagging, and telemetry program was implemented to track movements and survival under routine conditions and in response to large-scale operational manipulations. From 2013 - 2016, 908 sockeye were sampled and tagged with radio transmitters and 118 with acoustic accelerometers to track fine-scale movements and swimming speeds, and to evaluate the effects of Seton Dam operations and dilution of Seton River, in conjunction with physiological and environmental variables impact on migratory behaviour. Radio telemetry was primarily used to study the influence of dilution on fish migratory behaviour in the Fraser River, at the Seton Generating Station, until entrance to the Seton River, while acoustic accelerometers allowed for measurements of swim speed and energy expenditure in the Seton Dam tailrace and during Seton Dam passage. A total of 2,841 additional sockeye were tagged with Passive Integrated Transponders (PIT) to estimate survival through key segments of their migration and to supplement migration timing and success data collected from radio and acoustic transmitters. In addition, 337 pink salmon and 35 coho were either radio or PIT-tagged to assess their migratory behaviour. All fish captured for telemetry research were also assessed for injuries.

Two major field experiments were used during monitoring which generated the main results used to inform the management questions: 1) a dilution level increase in 2015 and 2) alternative Seton Dam operations in 2014 and 2016. Regular flow management was not producing sufficient variation and operational manipulations were required to assess the impact of Seton Dam operations and dilution on migration. In the first experiment, the tunnel that diverts Cayoosh Creek flow into Seton Lake was closed for one week during the 2015 Gates Creek sockeye migration, diverting all Cayoosh Creek flow into Seton River and increasing dilution to 30%, above the established<20% target. The effects of elevated dilution levels on salmon migratory behaviour and success were monitored during this period. In the second experiment, water release locations at the Seton Dam were altered during the Gates Creek sockeye migration in 2014 and 2016.

Operations were changed from discharge through Siphon 1 adjacent to the fishway entrance to discharge through Siphon 4, which is further from the entrance. Operating Siphon 4 significantly reduced water velocities in the approach to the fishway, but also decreased attraction flows for salmon.

Current dilution targets outlined under the Bridge River Water Use Plan, which stipulate thresholds of <20% dilution of the Seton River during Gates Creek migration and <10% dilution during Portage Creek migration, were found to be effective for minimizing delays in spawning migrations for both Gates Creek and Portage Creek sockeye populations. Y-maze experiments found that both Gates Creek and Portage Creek sockeye had strong preference for 0% dilution of Seton River compared to Seton River water diluted beyond the dilution targets. Tracking of Gates and Portage Creek sockeye in the Fraser River between the Seton Generating Station and the mouth of the Seton River suggested that female Gates Creek sockeye could be particularly sensitive to dilution levels above operational targets, either failing to complete migration or delaying entrance to the Seton River. The injury assessment revealed that head injuries that could result from attempts to enter the Seton Generating Station were uncommon—the most commonly occurring injuries originated from downstream net fisheries. Y-maze experiments found that pink salmon do not exhibit a preference for 0% diluted Seton River water compared to 50% dilution. Telemetry studies also found pink salmon appear to be unaffected by changes in dilution. Due to low return numbers of coho and Chinook salmon, the effects of operations on these two species could not be directly assessed. However, based on a literature review, these species are expected to respond similarly to natal water dilution as sockeye, and given the overlap in the timing of the dilution targets with Chinook and coho salmon migration, maintaining the dilution targets for Gates and Portage Creek sockeye should also be sufficient to prevent delays of Chinook and coho salmon in the system.

Seton Dam operations can be modified to improve Gates Creek sockeye salmon survival to spawning grounds. Field experiments found that despite large differences in tailrace flow fields between Siphon 1 and 4 operations, and reduced velocities at the fishway entrance following the changes to water release at Siphon 4, Gates Creek sockeye were attracted to the fish ladder and passed the Seton Dam with high (>95%) success regardless of the flow configuration at the observed discharges. However, post-passage survival of Gates Creek sockeye to spawning grounds was improved by 10 – 20 % for fish that passed Seton Dam during Siphon 4 rather than the fish water release gate and Siphon 1. Survival improvements were seen despite longer passage times during Siphon 4 releases. This alternative water release reduced swimming speeds and energy expenditure during passage through the Seton Dam tailrace, thereby increasing survival of Gates Creek sockeye to spawning grounds. This project was unable to examine the effects of the alternative Seton Dam flow configurations on Portage Creek sockeye. Discharges specified in the Water Use Plan hydrograph for Seton Dam (~15 – 18 $m^3 \cdot s^{-1}$) could not be met for the periods that coincided with Portage Creek sockeye migrations, as discharge at Siphon 4 alone is 25 $m^3 \cdot s^{-1}$. However, it is possible that Portage Creek sockeye could receive a similar benefit as Gates Creek sockeye from an alternative water release scenario.

BRGMON-14 FINAL STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES

Objectives	Management Questions	Management Hypotheses	Final Management Question 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.	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? *And* 1a) 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%.	***Rejected:*** Water preference tests indicated that Gates Creek sockeye could be expected to delay at dilution levels >20%. Telemetry results at different dilution levels found increased wandering and decreased entrance success to Seton River when dilution increased. Experimentally elevating dilution to 30% reduced entry success into the Seton River, especially for females. The current <20% dilution target appears effective.
		H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 10%.	***Rejected:*** Water preference tests indicated Portage Creek sockeye could be expected to delay at dilution levels >10%. Telemetry observations found increased dilution had a significant effect on the number of forays and time fish spent in the Seton Generating Station tailrace. The current <10% dilution target appears effective.
		H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.	***Rejected:*** Water preference tests indicate Gates Creek sockeye are sensitive to small changes in dilution, responding differentially to 10% shifts in dilution level. Telemetry results during the field dilution experiment suggested Gates Creek sockeye are sensitive to dilution, and that increased dilution above the <20% target caused a 10 - 30% decrease in fish successfully migrating to the Seton River and increases travel times to the Seton River by 29%.

Objectives	Management Questions	Management Hypotheses	Final Management Question Status
		H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.	***Rejected:*** Water preference tests indicate Portage Creek sockeye are sensitive to small changes in dilution, responding differentially to 10% shifts in dilution level. Telemetry observations suggested Portage Creek sockeye are sensitive to dilution above the <10% target, and that increased dilution can delay or otherwise negatively affect migration.
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* (Continued next page) (Continued) To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	2) 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.	***Rejected:*** Water preference tests found pink salmon do not prefer undiluted Seton River water compared to Seton River water diluted to 50%. Behaviour monitoring showed pink salmon do not delay at the Seton River Generating Station. Operations did not appear to have a significant impact on their migration.
		H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.	***Rejected:*** Review of available literature suggests Chinook salmon have similar olfactory sensitivities to sockeye. Chinook salmon that spawn in the Seton-Anderson Watershed are thus expected to respond similarly to sockeye if current dilution targets are exceeded.
		H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.	***Rejected:*** Review of available literature suggests that coho salmon have similar olfactory sensitivities similar to sockeye. Coho salmon that spawn in the Seton-Anderson Watershed are thus expected to respond similarly to sockeye passage if current dilution targets are exceeded.

Objectives	Management Questions	Management Hypotheses	Final Management Question Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.	3) Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam? *And* 3a) 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.	***Not rejected*:** Altering water release from the routine Siphon 1 release to an alternative Siphon 4 release did not significantly alter attraction efficiency of Gates Creek sockeye. Attraction efficiency for pink salmon was lower than sockeye as they can spawn downstream of the dam. Portage Creek sockeye exhibited similarly high attraction efficiencies as Gates Creek sockeye under routine conditions. Testing altered water release strategies during Portage migrations was not possible due to discharge restrictions, but Portage sockeye are expected to respond similarly to Gates Creek Sockeye.
		H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.	***Not rejected:*** Changes from routine water release to alternative release did not alter passage efficiency of Gates Creek sockeye salmon. However, the alternative water release improved post-passage survival to spawning grounds of Gates Creek sockeye salmon. This likely occurred because fish were required to do more burst swimming under the routine water release. Effects of an alternative Seton Dam release on Portage Creek salmon could not be tested as alternative release during their migration period would exceed the Seton Dam Water Use Plan hydrograph. The effects of alternative operations on passage by Portage sockeye are expected to be different than Gates sockeye due to differences in physiological and migration conditions between the early- and later-run sockeye. There is also reduced total discharge from the Seton Dam during the Portage migration.

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

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Funding and logistic support for the BRGMON-14 adult fish passage monitoring program was provided through St’át’imc Eco-Resources, BC Hydro, the Natural Sciences and Engineering Research Council of Canada, and Mitacs. Infrastructure and additional support were provided through the Ocean Tracking Network of Canada, and Fisheries and Oceans Canada. The authors would like to thank the following individuals for their contributions to the program: Ahmed Gelchu, Dorian Turner, and Jeff Walker (BC Hydro); Wesley Payne, Jessica Hopkins, Roxx Ledoux, Allison James, Avaleen Adolph, Bonnie Adolph and David Levy (St’át’imc Eco-Resources); Don McCubbing, Jason Ladell, Doug Braun, and Stephanie Lingard (Instream Fisheries Research Ltd.); David Zhu, Wenming Zhang, and Yu Qian (University of Alberta); Jayme Hills, Kristi Miller, and David Patterson (Fisheries and Oceans Canada); Harry O'Donaghey, Leo O'Donaghey, Lance O’Donaghey, and Chris Fletcher (N'Quatqua First Nation); ; Jenn Carter (Simon Fraser University); Carson White, Melanie Kuzyk, and Andrew Lotto (The University of British Columbia; UBC); Eduardo Martins (University of Northern Alberta); Steve Cooke (Carleton University). Nicholas Burnett, Collin Middleton and Vanessa Minke-Martin (University of British Columbia) made significant contributions to the collection, analysis and interpretation of the data. Arthur Bass and Matthew Drenner (University of British Columbia) also assisted with data collection and analyses. Matt Casselman, as a UBC researcher before representing BC Hydro on this project, was instrumental in data acquisition, processing, analysis, and write-up. Thank you, Matt, for all your hard work and great ideas.

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1 INTRODUCTION

1.1 Background

The Bridge River Power Development Water Use Plan 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 (*Oncorhynchus* spp.) species migrate through the Seton-Anderson watershed including two genetically-distinct sockeye (*O. nerka*) populations (Gates and Portage Creek sockeye), coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and steelhead trout (*O. mykiss*) (BC Hydro 2000). Except for pink salmon, the primary spawning grounds of each species are upstream of Seton Dam. To access spawning areas, adult salmon must migrate up the Fraser River, pass the Seton Generating Station tailrace, enter the Seton River, negotiate the Seton Dam tailrace, and locate and ascend the Seton Dam fishway. The fish then migrate through Seton Lake to Portage Creek, where they may spawn or continue through Anderson Lake to the Gates Creek spawning area.

Recommendations within the Bridge River Water Use Plan by the Bridge River Water Use Plan Consultative Committee included the implementation of an adult fish passage monitoring program in the Seton-Anderson watershed to identify factors that may impede the successful upstream migration of salmon through this migration route. Specifically, the Consultative Committee recommended the monitoring program address uncertainties in the effects of 1) Seton River dilution by Cayoosh Creek on salmon migration, and 2) current Seton Dam and fishway operations on salmon passage.

Target dilution levels for Cayoosh Creek discharge to total Seton River discharge are a key component of the current Bridge River Water Use Plan. All species of Pacific salmon are guided by the odour of their natal water during the spawning migration. For salmon that spawn above the Seton Dam, dilution of water flowing out from Seton Dam by Cayoosh Creek reduces the strength of the natal water odour in the Seton River, which could negatively affect the ability of salmon to navigate through the system. Current dilution targets were adopted from findings of the International Pacific Salmon Fisheries Commission (IPSFC) on population-specific water preference behaviour exhibited by Gates Creek and Portage Creek sockeye (Fretwell 1989). The IPSFC research found that returning sockeye prefer water in the Seton Generating Station tailrace to water in the Seton River when dilution levels in the Seton River are elevated. This preference could encourage holding behaviours at the Seton Generating Station tailrace, which could delay the migration and affect migration or spawning success. Dilution targets (BC Hydro 2011) are to maintain <20% Cayoosh Creek water in the Seton River during the Gates Creek migration (20 July to 31 August), and <10% Cayoosh Creek water in the Seton River during the Portage Creek migration (28 September to 15 November). Maintaining target dilutions during the sockeye migration are intended to reduce the amount of time migrating salmon spend in the Seton Generating Station tailrace and encourage upstream migration from the Fraser River into the Seton River.

The target dilution levels used to reduce migratory delay are based on behavioural experiments and telemetry performed in the early 1980's. Neither the preference of sockeye for different levels of dilution nor the effectiveness of current dilution targets has ever been fully evaluated. Recent studies (Hinch and Roscoe 2008), have shown a high level of sockeye migration failure can still occur at dilution levels well within the current targets. Further, we do not fully understand how target dilution levels influence the behaviour of salmon species other than sockeye. Pink salmon, for example, may be less sensitive to changes in the dilution level (Fretwell 1989). Thus, there is a need to assess whether the current Seton River dilution targets are effective for all species of salmon. This includes the need for a controlled field experiment in which dilution levels are manipulated and salmon are tracked through the system, which has never been previously done.

In addition to dilution levels in the Seton River, operations at the Seton Dam during migration could also significantly alter the migration behaviour and spawning success of Gates and Portage Creek sockeye. Sockeye salmon passage through the Seton Dam fishway was examined in 2005 (Pon et al. 2006; Pon et al. 2009a, Pon et al. 2009b). A follow-up investigation in 2007 monitored sockeye migration above Seton Dam from the Seton Generating Station tailrace to spawning grounds (Roscoe and Hinch 2008; Roscoe et al. 2010; Roscoe et al. 2011).

The most significant cause of migratory failure to the Seton Dam was failure to locate the fishway entrance. Complex flow fields in the Seton Dam tailrace were believed to delay migration and reduce fishway attraction efficiency, particularly when discharge from the dam was high (60 $m^3 \cdot s^{-1}$) (Roscoe and Hinch 2008). After locating the fishway entrance, passage success through the fishway structure was high. Upstream migratory failure was also observed as post-passage mortality in Seton and Anderson Lakes. Increased stress appeared to be the primary cause of mortality (Roscoe and Hinch 2008). Furthermore, migration success was significantly lower in females than males, which is of concern since population-level abundance is largely governed by female success (Gilhousen 1990). Thus, improved operations at the Seton Dam could ultimately improve migration success of sockeye.

Despite the success of previous investigations, there were several limitations. First, dam-naïve fish were never analysed. Salmon were captured after successful passage of the dam, then transported downstream and tracked as they attempted to pass the dam for a second time. This could have led to underestimates of fish passage success (Roscoe and Hinch 2008). Second, passage has only been tested under routine operational conditions, in which water is released directly adjacent to the fishway entrance (Pon et al. 2009; Roscoe et al. 2011). Third, physiological information to prove mechanisms was limited by technology. Swim speeds, from which we can estimate energy used by salmon as they navigate and ascend the fishway, could not be measured. Fourth, detailed measurements of flow conditions in the dam tailrace were never made.

A multi-year investigation of Seton Dam fish passage was needed in which: 1) dam-naïve salmon are tracked as they pass the dam for the first time; 2) operational conditions are manipulated, allowing comparison of attraction efficiency of routine conditions (identified as a significant barrier to passage success [Roscoe and Hinch 2008]) to that of an alternate release condition; 3) swim speeds and energy use are measured to determine whether the energetically-demanding process of dam passage has an influence on passage success, post-passage survival, or spawning success; and 4) detailed measurements of flow conditions in the Seton Dam tailrace can be obtained, which can then be related to fish movement behaviour. In addition, fish counter enumeration efficiency needs be improved to better relate passage success to dam operational conditions. Operating conditions at Seton Dam can then be correlated with migration success, post-passage survival, and environmental variables to identify factors impeding salmon migration and mitigation measures can be formulated.

BRGMON-14 was a six-year field investigation (2012 to 2016) of how Seton River dilution, Seton Dam operations, and environmental variables influenced the behaviour and physiology of salmon in the Seton-Anderson watershed. The methods used built upon previous studies while incorporating new enhanced monitoring techniques. The Pacific Salmon Ecology and Conservation Lab at the University of British Columbia (UBC) carried out physical parameter monitoring, conducted behavioural experiments, and used telemetry to assess fish migration. This group also collaborated with the University of Alberta to measure Seton Dam tailrace flow fields. Instream Fisheries Research Inc. conducted fish passage enumeration at the Seton Dam fishway using an electronic fish counter and video monitoring. This report summarizes the methods and results of the BRGMON-14 monitoring program from 2012 to 2016, addresses the Management Questions and Hypotheses outlined in Terms of Reference, and makes recommendations to St'át'imc Eco-Resources Ltd. and BC Hydro on operational modifications to the hydroelectric facilities within the Seton-Anderson watershed to improve salmon passage.

1.2 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 Creek dilution in Seton River.
3. To identify operating strategies that will mitigate impacts to upstream migration.

To meet the objectives, a series of management questions and hypotheses were developed (see below). The management questions seek to answer how dam operations influence salmon migratory and spawning success in the Seton-Anderson watershed. The first question asks whether the current targets for dilution of natal water in the Seton River are effective in mitigating migratory delay of Gates and Portage Creek sockeye, and how sensitive these two populations of sockeye are to variation in the dilution of natal water. Uncertainty exists within the Bridge River Water Use Plan operational requirements for the Seton Generating Station because Seton River dilution levels were derived from studies that were limited in scope and have not been re-evaluated. The management null hypotheses are that migrating Gates and Portage Creek sockeye are not delayed when dilution levels are maintained below the current targets (H_{O1} and H_{O2}), and that there is no predictable relationship between dilution levels and migratory delay in Gates or Portage Creek sockeye (H_{O3} and H_{O4}), which would indicate they are not sensitive to variations in the dilution of natal water.

The second management question asks how the operation of the Seton Generation Station affects pink, coho and Chinook as the migrate through the system. The management null hypotheses are that each of the species delay at the tailrace of the Seton Generating Station (H_{O5}, H_{O6} and H_{O7}). Observations of pink salmon in the IPSFC research was limited (four individuals tracked with radio transmitters), and pink salmon were not analyzed in more recent studies. Coho and Chinook salmon have never been assessed in this system.

The third management question is whether operation of the Seton Dam and fishway affects salmon passage, and whether operational changes can mitigate migration issues at the dam. Previous findings indicate that passage through the fishway structure is high, but that attraction to the fishway entrance is relatively low (Pon et al. 2006). Failure to locate and enter the fishway entrance was therefore the primary cause of passage failure. The management null hypotheses that address this management question are that operations of the dam and fishway do not affect attraction to the fishway (H_{O8}) or passage of the fishway (H_{O9}).

The Methods (Section 2) and Results (Section 3) of this report are organized into sub-sections in accordance with the management questions, and the corresponding hypotheses are addressed in their associated sub-sections. Specific management questions and hypotheses are stated below.

1.3 Management Questions

The Management Questions for the BRGMON-14 program are:

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?

1a. How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

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

3a. What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

1.4 Management Hypotheses

A series of Management Hypotheses support addressing the BRGMON-14 Management Questions. A set of null hypotheses was developed to address Management Question 1 and the effectiveness of the current dilution targets for Gates Creek and Portage Creek sockeye salmon migration:

H_{1O}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 20%.

H_{2O}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 10%.

Variations in the dilution level necessitate a secondary set of hypotheses to test the sensitivity of Gates Creek and Portage Creek sockeye migration behaviour and address Management Question 1a. The null hypotheses are:

H_{3O}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.

H_{4O}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.

Prior to the BRGMON-14 program, investigations focused on sockeye because of their abundance in the Seton-Anderson watershed and high cultural and economic value. However, it has not been determined if Seton Generating Station operations caused pink, Chinook, or coho salmon to delay migrating to the Seton River. Management Question 2 will be addressed by testing the following hypotheses:

H_{5O}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.

H_{6O}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.

H_{7O}: 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 and 3a:

H_{8O}: Operation of Seton Dam and fishway does not affect attraction to the fishway.

H_{9O}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.

1.5 Study Area

The study area for the BRGMON-14 monitoring program encompassed the entire migration route of salmon within the Seton-Anderson watershed and the Fraser River near the Seton River confluence. Migration was studied 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, Fraser River, Seton River, Cayoosh Creek, and Seton Dam (Figure 1.2). In addition, the migratory success of salmon to spawning grounds at Gates Creek and Portage Creek was quantified.

Cayoosh Creek merges with the Seton River approximately 1 km downstream of the Seton Dam, where it dilutes the natal odours present in the Seton River. Upstream of this confluence, Seton River receives its water from the outflow of Seton Lake, the source of the natal chemical cues that guide the upstream migration of any salmon that spawn above the dam, including Gates Creek and Portage Creek sockeye salmon. Some of the water exiting Seton Lake passes through Seton Dam before entering the Seton River, while the rest is diverted to the power canal, where it flows to the Seton Generating Station. When the amount of water in Cayoosh Creek increases, or the amount of Seton Lake water passing through the dam decreases, the dilution level in the Seton River is elevated. To successfully migrate to spawning grounds, salmon must continue past the tailrace of the Seton Generating Station—an undiluted source of odours—as they migrate up the Fraser River, and then enter the Seton River, which may be diluted. Dilution targets are set and the higher the dilution the lower the concentration of natal water in the Seton River.

Detailed examination of fish passage was 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 diversion dam consisting of a radial gate, five siphons, a fish water release gate, and fishway. To access Seton Lake and spawning grounds, migrating salmon must navigate the Seton Dam tailrace, locate the fishway entrance adjacent to the fish water release gate, 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 in the exit basin. Migrating salmon must pass through the fish counter to enter Seton Lake.

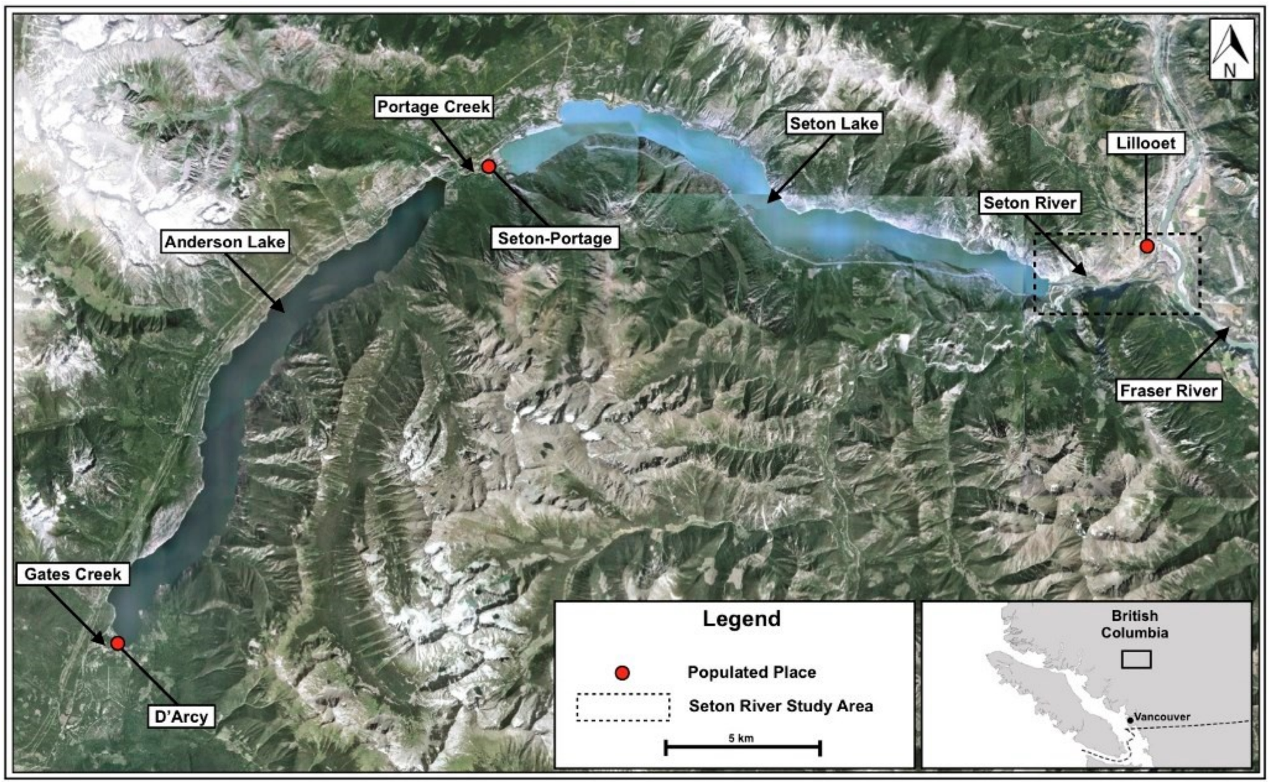

Figure 1.1 **Overview of the Seton-Anderson watershed and study area for the BRGMON-14 monitoring program.**

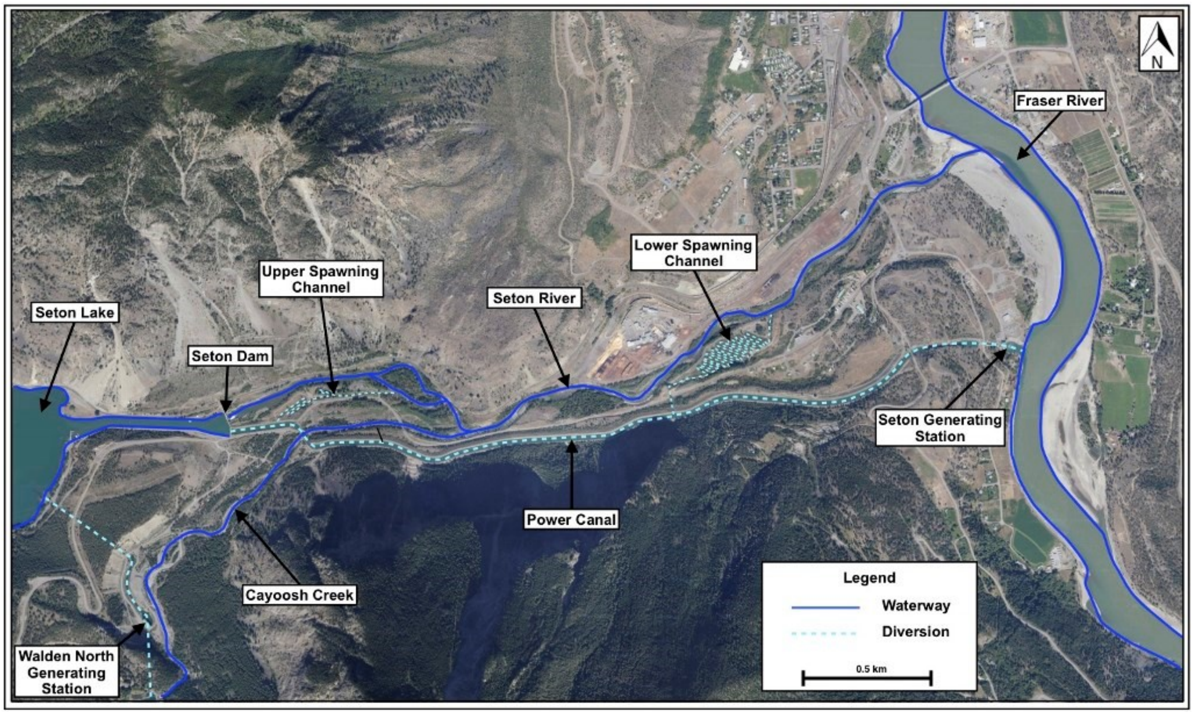

Figure 1.2 **Waterways and diversion infrastructure within the Seton River study area.**

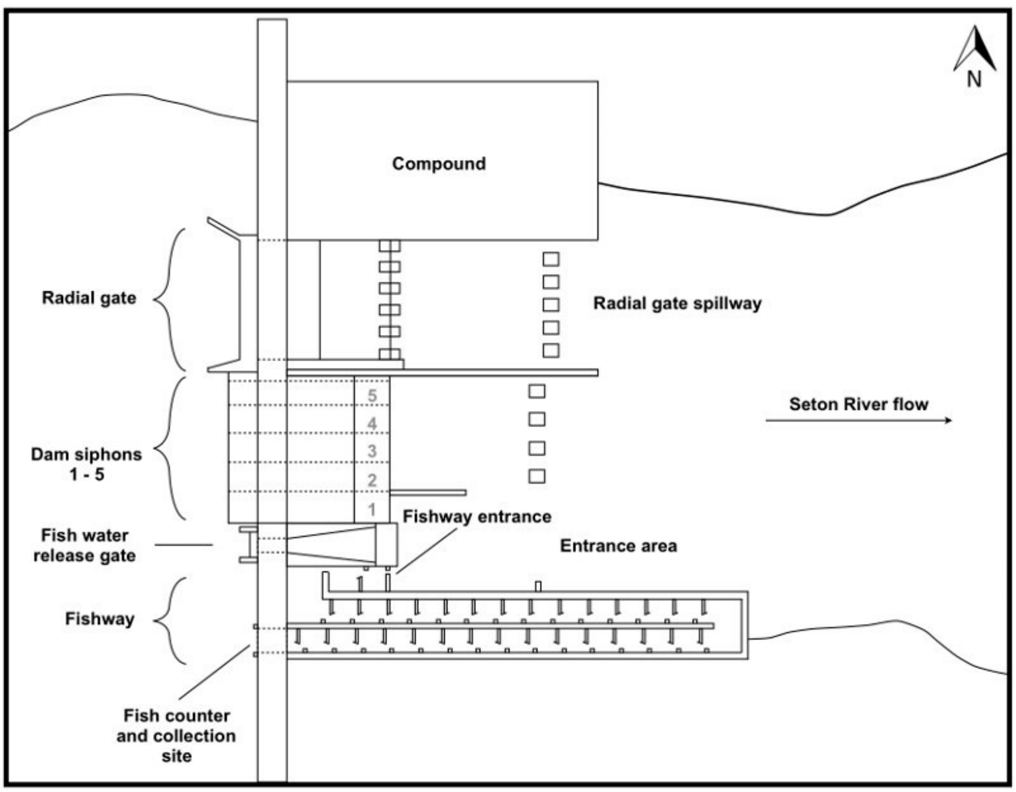

Figure 1.3 **Schematic of Seton Dam showing water conveyance structures (left), fishway entrance are (bottom), and the radial gate spillway (top).**

2 METHODS

2.1 Physical Parameters

Monitoring of physical parameters important to salmon migration began in 2012 and continued through to the end of the 2016. The parameters monitored included discharge, water temperature, and water conductivity. Tailrace flow fields were monitored in 2013 and 2014.

2.1.1 Seton River Hydrology and Dilution Levels

Discharge data for the upper Seton River and Cayoosh Creek were obtained from the Water Survey of Canada. Discharge data for Seton Dam, the Seton River spawning channels, and the Seton Generating Station were obtained from BC Hydro Power Records. Mean daily discharge for the upper Seton River and Cayoosh Creek were calculated from the hourly discharges recorded by Water Survey Canada gauging stations 08ME003 (Seton River above Cayoosh Creek) and 08ME002 (Cayoosh Creek) (Figure 2.1).

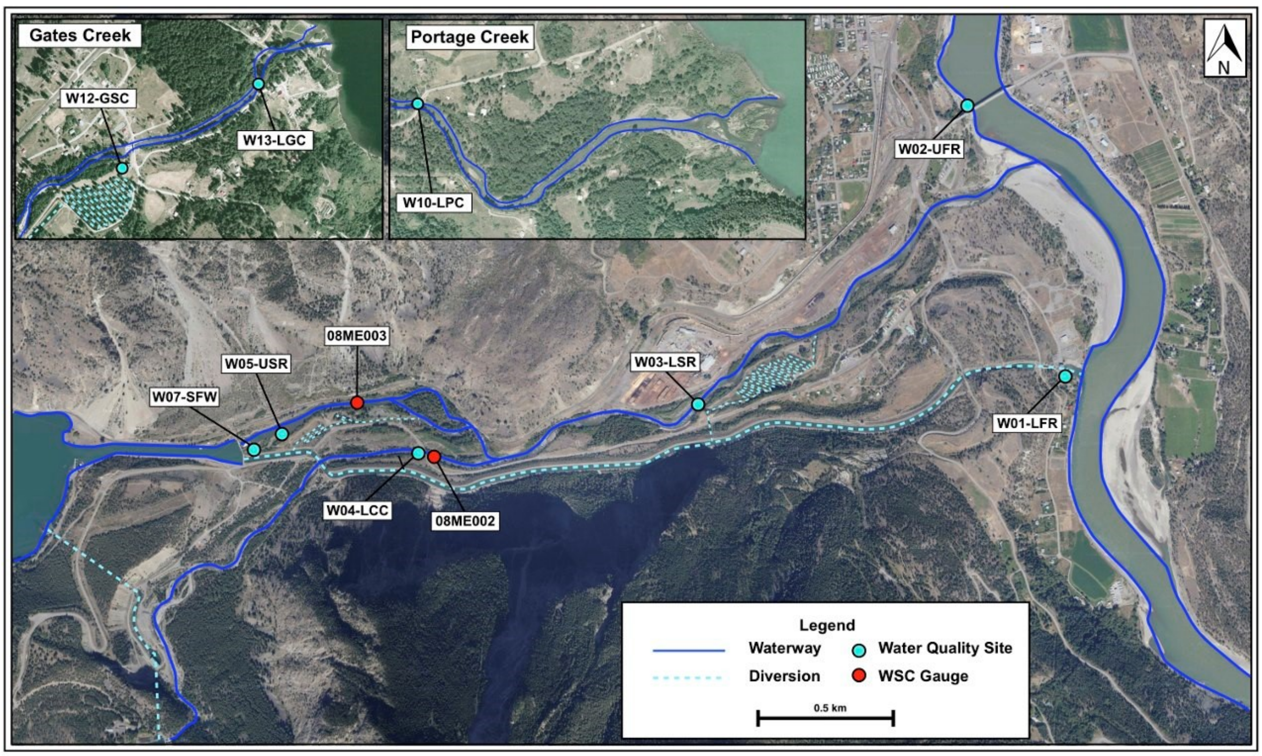

Figure 2.1 Water quality sites in the Seton River (main map), Gates Creek spawning channel (insert, left), and Portage Creek (insert, right).

Mean daily discharge of individual conveyance structures at Seton Dam and the upper and lower spawning channels was calculated from the hourly discharge records provided by BC Hydro. Lower Seton River discharge was calculated as the sum of the discharge of the upper Seton River, Cayoosh Creek, and the spawning channels. Hourly discharge data were used in data analysis.

The mean daily dilution level (Equation 1) for the Seton River was calculated by BC Hydro Power Records using the daily average discharge of each location. In addition, we report natal water concentration as the percentage of pure Seton River water in the Seton River after it has been mixed with water from Cayoosh Creek. It is the inverse of dilution.

$$Dilution = \frac{Cayoosh\ Creek}{Cayoosh\ Creek + Seton\ River + Spawning\ Channels} \qquad \text{Equation 1}$$

2.1.2 Tailrace Flowfields

A 2-dimensional ChannelMaster H-Acoustic Doppler Current Profiler (ADCP; Teledyne RD Instruments, Poway, CA, USA) was used to measure water velocity across 43 transects in the Seton Dam tailrace (Figure 2.2). The ADCP was either manually positioned from the riverbank (S1 to S35 in Figure 2.2) or lowered into the tailrace from the dam compound (S36 to S38) or fishway wall (X1 to X5) using a custom-built frame. Transects S1 to S38 were taken at a depth of 0.5 m, while transects X1 to X5 were taken every 0.5 m from 0.5 m below the water surface to 0.5 m above the riverbed. Each transect was approximately 20 m long with water velocity measurements taken at 0.20 m to 0.25 m segments along the transect. Water velocity measurements were taken for a minimum of 5 min with a 5.5 s sampling interval. Surface particle tracking was used to estimate water velocities where the ADCP measurements were attenuated by highly turbulent and aerated water. Movements of test particles of known dimensions were recorded by digital video cameras recording at 120 frames per second. Video analysis was used to track the particles and calculate surface water velocities. Measurements were taken in 2013 and 2014 of routine flow scenarios, as well as an alternative flow scenario in 2014 (described in 2.6.2).

River bathymetry was measured in October with a downward-facing 3.0 MHz RiverCat-ADP (SonTek, San Diego, CA, USA) mounted to aluminum hulls and towed across the tailrace. A total of 40 bathymetry transects were completed. The origin of each ADCP and bathymetry transect was measured using a RTK-GPS system (Trimble Navigation Limited, Sunnyvale, CA, USA). ADCP and bathymetry data were post-processed using the software packages supplied by the ADCP manufacturers and imported to Microsoft Excel and Matlab for analysis.

Figure 2.2 **Acoustic Doppler Current Profiler measurement transects in the Seton Dam tailrace (S1-S38) and at the fishway entrance (X1-X5) in 2014.**

2.1.3 Water Temperature and Conductivity

Water temperature data for 2012 to 2016 were collected at the water quality sites established in 2012 - 2014 (Figure 2.1). TidbiT v2 water temperature loggers (± 0.2°C accuracy) (Onset Computer Corporation Inc., Bourne, MA, USA) recorded hourly water temperature at all sites except at the Seton Dam fishway (W07-SFW) and lower Gates Creek (W13-LGC) where temperature was set to record at 15 min intervals starting in 2014, and the Upper Fraser River site (W02-UFR), where it was not possible to install a temperature logger. Duplicate temperature loggers were installed at most sites to ensure data security.

Additional water temperature data were obtained for the Fraser River to estimate the thermal experience of salmon prior to entering the Seton River and water temperature in the Fraser River between the Seton River and Seton Generating Station. Water temperature data were obtained from Fisheries and Oceans Canada for the Fraser River at Qualark Creek (approximately equidistant from the Seton River and the upstream most tidal region of the Fraser River near Mission) to estimate the average thermal regime encountered by sockeye during their upstream migration in 2013 - 2014. Data from the Fraser River at Texas Creek (WSC station 08MF040) was used to estimate sockeye thermal experience in 2015 (Environment Canada – Water Survey Canada, 2017) as temperature monitoring at Qualark Creek was discontinued in 2014. Hourly temperature readings of the Fraser River at Texas Creek were used in telemetry models to estimate the thermal experience of sockeye migrating from the Seton Generating Station to the Seton River.

Specific conductivity measurements were collected to compare the water chemistry of the Seton River and Cayoosh Creek. Monitoring was carried out in 2013 - 2015 at three sites: the lower Seton River (W03-LSR), lower Cayoosh Creek (W04-LCC), and the upper Seton River above the Seton River-Cayoosh Creek confluence (W05-USR) (Figure 2.1). The upper Fraser River site (W02-UFR) was also monitored but only in 2013. Specific conductivity measurements ($\mu S \cdot cm^{-1}$) were taken using a hand-held YSI Pro30 conductivity meter (YSI Inc., Yellow Springs, OH, USA). Measurements were taken daily so long as personnel were available. In 2015, monitoring began on 01 August 2015 but was discontinued on 19 August 2015 due to the meter malfunctioning. No measurements of conductivity were taken in 2016.

2.2 Population Assessments: Estimates of Return Numbers, Run Timing, and Telemetry

2.2.1 Resistivity Counter

Detailed estimates of run timing and size were collected to assess the effects of dilution and water releases on salmon. To this end, a resistivity fish counter was operated at Seton Dam from 2013 - 2016 to estimate the annual abundance and run timing of Gates Creek and Portage Creek sockeye, coho salmon, and Chinook salmon. Pink salmon abundance and timing was only estimated for the years they were present in the Seton River (2013, 2015). Counter operations were generally consistent across years, with minor modifications in the installation made each year to improve detection efficiency and validation capacity.

Each study year, InStream Fisheries Research Inc. installed and monitored a fish counter at the top of the Seton Dam fishway (Figure 1.3). The counter was operated from the last week of July, prior to the start of the Gates Creek sockeye migration period, until late-November, after the end of the Portage

Creek sockeye migration period. The sensor unit consisted of eight sensor tubes connected to two Logie 2100c resistivity fish counters (Aquantic Ltd., Scotland, UK). Each sensor tube was monitored by a single counter channel. The counter was used to identify the run timing of different species and populations through the Seton system and to estimate abundances. Details of the structure and operation of the counter, as well as the methods used to generate abundance estimates from counter data, are provided in Casselman et al. (2015).

2.2.2 Fish Capture, Sampling and Telemetry

The migration behaviour and survival of Gates and Portage Creek sockeye salmon, pink salmon, and coho salmon was studied using different telemetry techniques. The migration of Chinook salmon could not be studied because no fish were caught during the monitoring program. The scope of telemetry studies varied each year and with each species depending on the Management Questions being addressed. After a 2012 pilot season in which different types of tags were tested to determine those most suitable for this system, activities in 2013 to 2016 included the use of radio, acoustic, and passive integrated transponder (PIT) telemetry.

2.3 Fish Capture and Tagging

Fish for telemetry studies were captured either from the top exit pool of the Seton Dam fishway (2012 and 2013) or using a fish fence installed in the Seton River approximately 200 m downstream of Seton Dam (2013 through 2016; Figure 2.3). In 2012, a small number of Gates Creek sockeye were tagged at the fishway between 17 August and 28 August. In subsequent years, the Seton River fish fence was used to capture fish. It was installed in the Seton River in the last week of July or the first week of August. In 2013 and 2014, the fish fence operated until late-October to capture Portage Creek sockeye and coho salmon. In 2015 and 2016, the fish fence operated until early-September to capture only Gates Creek sockeye. One exception with the use of the fish fence occurred between 07 August and 14 August 2013. During this period Gates Creek sockeye were collected from the fishway due to difficulties installing the fish fence in time for the Gates Creek sockeye migration.

To successfully capture fish, the fish fence was closed daily for five to ten hours beginning at 6 am. Following capture, fish were transferred to holding pens and held for 0.5 – 1.0 h prior to tagging. When fish were not being captured, sections of the fish fence were removed to allow migrating fish to travel unimpeded. Daytime closures sought to minimize any undue influence on the behaviour of tagged fish. Fish captured between 2013 and2016 were tagged with standard protocols that applied acoustic, radio, or PIT tags. Tagging in 2012 required a modified tagging procedure to accommodate external accelerometer data loggers attached to some fish.

Figure 2.3 Full-spanning fish fence in the Seton River in 2014.

2.3.1 Tagging and Sampling

Following capture and holding, fish were transferred to a V-shaped trough supplied with fresh water and manually restrained. Somatic lipid (fat) concentration was measured using a FM 693 Fish Fatmeter (Distell, West Lothian, Scotland, UK) (Crossin and Hinch 2005). For Gates Creek sockeye, fish with a Fatmeter reading greater than 2.7% were not tagged in 2013 through 2016, as these fish had a high probability of being strays (Casselman et al. 2015). Fork length was then measured to the nearest 0.5 cm and sex estimated.

All fish tagged from 2013 through 2016 received a 32 mm HDX PIT tag (Oregon RFID, Portland, OR, USA) implanted in the dorsal musculature and a 12” spaghetti tag (Floy Tag & Mfg. Inc., Seattle, WA, USA) secured behind the dorsal fin. Radio-tagged fish received a Pisces5 radio transmitter (Sigma Eight Inc., Newmarket, ON, Canada) inserted into the stomach using a plastic plunger. In 2013-2014, radio-tagged Gates Creek sockeye also received an iButton DS1921Z or DS1922L temperature logger (Maxim Integrated, San Jose, CA, USA) attached to the radio transmitter and water-proofed using a liquid plastic coating. Acoustic-tagged fish in 2012 received either an acoustic accelerometer transmitter (V9AP-2x or V13A-1x, Vemco, Bedford, Nova Scotia, CA) inserted into the stomach or a combination of a Pisces5 radio transmitter and externally-attached X8M-3 accelerometer logger (Gulf Coast Data Concepts, Waveland, MS, USA). Accelerometer loggers were housed in custom-made plastic enclosures and attached posterior to the dorsal fin using metal wiring inserted through the dorsal musculature. In 2013 and 2014, acoustic-tagged fish only received the V13A-1x transmitter as 2012 studies found it to be the most appropriate tag for studying Seton Dam passage (see Year 1 report).

A DNA sample was taken from the adipose fin of all tagged fish using a hole punch and the sample stored in 95% ethanol or on Whatman paper. Stock identification DNA analysis was carried out for all radio and acoustic tagged fish in 2012 through 2014. Samples were processed at Fisheries and Oceans Canada (DFO) Pacific Biological Station.

For radio and acoustic-tagged fish in 2013 and 2014, a blood sample was withdrawn into heparinized Vacutainers using a caudal punch (Houston 1990). Vacutainers were then centrifuged, plasma withdrawn, and samples frozen in liquid nitrogen until they were transported to UBC and stored in a -80°C freezer. Blood samples were later transferred to DFO's West Vancouver Laboratory for analysis. Glucose, lactate, and testosterone were analysed to determine whether they interact with environmental or operational conditions thus provide insight into the mechanisms behind migratory behaviour and survival of fish.

2.3.2 Fish Release

Fish tagged at the Seton River fish fence were released either at the fence site immediately after tagging or briefly held post-tagging then transported downstream to the Fraser River for release. On the Fraser River, release sites on the west (FRW) and east river (FRE) banks were used in 2013, both were approximately 1 km downstream of the Seton Generating Station (Figure 2.4). In 2014 through 2016, only the release site on the west side of the Fraser River was used to reduce transport times and because of site access restrictions. A subset of fish in 2013 were released in the lower Seton River, downstream of the Cayoosh-Seton confluence and 3.9-km downstream of the Seton Dam. Fish released on the Fraser River were transported to the release site in groups of 10 to 15 fish in a 1,000-L aerated and oxygenated transport tank. Loading densities were approximately 50% of the maximum recommended loading density for adult salmon (Shepard and Bérézay 1987). Dissolved oxygen was maintained at 90 to 110% saturation and transport times from loading to released ranged from 25 to 40 min. Fish tagged at Seton Dam were temporarily held in a 1,000 L aerated and oxygenated tank post-tagging for a maximum of 0.75 h.

The tag types deployed at the Seton River fish fence and Fraser River release sites were dependent upon the type of monitoring required. Radio-tagged fish were released in the Fraser River to study migration past the Seton Generating Station while acoustic-tagged fish were released at the fence to study migration past Seton Dam. PIT-tagged fish were released at the Fraser River site to serve as comparisons with radio-tagged fish to determine whether the increased handling associated with radio tagging affected survival. PIT-tagged fish released at the Seton River fence were used for comparison with acoustic-tagged fish, and for study of Seton Dam passage.

For radio-tagged fish, upstream capture and downstream release is a common method to study salmon migration in regulated rivers (Thorstad et al. 2003; Naughton et al. 2005; Caudill et al. 2007) and there is little evidence to suggest that adult salmon have the ability to learn migration routes (Hansen and Jonsson 1994; Thorstad et al. 2003).

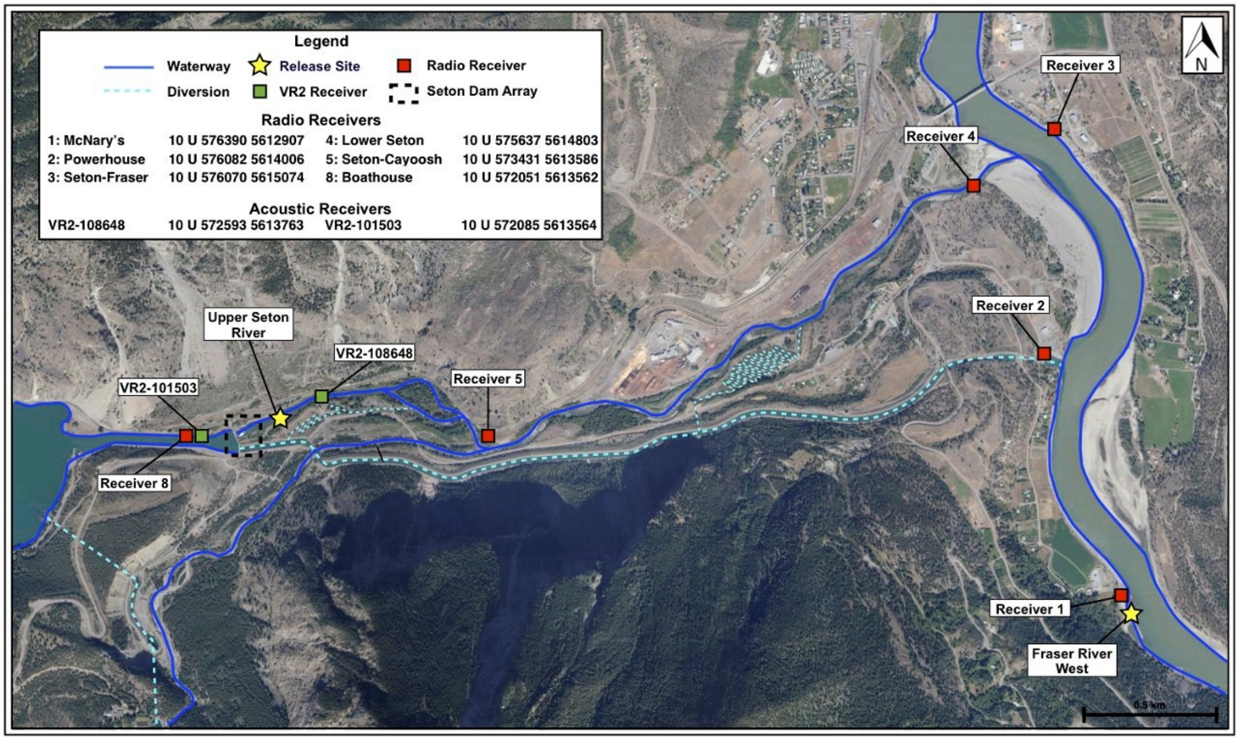

Figure 2.4 **Release sites, acoustic receivers, and radio receivers in the Fraser River and lower Seton River in 2013-2016.**

2.3.3 Tag Recovery

Tag recoveries were carried out in the Seton River and Gates Creek to estimate the cause of migration failure, assess the spawning success of tagged fish, and provide a means to estimate the detection efficiency of the telemetry arrays located furthest upstream. Tag recovery efforts focused primarily on the Gates Creek spawning channel and Gates Creek. Deceased fish were identified by the external spaghetti tag or, for radio-tagged fish, located using a portable SRX-400 radio receiver. Tags were removed from recovered fish and, where possible, female spawning success estimated as either 0% (skeins tight, no egg deposition), 50% (partial egg deposition, >500 eggs remaining in body cavity), or 100% (<500 eggs remaining in body cavity). Limited tag recovery efforts took place at Portage Creek due to the low likelihood of recovering tags.

Tagged fish caught in local fisheries at Portage Creek or in the Fraser River were recovered through self-reporting by anglers, canvassing by UBC staff and students, or streamside surveys. Mobile radio-tracking was used to estimate the number of radio tags that were captured by local fisheries but not reported, although this was not possible for PIT-tagged fish. Additional mobile radio-tracking was performed on the Seton River, Bridge River, and Fraser River to locate radio-tagged fish that did not migrate past Seton Dam. Radio transmitters that were repeatedly tracked to the same location but could not be recovered were classified as mortalities.

2.3.4 Telemetry Array

Unique receivers were required for each of the three tag types used in this project. Migration of radio-tagged fish was monitored using up to 11 radio receivers installed at sites on the Fraser River, and Seton River (Figure 2.4), in the Seton Dam tailrace (Figure 2.5), and at Portage Creek and Gates Creek (Figure 2.6). Receivers upstream of the lower Seton River receiver were used to account for imperfect detection efficiency at the lower Seton River receiver and improve the estimate of Seton River entry success and passage time prior to Seton River entry. Manual tracking with a portable SRX 400 receiver was used to supplement fixed radio telemetry.

Each receiver station consisted of an Orion (Sigma Eight Inc., Newmarket, ON, CA) or SRX 400 receiver (SRX 400, Lotek Wireless Inc., Newmarket, ON, CA) connected to one or two Yagi 3- or 5-element antennas and powered by deep cycle batteries. Data on the receivers were downloaded frequently and batteries changed as required. Receivers in the Fraser River at the release site (Receiver 1) and the Seton River-Fraser River confluence (Receiver 3) were used to determine if fish exited the study area. At the Seton Generating Station (Receiver 2), the receiver detection range was adjusted to provide coverage of the entire tailrace to the confluence with the Fraser River to detect fish entering and exiting the tailrace. In the Seton River, a receiver upstream of the confluence with the Fraser River confirmed river entry (Receiver 4) while a receiver upstream of the Cayoosh Creek confluence (Receiver 5) acted as a migration checkpoint. At Seton Dam, two receivers were used to detect arrival and residency in the tailrace (Receiver 6) and attempts to enter the fishway (Receiver 7). Passage of Seton Dam was confirmed with a receiver in the forebay (Receiver 8) and survival through Seton Lake assessed with a receiver on Portage Creek (Receiver 9). Successful arrival at spawning grounds was confirmed with a receiver in lower Gates Creek (Receiver 10) and at the entrance to the Gates Creek spawning channel (Receiver 11).

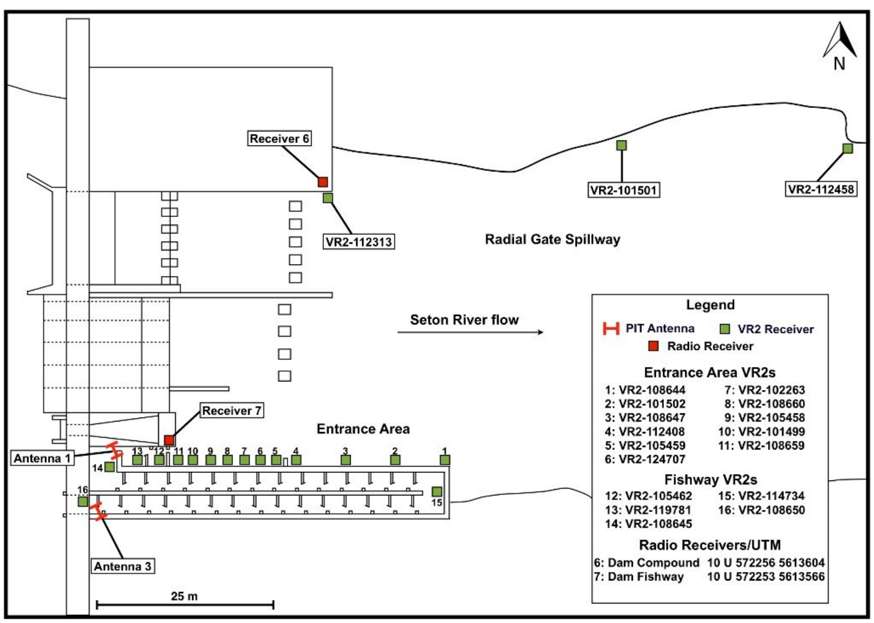

Figure 2.5 Location of radio receivers and PIT antennas in the Seton Dam tailrace and fishway in 2015. The detection range of radio Receiver 6 extended to the right-edge of the figure. Acoustic receivers deployed in 2014 are show for reference.

Underwater VR2 acoustic receivers (Vemco, Bedford, Nova Scotia, CA) were deployed to capture location and accelerometer data from acoustic-tagged fish. In the Seton Dam tailrace and fishway, six VR2 receivers were installed in 2012, 17 installed in 2013, and 19 installed in 2014 (Figure 2.5). Receivers were secured to concrete bases, lowered into the tailrace, and attached to the dam or riverbank with rope so they could be recovered. Receivers were positioned along the fishway wall on the south bank of the tailrace, in the radial gate spillway on the north bank, and in the fishway entrance and exit basins. Additional VR2 receivers were also installed in: the Seton Dam forebay to detect fish exiting the Seton Dam fishway (2012 - 2014); in the Seton River and Fraser River to detect any fish that may have fallen back downstream from Seton Dam (2013 -2014); at Portage Creek to detect fish exiting Seton Lake (2014); and at the Gates Creek mouth and Gates Creek channel to detect fish that reached spawning grounds (2013, 2014) (Figure 2.6).

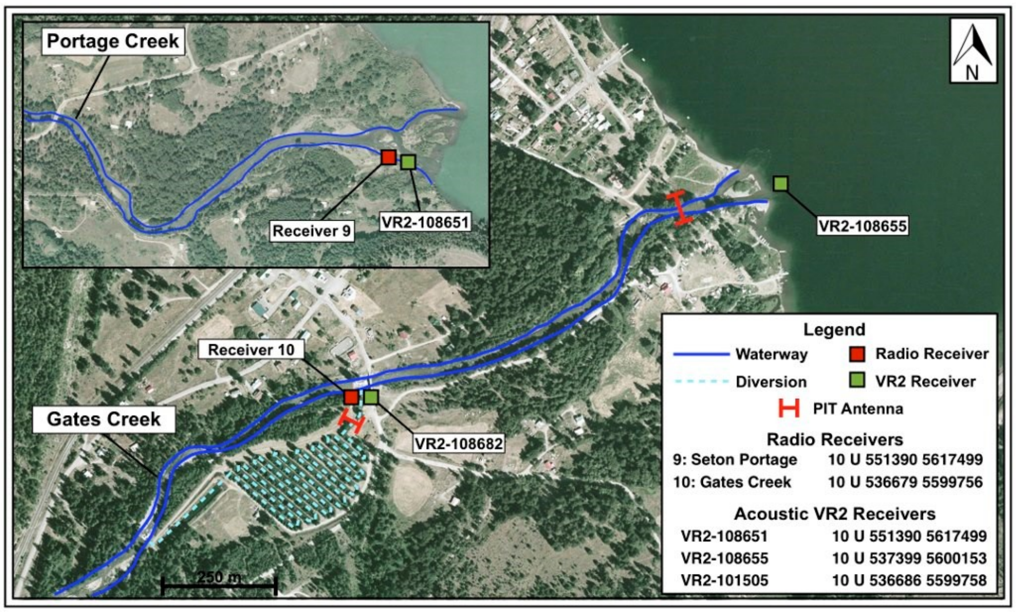

Figure 2.6 **Location of radio receivers and PIT antennas in Portage Creek, Gates Creek and the Gates Creek spawning channel in 2015. Acoustic receivers deployed in 2014 are shown for reference.**

Migration of PIT-tagged fish was recorded with 'pass-through' PIT antennas installed in the entrance and exit basins of the Seton Dam fishway (Figure 2.5). Antennas were constructed out of 1.5" PVC pipe with 12-gauge stranded electrical wire and positioned on the upstream side of the vertical slot baffles in the fishway entrance and exit basins. Each antenna was connected to a tuner box and HDX tag reader (Oregon RFID, Portland, OR, USA). The antenna in the entrance basin was used to confirm entrance into the fishway and the antenna in the exit basin used to confirm successful passage of the fishway and Seton Dam. In 2016 only, a third Seton Dam PIT antenna was installed at the Seton River fish fence to detect fish entering the Seton tailrace following release downstream in the Fraser River and migration back to the Seton River. The antenna was positioned immediately upstream of the portion of the fence that was removed to allow fish passage when the fence was not activity fishing.

Up to two PIT antennas were installed on Gates Creek. In 2013 - 2016, a PIT antenna was installed at the entrance to the Gates Creek spawning channel. The antenna was constructed using stranded electrical wire fed through a garden hose loop and held on the creek bed with sandbags. Antenna operation was continuous in most years; however, power outages did occasionally interrupt operations. The channel antenna operated until the removal of the Gates Creek fish fence, after which time fish could access upper Gates Creek without approaching the channel entrance. In lower Gates Creek from 2014 to 2016, a 20 m wide full-span PIT antenna was installed 120 m upstream of Anderson Lake to detect fish near the mouth of Gates Creek. Power to the antenna was provided by 6V deep-cycle batteries running in series at 18V that were changed every 3 to 4 days. Due to malfunctioning battery chargers, antenna coverage was not continuous in 2014 or 2015, although in 2015 the antenna did operate continuously during the peak spawning period for Gates Creek sockeye (early September). Antenna operation in 2016 was continuous. Operation of the antenna continued as late in the Gates Creek sockeye migration as possible, although heavy rain events in 2015 and 2016 increased Gates Creek flows and disabled the antenna near the end of September.

2.4 Influence of Seton River Dilution on Sockeye Salmon Migration

<u>Management Questions:</u>

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 populations?

1a) How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

Three approaches were used to assess the effectiveness of dilution targets on Gates and Portage Creek sockeye. First, a stream-side water preference experiment was conducted to assess how sensitive the salmon are to changes in dilution (Section 2.4.1). Second, the movements of Portage and Gates Creek sockeye were observed from the Fraser River (downstream from the powerhouse tailrace) until they has passed Seton Dam using radio telemetry (Section 2.3) to determine how dilution and other environmental and physiological factors influence their migratory behaviour (Section 2.4.5). Following the stream-side and observational studies, a field-based experiment was conducted on Gates Creek salmon to test the effects of dilution levels that exceed the current dilution target (Section 2.4.6). In this experiment, fish were tracked through the system while the dilution level was held above the current dilution target.

In addition, past research in this system suggested that the undiluted water exiting the Seton Generating Station could encourage salmon to push against the metal gates that block their entrance into the generating station, and that such behaviour could cause physical injuries. Although injuries do not directly address the management questions, injuries were noted as a concern and an injury assessment was conducted to determine whether the Seton Generating Station could contribute to a significant proportion of the injuries observed in returning salmon (see Section 2.6).

2.4.1 Water Preference Behavioural Tests

Water preference experiments were carried out in 2013 and 2014 to determine whether migrating Gates Creek and Portage Creek sockeye preferred undiluted Seton River water from Seton Lake to Seton River water diluted with Cayoosh Creek water. This behavioural experiment was conducted in stream-side tanks without the use of telemetry. As such, capture, handling, and sampling methods differ from those described in Section 2.3.

The current dilution targets were primarily derived from a behavioural experiment conducted by the IPSFC (Fretwell 1989). This research has never been re-evaluated, despite several limitations. First, the behavioural tests were conducted using salmon captured by brail net, a method that can cause injury and undue stress to the fish. Second, the salmon were tested in groups but statistically analyzed as individuals. This approach necessitates the assumption that individuals behaved independently of one another, which is unlikely for schooling salmon. Third, preference was determined by location of the fish within the test apparatus after a pre-determined amount of time, which is a relatively coarse estimate of behavioural choice. Furthermore, temperatures in the Fraser River have steadily increased over the past several decades (Patterson et al. 2007), which could affect the physiological state and potentially the behaviour of fish. Variation across years in open ocean productivity, which influences the somatic energy of Pacific salmon (Crossin et al. 2004), could also cause differences in migratory behaviour. The study in this section addressed these issues and provided further analyses under the differing environmental conditions. Salmon were captured by dipnet from the Seton Dam fish ladder, tested individually, and detailed measures of their behaviour were analyzed.

2.4.2 Fish Collection and Holding

Gates Creek sockeye were collected in 2013 from 03 August to 24 August (n = 174) and in 2014 from 01 August to 29 August (n = 164). Portage Creek sockeye were collected in 2014 from 29 September to 09 October (n = 108). All Gates Creek sockeye were individually captured via dip-net from the exit basin of the Seton Dam fishway while all Portage Creek sockeye were collected from the Seton River fish fence (see Section 2.3). Upon capture, Gates Creek sockeye were screened using the Fatmeter to identify and remove potential strays. Portage Creek sockeye were not screened with the Fatmeter due to the unknown relationship between fat content and stock identity during the Portage Creek sockeye migration period. However, the potential for fish from other stocks to join the run during this late migration period was judged to be low. Collected fish were transported in a 1,000-L oxygenated transport tank in groups of 12 to a 10,000-L holding tank in the Seton Dam compound. The holding tank received a continuous flow of water from the Seton Dam forebay. Within the holding tank, fish were individually held in 8” (diameter) x 28” (length) cylindrical isolation chambers made from PVC pipe for one to eight hours prior to experiments.

2.4.3 Experimental Apparatus

Water preference experiments were carried out at the Seton Dam compound using a custom-built Y-Maze. Water supply for the Y-Maze was supplied by two 11,365-L polyethylene supply tanks (Premier Plastics Inc., Delta, BC, Canada). One supply tank was used exclusively for Seton River water while the other contained the test mixture of Seton River water diluted with Cayoosh Creek water (Figure 2.7). 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 trucked from Cayoosh Creek to the supply tanks using a 2,000-L transport tank. Prior to water transport, the transport tank was disinfected with Ovadine (Syndel Laboratories, Qualicum Beach, BC, Canada) to eliminate any residual odours. Ambient temperatures could influence the water temperature in the supply tanks, so the tanks were filled at the beginning of each day with fresh water. During the day, the tanks were refilled as required, and drained at the end of each experiment day to flush out any residual odours in the Y-maze apparatus that may have accumulated during that day's trials. A test mixture dilution level was pre-mixed in the supply tank. Water from the tanks was gravity-fed to two 1,135-L mixing tanks before draining into the Y-Maze.

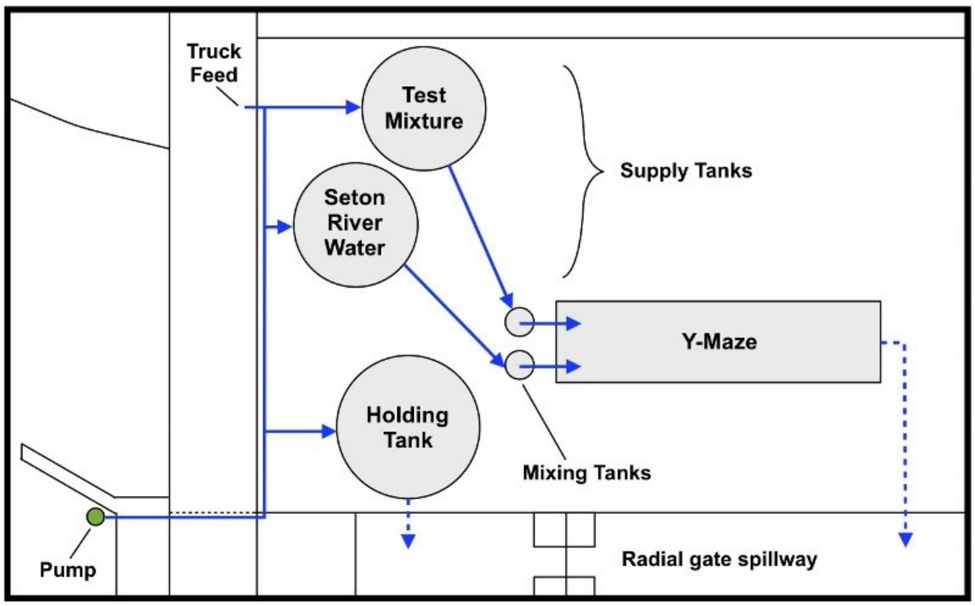

Figure 2.7 **Overview of the Y-Maze test apparatus installed at the Seton Dam compound. Supply tanks were filled with water pumped from the Seton River or truck transported from Cayoosh Creek and drained into supply tanks (truck feed). Each supply tank could feed water to either of the mixing tanks.**

The Y-Maze was a custom-built plywood test chamber (Figure 2.8) sealed with fiberglass and an odorless waterproof gelcoat. During dilution level experiments, water from each mixing tank gravity-fed into one of two test arms at a rate of 40 L·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 all trials, the test mixture was alternated daily between arms to control for any bias for either of the arms. 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 and video saved to a DVR unit.

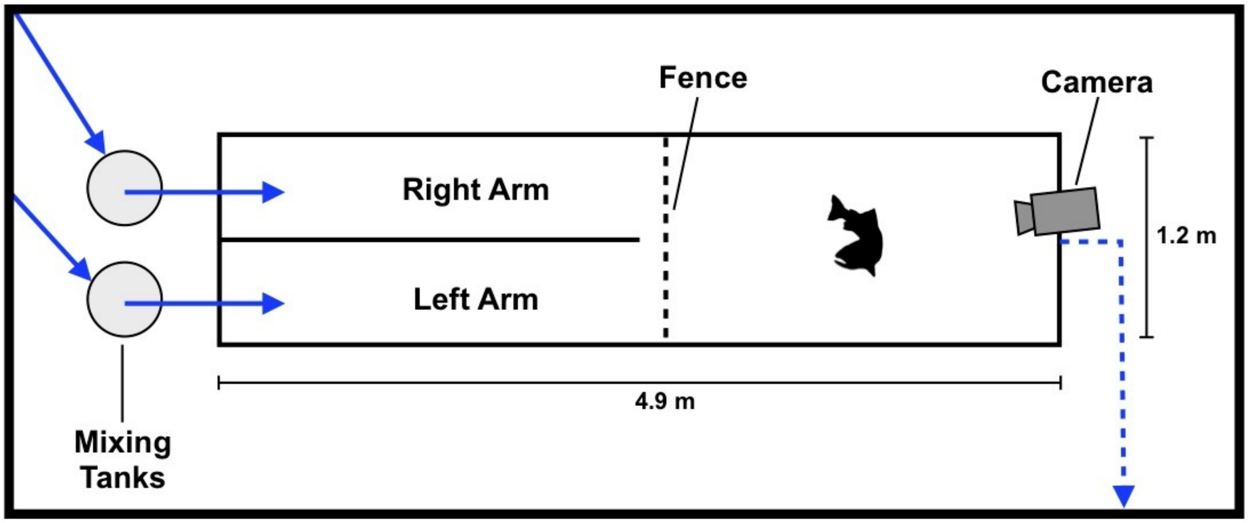

Figure 2.8 **Detailed view of the Y-Maze used for water preference experiments.**

2.4.4 Experimental Protocol

Fish to be tested were transferred from the 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 fence was placed at the entrance to the Y-Maze arms to prevent fish from accessing the arms, while allowing 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. At the end of each trial, basic morphological measurements and blood samples were taken from the fish and an adipose clip taken for DNA stock identification. This used the same sampling protocol as tagged fish (see Section 2.3).

Different dilution levels were tested by presenting fish with different dilution levels in each arm of the Y-maze and determining their preference. One arm of the Y-maze always contained pure Seton River water, and the other arm contained a mixture of Seton River and Cayoosh Creek water (except during the control test). In 2013, Gates Creek sockeye water preference experiments were carried out at 5%, 20%, and 50%. A control test was also conducted—in which pure Seton River water was presented in both arms—to determine whether the fish demonstrated a preferential bias for either of the arms. In 2014, Gates Creek sockeye were tested at a 30% dilution level. Portage Creek sockeye water preference was tested in 2014 at dilution levels of 10% and 20%. The need to conduct a control test to determine preferential bias for either arm in Portage Creek sockeye was eliminated by alternating the test mixture between the two Y-Maze arms. BC Hydro currently manages dilution level to below 20% during the Gates Creek sockeye migration, and below 10% during the Portage Creek sockeye migration.

Fish preference during the experiments was quantified by determining the number of times a fish entered each arm of the Y-Maze, the amount of time spent in each arm, and the proportion of time spent in each arm. Data from all fish were pooled and 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, even after transformation, 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 arms combined. Stock identification DNA analysis identified a small number of stray sockeye that were removed from analysis in 2013 (n = 10) and 2014 (n = 10).

The Gates and Portage Creek sockeye were predicted to exhibit a preference for pure Seton River water when paired with water diluted above the current management targets, but not when pure Seton River water was paired with water diluted below the dilution level targets. Such a result would indicate that the salmon prefer the pure "Seton River" water in the Seton Generating Station tailrace to water in the Seton River that exceeds the target dilution levels, and consequently may delay their migration (i.e., failure to support H_{O1} and H_{O2}).

2.4.5 Migration Behaviour Under Target Dilution Levels

In addition to preference experiments, the effect of dilution on salmon migration was assessed using observations of fish under different dilution levels encountered during normal BC Hydro operations, the whole-system manipulation of dilution levels in the Seton River, and through a literature review of the effect of changes in olfactory cues on a variety of Pacific Salmon in other systems. Radio telemetry was used to determine the behaviour of migrating fish, including how much time was spent at the Seton Generating Station tailrace and the extent fish moved between the Seton River and the generating station.

2.4.5.1 Fish Capture and Tagging

In 2013, 2014 and 2015, Gates and Portage Creek were captured and tagged with radio transmitters (see Section 2.3). Gates Creek sockeye were tagged from 05 August to 02 September 2013 (n = 138) and 05 August to 07 September 2014 (n = 166) and 02 August to 04 September 2015 (n = 206). Portage Creek sockeye were tagged from 03 October to 09 October 2013 (n = 24) and 27 September to 09 October 2014 (n = 189). The low capture and tagging numbers of Portage Creek sockeye in 2013 and the lack of captures in 2015 were due to the presence of large numbers of pink salmon, which co-migrate in large numbers (up to ~0.8 million) with Portage Creek sockeye on odd-numbered years. Portage Creek sockeye abundance was also low in 2013. The co-migration of these species made the capture of Portage Creek sockeye extremely difficult. Captured salmon were transported and released in the Fraser River, downstream of the Seton Generating Station.

A radio telemetry array (described in Section 2.3) was used to track the fish from the Fraser River to spawning grounds and receivers were configured to limit the detection radius. The powerhouse receiver was configured to detect tags only in the tailrace and not in the adjacent Fraser River. The receiver at the Seton-Fraser confluence was configured to only detect tags within a ~100 m radius of the Seton River mouth. The receiver at the Fraser River release site served as a 'gate' for detecting individuals returning to Fraser River, whereas receivers upstream in the Seton River confirmed Seton River entry or arrival at the Seton Dam. All receivers operated >90% of the study duration, providing sufficient ability to monitor fish movements (e.g. Release Site: 92.4%; Seton Powerhouse: 98.3%; Lower Seton River: 94.8%; Seton-Fraser confluence: 91.2%; Seton-Cayoosh confluence: 91.2%; Seton Dam: 95.7%).

Raw telemetry data were filtered to remove false detections and generate migration histories. Migration behaviour was quantified by: (1) counting the number of entries individuals made into the Seton Generating Station tailrace (hereafter ‘forays’) as a measure of attraction to the outflows at this facility; (2) determining the number of inter-receiver movements (hereafter ‘wandering’) in the Fraser River between radio receivers at the Seton Generation Station and the Seton-Fraser confluence as an index of migration confusion; and (3) summing the duration of each foray into the Seton Generating Station tailrace as an estimate of the total amount of migration delay incurred by individuals at this facility (hereafter ‘delay’). To ensure that the number of forays and thus delay at the powerhouse were representative of true migration behaviour, each metric was calculated based on detections that were part of ‘residence events’. Residence events for a given fish were defined as a series of consecutive detections at an individual receiver separated by no more than 30 minutes. The duration of a residence event continued indefinitely until being terminated when either: (1) the time elapsed between any two consecutive detections was > 30 minutes; or when (2) a detection was recorded on another receiver.

Individual migration histories were visually examined to count the number of wandering events in the Fraser River. Every change in direction prior to final assignment of fate was classified as a single wandering event. Fish with wandering values of zero exhibited directed movements in the Fraser River, while fish with increasing wandering values exhibited the same corresponding number of changes in direction prior to final assignment of fate. Fate was assigned to individuals as having: (1) successfully entered the Seton River if their last known detection occurred at any receiver upstream of the Seton-Fraser confluence or into the Seton-Anderson watershed; (2) passed the Seton River and migrated further upstream in the Fraser River if their last detection occurred at the Seton-Fraser confluence; (3) exhibited fallback downstream in the mainstem Fraser River if their last detection occurred at the release site receiver; or (4) be of unclassified fate if detections did not conform any of the aforementioned patterns.

Of the 304 Gates Creek sockeye originally released for this study, 90% (274/304) successfully entered the Seton River, 4% (12/ 304) migrated upstream of the Seton-Fraser confluence, 3% (9 of 304) fell back downstream in the Fraser River, and 3% (9/304) had unclassified fates. Of the 213 Portage Creek fish released, 80% (170/ 213) successfully entered the Seton River, 6% (13/ 213) migrated upstream of the Seton-Fraser confluence, 13% (28/213) fell-back downstream, and 1% (2/213) had unclassified fates. Fish that fell back downstream after release and did not re-enter the study area may have suffered from some form of experiment-induced stress. However, given that this occurred in a relatively small component of released fish, and 93% and 86% of Gates Creek and Portage Creek sockeye, respectively, reached the Seton River, the handling and transport approaches were unlikely to have significantly affected the behaviour and short-term survival of fish.

2.4.5.2 Statistical Analysis of Observation Data

Both generalized linear (GLM) and linear models (LM) were used to relate migration behaviour to characteristics of individual migrants and the environmental conditions they encountered. The analyses included three specific models to examine different response variables: (1) the number of forays made into the powerhouse tailrace (Poisson or negative binomial GLM), (2) the number of wandering events between the powerhouse tailrace and Seton-Fraser confluence (Poisson or negative binomial GLM), and

(3) the total amount of migration delay incurred at the powerhouse tailrace (LM). All analyses were conducted on each of the Gates Creek and Portage Creek sockeye populations independently given the different run-timing and environmental conditions experienced by the two populations.

2.4.5.3 Model Construction

All global models included explanatory variables to account for effects of sex, physiological state (blood plasma glucose and lactate levels), and the maturity level (blood plasma testosterone level) of individuals at the time of tagging. Preliminary analyses included interactions between sex and testosterone to test for the differences in reproductive behaviour this hormone can have between males and females (Truscott et al. 1986; Ueda 2011). However, no significant effects were observed, so this interaction was removed from the models reported on below. Additionally, each model included variables to account for the effects of environmental conditions on different migrant behaviours, including: temperatures encountered in the Fraser River and in the Generating Station tailrace, the temperature differential between these two locations as a measure of thermal refuge potential, and the natal water concentration of the Seton River plume. Neither Fraser River nor Seton River discharge were included in any of the models because Gates Creek and Portage Creek sockeye migrate up-river when flows are lowest in the migration season and at levels unlikely to affect behaviour (Rand et al. 2006; Macdonald et al. 2007). Moreover, water temperature and discharge were highly correlated ($r = 0.89$).

Seton Generation Station discharge for each foray to the tailrace was calculated similar to other environmental variables. Discharge for each foray was calculated using a weighted average based on the amount of time each fish was in the Generating Station tailrace. Seton Generating Station discharge was also not included in any analyses because all fish experienced consistent discharge of ~87.3 $m^3 \cdot s^{-1}$ in the tailrace. The consistent nature of the weighted average of discharge per foray also occurred during nightly shutdowns in 2013, and there were no records of fish in the Seton Generating Station tailrace during shutdowns, possibly due to a lack of attraction flows. Because there was such little variation in the Seton Generating Station discharge parameters, it was not included as a co-variate in analyses.

Three different models (in addition to those listed Section 2.4.5.2) were used to test methods of calculating weighted averages for environmental variables. Calculations of environmental variables were based on residence events and dependent on each model response. In the model for the number of forays, environmental conditions at the time a fish entered the tailrace were averaged for all forays an individual made. In the first model, measurements were used from the time of an individual's first detection of every foray into the Generating Station tailrace to represent what conditions were like during movement into the tailrace. In the second model, means were weighted based on the duration of residence events that occurred when individuals changed migration direction between the Seton Generating Station tailrace and the Seton-Fraser confluence. In the third model, means were weighted by the duration of each foray into the Seton Generating Station. Because each of the models included explanatory variables that were measured on different scales (e.g. °C, %), and to facilitate comparisons of the relative effect size of each, all the data for these variables were standardized by centering (subtracting the mean) and dividing by two standard deviations (Gelman 2008; Schielzeth 2010).

Data exploration protocols were applied to each model separately (described in Zuur et al. 2010). Examinations of Cleveland dotplots were used to identify outliers and variables with inordinate values to most of observations were removed (1 – 4 observations per model). Pearson correlation coefficients >0.7 and variance inflation factors (VIF) > 3 were used as thresholds to identify collinear variables. In models for the number of forays and total migration delay for Portage Creek sockeye, the Fraser River temperature variable was highly collinear with the natal water concentration variable. To account for this, tagging date was substituted for Fraser River temperature because the two were related ($r = -0.68$). However, Fraser River temperature was not collinear with the natal water concentration variable (VIF < 3). All models were constructed based on a sample size of at least ten observations per explanatory variable.

The first and second models were initially fit with a Poisson GLM and assessed for over-dispersion by summing the square of the Pearson residuals and dividing by the degrees of freedom (McCullagh and Nelder 1989). Because the dispersion parameter was > 1, models were subsequently re-fit with a negative binomial error distribution (O'Hara and Kotze 2010). All GLMs fit the data adequately as assessed by a Chi-square test ($P > 0.05$; Smyth 2003). In the third model, the response variables were log-transformed to satisfy assumptions of linearity and homogeneity of residual variance (both assessed visually); linear model fits were evaluated using adjusted-R^2.

2.4.5.4 Model selection and multi-model averaging

In each analysis, models with all possible subsets of explanatory variables were fit to the data. Models were then ranked using the bias-corrected Akaike Information Criterion (AIC_C) and compared using AIC_C weights (w_i), which describes the probability of a model in a candidate set being the most parsimonious, given the data (Burnham and Anderson 2003). Uncertainty in model selection was accounted for by calculating model-averaged estimates of the coefficients using the 'zero' method (Grueber et al. 2011), where variables not included in the models were assigned coefficient values of 0 to indicate no effect. Only models included in the 95% confidence set were used for model averaging (Burnham and Anderson 2003), and only explanatory variables with 95% confidence intervals that did not include zero were considered to have an important effect on the response.

2.4.6 Migration Behaviour Under Experimental Dilution Levels

Whole-system studies of the effect of dilution of natal water in the Seton River with water from Cayoosh creek supplemented water preference experiments and telemetry studies. Field telemetry studies completed in 2013 and 2014 observed the migratory behaviour of Gates and Portage Creek sockeye under managed dilution levels (Section 2.4.5). In both years, the studies were unable to compare sockeye migration during high dilution levels to migration during low dilution levels. High dilution levels either coincided with near-lethal temperatures for sockeye (such as in 2013) or simply did not occur during the migration period (such as in 2014). In 2015, an experimental approach was taken to ensure dilution levels exceeding the target dilution for the Gates Creek run could be compared to dilution levels below the target.

Experimental manipulation of dilution levels was achieved by modifying operations of the Walden North dam on Cayoosh Creek. To create dilution levels that exceeded the 20% target, stop-logs were installed at the Seton Lake diversion tunnel from 07 August to 14 August 2015. This prevented the diversion of Cayoosh Creek discharge from Walden North into Seton Lake. Instead, water in Cayoosh Creek flowed to the Seton River confluence, where it diluted the Seton River to approximately 30%. To attain a dilution level below the target, some of the water in Cayoosh Creek was diverted into Seton Lake, thereby reducing the amount of water flowing into the Seton River and creating a dilution level of ~8%. This reflects the operations currently being employed during most of the salmon migration. The low dilution levels occurred from 18 August to 30 August 2015. A major rainfall event near the end of the experiment caused dilution levels to increase up to 20% from 30 August to 01 September 2015. Fraser River temperature and discharge generally decreased over the duration of the experiment, ranging from 14.0 – 19.4 °C (mean = 17.7 ± 1.6 °C), and 1101 – 1909 $m^3 \cdot s^{-1}$ (mean = 1475 ± 251 $m^3 \cdot s^{-1}$), respectively. During data exploration, Fraser River discharge was identified as collinear with date and Fraser River temperature and was therefore excluded from analyses.

Gates Creek sockeye were captured at the fish fence and tagged with radio and PIT tags following the procedures described in Section 2.3. During the period of high dilution levels from 07 August to 14 August 2015, 76 fish were captured and tagged. During the period of low dilution levels from 18 August to 30 August 2015, 129 fish were captured and tagged. They were released on the west bank of the Fraser River, approximately 1 km downstream of the Seton Generating Station, following the release procedure described in Section 2.3.

Radio telemetry detection data confirmed that all sockeye (n = 76) released during high dilution levels entered the Seton River under high dilution conditions, and therefore did not experience low dilution conditions. However, radio telemetry detection data revealed several fish released immediately prior to the high dilution level treatment (n = 6) and prior to a heavy rainfall event (n = 12) experienced multiple levels of dilution. Because our objective was to test for effects of the dilution manipulation experiment itself, these fish were excluded from summary statistics and statistical models when making direct comparisons between diluted and regular flows (i.e., n = 187 for models testing effects of diluted flows on river entry success and on delay at the Seton Generating Station). However, full sample sizes (n = 205) were used for summary statistics when direct comparisons between diluted and regular flows were not examined (e.g. overall river entry success). A subset of fish was also used for Cox mixed-effects survival models (n = 192). Conditioning these models by individuals and following each fish over time accounted for multiple levels of natal water conditions over the experiment.

2.4.6.1 Statistical Analysis of Dilution Experiment

During the whole-system experiment of high and low dilution levels, radio telemetry was used to assess: 1) movements of fish from the downstream release site into the Seton River using logistic regression (Seton River Entry); 2) the time it took to travel between the release site and dam using time-to-event analysis (Entry Delay); and 3) the length of time fish delayed at the Seton Generating Station using an analysis of covariance (Generating Station delay). The nature of this whole-system experiment meant that it was impossible to isolate the effect of run-timing (e.g. temporal correlations such as reproductive maturity of individual fish that arrive at the study area across time) from the dilution treatment, and thus, all models were structured as mixed effects models and included release date (hereafter, date-of-release) as a random effect, or blocking effect, to account for temporal correlations associated with run-timing.

All models were fit with similar explanatory variables. In addition to dilution, all models included explanatory variables for sex of the fish and scaled variables for Fraser River temperature and individual fish gross somatic energy because these variables have been previously identified as important variables influencing behaviours of homing sockeye (Crossin et al. 2008; Jefferies et al. 2012; Martins et al. 2012).

The first logistic regression analysis used Generalized Linear Mixed Models (GLMMs) with binomially distributed errors [R package: “lme4” (Bates et al 2015)] to compare Seton River entry success (1 = detected in Seton River, 0 = not detected in Seton River) for sockeye released under high and low dilution (categorical explanatory variable). A full model was fit including scaled variables for temperature and gross somatic energy as co-variates. An additional model that included only significant covariates was fitted to predict the effect of dilution on Seton River entry success.

The second time-to-event analysis used a Cox Proportional Hazard Mixed Model [R package: “coxme” (Therneau 2015)] to examine the influence of Seton River dilution on the likelihood of sockeye entering the Seton River at any given time interval. Cox Proportional Hazard Models permit “censoring” of individuals that failed to enter the Seton River and allow for incorporation of time-varying explanatory variables that account for fish experiencing multiple levels of environmental conditions that fluctuate during migration (Castro-Santos & Haro 2003; Kleinbaum & Klein 2012). This approach took advantage of the full data set including fish that did not enter the Seton River.

Time-varying explanatory variables in the time-to-event analysis included scaled variables for dilution and Fraser River temperature. To create a data set of time-varying variables, hourly measures of environmental conditions were paired with individual fish detection histories. Fish identity was also included as a random effect (in addition to date-of-release) to account for repeated measures on individual fish. The number of hours from release to sunset was also included as an additional explanatory variable to test for diel effects (i.e., to test if fish released later in the day delay migration overnight). All other explanatory variables, interaction terms, and random effects were as described above. Kaplan-Meier curves were used to visually examine differences in time to entering the Seton River between treatments and to estimate time differences between groups of fish.

A final analysis of covariance (ANCOVA) analysis was used to examine the relationship between time fish spent at the Seton Generating Station. Because the longer a fish spends at the Seton Generating Station is directly proportional to the time it takes for a fish to travel from their release site following tagging to the confluence of the Seton and Fraser Rivers (migration time) we developed GLMMs that were based on basic correlation between migration time and time at the generating station. A scaled variable of gross somatic energy was included as a co-variate and date-of-release was include as a random effect to account of the influence of run timing, as with other models. Two interactions were tested specifically to demonstrate the relationships between time fish spent at the generating station and migration time. The first interaction was between dilution and time spent at the generating station. This interaction will show whether dilution influences time at the generating station. The second interaction is that between sex of the fish and dilution, this interaction will demonstrate if there are sex specific differences in the time spent at the generating station with and without dilution. Because these interactions were significant the main effects of these models, time at the generating station, we separated the original data set into subsets based on dilution and sex to look for the significance of time at the generating station and migration time.

Prior to analysis, data exploration (e.g., examining collinearity, outliers, normality, interactions) and specification of random effects followed protocols presented in Zuur et al. (2010) and Zuur et al. (2009), respectively. All data exploration and analyses were performed in R. Studio running R v. 3.3.0 (R Core Team 2017) and the "tidyverse" package (Wickham 2017). A Pearson Correlation coefficient > 0.6 and variance inflation factor score > 3.0 indicated Fraser River discharge was collinear with release date and Fraser River temperature and was therefore excluded from all models. The significance of interaction terms was tested during initial model fitting, and non-significant interactions were excluded from final models. Significant interaction terms were explored further using model subsets that only included significant explanatory variables from the full model.

2.5 Seton Dam Operations and Fish Passage

Management Questions

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

3a) What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

To address the third objective (To identify operating strategies that will mitigate impacts to upstream migration), two management questions were asked: 1) can dam operations be modified to improve passage, and 2) do dam operations influence post-passage survival to spawning grounds. First, the attraction and passage efficiencies of the Seton Dam under routine operating conditions were analyzed (Section 2.8.4). Although attraction and passage efficiencies were high, telemetry in 2013 (Minke-Martin et al 2018, Burnett et al 2014a) indicated potential post-passage fitness consequences due to the large amounts of energy required to navigate through the dam tailrace to the fishway entrance. Subsequently, the effects of an alternate water release pattern on attraction, passage, and post-passage survival was examined in replicate studies in 2014 and 2016 (Section 2.8.5). Data spanning 2012-2016 were also compared to provide a summary of passage rates at the Seton Dam (Section 2.8.4).

2.5.1 Dam Passage Under Routine Operating Conditions

Following preliminary radio telemetry work at the dam in 2012, passage at the Seton Dam was monitored in Gates Creek sockeye in 2013 using acoustic tags (n = 68), radio tags (n = 205) and PIT-tags (n = 324). Passage of Portage Creek sockeye was examined using radio tags (n = 24) and PIT tags (n = 14) in 2013, as well as acoustic tags (n = 10), radio tags (n = 191) and PIT tags (n = 434) in 2014. In 2014, passage of Gates Creek sockeye was tracked during experimental manipulation to the water release operations at the dam (Section 2.8.1). Passage of pink salmon was also monitored using radio tags (n = 58) and PIT tags (n = 280) in 2013. The fish capture, tagging, and sampling procedures are described in Section 2.3. From 07 August to 14 August 2013 Gates Creek sockeye were captured via dipnet from the Seton Dam fishway, and from 15 August to 02 September 2013 they were captured at the Seton fish fence. Portage Creek sockeye were captured from the fish fence from 17 September to 09 October 2013 and from 26 September to 15 October 2014. Pink salmon were captured from the fish fence from 20 August to 21 September 2013. The telemetry arrays used to collect information from the tagged fish are described in Section 2.3. During this study of dam passage, water was released through the fish water release gate and siphon 1 which is the normal operational procedure for discharge from the Seton Dam during the Gates Creek sockeye migration (Figure 1.3).

Fishway attraction efficiency (number of fishes that located and entered the fishway divided by the total number of fishes that reached the dam tailrace post-release) and passage efficiency (number of fish that passed the fishway divided by the number of fish that located and entered the structure) were determined using a combination of acoustic-, radio- and PIT-telemetry data (Table 2.1). In addition, the total amount of time each fish spent in the tailrace prior to passage or falling back (entrance delay) was quantified for acoustic- and radio-tagged fish. The number of times each fish crossed the tailrace from the radial gate spillway to the fishway entrance (tailrace crossings) was also quantified for acoustic-tagged fish (this fine scale behaviour could not be estimated using radio telemetry).

Table 2.1 Metrics used to assess Seton Dam fish passage and the calculations used according to tag type

Metric	Tag Type	Calculation
Attraction Efficiency	Radio Acoustic	$\frac{\text{Number of fish detected at the Seton Dam fishway entrance}}{\text{Number of fish detected in the Seton Dam tailrace}}$
	PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway entrance}}{\text{Number of fish released into the Seton Dam tailrace}}$
Entrance Delay or Tailrace Delay	Radio Acoustic	$\left(\begin{array}{c}\text{Time of first detection at}\\ \text{Seton Dam fishway entrance}\end{array}\right) - \left(\begin{array}{c}\text{Time of first detection in}\\ \text{Seton Dam tailrace}\end{array}\right)$
	PIT	$\left(\begin{array}{c}\text{Time of first detection at}\\ \text{Seton Dam fishway entrance}\end{array}\right) - \left(\begin{array}{c}\text{Time of release into}\\ \text{Seton Dam tailrace}\end{array}\right)$
Passage Efficiency	Radio Acoustic PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish detected at the Seton Dam fishway entrance}}$
Overall Success	Radio Acoustic	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish detected in the Seton Dam tailrace}}$
	PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish released into the Seton Dam tailrace}}$

2.5.2 Acoustic Tag Statistical Analysis

Acoustic tags allowed for measurement of swimming activity in the acoustic-tagged fish. Acoustic accelerometer transmitters measure acceleration in three axes (range: 0 – 4.901 $m \cdot s^{-2}$) for 10 s at a sampling frequency of 10 Hz. Acceleration data are then averaged for that 10 s period [root mean square (RMS) acceleration = $\sqrt{X^2 + Y^2 + Z^2}$] and transmitted every 13 – 17 s to receivers. RMS acceleration data were converted to swimming speed in units of body lengths per second (BL s^{-1}) following the calibrations of Wilson et al. (2013). Acceleration data were further converted to estimates of oxygen consumption (MO_2, mg O_2 kg^{-1} min^{-1}) for Fraser River 'early Summer-run' sockeye (intermediate difficulty category; Wilson et al., 2014) using corresponding hourly Seton River temperatures in the following equation:

$$\boldsymbol{MO_2 = [2.81 + (0.89 \cdot A) + (0.05 \cdot T) - (0.03 \cdot L) + 1.21 - (0.32 \cdot A)]^2} \quad \text{Equation 2}$$

where A is RMS acceleration, T is water temperature and L is fork length. The degree to which anaerobic metabolism contributed to swimming in the dam tailrace ('anaerobic recruitment') was calculated for acoustic-tagged fish. To do this, we divided the amount of oxygen consumed after anaerobic swimming efforts (i.e., EPOC; see Lee et al. 2003a) by the total amount of oxygen consumed because of aerobic and anaerobic contributions to swimming. Anaerobic recruitment is expressed as a percentage, where higher values reflect the greater EPOC required to restore tissue and cellular oxygen levels and re-establish metabolic homeostasis following anaerobic muscle recruitment. Acceleration data collected from four acoustic receivers on the northern bank of the Seton River adjacent to and in the radial gate spillway were pooled and represent the swimming speeds from the "radial gate spillway" habitat (ca. 300 m^2; low flow area). Data from seven acoustic receivers along the outer fishway wall and the receiver in the first pool of the fishway were combined and represent the swimming speed of sockeye in high flows surrounding the fishway entrance (ca. 400 m^2). Within-fishway swimming speeds were pooled from four acoustic receivers positioned in the fishway.

Generalized linear models (GLMs) were used to predict dam passage (family: binomial, link: logit), anaerobic recruitment (family: Gaussian, link: identity), and tailrace crossings (family: Poisson, link: log) by Gates Creek sockeye. A final GLM was used to predict the ability of migrants who successfully passed Seton Dam to reach spawning grounds in Gates Creek (family: binomial, link: logit). Seven explanatory variables (biotic and abiotic) were included in each of the four model sets unless that variable was in fact the response variable. Biotic explanatory variables included: (1) sex (male [1], female [0]), (2) anaerobic recruitment (%), (3) tailrace delay (h), and (4) tailrace crossings. Abiotic explanatory variables included (5) the maximum Seton River temperature (°C) and (6) mean flows ($m^3 \cdot s^{-1}$) from siphon 1 each individual fish experienced while present in the dam tailrace. Cooke and Hinch (2013) reason that capture location (i.e., use of fishway-naive and fishway-non-naive fish) affects the ability of migrants to locate, enter, and ascend a fishway.

Capture location (7; fence caught [1] or fishway caught [0]) was included as a fixed factor in all models to account for its effects when testing our main hypothesis. However, the relative effect of capture location is presented on all response variables to show the importance of considering capture location when conducting and interpreting the results of fish passage studies (Cooke and Hinch 2013). All variables were tested for multicollinearity using variance inflation factors (VIFs); flows from the fish water release gate were collinear (VIF > 3) with the maximum Seton River water temperature fish experienced (Zuur et al. 2010). Consequently, the fish water release gate was removed as an explanatory variable, as the discharge from siphon 1 provided much of encountered flows below the dam during the study period. Attraction efficiency was not modeled because only one individual failed to pass the fishway after locating and entering the structure (i.e., 98% passage efficiency); therefore, results would be nearly identical to those of the dam passage model. Tailrace crossings was not included as an explanatory variable in the dam passage model, as it was highly collinear with both attraction and passage efficiency. Individuals that failed to reach the tailrace post-release were omitted from the models.

All candidate models were generated using the R (ver. 3.0.2; R Development Core Team 2012) package "MuMIn" (Barton 2012) and compared using AICc to determine the most parsimonious models. Models were further analyzed using AICc weights (w_i), which describe the relative weighting of each candidate model based on the amount of information lost (Wagenmakers and Farrell 2004). Average parameter estimates were calculated using the natural average method (Grueber et al. 2011) and a 95% confidence set (Burnham and Anderson 2002). All data were standardized by centering (subtracting the mean) and dividing by 2 SD (Gelman 2008), allowing for the direct comparison of the relative effect sizes of explanatory variables. Model-averaged standardized coefficients for binary explanatory variables were exponentiated to provide an interpretable odds ratio. Model fits were evaluated using the percentage and significance of deviance explained by a GLM (Kindt and Coe 2005). A one-way ANOVA and Tukey post hoc tests were used to compare the swimming speeds of male and female Gates Creek sockeye. Residuals were examined for homoscedasticity, normality, and independence. Data are presented as mean ± SE, and statistical analyses were considered significant at $\alpha = 0.05$.

2.6 Assessment of Injuries in Relation to Generating Station Operations

Past research in the Seton-Anderson system noted the occurrence of head injuries on some individuals (Fretwell 1989). Repeated attempts by fish holding in the tailrace of the Seton Generating Station to enter the generating station was identified as a potential contributor to these injuries. To determine if fish were injuring themselves at the generating station or if fish were arriving to the Seton system with injuries incurred downstream, injuries on each captured fish were recorded and classified.

The mechanism of injury, whether incurred at the generating station or elsewhere, could present different impacts to migrating fish. In addition to acting as a potential entryway for infectious disease, damage to the snout region of a salmon could disrupt olfactory capabilities, and potentially weaken their ability to detect chemical directional cues. Other injuries can also cause physiological impairment that can reduce migratory survival or spawning success. To determine whether such injuries occur in a significant proportion of the salmon migrating through the system, an injury assessment of salmon captured at the fish fence was conducted in 2014-2016.

A base level of injury assessment was applied to all tagged fish from 2013 through 2016, as well as all deceased salmon collected from the Seton River fish fence, to assess the severity and origin of any injuries. Injuring monitoring protocols in 2013 were preliminary, and were updated in 2014; therefore, only 2014-

2016 injury monitoring data is presented. If injuries were present, the severity was qualitatively assessed as either minor (would not be expected to impair migration), moderate (could be expected to impair migration), or severe (expected to impair migration). The origin of the injury was also estimated for all fish. Finally, a photograph was taken of the tagged fish to document injuries. Radio-tagged fish received a more-detailed injury assessment with additional categories to record the extent of injuries (Table 2.2).

Table 2.2 Injury monitoring protocol performed on radio-tagged fish

Injured	Severity	Injuries Assessed	Injury Origin
Yes / No	Minor Moderate Severe	- Scale loss (%), fungus cover (%), sea lice (%) - Wound Depth (1: Scales missing, skin visible; 2: Skin missing, muscle visible; 3: Muscle missing; 4: Organs, bones, cartilage visible) - Injured eyes (0/1/2) - Number of fins injured (0-7) - Fin injury type (exposed rays, split fin, portion missing, necrotic tissue, peripheral erosion, other) - Vent (normal/inflamed) - Old wound (presence/absence)	Gillnet Sea Lice Hook Wound Predator Lamprey Unknown Other

2.7 Effects of Dilution on Pink, Coho and Chinook Salmon

Management Question:

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

In addition to the two populations of sockeye, there are pink, Chinook and coho salmon that spawn in the Seton-Anderson system. Whereas sockeye consistently return in relatively large numbers, the other species do not. Pink salmon spawn in the Fraser River system on odd-numbered years only, while Chinook and coho salmon populations in the Seton-Anderson system are substantially smaller than that of sockeye. The behavioural responses of pink salmon to diluted Seton River water were tested (Section 2.7.1) using the same stream-side experimental set-up as the Gates and Portage Creek sockeye tests (Section 2.4.1). Pink salmon were also released in 2013 into the Fraser River and tracked through the Seton-Anderson system (Section 2.7.2), following the same protocols used for sockeye (Section 2.4.5). Due to low numbers of captured Chinook and coho salmon, a literature survey was conducted to assess the potential influence of operations on these species (Section 2.5.3).

2.7.1 Water Preference Behavioural Tests on Pink Salmon

The behavioural responses of pink salmon to diluted Seton River water were analysed using the same experimental method described in Section 2.4.1. Pink salmon were collected from 9-23 September 2013 (n = 163) via dipnet from the top pool of the Seton Dam fishway and from the Seton River fish fence. As population identity in the Fraser River system is less defined in pink salmon than other Pacific salmon species (Beacham et al. 1985), individuals were not screened using the Fatmeter to identify and remove potential strays. The holding and experimental methods used for pink salmon were nearly identical to those described in Section 2.4.1, aside from the dilution levels that were tested.

2.7.2 Observed Movements of Pink Salmon Under Current Operational Dilution Levels

In addition to water preference experiments on pink salmon, behaviours were also examined and compared to the more detailed work on Gates Creek and Portage Creek sockeye. The movements of pink salmon were assessed using both radio telemetry and PIT tag receivers to determine if movements of pink salmon were similar to the more extensive work completed on Sockeye. Pink salmon were tagged along with sockeye (see Section 2.3). Pinks were captured at the fence near Seton Dam and outfitted with either radio-tags or PIT tags. Radio-tagged fish were released downstream in the Fraser River and PIT tagged fish were released at the site of capture at the fence. Radio-tagged fish were detected using the same telemetry array and methods described in Section 2.3 and Section 2.4.2, PIT fish were detected using the arrays located in the Seton Dam fishway and Gates Creek spawning channel.

Pink salmon migration behaviour was quantified by: (1) establishing the number of forays individuals made into the Seton Generating Station tailrace as a measure of attraction to this facility; (2) summing the duration of each foray into the Generating Station tailrace as an estimate of the total amount of migration delay incurred by individuals at this facility. Foray and duration metrics were calculated based only on detections that were part of 'residence events'. Residence events for a given fish were defined as a series of consecutive detections at a given receiver separated by no more than 30 minutes. The duration of a residence event could continue indefinitely until being terminated when (1) the time elapsed between any two consecutive detections was > 30 minutes, or when (2) a detection occurred at another receiver site.

2.7.3 Expected Influence of Dilution on Chinook and Coho Salmon

The numbers of Chinook and coho salmon encountered at the Seton River capture site were low. No Chinook salmon were captured and tagged, and only a small number of coho salmon were tagged and released in the Fraser River. To address H_{O6} and H_{O7}, a literature survey was conducted to compare the responsiveness of coho and Chinook salmon to natal odours with that of sockeye. Using this information, the effectiveness of current dilution targets for Gates Creek and Portage Creek sockeye salmon in mitigating delays to coho and Chinook salmon could be assessed through comparison to the findings for sockeye.

To locate published research on coho, Chinook and sockeye, ISI *Web of Knowledge* and *Aquatic Sciences and Fisheries Abstracts* were searched to identify studies that related olfaction to migration in salmon.

The following topic search terms were used: 'olfact*' AND (homing OR migrat* OR selection OR spawn* OR navigat*) AND (salmon* OR oncorhynchus). The search was supplemented by inclusion of studies that did not appear in the search results but were cited in the collected papers. Papers that focused on physiological or behavioural responses to natal water odours were interpreted, and the olfactory abilities and sensitivities of these species to natal odours were contrasted.

2.8 Alternative Seton Dam Operations

2.8.1 Implementation of Alternate Flow Scenario

An alternative flow scenario at Seton Dam was implemented once in 2014 and twice in 2016. The alternative flow scenario was tested during the Gates Creek sockeye migration period in both years due to the abundance of fish in this run, the higher Seton Dam discharges permitted under the Bridge River Water Use Plan during August (BC Hydro 2011), and the ease of detecting PIT-tagged fish that reached spawning grounds at Gates Creek. In 2014, the alternative flow occurred between 08 August and 19 August 2014. Prior to 08 August 2014, BC Hydro operated Seton Dam according to routine operating procedures with the fish water release gate and Siphon 1 used to discharge water. On 08 August 2014, discharge from the fish water release gate was reduced from 7.6 $m^3 \cdot s^{-1}$ to 1.9 $m^3 \cdot s^{-1}$ and the siphon discharge changed from Siphon 1 to Siphon 4. The change in the siphon from Siphon 1 to Siphon 4 resulted in a corresponding increase in siphon discharge from 21 $m^3 \cdot s^{-1}$ to 25 $m^3 \cdot s^{-1}$ (Figure 2.9). During a scheduled ramp-down on 19 August 2014, BC Hydro returned Seton Dam to routine operating conditions by increasing fish water release gate flows to 2.5 $m^3 \cdot s^{-1}$ and reverting siphon discharge from Siphon 4 to Siphon 1.

Following the results obtained in 2014, a replicate study was requested by BC Hydro for 2016. Although the 2014 study generated some clear findings, there were some limitations of this work. Notably, the alternative condition was only tested once during the early portion of the Gates Creek sockeye migration period and few fish were tagged and released. As a result, it is difficult to determine with certainty whether the differential results under the two conditions were due to flow patterns or to behavioural changes relating to migration timing (slower migration rates have been observed in fish migrating to Seton Dam earlier in August). Furthermore, before modifications to BC Hydro operations are considered, potential benefits to the alternative flow condition need to be confirmed. Thus, in 2016 a second water release trial was performed where two periods of alternative flows where water was released from Siphon 4 were interspersed with the routine water release from Siphon 1. Gates Creek sockeye were PIT-tagged and followed from release just downstream of the Seton Dam to the Gates Creek spawning channel. This second trial was used to confirm 2014 mechanistic results and allow the isolation of run timing effects from dam operations.

In 2016, matching changes to conveyance structures were made, except the change from routine to alternative flows occurred twice from 11 August to 18 August 2016 and again from 25 August 2016 to 01 September 2016. Routine flows occurred before, between, and after the two alternative flow scenarios in 2016.

2.8.2 Fish Tagging and Monitoring

To determine the effect of routine and alternative operations on passage and post-passage survival, Gates Creek sockeye were captured and tagged with acoustic and PIT tags in 2014, and radio tags and PIT tags in 2016. Capture and tagging followed the procedures in Section 2.3.

In 2014, acoustic tags were used to assess Gates Creek sockeye dam passage under the routine and alternative flow scenarios. In 2014, 45 acoustic-tagged fish were released during alternative conditions. An additional 592 sockeye were tagged with PIT tags in 2014 to supplement the dam passage and post-passage survival data (i.e., survival from the top of the fishway to Gates Spawning channel) from the acoustic-tagged fish. Releases in 2014, occurred during the routine flow conditions from 04 August to 07 August 2014 and 27 August to 04 September 2014, and during alternative flow conditions from 10 August to 13 August 2014.

In 2016, a total of 113 radio-tagged fish (67 male, 46 female) and 550 PIT-tagged fish (294 female, 256 male) were released and monitored. Unlike the PIT-tagged and acoustic-tagged fish, which were released above the fence, radio-tagged fish in 2016 were released in the Fraser River, as these fish were also used to assess the dilution issue. In 2016, fish were released during routine flows from 07 August to 10 August and 19 August and 24 August 2016. During alternative flows fish were released on 13 August to 17 August and 26 August and 31 August 2016. There were only PIT tagged fish released during alternative flows. Radio-tagged fish were used to determine estimates of dam passage during routine flows, while PIT-tagged fish were used to assess timing and survival difference between routine and alternate flows.

Figure 2.9 **Flow fields in the Seton Dam tailrace during routine and alternative BC Hydro operations.**

For the 2014 study, fork length was measured, which could be used in conjunction with acoustic accelerometer data to measure swim speed in the dam tailrace and forebay (Wilson et al. 2013). Seton River water temperatures were recorded as described in Section 2.3 and were used for the 2014 swimming speed and oxygen consumption analyses.

Tagged fish were tracked using the acoustic, radio, and PIT telemetry arrays described in Section 2.3 with sample sizes outlined in Table 2.3. For the 2014 study, the total amount of time (in h) acoustic-tagged fish spent in the dam tailrace (0 – 60 m downstream of dam face) before eventual passage or fallback was quantified, as passage time can strongly influence dam passage (Burnett et al., 2014b) and survival to spawning grounds (Caudill et al., 2007). A ratio between the amount of time acoustic-tagged fish spent near the fishway entrance and in the radial gate spillway (30 m away from fishway entrance) was developed to determine if fish spent a disproportionate amount of time in one area of the dam tailrace. Using acoustic-telemetry data, the number of times acoustic-tagged sockeye crossed the tailrace from the radial gate spillway to the fishway entrance (hereafter, tailrace crossings) was quantified. Tailrace crossings have previously been linked to passage success at Seton Dam (Burnett et al., 2014a, 2014b). Finally, the total amount of time (in hours) acoustic-tagged fish spent in the dam forebay following dam passage was quantified using a single acoustic receiver.

Table 2.3 Summary of 2013-2016 annual releases of tagged Gates Creek sockeye, Portage Creek sockeye, pink salmon, and coho for all tag types.

Stock	Tag Type / Release Site	2013	2014	2015	2016
Gates Creek sockeye	Acoustic (Seton Fence)	60[a]	45	-	-
	PIT (Seton Fence)	300	565	457	433
	Radio (Fraser River)	168[b]	166	206	133
	PIT (Fraser River)	-	191	197	102
Portage Creek sockeye	Acoustic (Seton Fence)	-	10	-	-
	PIT (Seton Fence)	14	-	-	-
	Radio (Fraser River)	24[c]	191	-	-
	PIT (Fraser River)	-	193	-	-
Pink salmon	PIT (Seton Fence)	280	-	-	-
	Radio (Fraser River)	58[d]	-	-	-
Coho Salmon	PIT (Seton Fence)	30	2	-	-
	Radio (Fraser River)	1	7	-	-

[a]2013 acoustic releases were a combination of upper (n = 30) and lower (n = 30) Seton River releases. [b]2013 releases of Gates Creek sockeye occurred at the Fraser River west (n = 81) and east site (n = 87). [c]Portage Creek sockeye were released at Fraser River west (n = 12) and east (n = 12) sites. [d]Pink salmon were released at the Fraser River west (n = 30) and east (n = 28) sites.

As in Section 2.5.1, acoustic accelerometers were used to estimate oxygen consumption using Equation 2. Again, anaerobic recruitment is expressed as a percentage, where higher values reflect the greater EPOC required to restore tissue and cellular oxygen levels and re-establish metabolic homeostasis following burst swimming.

2.8.3 Effects of Alternative Flow Scenario on Passage and Post-Passage Survival

The effects of the alternative flow scenario on passage and post-passage survival were analyzed in 2014 and 2016. Results of the alternative flow scenario were compared with passage under routine scenarios in the same year. Telemetry was conducted using the same methods as described in 2.5, apart from the addition of radio-tagged fish in 2016 (see 2.8.2). In the same fashion as the research described in 2.5, acoustic tags were used in 2014 to assess swimming speeds and estimate energy use (see Burnett et al. (2017).

2.8.4 Statistical Analyses of Sockeye Passage During Different Dam Operations

Sockeye passage of Seton Dam and their survival to spawning grounds at Gates Creek was investigated in two separate studies, one in 2014 and a second in 2016. The original pilot study in 2014 (Burnett et al. 2013, Burnett et al. 2016) focused on identifying and describing the activity, behaviour, passage success, and ultimately spawning success of Gates Creek Sockeye. Portions of that work that are applicable to the management questions are provided here. Key gaps in the 2014 work were addressed in the 2016 study; namely that only a single change in dam operations, where water was released from Siphon 4, was performed and that a larger number of PIT-tagged fish was used to track passage and survival.

In 2014, Welch's two-sample t-tests were used to compare water temperatures and discharges experienced in the Fraser River prior to dam passage by sockeye released under the two flow conditions. Non-parametric tests were used when assumptions of normality and homoscedasticity were not met. Mann–Whitney U-tests were used to compare the swimming speed and behaviour of acoustic-tagged sockeye under the two flow conditions. Monte Carlo simulations were used to generate posterior distributions (95% credible intervals) around the survival estimates (i.e. dam passage, post-passage survival to spawning grounds and survival from release to spawning grounds) of PIT-tagged sockeye. Simulations drew 1000 samples from a binomial beta distribution.

A generalized linear model was used to predict the spawning success (family: binomial, link: logit) of the PIT-tagged females that entered the artificial spawning channel at Gates Creek. The full model included three explanatory variables: (i) flow condition (alternative or baseline), (ii) longevity (in days) and (iii) Julian date of arrival on spawning grounds. All variables were tested for multicollinearity using variance inflation factors; all variables had a variance inflation factor <2 (Zuur et al., 2010).

All candidate models were generated using the R (version 3.0.2; R Core Team, 2013) package 'MuMIn' (Barton, 2012) and compared using AICc (for small sample sizes) to determine the most parsimonious models. Relative effect sizes presented herein are from the top model from the candidate set that was well supported (i.e. AICc weight (w_i) two to three times that of other models). Model fits were evaluated using adjusted-R^2 values. All data are presented as means ± SEM unless otherwise noted. Statistical analyses were considered significant at $p < 0.05$.

In 2016, differences between the time it took Gates Creek sockeye to pass the dam after release during routine and alternate flow scenarios was tested using Cox proportional hazard mixed models [R package: "coxme" (Therneau 2015). Kaplan-Meier curves were used to visually examine differences in Seton Dam passage time between treatments. Fish identity was used as a random effect in proportional hazard models to account for repeated measures on individual fish. Date-of-release (DOR) was included as a random effect to account differences in behaviour associate with run timing. Individual fish gross somatic energy (GSE), and sex were included as covariates in all models examined.

Survival to spawning grounds was assessed using difference between fish that successfully cross the dam and those that made it to the Gates Creek spawning grounds. Survival of Gates Creek sockeye from release to Gates Creek and the spawning grounds was determined using PIT tag detections. Survival of fish from the release site to spawning grounds was calculated using PIT tag readers installed from the release fence to Gates Creek spawning grounds. Fishway passage was assessed using the PIT tag readers at the top and bottom of the fishway.

2.9 Review of Gates Creek Sockeye Passage of Seton Dam Over Multiple Years

Passage of Gates Creek sockeye through Seton Dam was incorporated in the research of several different studies. This includes the analysis of passage during routine dam operations in 2013 (Section 2.8.2), during the alternate water release experiment in 2014 and 2016 (Section 2.8.1), and during the field dilution experiment in 2015. Additionally, dam passage of Gates Creek sockeye was assessed in research that predates this project, during pilot studies in 2012, and during a new research project in 2017. This section provides a summary of passage data to allow for comparison across multiple years. Methods for fish capture, tagging and data collection for 2012-2017 follow those outlined in Section 2.3. Methods for 2005 and 2007 are detailed in Pon et al. (2006) and Roscoe and Hinch (2008), respectively.

3 RESULTS

3.1 Physical Parameters

3.1.1 Seton River Hydrology and Dilution Level

Discharge and the dilution levels in the Seton River during the Gates Creek sockeye migration (20 July to 31 August) varied both within and between years. Increases in discharge (Figure 3.1) and the dilution levels (Figure 3.2) typically resulted from planned operational changes at Walden North, as Seton Dam discharges were maintained within the Bridge River Water Use Plan target hydrograph each year and Cayoosh Creek discharge was low during August. For example, from 07 to 16 August 2013, Walden North maintenance ceased flows into the Seton Lake diversion tunnel, increasing Cayoosh Creek flows by ~10 $m^3 \cdot s^{-1}$ and increasing the lower Seton River dilution level to 27 - 41%. In 2015, a planned experimental dilution levels increase occurred from 07 to 13 August 2015 that diverted Walden North flows into Cayoosh Creek, increasing discharge by ~7 $m^3 \cdot s^{-1}$ and the lower Seton River dilution levels to 28 - 29%. The 2015 increase was temporary and a ramp-down that started 14 August 2015 returned Cayoosh Creek discharge to pre-experiment levels over 4 days such that the dilution level was 9% on 18 August 2015. Outside of these periods, natural fluctuations in discharge and the dilution levels were brief and infrequent, with rain events increasing Cayoosh Creek discharge and the dilution levels at either the start (2013, 2014, 2016) or end (2015) of the Gates Creek sockeye migration period; however, few Gates Creek sockeye were migrating during these periods (see Section 3.3).

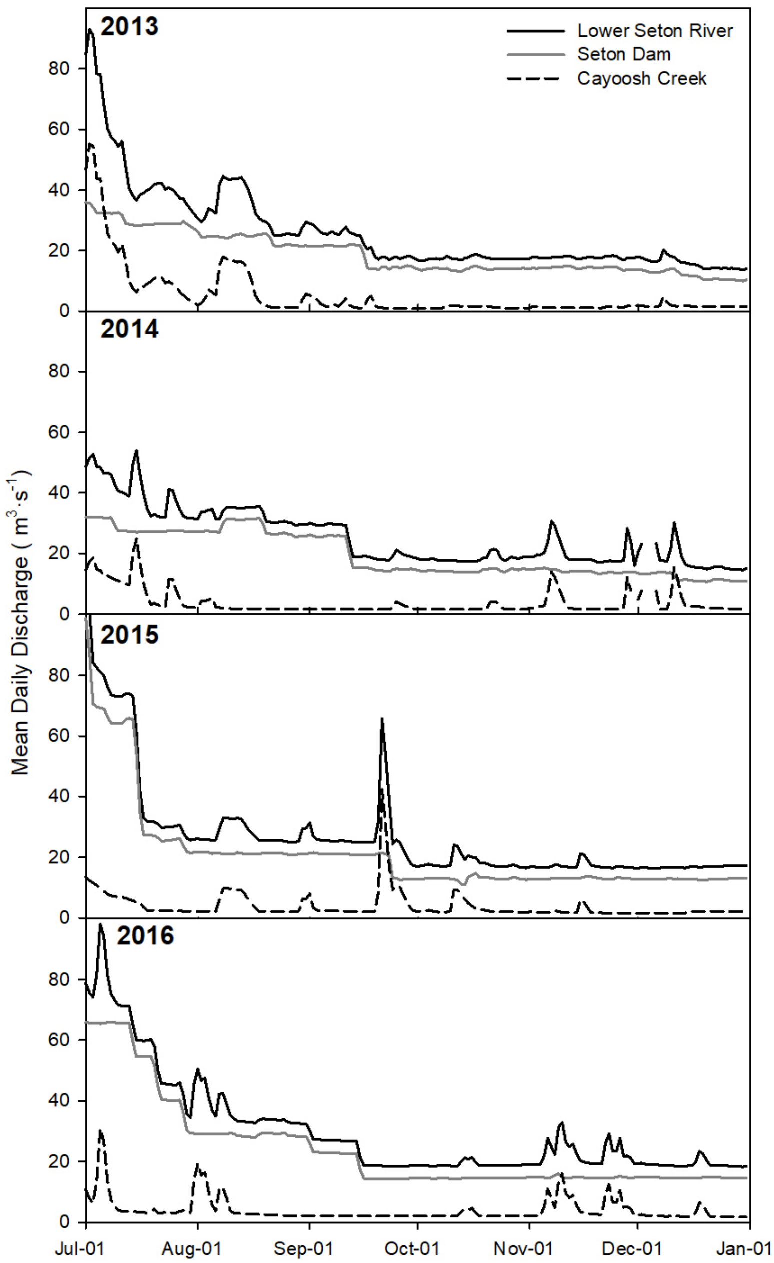

Figure 3.1 **Discharge in 2013 - 2016 for waterways used to calculate the dilution levels in the lower Seton River (BC Hydro data). Spawning channel discharge was constant in 2013 - 2016 and is not shown.**

Decreases in discharge and the dilution level were also observed. In 2014, an experimental flow scenario at Seton Dam increased discharge from 08 to 19 August 2014 by ~4 $m^3 \cdot s^{-1}$, decreasing the dilution level from ~7% to ~5%, the lowest dilution level observed from 2013-2016. Overall, mean lower Seton River discharge during the Gates Greek sockeye migration period was 34.6 $m^3 \cdot s^{-1}$, 33.4 $m^3 \cdot s^{-1}$, 28.1 $m^3 \cdot s^{-1}$, and 31.8 $m^3 \cdot s^{-1}$ in the years 2013 - 2016, respectively.

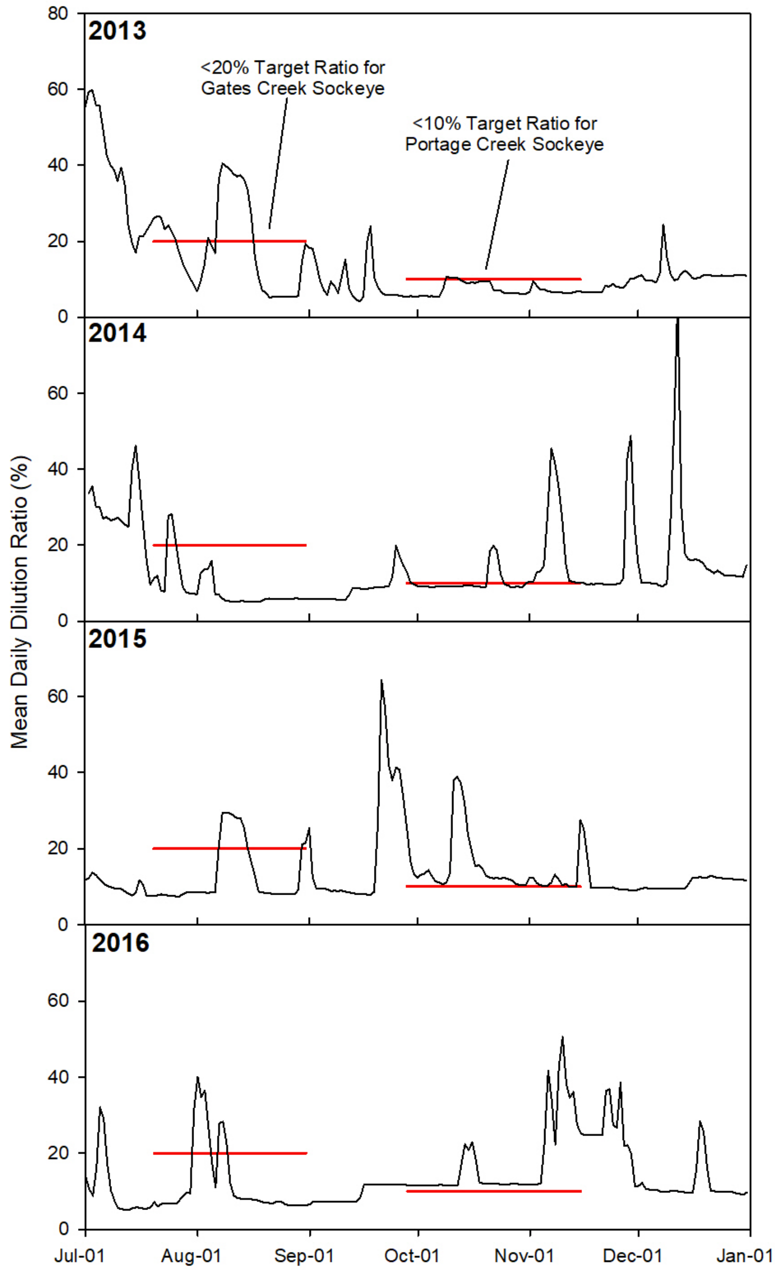

Figure 3.2 **Daily dilution level of the Seton River in 2013 - 2016 (BC Hydro data). Target dilution levels for the Gates Creek (<20%) and Portage Creek (<10%) sockeye migration periods are shown in red (BC Hydro 2011).**

Increases in discharge and the dilution levels during the Portage Creek sockeye migration period (28 September to 15 November) occurred in 2014 and 2016 following rain events. Changes in the dilution level were typically greater during the Portage Creek sockeye migration period relative to the Gates Creek sockeye migration period because Seton Dam discharge was decreased mid-September to <20 $m^3 \cdot s^{-1}$ following the Bridge River Water Use Plan target hydrograph (Figure 3.3). As a result, Portage Creek sockeye experienced dilution levels up to 45% in 2014, with above target ratios occurring for 21 of

49 days during the migration period, and dilution levels up to 39% in 2015, with the dilution levels exceeded for 48 of 49 days in 2015. However, the dilution levels were typically within 3% of the 10% target ratio for Portage Creek sockeye with the dilution levels exceeding 13% for 12 days in 2014 and 16 days in 2015. Mean Seton River discharge during the Portage Creek sockeye migration period was 17.6 $m^3 \cdot s^{-1}$, 19.3 $m^3 \cdot s^{-1}$, 17.9 $m^3 \cdot s^{-1}$, and 13.5 $m^3 \cdot s^{-1}$in the years 2013-2016 respectively.

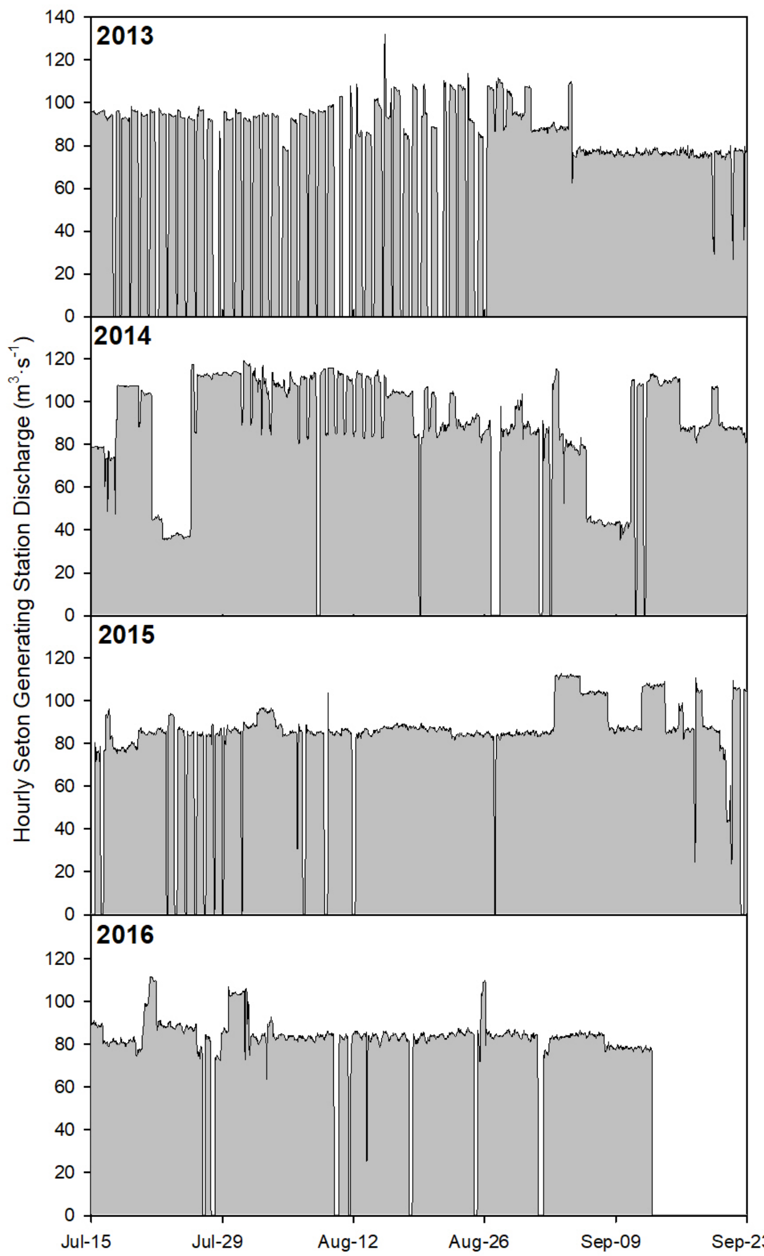

Figure 3.3 **Seton Generating Station discharge from 15 July to 23 September from 2013 – 2016 encompassing the Gates Creek sockeye migration period (20 July – 31 August) (BC Hydro data). Gaps in the grey areas indicate Seton Generating Station shutdowns.**

Seton Generating Station operations varied during the Gates Creek sockeye migration period in 2013 - 2016 (Figure 3.4). From 20 July to 26 August 2013, daily shutdowns occurred at night for 4 - 19 h with most shutdowns lasting 5 - 7 h. Water was not discharged into the tailrace during these periods; therefore, Gates Creek sockeye would not receive any Seton River olfactory cues from the tailrace during shutdowns. In 2014 and 2015, shutdowns were required on days Seton Dam conveyance structures were changed or a ramp-down occurred (08, 18 August and 12 September in 2014; 07,14 August in 2015; 10, 11, 18, 25 August in 2016). However, outside of these operations, shutdowns were infrequent.

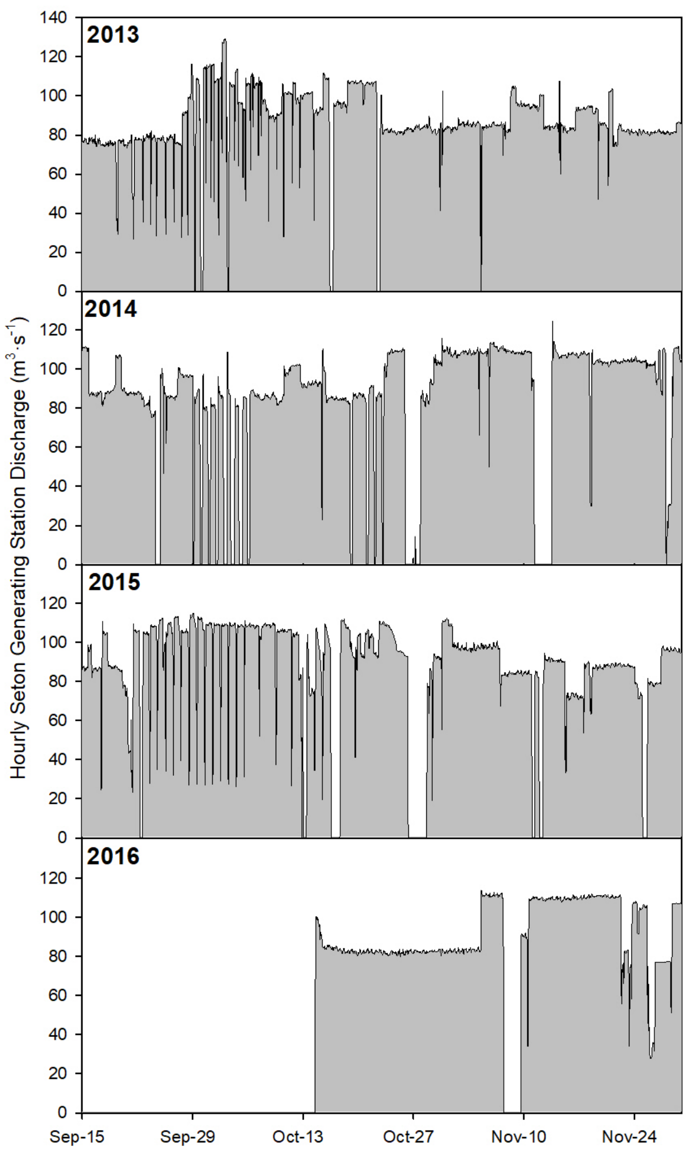

Figure 3.4 **Seton Generating Station discharge from 15 September to 23 November from 2013 - 2016, encompassing the Portage Creek sockeye migration period (31 September – 15 November) (BC Hydro data). Gaps in the grey areas indicate Seton Generating Station shutdowns.**

Shutdowns at the Seton Generating Station also occurred during the Portage Creek sockeye migration period (Figure 3.4). Shutdowns primary occurred in the first week of October 2014, although reductions in discharge also occurred in early September of 2013 and 2015. In 2016, the Seton Generating Station was shutdown from 12 September to 14 October. Like Gates Creek sockeye, Portage Creek sockeye migrating past the Seton Generating Station during these shutdowns would not have encountered any natal water olfactory cues in the tailrace. For both Gates Creek and Portage Creek sockeye telemetry, shutdowns were accounted for by calculating tailrace conditions at the time of each tailrace entry.

3.1.2 Seton Dam Discharges

Seton Dam discharge and flow patterns are an important component of the Gates Creek sockeye telemetry studies that occurred from 2012 - 2016. Seton Dam discharge and conveyance structure use varied within and across years (Figure 3.5).

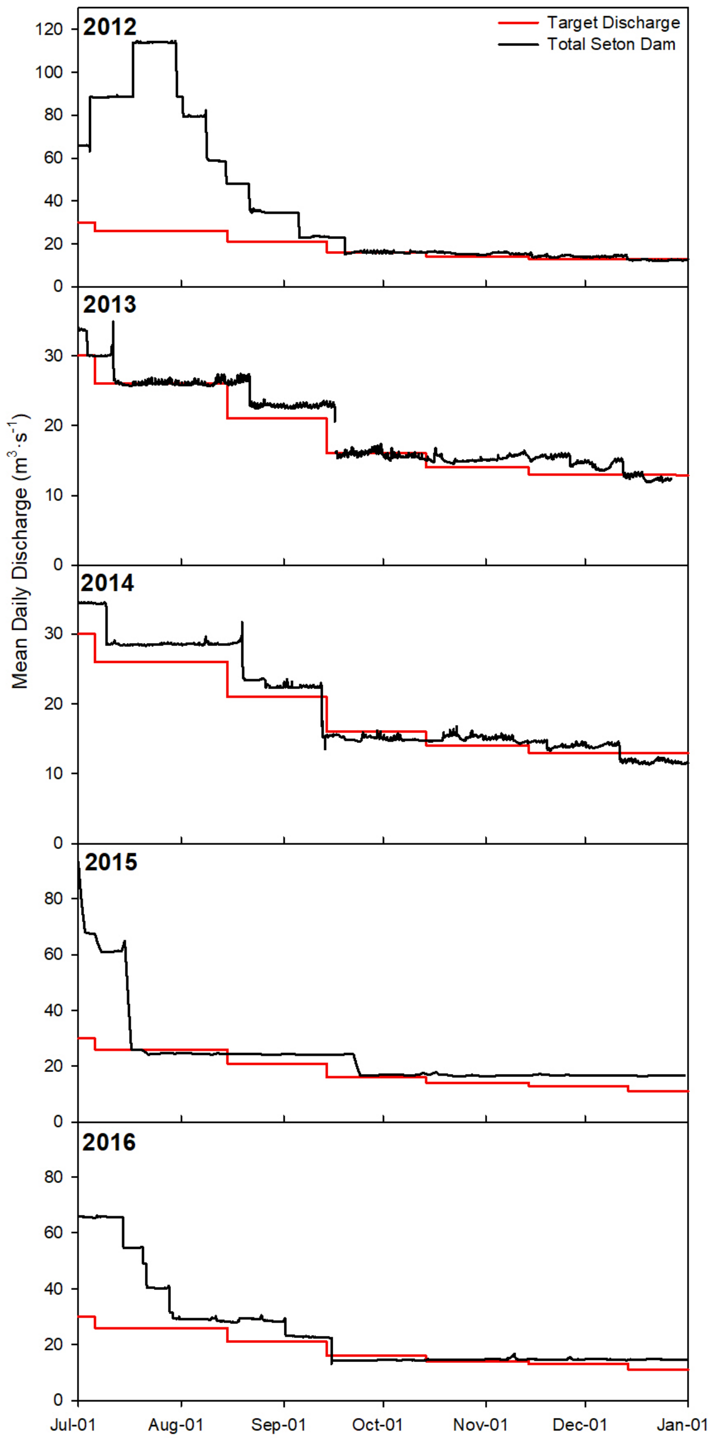

Figure 3.5 **Discharge for Seton Dam and each conveyance structure in 2012 - 2016 (BC Hydro data). Fishway and radial gate discharges are not shown.**

The greatest Seton Dam discharges occurred in 2012, with >100 $m^3 \cdot s^{-1}$ released at the start of the Gates Creek sockeye migration period. However, discharge was reduced to 48.0 $m^3 \cdot s^{-1}$ before tagging started in mid-August 2012 and was later reduced to 35.0 $m^3 \cdot s^{-1}$ via closure of Siphon 3 and increased discharge from the fish water release gate. Radial gate openings also occurred in 2012, with one opening on 21 August temporarily increasing discharge by 11 - 16 $m^3 \cdot s^{-1}$ for <2 h during Gates Creek sockeye telemetry studies.

In 2015, discharge at Seton Dam unexpectedly decreased from 26.2 $m^3 \cdot s^{-1}$ to 21.8 $m^3 \cdot s^{-1}$ on 27 July – possibly due to an air blockage in Siphon 1. As a result, BC Hydro did not carry out a Seton Dam ramp-down in August 2015 and Seton Dam discharge was constant throughout August. Fishway discharge was constant across all study years.

3.1.3 Seton Dam Routine and Alternative Operations

In 2013 - 2015, total Seton Dam discharges were within the Bridge River Water Use Plan target hydrograph range throughout the Gates Creek sockeye migration period. In 2016, total Seton Dam discharges were exceeded from August 11th to 18th and again from 25 August 25 to 1 September; however, these dates corresponded to the dates of the alternative flow trials. The conveyance structures used to release water varied between years due to the alternative flow scenario testing in 2014 and 2016 and unexpected operational changes in 2015. In 2013, BC Hydro operated Seton Dam normally with two discharge conditions (26.2 $m^3 \cdot s^{-1}$ and 22.8 $m^3 \cdot s^{-1}$) during August, separated by a 21 August ramp-down where fish water release gate discharge was decreased as per the WUP. In 2014 and 2016, an experimental alternative flow scenario was tested where an initial discharge scenario was changed to the alternative scenario by reducing fish water release gate discharge to a minimum, closing Siphon 1, and opening Siphon 4. In 2014, the alternative flow scenario increased discharge by 3.6 $m^3 \cdot s^{-1}$ but decreased flows around the fishway entrance. The alternative scenario was tested from 08 to 19 August 2014, after which time routine flows conditions were re-established. The routine and alternative flow scenarios were alternated weekly in 2016 (Table 3.1). Changes in discharge and conveyance structure use between the routine and alternative flow scenarios are summarized in Table 3.1.

Table 3.1 **Average mean daily Seton Dam discharge and conveyance structure discharge during the 2014 and 2016 routine and alternative flow scenarios as estimated by BC Hydro (BCH) for the Fishway, Fish Water Release Gate (FWRG), Siphon 1 (SSV1) and Siphon 4 (SSV4).**

Year	Flow Scenario	Date	Discharge ($m^3 s^{-1}$)				
			Total (BCH)	Fishway	FWRG	SSV1	SSV4
2014	Routine	09 July – 08 Aug	25.0*	1.1	7.6	16.3*	-
	Alternative	08 Aug – 19 Aug	28.6	1.1	1.9	-	25.6
	Routine	19 Aug – 26 Aug	23.4	1.1	2.5	19.8	-
	Routine	26 Aug – 12 Sept	22.4	1.1	1.4	19.9	-
2016	Routine	30 Jul – 11 Aug	29.1	1.1	8.2	19.8	-
	Alternative	11 Aug – 18 Aug	28.1	1.2	1.4	-	25.5
	Routine	19 Aug – 25 Aug	29.3	1.2	8.3	19.8	-
	Alternative	25 Aug - 01 Sept	28.928.3	1.1	1.7	-	25.5

*BC Hydro’s estimated total Seton Dam and SSV1 discharge from 09 July to 08 August 2014 was reduced by .5 $m^3 s^{-1}$ to adjust for a known SSV1 blockage.

3.1.4 Seton Dam Routine and Alternative Tailrace Flow Fields

In 2014, ADCP unit and particle tracking were used to measure flow velocities in the Seton Dam tailrace during two discharge scenarios: the routine flow scenarios where water was released from Siphon 1 and the fish water release gate; and an alternative flow scenario where water was released primarily through Siphon 4 (Table 3.1). The alternative flow scenario was intended to reduce flow velocities surrounding the fishway entrance to improve fish passage. Flow measurements were not taken in 2016 but were expected to match those measured in 2014 during routine and alternative scenarios.

3.1.5 Routine Operations Flow Fields

Discharge from Siphon 1 and the fish water release gate created highly turbulent water in the fishway entrance area during the routine scenario, preventing ADCP measurements of flow velocities through most of the entrance area (Figure 3.6). However, particle tracking in the primary Siphon 1 flows estimated surface flow velocities up to 4.2 $m \cdot s^{-1}$ downstream. At the downstream end of the fishway, where ADCP measurements were possible, peak flow velocities ranged from 4.5 - 4.8 $m \cdot s^{-1}$ at a depth of 0.5 m. Fish migrating upstream would likely have to overcome these velocities to access the fishway entrance. Upstream of the Siphon 1 discharge and immediately downstream of the fishway entrance, flow velocities were <2 $m \cdot s^{-1}$ as measured with ADCP transects. Both upstream and downstream flows occurred near the fishway entrance, likely caused by flows from the fish water release gate and Siphon 1 interacting with the submerged baffle wall.

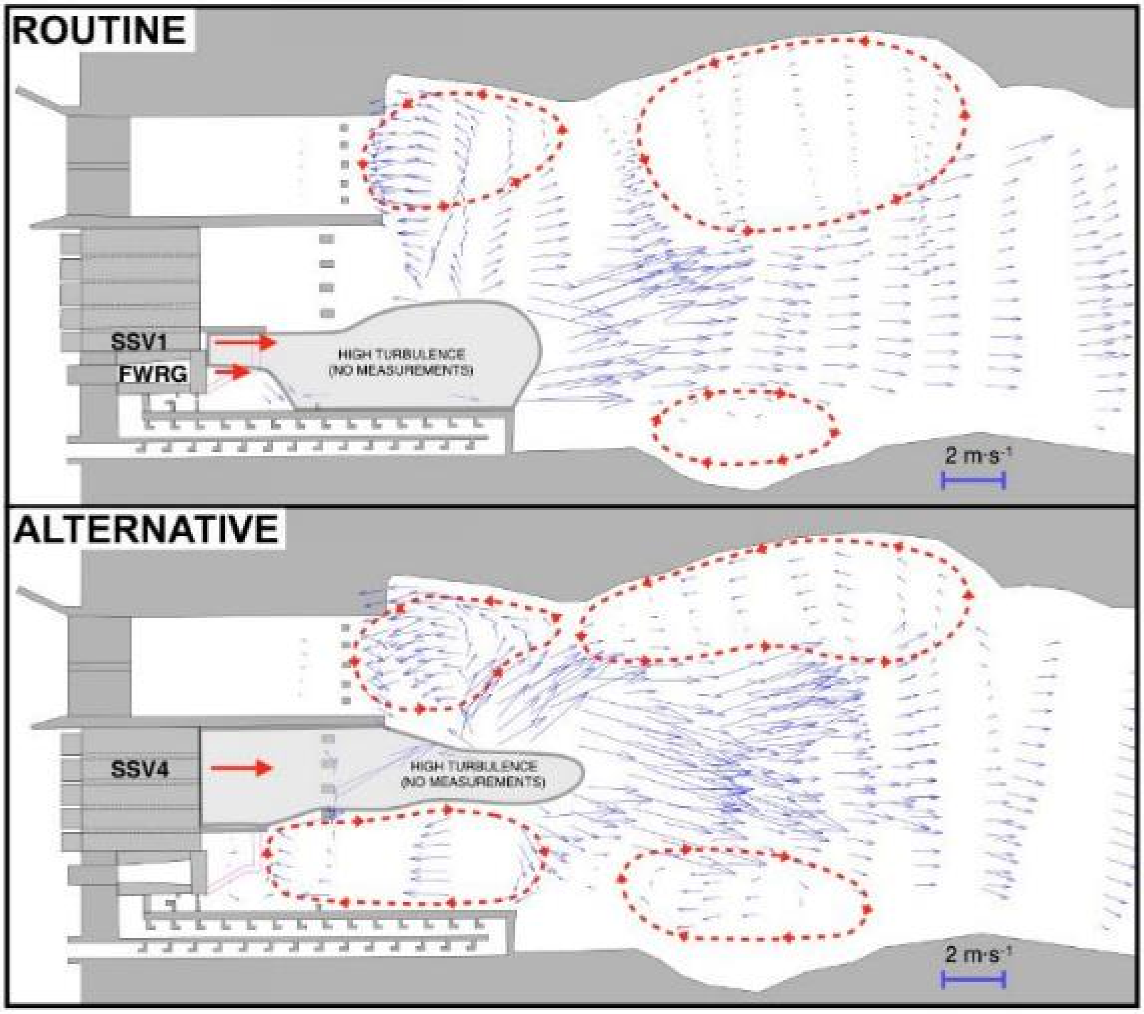

Figure 3.6 **ADCP measurement transects and calculated flow velocities (blue arrows) and estimated flow fields (red arrows) in the Seton Dam tailrace in 2014 under routine BC Hydro operations (top) and an alternative flow scenario (bottom).**

Discharge from Siphon 1 created three vortices in the tailrace (Figure 3.6 - Routine). Two large vortices were located on the northern bank of the Seton River and a third, smaller vortex was located on the southern bank downstream of the fishway. Flow velocities up to approximately 1 $m \cdot s^{-1}$ were measured in each vortex. The location, size, and flow velocities within the vortices were similar to those observed in 2013 during a similar flow scenario. Vortices on the northern bank were likely generated by the interaction of downstream flows with shallow gravel bars in the tailrace.

3.1.6 Alternative Operation Flow Fields

Release of water from Siphon 4, rather than Siphon 1 and the fish water release gate, relocated the primary discharge from Seton Dam to approximately 10 m from the fishway entrance area and into the centre of the tailrace (Figure 3.6 - Alternative). As a result, fish migrating to the fishway entrance would not be required to overcome turbulent flows from Siphon 4, although fish could still experience these flows. Peak velocities in the Siphon 4 discharge were up to 6.6 $m \cdot s^{-1}$ and extended 24 m downstream, beyond the end of the radial gate wall. Flow velocities up to 4.3 $m \cdot s^{-1}$ extended 75 m downstream. However, downstream of the Siphon 4 discharge plume, flow velocities decreased to <2.5 $m \cdot s^{-1}$ and then to <1 $m \cdot s^{-1}$ as the tailrace widened into the Seton River.

The alternative discharge from Siphon 4 produced two vortices on the northern bank of the tailrace and two vortices on the southern bank, one within the fishway entrance area. Vortices on the northern bank were similar in location to those observed under routine operations, although the proximity of the Siphon 4 discharge plume to the northern bank reduced the size of both vortices while increasing flow velocities. On the southern bank, the vortex that was observed downstream of the fishway under routine operations increased in size under the alternative scenario. A fourth vortex, that was not observed under routine operations, was created in the entrance area adjacent to the fishway wall.

At the fishway entrance, downstream flows from the fishway and fish water release gate, and upstream flows from the vortex in the fishway entrance area, created a flow interface 8-10 m downstream of the fishway entrance. The velocity of downstream flows from the fishway and fish water release gate discharge were <0.5 $m \cdot s^{-1}$ whereas upstream flows from the vortex were 0.5-1.0 $m \cdot s^{-1}$. As a result, flows immediately downstream of the fishway entrance may have been limited under the alternative flow scenario, although comparison with routine conditions is not possible, as flows could not be measured near the fishway entrance. Regardless, flow velocities throughout the entrance area were reduced under the alternative scenario and the direction of flows reversed from downstream to upstream.

3.1.7 Water Temperature

The thermal experience of Gates Creek and Portage Creek sockeye prior to entering the Seton-Anderson watershed was estimated from 2013 - 2016 using the temperature of the Fraser River at Texas Creek ~17 km downstream of the Seton River.

During the Gates Creek sockeye migration, Fraser River temperatures were 15.2 - 21.5°C (2013), 15.0 - 20.5°C (2014), 14.0 - 20.9°C (2015), and 16.7 - 20.5°C (2016) at Texas Creek. Fraser River temperatures exceeded 20°C, a known thermal stress threshold for sockeye, continuously in 2013 from 04 to 18 August, whereas temperatures >20°C occurred intermittently during daytime peaks in 2014 from 15 to 19 August, in 2015 continuously from 10 to 15 July, and in 2016 from 10 to 18 August and for a brief period on 20 July. Downstream Fraser River temperatures would be expected to exceed those measured at Texas Creek. Although determining the Fraser River thermal experience of fish is difficult, relative comparison across years suggest Fraser River temperatures in 2013 were likely the most stressful for Gates Creek sockeye of the years studied and affected a large portion of the run. Temperatures in 2014, 2015, 2016 were overall less stressful, although at times exceeded 20°C and would have caused thermal stress for fish arriving at the Seton River in mid-August 2014, early-August 2015, and mid-August 2016.

Portage Creek sockeye migrating past Texas Creek (10 September to 06 October) experienced Fraser River temperatures of 10.2 - 18.3°C in 2013, 10.9 - 15.1°C in 2014, 10.3 - 15.8°C in 2015, and 9.8 – 14.4°C in 2016. Fraser River temperature in 2014 and 2016 displayed the same temporal trend, declining to <15°C by early-September; however, temperatures >15°C persisted until mid-September in 2013. The optimal temperature for Portage Creek sockeye is unknown, but it is expected to be similar to Weaver Creek sockeye (another Fraser River late-run population), which have an optimal temperature of 14.5°C. Temperatures approaching 18°C in 2013 may have created stressful thermal conditions.

Sockeye salmon are known to make use of thermal refuges during periods of high temperature (Mathes et al. 2010). The Seton Generating Station tailrace provided a thermal refuge from the Fraser River during the Gates Creek sockeye migration period. The timing, magnitude and duration of the refuge varied year-to-year, with temperatures in the tailrace up to 3.9°C, 5.2°C, 2.9°C and 4.8°C cooler than the Fraser River in 2013 - 2016, respectively. Temperature differences >1°C occurred for 35% and 30% of the migration period in 2013 and 2014, 10% of the migration period in 2015, and 45% of the migration period in 2016. However, temperature differences >1°C when the Fraser River also exceeded 20°C, occurred for 19% of the migration period in 2013, 5.6% in 2014, 0% in 2015 and 17% in 2016.

Water temperature patterns in the Seton River study area paralleled those in the Fraser River each year, with elevated temperatures occurring in 2013, relative to 2014 to 2016 (Figure 3.7). In 2013, extreme environmental conditions increased water temperatures throughout the study area. Temperatures reached a maximum on 11 August 2013, with mean daily temperatures in the lower Seton River (19.7°C), Cayoosh Creek (15.9°C), and the Seton Dam fishway (23.0°C) coinciding with maximum Fraser River temperatures (21.5°C). Maximum temperatures in the Seton River study in 2013 area occurred in the Seton Dam fishway, where hourly temperatures were >20°C continuously from 10 to 18 August 2013, reaching a maximum of 23.7°C on 11 August 2013 and creating extremely stressful migration conditions for Gates Creek sockeye. In comparison, temperatures in the Seton River in 2014, 2015 and 2016 were never at or above 20°C, with the Seton Dam fishway temperature briefly exceeding 20°C for 5 h on 05 August 2014 (20.4°C maximum) and for 5 h on 14 and 20 August 2015 (20.2°C maximum).

After August, monthly maximum temperatures in the Seton River occurred at the start of each month and across all years were approximately 17°C in September, 15°C in October, and 12°C in October. Slightly warmer temperatures during the Portage Creek sockeye salmon migration were observed in 2014-2016 than 2013; however, these modest temperature increases were not expected to impair migration in any year.

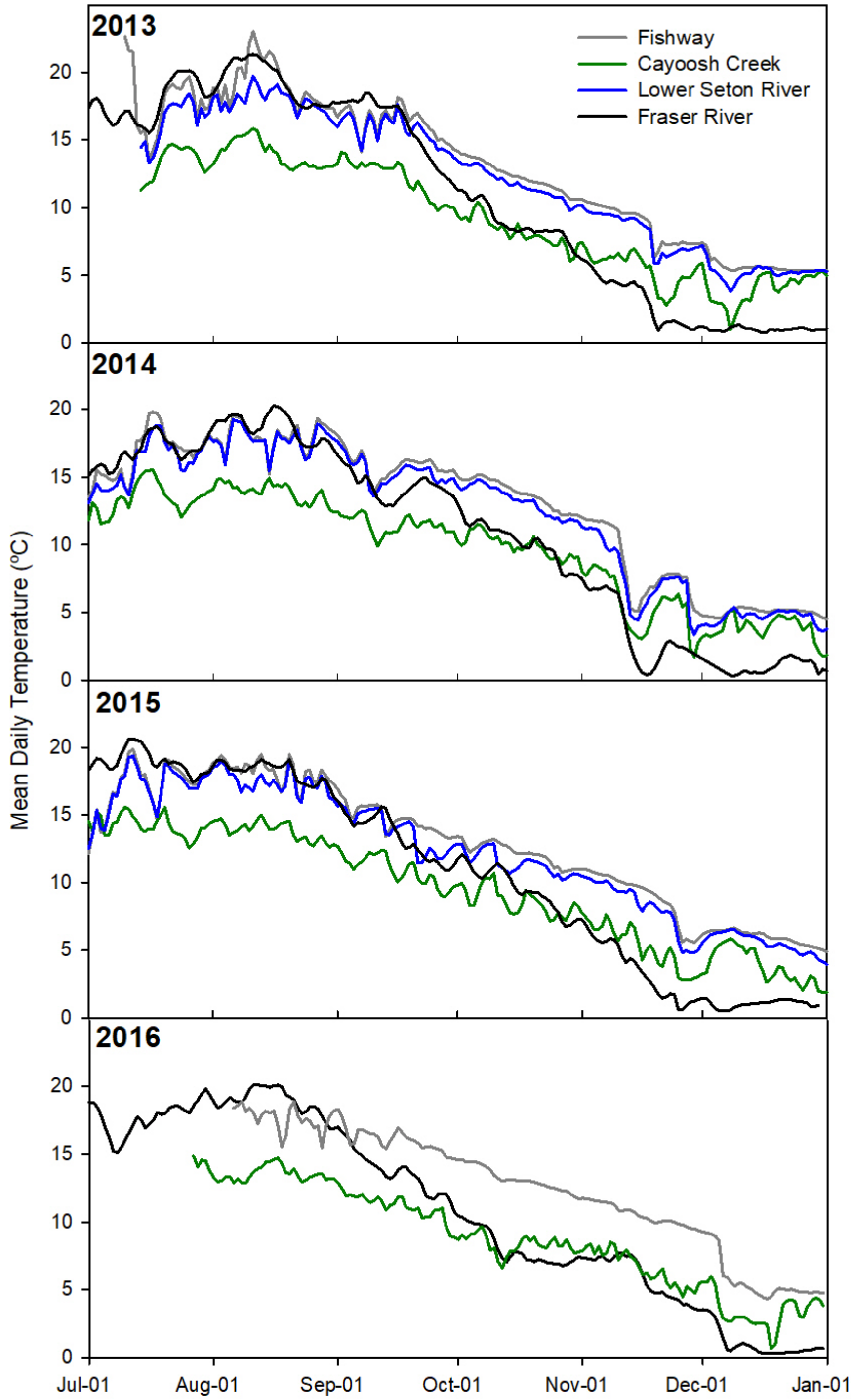

Figure 3.7 **Temperature of the Fraser River, Cayoosh Creek, Seton River and Seton Dam fishway in 2013 - 2016.**

Rapid increases in water temperature and high maximum daily temperatures were observed in the fishway during shutdowns of the Seton Generating Station in 2013 (Figure 3.8). Increases in fishway temperatures occurred regularly during Seton Generating Station shutdowns in 2013. For example, fishway temperatures increased 3.7°C (19.0 - 22.7°C) in 4 h during an overnight shutdown on 10 August 2013 and the maximum fishway temperature (23.7°C) occurred on 11 August 2013 during a shutdown. However, temperature increases coincided with extreme Seton Lake surface water temperatures and a maintenance shutdown of the Walden North diversion to Seton Lake from 07 to 16 August 2013. Therefore, the rapid increases in fishway water temperatures during shutdowns were probably due to high-temperature Seton Lake water being drawn into Seton Dam fishway.

Indeed, Seton Generating Station shutdowns in 2014 and 2015, when environmental temperatures were less extreme, had a reduced influence on fishway temperatures with a 26 August 2014 shutdown associated with a 1.7°C increase in fishway temperature within 24 h and a 11th August 2015 shutdown associated with a 2.0°C increase in <4 h. Further, rapid decreases in water temperature that do not appear to be associated with Seton Generating Station shutdowns occurred in 2014 on the 3, 14 and 20 August with similar events occurring in 2015 on 15 and 22 August, suggesting temperature changes are not driven by the Seton Generating Station alone. These patterns were largely similar in 2016.

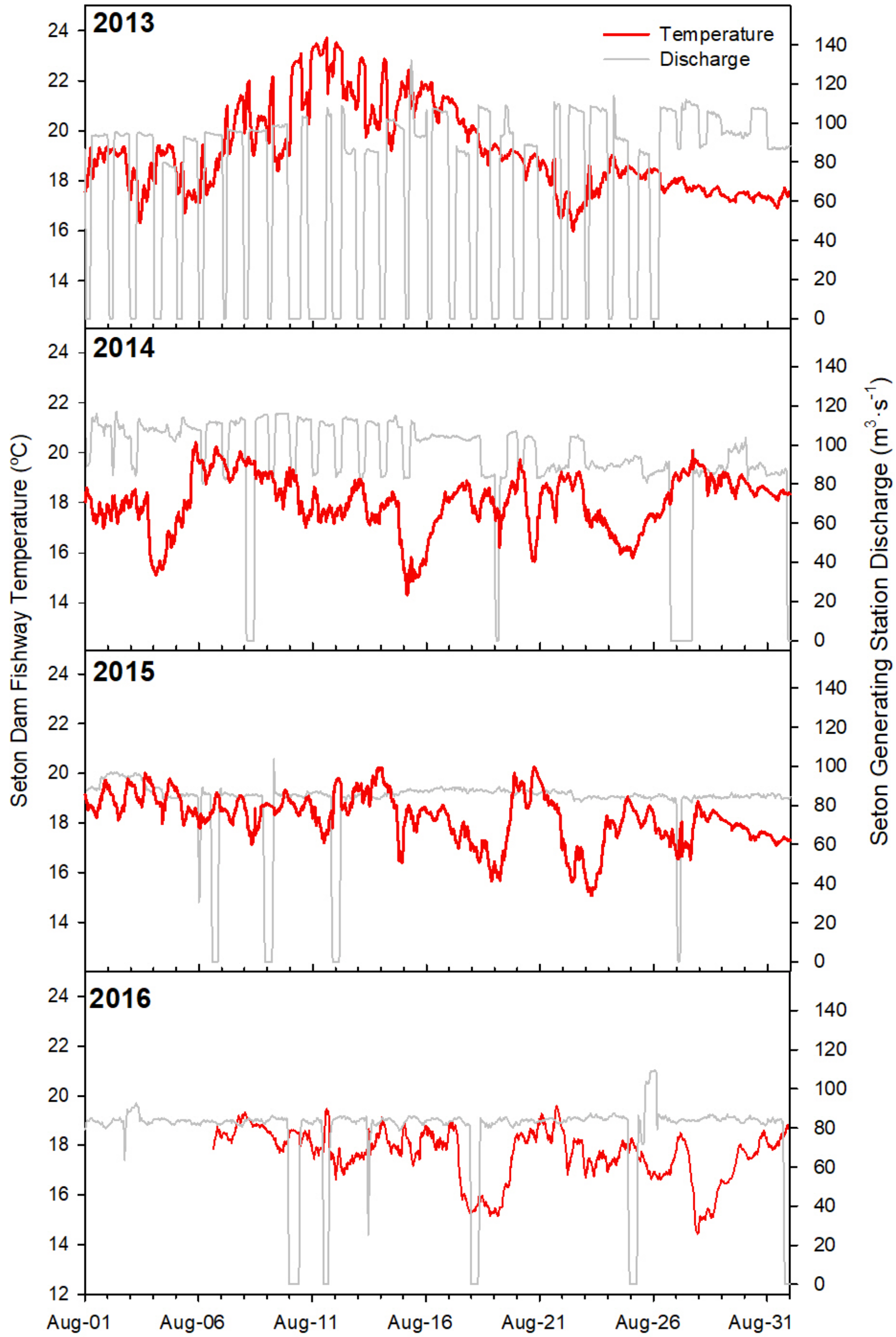

Figure 3.8 **Seton Dam fishway temperature and Seton Generating Station discharge in 2013 to 2016.**

3.1.8 Conductivity

Specific conductivity measurements in 2012 - 2015 displayed similar trends across years (Figure 3.9). Specific conductivity in Cayoosh Creek gradually increased throughout the study period, whereas conductivity gradually decreased in the upper Seton River. As a result, the greatest differences in conductivity occurred during the Portage Creek sockeye migration period. In 2015, conductivity measurements were collected from 01-19 August; however, readings displayed greater variation than previous years, probably due to a malfunctioning conductivity meter that failed on 20 August. Although no readings were taken for the remainder of 2015, initial readings displayed the same overall trends as in previous years.

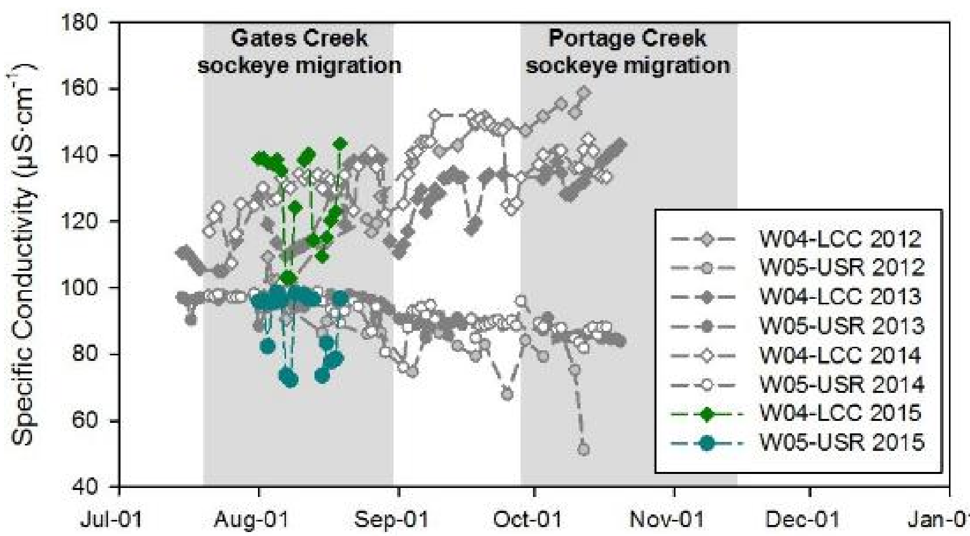

Figure 3.9 **Specific conductivity readings from Cayoosh Creek (W04-LCC) and the upper Seton River (W05-USR) during the target dilution periods for Gates Creek and Portage Creek sockeye.**

3.2 Population Assessments: Estimates of Return Numbers and Run Timing

Abundance and run timing estimates were generated for Gates Creek and Portage Creek sockeye, pink salmon, and coho salmon using the resistivity fish counter in the exit basin of the Seton Dam fishway and were provided by Instream Fisheries Research. Chinook salmon abundance could not be estimated. Detection efficiencies for the fish counter from 2013 – 2015 are detailed in Casselman et al. (2015) and for 2016 are provided below. Pink and coho salmon spawn both above and below Seton Dam, so the number of fish reported here are only a portion of the total Seton River population.

3.2.1 Gates Creek Sockeye Salmon

Annual abundance estimates for the Gates Creek sockeye population were 54,800 in 2013, 27,192 in 2014 (credible intervals 25,771 to 28,611), 26,206 in 2015, and 25,470 in 2016. Credible intervals could not be calculated for 2013 due to issues with the operation of the fish counter. In 2015 and 2016 credible intervals were not calculated, but mean counter accuracy was 81.3% and >96% in 2015 and 2016 respectively. Daily migration typically peaked during the early morning (05:00 - 07:00 h), and occasionally in the late afternoon (16:00 - 18:00 h). Migration was slower during the day (07:00 -16:00 h) and at night (18:00 - 5:00 h). Although these migration patterns generally align with the known migration behaviour of sockeye salmon, morning and late-afternoon peaks in the migration period were likely influenced by fish fence operations, that typically closed the fence at 6:00 and opened the fence at 15:00-18:00.

3.2.2 Portage Creek Sockeye Salmon

The large return numbers of pink salmon in 2013 did not allow for an estimate of Portage Creek sockeye returns. In 2014, a mean estimate of 38,812 (Credible Intervals 32,392 and 45,231) Portage Creek sockeye passed through the Seton Dam between 11 September and 04 November. The start date for Portage Creek sockeye was set as 11 September to correspond with the 10 September end date for Gates Creek sockeye and was based on DNA stock assessment results from telemetry tagging studies. In 2015, a mean estimate of 2,253 Portage Creek sockeye passed through the Seton Dam between 11 September and 09 October 2015. The migration start date for Portage Creek sockeye was again set as 11 September to correspond with the 10 September end date for Gates Creek sockeye. Daily migrations typically peaked in the morning (07:00-09:00) and late afternoon (15:00-18:00 h), with lower migration during the day (09:00-15:00 h) and at night (18:00 -06:00 h).

3.2.3 Pink Salmon

In 2013, a high number of pink salmon passed through the Seton Dam fishway from 09 September to 02 October and continued to pass in lower numbers until 28 October. Migration of pink salmon overlapped with that of all other salmon populations, and, as with Portage Creek sockeye in 2013 an accurate estimate could not be made. In 2015, a mean estimate of 87,032 pink salmon passed through the Seton Dam between 20 August and 04 October. The peak in pink salmon migration was observed between 07 September and 23 September with daily migration rates ranging from 2,004 to 8,964 fish per day during this period. Migration was consistent throughout daytime hours in both years and was relatively low at night.

3.2.4 Coho Salmon

An estimated 2,334 coho salmon passed through Seton Dam between 02 October and 05 November 2013. 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. In 2015, a mean estimate of 667 coho salmon passed through the Seton Dam between 11 October and 05 November. The peak in coho salmon migration was observed between 17 October and 04 November with migration rates of 17 to 54 fish per day during this period. Passage of coho salmon was not assessed in 2014 or 2016 but 30 coho were PIT tagged in 2013.

3.3 Fish Capture and Tagging

3.3.1 Gates Creek Sockeye

From 2012 - 2016 a total of 2,973 sockeye were tagged during the Gates Creek sockeye migration period. Stock identification DNA analysis – used to confirm sockeye as Gates Creek stock - was carried out during pilot studies in 2012 and for a subset of fish in 2013. Stock ID results were used to identify a relationship between gross somatic energy (GSE) and stock identification. Of sockeye confirmed as Gates Creek stock in 2012 - 2013, 90% were found to have GSE density estimates <7.2 MJ·Kg^{-1} whereas 90% of stray sockeye present in the Seton River had GSE density estimates >7.2 MJ·Kg^{-1} (Casselman et al. 2013). Therefore, in 2013 - 2016, GSE screening was applied at the time of tagging to identify Gates Creek sockeye from strays. In 2014, 89 sockeye tagged during the Gates Creek migration period were identified as potential strays via GSE screening. These fish received either a PIT (n = 86) or radio tag (n = 3) but were not included in migration analyses. In 2015 and 2016, tags were not applied to sockeye identified as strays from GSE estimates. Sample data from sockeye identified as Gates Creek sockeye is presented in Table 3.2.

Table 3.2 Mean fork length and estimated gross somatic energy (GSE) density of Gates Creek sockeye sampled in 2013-2016

Year	Sex	Number of Fish	Fork Length (cm)	GSE (MJ·kg^{-1})
2013	Both*	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
2014	All*	924	59.7 ± 4.0	5.8 ± 0.6
	Male	376	61.0 ± 4.4	5.7 ± 0.6
	Female	543	58.7 ± 3.5	5.9 ± 0.6
2015	All	860	58.1 ± 3.0	5.6 ± 0.6
	Male	423	59.2 ± 2.6	5.4 ± 0.6
	Female	437	56.9 ± 2.9	5.7 ± 0.6
2016	All	752	58.5 ± 3.2	5.8 ± 0.6
	Male	367	60.4 ± 2.7	5.8 ± 0.6
	Female	385	56.7 ± 2.5	5.8 ± 0.6

All values are presented as mean ± SD. *A sex estimate was not available for all fish in 2013 and 2014.

3.3.2 Portage Creek Sockeye, Coho, and Pink Salmon

Sampling results for Portage Creek sockeye and coho salmon are presented in Table 3.3. Portage Creek sockeye were primarily tagged in 2014 due to high abundance in 2014 and overlap with pink salmon migration in 2013 and 2015. As a relationship between GSE density and stock identification had yet to be established for Portage Creek sockeye, no GSE screening occurred in 2014. Generally, there is a low likelihood of strays during the Portage Creek sockeye migration period due to the late run timing of this population amongst Fraser River sockeye. As a result, all fish tagged during the Portage Creek sockeye migration period were included in sampling results and migration analyses. Males made up 62% of the Portage Creek sockeye collected in 2014. Coho salmon were also collected in small numbers in 2013 and 2014. In 2013, 277 pink salmon were tagged with PIT-tags, and 60 pink salmon tagged with radio-tags (Table 3.3).

Table 3.3 **Mean fork length and estimated gross somatic energy (GSE) of Portage Creek sockeye, coho, and pink salmon sampled in 2013 and 2014. All values presented as means ± standard deviation.**

Year / Sex		Number of Fish	Fork Length (cm)	GSE ($MJ\cdot kg^{-1}$)
Portage Creek				
	All	24	56.9 ± 1.9	4.9 ± 1.8
2013	Male	9	57.8 ± 2.0	3.2 ± 2.0
	Female	15	56.3 ± 1.6	5.9 ± 0.7
	All	661	60.4 ± 3.0	5.6 ± 0.5
2014	Male	410	61.9 ± 2.4	5.5 ± 0.4*
	Female	249	58.1 ± 2.2	5.7 ± 0.5
Coho salmon				
	All	30	60.8 ± 5.2	7.4 ± 1.5
2013	Male	24	61.1 ± 5.6	7.8 ± 0.7
	Female	6	59.3 ± 2.9	6.2 ± 2.9
	All	9	57.0 ± 4.8	7.4 ± 0.6
2014	Male	2	56.3 ± 1.1	7.6 ± 0.4
	Female	7	57.2 ± 5.4	7.4 ± 0.7
Pink salmon				
	All	337	52.8 ± 3.15	6.4 ± 0.9
2013	Male	181	54.0 ± 3.42	6.4 ± 0.9
	Female	156	51.5 ± 2.17	6.4 ± 0.8

Salmon were released either in the Fraser River, downstream of the Seton Generating Station, or at the capture site in the Seton River. Radio-tagged fish were released in the Fraser River to assess the influence of Seton River dilution on the migratory behaviour of the salmon as they approached the Seton-Anderson system. Acoustic-tagged fish were released in the Seton River to analyse the migratory behaviour and energy-use of sockeye as they approached and ascended the Seton Dam fishway. PIT-tagged fish were released at each of the two sites to provide more data for each of these two aims.

3.4 Influence of Seton River Dilution on Sockeye Salmon Migration

Management Questions:

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 populations?

1a) How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

3.4.1 Water Preference Behavioural Tests

The potential sensitivity of migrating adult salmon to changes in the dilution level was tested by analysing the behaviour of the salmon in controlled experimental chambers. Salmon were held in a Y-maze receiving undiluted Seton Lake water in one arm and diluted Seton Lake water in the other arm. Their behaviour was then analysed to determine whether the salmon exhibited a preference for water entering either of the two arms. Multiple tests were conducted using different dilution levels.

3.4.1.1 Gates Creek Sockeye

Gates Creek sockeye displayed no water preference during control tests. 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) (Figure 3.10), the proportion of time spent in each arm (Wilcoxon signed rank one sample test: μ = 0.5, V = 121, p = 0.31) (Figure 3.11) or in the number of arm entrances (Student's t-test: t = -1.10, p = 0.29) (Figure 3.12). Increasing the dilution level to 5% or 20% did not result in a water preference by Gates Creek sockeye. At 5% and 20%, no difference was found in the total time spent in each arm (5%: Student's t-test: n = 9, t = 1.92, p = 0.09; 20%: Student's t-test: n = 26, t = -0.58, p = 0.57), the proportion of time spent in each arm (5%: One-sample t-test: μ = 0.5, t = -2.11, p = 0.07; 20%: One-sample t-test: μ = 0.5, t = 0.62, p = 0.54), or entrances (5%: Student's t-test: t=1.60, 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 level was 30%. At a 30% dilution level, fish spent more time in the arm containing 100% Seton River water (Student's t-test: n = 30, t = 5.64, p <0.01) and a greater proportion of time in the arm (One sample t-test: μ = 0.5, t = -6.24, p <0.01)). There was no significant difference in the number of entrances into each arm (Wilcoxon signed rank test: n = 30, V = 247, p = 0.17). At a 50% dilution level, fish spent significantly more time in the arm containing 100% Seton River water (Student's t-test: n = 26, t = 4.32, p<0.01), spent a greater proportion of time in this arm (One-sample t-test: μ = 0.5, t = -4.3206, p <0.01), and entered the arm more frequently (Student's t-test: n = 26, t = 2.14, p = 0.04).

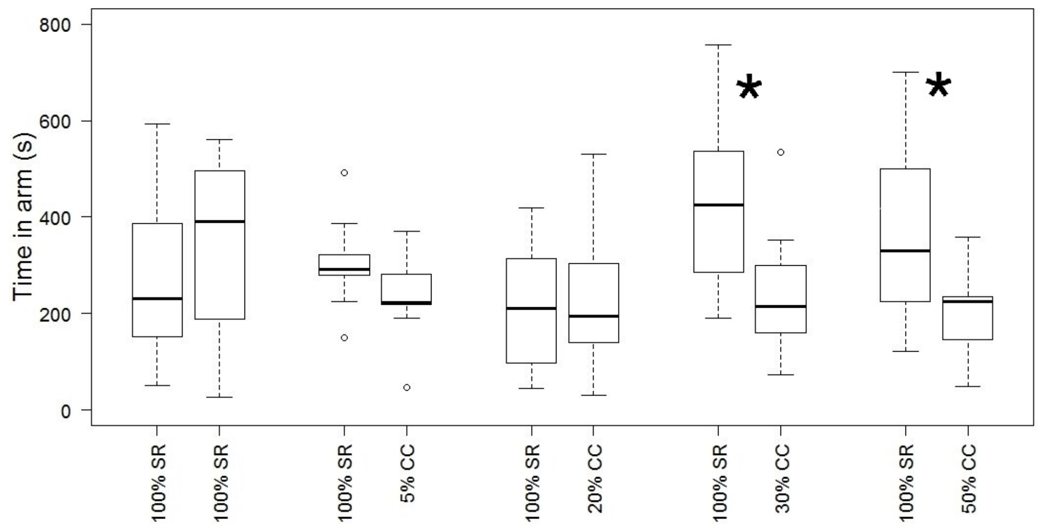

Figure 3.10 **Time spent by Gates Creek sockeye in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution levels. Upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference.**

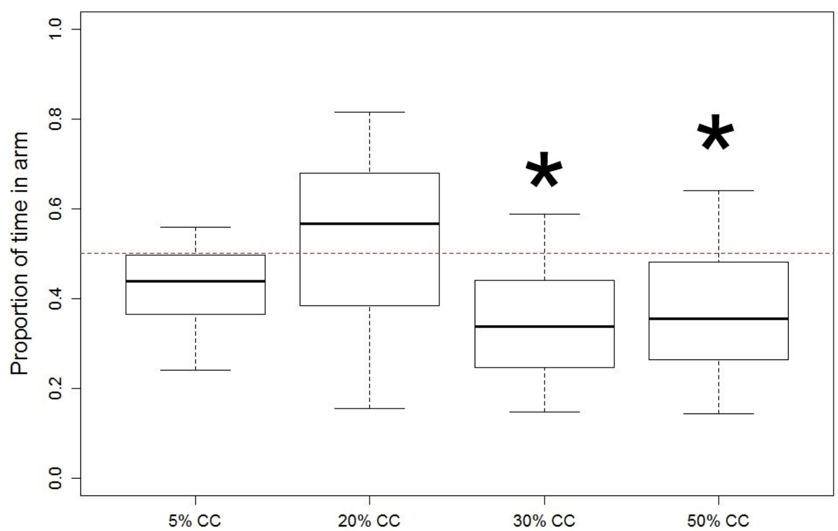

Figure 3.11 **The proportion of time spent by Gates Creek sockeye in the dilution mixture arm of the Y-Maze during water preference tests. Dilution levels of 5, 20, 30 and 50% Cayoosh Creek (CC) were tested against pure Seton River water. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicated a significant difference.**

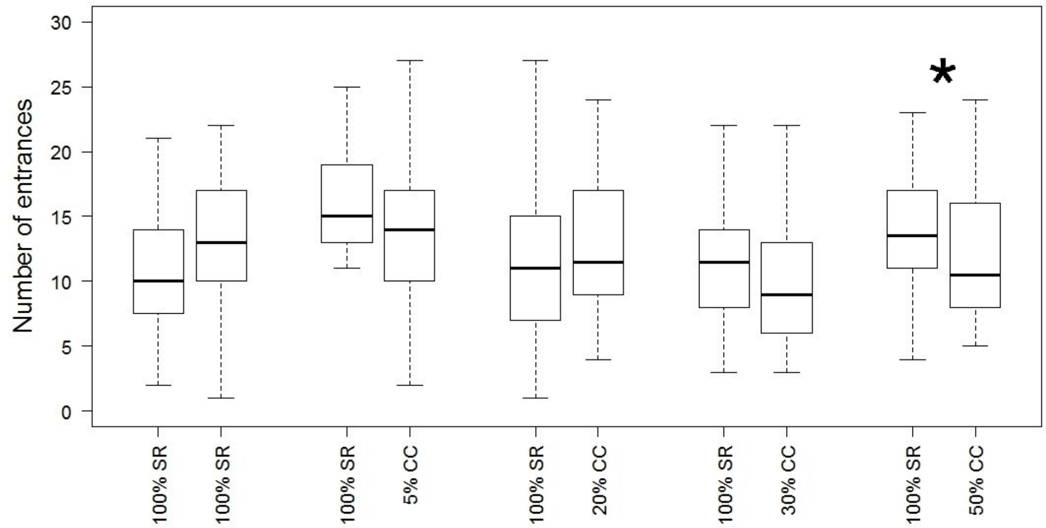

Figure 3.12 **The number of entrances into each arm on the Y-Maze by Gates Creek sockeye in each arm of the during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution levels. The upper, lower, and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference.**

3.4.1.2 Portage Creek Sockeye

Portage Creek sockeye did not exhibit a preference for Seton River water when tested at a dilution level of 10%. There was no difference in the time spent by fish in either the arm of the Y-maze (Wilcoxon signed rank test: n = 35, V = 337, p = 0.73; Figure 3.13) or the proportion of time spent in the arm containing the 10% dilution mixture (One-sample t-test: t = -0.6935, p = 0.5; Figure 3.14). In addition, fish did not enter either arm more frequently (Student's t-test: t = 0.2253, p = 0.82; Figure 3.15).

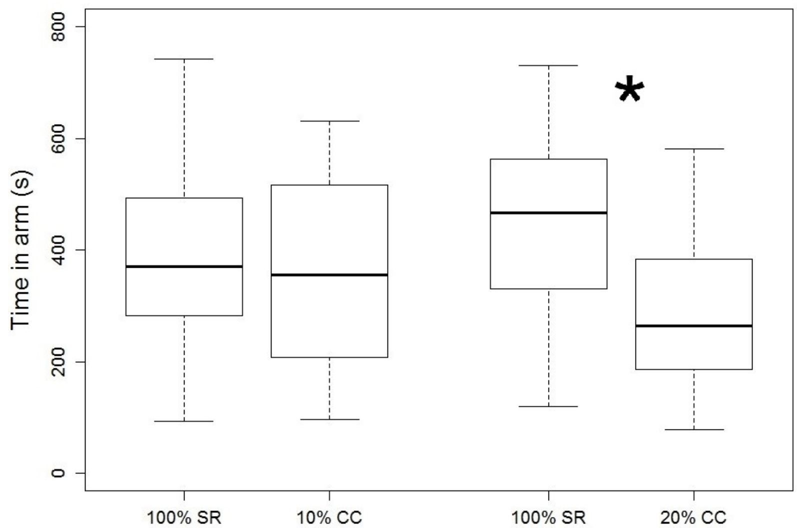

Figure 3.13 **The time spent in each arm of the Y-Maze by Portage Creek sockeye during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution level. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference**

Portage Creek sockeye did exhibit a preference when tested with a dilution level of 20%, spending significantly more time in the arm with 100% Seton River water (Student's t-test: n = 36, t = 3.7966, p <0.01) and a significant greater proportion of time (One-sample t-test: μ = 0.5, t = -3.4844, p = 0.001). However, there was no difference in the number of entrances into each arm (Student's t-test: t = 0.8992, p = 0.375).

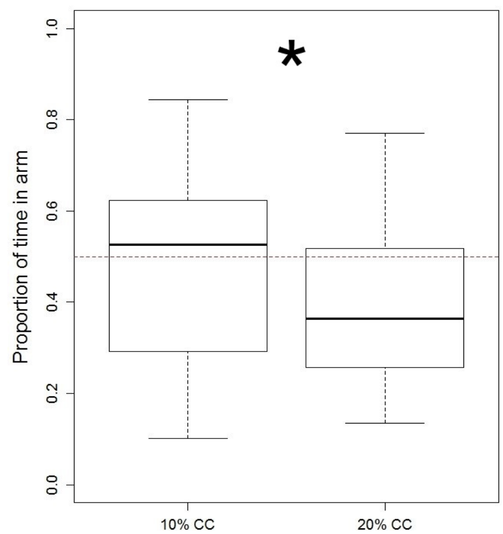

Figure 3.14 **The proportion of spent in each arm of the Y-Maze by Portage Creek sockeye during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution level. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference**

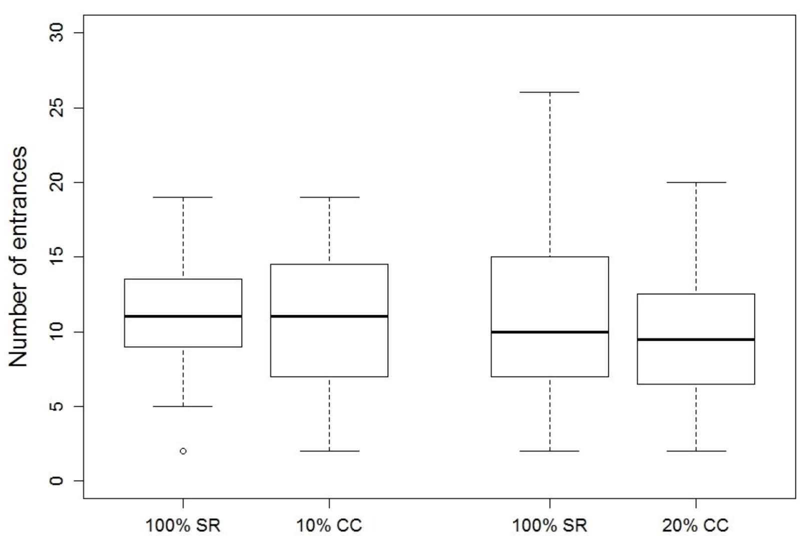

Figure 3.15 **The number of entrances into each arm of the Y-Maze by Portage Creek sockeye during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution level. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers**

- *Behavioural water preference experiments used different behavioural metrics to determine if Gates Creek sockeye and Portage Creek sockeye preferred undiluted Seton Lake water to Seton Lake water diluted to different dilution levels.*
- *For multiple metrics, both Gates Creek and Portage Creek sockeye salmon preferred undiluted Seton Lake water when the dilution levels increased above the current target levels of 20% for Gates Creek sockeye and 10% for Portage Creek sockeye.*

3.4.2 Sockeye Salmon Migration under Target Dilution Levels (2013 - 2014)

The water preference experiments of 3.4.1 were able to determine the sensitivity of sockeye salmon to dilution by testing their behavioural responses to various dilution levels in a controlled setting. While controlled experiments provide the opportunity to remove potential confounding factors, the behaviours reported in 3.4.1 may not accurately reflect the behaviour of Gates Creek and Portage Creek sockeye salmon in their natural environment. The radio-telemetry studies conducted in 2013 and 2014 complemented the controlled experiments by providing information on the migratory behaviours of sockeye salmon through the river system. The behaviours that were monitored included the number of forays into the Seton Generating Station tailrace, wandering between the Seton River and Seton Generating Station, and delay at the Seton Generating Station. Dilution rarely exceeded the target levels during the 2013 and 2014 migrations, so a field experiment in 2015 was conducted to track the migratory behaviour of Gates Creek sockeye salmon under a manipulated dilution level that exceeded the target (3.4.3).

3.4.2.1 Environmental Conditions Experienced by Gates and Portage Creek Sockeye

Observational studies of tagged sockeye salmon in 2013 and 2014 described the conditions that these two populations experience during migration and routine Seton Dam operations. The mean Fraser River temperature experienced by tagged Gates Creek sockeye in 2013 - 2014 was 18.3°C (±1.3°C; mean ± SD), although temperatures varied considerably over the entire 2013 and 2014 migrations, with some periods reaching near record summer highs (~ 21°C; Figure 3.16a). For more than 83% of both study years, dilution levels remained below the recommended 20% target for the Gates Creek population, with tagged fish on average experiencing dilution levels of 9.7% (±4.6%).

Portage Creek sockeye encountered Fraser River temperatures that were substantially cooler than temperatures in the Fraser River during the Gates Creek migration. Dilution levels in the Seton River remained below the 10% target for the Portage Creek population for over 87% of both 2013 and 2014 migrations, while the mean dilution level they experienced was 8.6% (±1.2%) (Figure 3.16b). Tagged Portage Creek sockeye did not experienced dilution level greater than 10% in 2014.

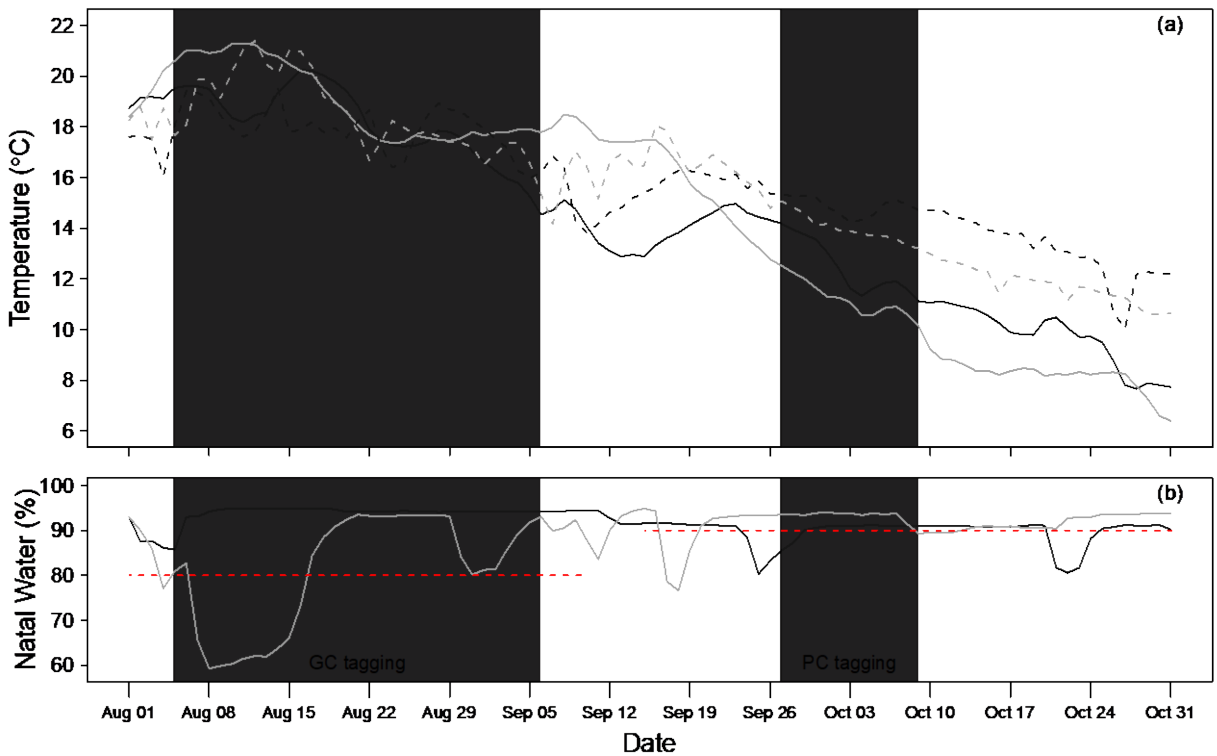

Figure 3.16 **Mean daily Fraser River (solid lines) and Seton Generating Station tailrace (dashed lines) temperatures (panel a), and natal water concentration of the Seton River and its plume (panel b) in 2013 (grey) and 2014 (black). Natal water concentration presented here, is the inverse of dilution of natal water levels presented throughout the report. The inverse of these percentages are equivalent to the dilution level. (80% natal water is equivalent to the 20% dilution target). Shaded grey boxes represent the general time periods in which Gates Creek (GC) and Portage Creek (PC) sockeye from each population were tagged in 2013-2014. Dashed red lines represent the current natal water concentration targets for Gates Creek (80%) and Portage Creek (90%) sockeye.**

3.4.2.2 Physiological State and Reproductive Hormone Levels

Mean levels of plasma glucose, lactate, and testosterone were compared between sexes, populations, and years for Gates and Portage Creek sockeye populations in 2013 and 2014. The purpose of this work was to try to identify any group of fish that may be experiencing larger levels of stress, as indicated by glucose, lactate, or testosterone levels, than other groups. Fish that experience more stressful conditions may be more vulnerable to changes in dilution levels or dam operations. We found no differences between years within each of the parameters measured for each population (Table 3.4). Glucose levels were remarkably similar among males and females, both within and between the populations. However, lactate was ~1.4 times higher in females compared to males in each population, and ~1.3 times higher among all Gates Creek fish relative to Portage Creek fish. Testosterone was considerably higher in females compared to males for both populations (5.6 times higher in Gates Creek population; 4.9 times higher in Portage Creek population), and Portage Creek sockeye had 2.2 times higher levels of this hormone than Gates Creek sockeye.

Table 3.4 Mean ± SD (range) of fork length, glucose, lactate, and testosterone for a subset female (F) and male (M) Gates Creek and Portage Creek sockeye salmon tagged in 2013 and 2014.

		Gates Creek		Portage Creek	
		2013	**2014**	**2013**	**2014**
Sample Sizes Females (F) Males(M)		*n* = 63 (F) *n* = 48 (M)	*n* = 83 (F) *n* = 62 (M)	*n* = 13 (F) *n* = 6 (M)	*n* = 41 (F) *n* = 30 (M)
Fork length (cm)	F	56.6 ± 3.0 (49 – 65.5)	57.4 ± 4.0 (51 – 63)	56.3 ± 1.9 (54 – 60)	58.3 ± 2.3 (49.5 – 62.5)
	M	60.0 ± 3.1 (52 – 67.5)	61.9 ± 4.0 (53 – 69)	57.8 ± 1.9 (55 – 61)	61.6 ± 2.9 (51.5 – 67)
Glucose (mmol L^{-1})	F	5.5 ± 1.3 (2.9 – 10.2)	4.5 ± 0.8 (3.0 – 9.3)	4.1 ± 1.1 (2.5 – 7.0)	4.6 ± 1.0 (2.6 – 7.5)
	M	5.6 ± 1.5 (4.2 – 13.7)	5.4 ± 1.4 (2.5 – 10.1)	3.7 ± 1.0 (2.2 – 5.3)	5.0 ± 0.8 (3.7 – 8.0)
Lactate (mmol L^{-1})	F	5.5 ± 3.7 (0.9 – 16.1)	5.0 ± 2.5 (1.4 – 11.0)	4.7 ± 2.1 (2.2 – 8.4)	3.8 ± 1.5 (1.5 – 8.5)
	M	3.6 ± 2.3 (0.8 – 10.2)	3.7 ± 1.9 (0.7 – 10.0)	2.6 ± 1.5 (0.9 – 4.7)	2.8 ± 1.1 (1.1 – 4.7)
Testosterone (ng ml^{-1})	F	82.0 ± 97.4 (1.1 – 398.1)	53.32 ± 56.5 (2.1 – 385.6)	148.8 ± 108.9 (18.3 – 365.2)	138.4 ± 73.3 (13.3 – 306.8)
	M	16.7 ± 17.7 (0.9 – 83.6)	8.0 ± 6.63 (1.2 – 31.1)	88.3 ± 66.7 (33.5 – 216.2)	16.57 ± 10.0 (5.7 – 42.9)

3.4.2.3 Seton Generating Station Attraction and Forays

Of all the sockeye released into the Fraser River in 2013 and 2014, 87% (265/304) and 91% (193/213), from Gates Creek and Portage Creek, respectively, made at least one foray into the Seton Generating Station tailrace. However, only fish that had complete physiological profiles were included in models predicting forays (255 Gates Creek and 90 Portage Creek sockeye). Fifty-six percent (142/255) of these Gates Creek fish made only one foray into the tailrace, while the remainder made up to eight forays (Figure 3.17a). In contrast, 43% of the modeled Portage Creek sockeye (39/90) made only one foray into the tailrace, while the remainder made up to 24 forays (Figure 3.17b). On average, modeled Portage Creek sockeye (3.6 forays ± 4.0) made nearly twice as many forays into the Seton Generating Station tailrace as Gates Creek sockeye (1.9 forays ± 1.4),

It appears the dilution of natal water in the Seton River could cause a change in behaviour that increases the time it takes for sockeye to pass Seton Dam. This effect was strongest in Portage Creek sockeye. Dilution of natal water and Seton Generating Station temperature had the largest effects on forays among Portage Creek sockeye and were included in most models from the 95% confidence set (Figure 3.17). Estimates for these effects were negative and had 95% confidence intervals that did not include zero, indicating that Portage Creek sockeye that encountered increased dilution levels or decreased Seton Generating Station temperatures made a greater number of forays into the tailrace.

Foray behaviour among Gates Creek sockeye was largely unaffected by the dilution levels experienced in 2013 and 2014 or by Seton Generating Station temperatures, as these effects were absent from most of the models in the 95% confidence set. However, very few Gates Creek sockeye experience high dilution in 2013 or 2014, and model selection results indicated a large amount of uncertainty in foray models for Gates Creek fish, whereas there was less uncertainty in models for Portage Creek sockeye. However, results from the dilution field experiment (see Section 3.4.6), in which dilution level was increased to 30%, suggest that Gates Creek sockeye do change their behaviour near the Seton Generating Station with increased dilution of natal water.

There was little indication that foray behaviour in fish from either Gates or Portage Creek populations was affected by the temperature differential between the Seton Generating Station tailrace and Fraser River.

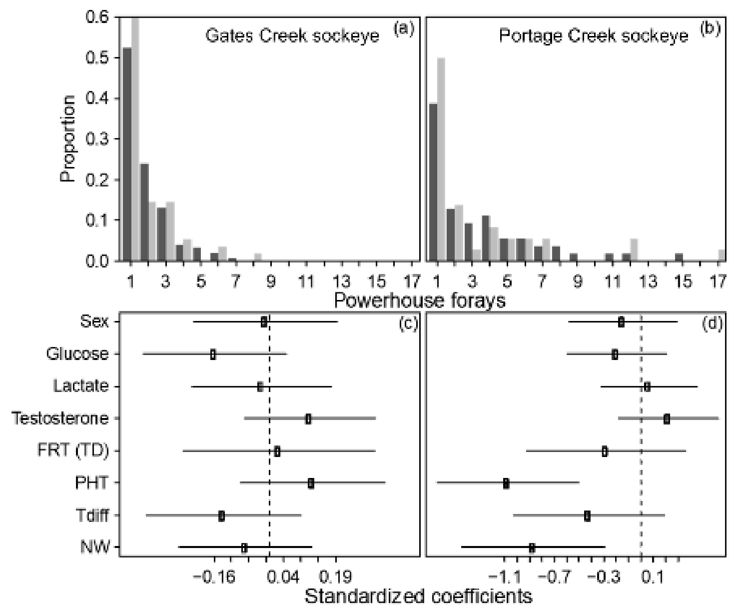

Figure 3.17 **The top panels are histograms of the number of forays female (grey bars) and male (black bars) Gates Creek (Panel a) and Portage Creek (Panel b) sockeye made into the tailrace (Seton Generating Station) as a proportion of all the individuals included in models predicting this behaviour. One Portage Creek female that made 24 forays was removed from the histogram for clarity. The bottom panels are model-averaged standardized coefficient estimates for models predicting the number of forays Gates Creek (Panel c) and Portage Creek (Panel d) sockeye made into the Seton Generating Station. Vertical dashed line indicates the coefficient value of zero. Abbreviations for predictor variables include Fraser River temperature (FRT), powerhouse (Seton Generating Station) temperature (PHT), temperature differential between the Fraser River and Generating Station (Tdiff), and natal water concentration (NW). FRT is shown with TD in parentheses to indicate that tagging date was substituted for Fraser River temperature in the Portage Creek foray model (panel d only). Note the difference in x-axis scales for Gates Creek and Portage Creek panels (c and d). Also note NW is the inverse of the variable 'dilution' therefore strong negative effects of natal water concentration (Portage sockeye Panel d) is the same as a strong positive effect of natal dilution.**

3.4.2.4 Wandering

Models predicting wandering behaviour included 235 Gates Creek and 78 Portage Creek sockeye with complete physiology and maturity profiles. Eighty-three percent (195/235) and 73% (57/78) of Gates Creek and Portage Creek sockeye, respectively, migrated upstream in the Fraser River directly to the Seton River without exhibiting any backwards, downstream movements from the Seton River-Fraser River confluence to the Seton Generating Station (Figure 3.18a, b). Males and females within each population displayed similar amounts of wandering, although there was more variability in this behaviour among Portage Creek sockeye.

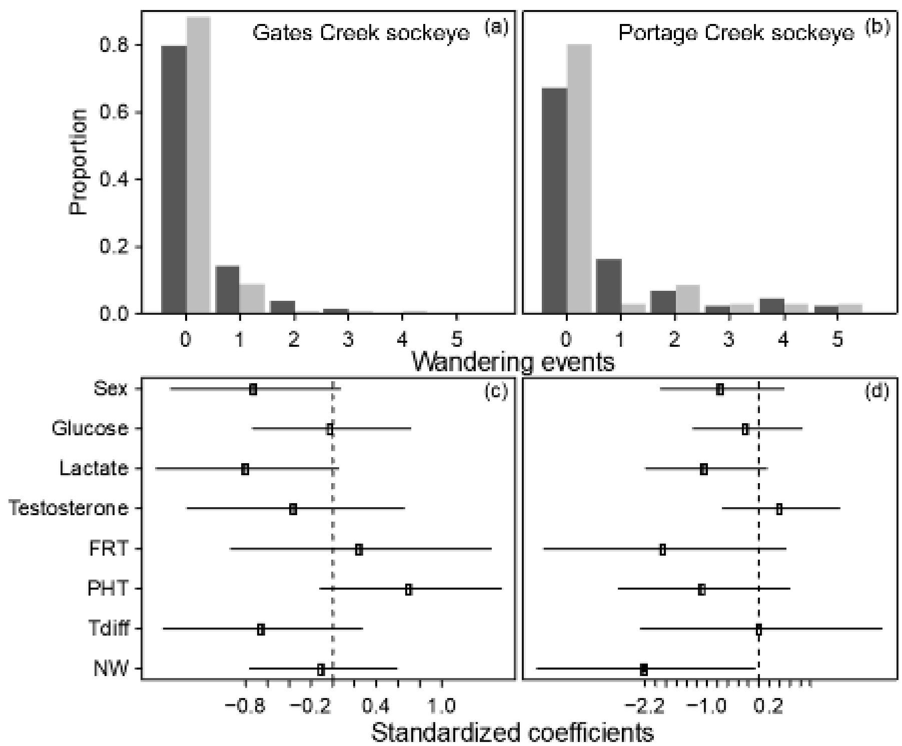

Figure 3.18 **The top panels are histograms of the number of wandering events by female (grey bars) and males (black bars) of Gates Creek (Panel a) and Portage Creek (Panel b) sockeye shown as a proportion of all individuals included in the models predicting wandering behaviour for each population. One Gates Creek female wandered 9 times and was removed from the histogram for clarity. The bottom panels are model-averaged standardized coefficient estimates for models predicting wandering for Gates Creek (Panel c) and Portage Creek (Panel d) sockeye. Vertical dashed line indicates the coefficient value of zero. Abbreviations for predictor variables include Fraser River temperature (FRT), powerhouse (Seton Generating Station) temperature (PHT), temperature differential between the Fraser River and Generating Station (Tdiff), and natal water concentration (NW). Note the difference in x-axis scales between panels. Note that natal water concentration (NW) is the inverse of the variable 'dilution' therefore negative effects of natal water concentration (Portage sockeye Panel d) is the same as a positive effect of natal dilution.**

Fraser River temperature had little effect on wandering behaviours of Gates Creek sockeye but was included in most of the models in the 95% confidence set for the Portage Creek population. Cooler temperatures in the Fraser River may have been reduced the amount of wandering behaviour exhibited by Portage Creek sockeye. Warmer temperatures at the Seton Generating Station may have been associated with increased wandering among Gates Creek sockeye and less wandering among Portage Creek sockeye. There was no evidence that the temperature differential between the Seton Generating Station tailrace and the Fraser River influenced wandering in either population. Dilution level (natal water concentration) was included in most of the models from the 95% confidence set for Portage Creek sockeye and had the largest effect of all predictors on wandering within this population. Wandering was reduced among Portage Creek sockeye that encountered lower dilution levels, while wandering among Gates Creek sockeye was largely unaffected by changes in dilution.

3.4.2.5 Delay at Seton Generating Station Tailrace

Data on fish from 256 Gates Creek and 90 Portage Creek sockeye with complete physiology and maturity profiles were used to estimate migration delay at the Seton Generating Station, or the total time fish spent in the tailrace.

The sex of fish had no effect on delay at the Seton Generating Station (Figure 3.19b, c). Mean delay of Gates Creek females (mean delay 5.3 h ± 6.4 SE) were only somewhat higher than Gates Creek males (mean delay 3.4 h ± 3.9 SE), and only slightly lower in Portage Creek females (mean delay 19.5 h ± 18.5 SE) compared to Portage Creek males (mean delay 23.4 h ± 27.1 SE). Overall, Portage Creek sockeye delayed almost 5 times longer than Gates Creek fish (mean delay 21.1 h versus 4.5 h) (Figure 3.19a). Portage Creek sockeye displayed a higher number of multiple wandering events than Gates Creek sockeye and spent a longer amount of time migrating from release to the Seton Dam. Portage Creek sockeye could delay because cooler water temperatures during the migration period allowed them to spend more time in the Fraser River without experiencing relatively high water temperatures.

There was an interaction between glucose levels and delay at the Seton Generating Station tailrace in the Gates Creek population, as individuals with higher plasma glucose concentrations spent less time in the tailrace. Elevated glucose can be indicative of recovery from swimming fatigue and excessive handling or confinement (Farrell et al. 1998; Roscoe et al. 2010). It is possible that Gates Creek sockeye were experiencing some modest physiological stress from migrating ~340 km up-river during peak summer temperatures. Plasma glucose levels at time of capture were similar to levels found previously in this population (Roscoe et al. 2010), but not as high as those recorded for summer-run sockeye salmon captured in the lower Fraser River (Donaldson et al. 2010). Because we found there was only limited opportunity for thermal refuge in the tailrace during the Gates Creek migration (Figure 3.16), exhausted or physiologically compromised individuals may have chosen to avoid this unfavourable area and move more quickly to the Seton River where flows and temperatures were lower and more conducive to physiological recovery. Indeed, it has been shown that sockeye salmon in the Columbia River migrate more rapidly toward natal tributaries as mainstem temperature increases (Naughton et al. 2005). Plasma glucose levels did not influence delay among Portage Creek sockeye, perhaps related to the lower temperatures they experience during their migration.

Dilution level (i.e., natal water concentration) had the largest relative effect size of all predictors on tailrace delay and was included in most models from the 95% confidence set for the Portage Creek population. Delay at the Seton Generating Station decreased when Portage Creek sockeye encountered decreasing dilution levels in the Seton River plume. Effects of temperatures in the Seton Generating Station tailrace itself were also well-supported in models for the Portage Creek population, with a strong negative effect indicating that Portage Creek sockeye delayed less during periods of elevated temperatures in the tailrace. Despite a similar trend among Gates Creek sockeye, 95% confidence intervals for the effect of Seton Generating Station tailrace temperature included zero. Finally, there was no indication that the temperature differential between the Seton Generating Station tailrace and the Fraser River affected delay in either Gates or Portage Creek sockeye populations, indicating that Gates Creek sockeye delay in the tailrace is unlikely to be associated with fish seeking thermal refuge.

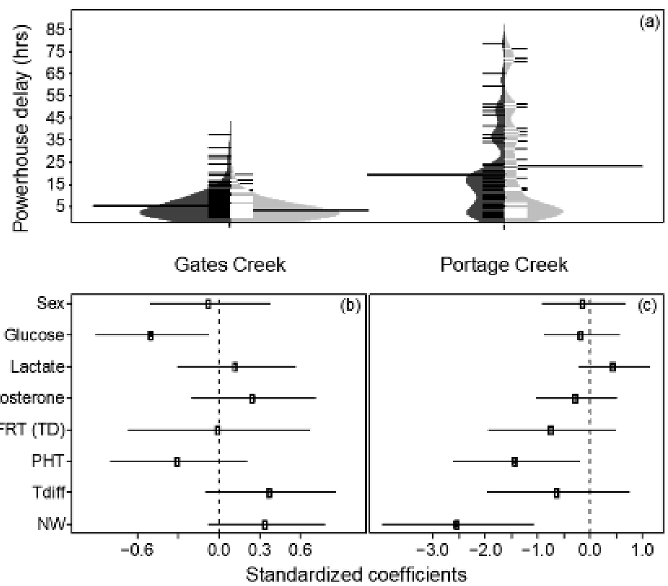

Figure 3.19 **Top panel show distribution plots of total migration delay in the powerhouse (Seton Generating Station) tailrace for female (black shading) and male (grey shading) Gates Creek and Portage Creek sockeye used in models predicting behaviour. Shaded polygons represent the distribution of individual delay times (small horizontal lines) and bold horizontal lines represent means. Bottom panels are model-averaged standardized coefficient estimates from models predicting the total amount of migration delay incurred by Gates Creek (Panel b) and Portage Creek (Panel c) sockeye in the Generating Station tailrace. Coefficient estimates with 95% confidence intervals that do not include zero are highlighted by solid black circles. Vertical dashed line indicates the coefficient value of zero. Abbreviations for model variables include Fraser River temperature (FRT), powerhouse (Seton Generating Station) temperature (PHT), temperature differential between the Fraser River and Generating Station (Tdiff), and natal water concentration (NW). FRT is shown with TD in parentheses to indicate that tagging date was substituted for Fraser River Temperature in the Portage Creek delay model (Panel c only). Note the difference in x-axis scales between panels, and that natal water concentration (NW) is the inverse of the variable 'dilution' therefore strong negative effects of natal water concentration (Portage sockeye Panel c) is the same as a strong positive effect of dilution.**

3.4.3 Effects of High Dilution on Gates Creek Sockeye Migration (2015)

In 2013 and 2014, Portage Creek sockeye showed a significant response to dilution in terms of forays, wandering and delay. Gates Creek sockeye, however, did not experience high dilution during these years. An experiment was therefore necessary to determine the effect of dilution on Gates Creek sockeye. During the Gates Creek sockeye migration in August, dilution in the Seton River is typically between 5% and 7%. Management targets from the Bridge River Water Use Plan aim to maintain a minimum of 80% natal water concentration or a dilution level of less than 20% in the Seton River. However, the natal water concentrations often exceed these targets because of events unrelated to hydroelectric operations such as heavy rainfall events. Evidence-based management targets were developed in the late-1980s using streamside preference experiments (Fretwell 1989) that were re-tested in 2013-2014 (Section 3.4). However, the effectiveness of the targets had not been studied in the field, as BC Hydro managed dilution to the target levels in 2013 and 2014. Therefore, whole-system trials manipulating the dilution level of the entire Seton River during migration were needed and in 2015 the previously derived targets were tested with a whole-system experiment.

3.4.3.1 Experimental Manipulation of Dilution

From the 07 to 15 of August 2015, dilution levels in the Seton River were experimentally increased while concurrently monitoring Gates Creek sockeye salmon migration in the Fraser River. Walden North operations were modified to increase diversion of water from the plant into Cayoosh Creek and the Seton River. This diversion increased the dilution of natal water levels of the Seton River to approximately 28% on 13 August 2015, exceeding 20% target dilution level in the Water Use Plan for the Gates Creek sockeye migration period (Figure 3.20). For analyses provided in this section (3.4.3), we refer to this period of experimentally increased dilution levels (i.e., dilution >20%) as “dilute conditions”. Following this experiment, Cayoosh Creek discharge into the Seton River was gradually decreased over 4 days, which decreased dilution levels to 8%. We refer to the period of low dilution (i.e., dilution <20%) as “routine conditions”. A major rainfall event in late August caused a second decrease in natal water concentrations (i.e., increase in the levels of dilution of natal water) over three days from August 30 – September 1 (Figure 3.20). On 30 August and 31 August, dilution levels were 21% and 22%, respectively, and on 01 September the Seton River reached dilution levels of 25%. After 01 September, dilution levels decreased and were below target levels for the remainder of the migration period. Fraser River temperature and discharge generally decreased over the study duration, ranging from 14.0 – 19.4 °C (mean = 17.7 ± 1.6 °C), and 1101 – 1909 $m^3 \cdot s^{-1}$ (mean = 1475 ± 251 $m^3 \cdot s^{-1}$), respectively.

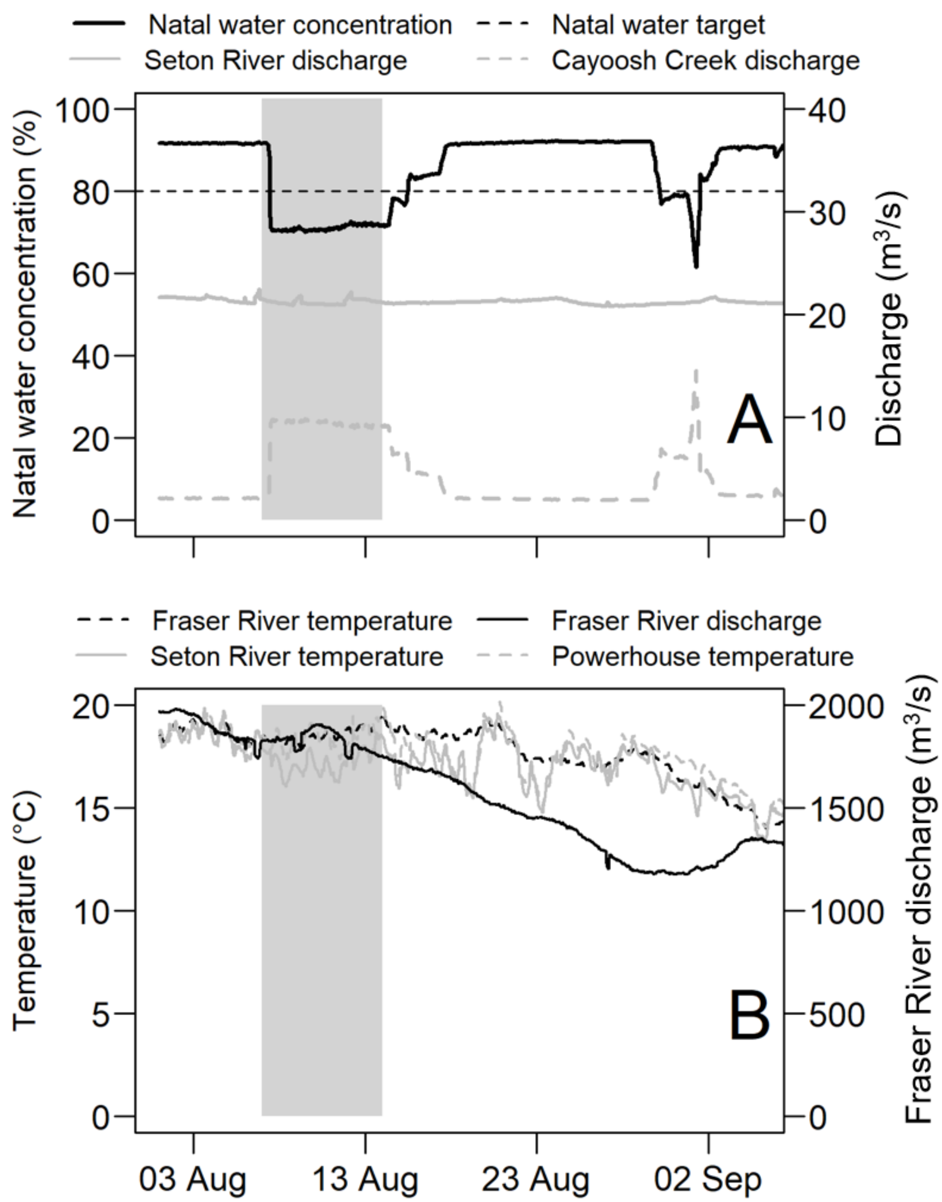

Figure 3.20 **Environmental variables measured over the study duration. Panel A shows natal water concentration and natal water targets (i.e., dashed horizontal black line at 80% natal water concentration or 20% dilution) for the Seton River, and Seton River and Cayoosh Creek discharge. The top panel (Panel A) shows the natal water concentration which is the inverse of dilution levels. The bottom panel (Panel B) shows temperature for the Fraser River, Seton River and the Seton Generating Station and Fraser River discharge. The shaded grey area indicates the period when natal water concentration in the Seton River was experimentally lowered to approximately 73% (i.e., a 28% dilution level) with Cayoosh Creek water.**

3.4.3.2 Gates Creek Sockeye Response to Experimental Manipulation of Dilution

Of the 193 Gates Creek sockeye radio-tagged during the 2015 dilution trials, 76 fish were tagged during dilute conditions between the 07 August and 14 August and an additional 117 sockeye were tagged during routine conditions between the 18 August and 30 August (Table 3.5). Radio telemetry detection data showed that all Gates Creek sockeye released during dilute conditions entered the Seton River while conditions were still dilute (>20% dilution), but six fish released immediately prior to the rainfall event on 30 August experienced both routine conditions and dilute (but not experimentally diluted) conditions. The six fish that experienced both dilute and routine conditions were excluded from statistical models except the Cox Proportional Hazard Model estimating delayed entry to the Seton River, which allow individuals that experienced multiple levels of a treatment to be included (Kleinbaum & Klein 2012).

3.4.3.3 Effect of Dilution on Seton River Entry Success

Table 3.5 The number of sockeye tagged and released near the Seton and Fraser River confluence in 2015. The number of fishes that entered the Seton River by natal water conditions and sex is shown along with proportion of fish that entered the Seton River. Numbers in parentheses are the percentage of column totals within each natal water condition.

Dilution conditions	Sex	Number tagged	Number entered	Proportion entered the Seton River
Dilute (>20% Dilution)	Male	44 (58%)	41 (65%)	0.93
	Female	32 (42%)	22 (35%)	0.69
	Total	76	63	**0.83**
Routine (<20% Dilution)	Male	61 (52%)	59 (52%)	0.97
	Female	56 (48%)	54 (48%)	0.96
	Total	117	113	**0.97**
Total	Male	105 (54%)	100 (57%)	0.95
	Female	88 (46%)	76 (43%)	0.86
	Total	193	176	**0.91**

Failing to meet dilution targets has a significant negative effect on entry of female Gates Creek sockeye in the Seton River. One hundred thirteen (97%) of the 117 of Gates Creek sockeye released during routine conditions (<20% dilution) entered the Seton River, and 63 (83%) of the 76 Gates Creek sockeye released during dilute conditions (>20% dilution) entered the Seton River (Table 3.6; Figure 3.21). Although temperature and gross somatic energy have been shown to have important effects on salmon migration, they were not significant covariates in the models we tested. Thus, we did not include them in a predictive model estimating migration success. The predictive model indicated a significant effect of dilution levels on Seton River entry success (Table 3.6; Figure 3.21), showing that when Water Use Plan dilution targets of <20% dilution are exceeded during the Gates Creek sockeye migration there is a substantial impact to migratory success that disproportionately affects females.

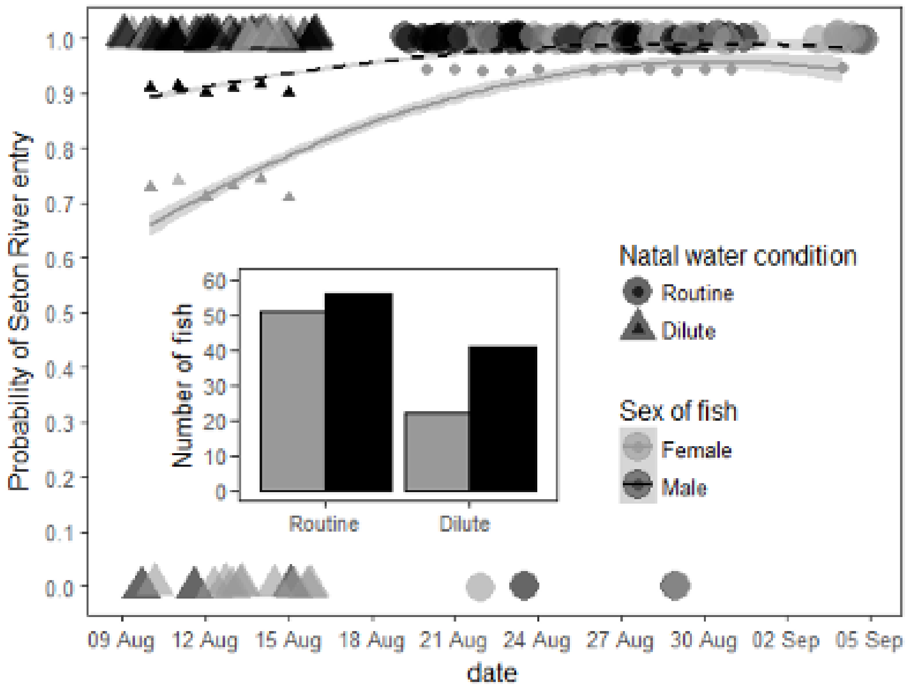

Figure 3.21 **The probability of 187 Gates Creek sockeye salmon released downstream of the Seton Generating Station entering the Seton River during the dilution level experiment in 2015. Individual male (dark symbols) and female (grey symbols) sockeye were either released during dilute natal water conditions in the Seton River (>20% dilution, <80% natal water; triangles) or routine natal water conditions (<20% dilution, >80% natal water; circles). Individual data are binomial and shown as large symbols. Small symbols and regression lines give predicted results of Generalized Linear Mixed Models and provide 95% confidence intervals on the line of best fit. Inset provides sample sizes.**

Table 3.6 Result from Generalized Linear Mixed Models (GLMMs) testing association between explanatory variables and Seton River entry success of 187 Gates Creek sockeye released downstream of the Seton Generating Station in 2015. Results are presented for a full model that includes non-significant covariates and for a predictive model that includes only significant covariates and the term for experimental dilution of natal water. Coefficients (coef) are standardized to provide direction and strength of the effect of each variable. Standard errors (SE) are also provided as are the results of likelihood ratio test of the variables. The interaction between natal water condition and sex was not significant (X^2 = 1.9, p=0.164), and was thus omitted from the final models. The mean standard error of the random effect in the full model was 0.26 (median = 0.26, range = 0.24, 0.26).

	Explanatory terms	coef (SE)	Odds ratio (95% CI)	X^2	DF	p-value
Full model	Intercept	2.7 (0.62)	15.5 (4.58, 52.53)	19.4	1	<0.001
R^2 = 0.264	Natal water condition (dilute)	-1.5 (0.82)	0.2 (0.04, 1.11)	3.4	1	0.067
	Sex (male)	1.2 (0.60)	3.5 (1.08, 11.16)	4.3	1	0.037
	Fraser River temperature	-0.3 (0.90)	0.7 (0.12, 4.20)	0.1	1	0.713
	Gross somatic energy	-0.3 (0.60)	0.7 (0.23, 2.31)	0.3	1	0.588
Predictive model	Intercept	2.8 (0.58)	16.7 (5.38, 52.12)	23.6	1	<0.001
R^2 = 0.262	Natal water condition (dilute)	-1.8 (0.62)	0.2 (0.05, 0.54)	8.8	1	0.003
	Sex (male)	1.3 (0.59)	3.7 (1.18, 11.78)	5.0	1	0.025

Exceeding dilution targets during the Gates Creek sockeye migration results in longer migration times, especially for females. During routine conditions, Gates Creek sockeye salmon took 19.3 ± 14.9 h (range = 2.8 to 87.9 h) to enter the Seton River after being released downstream. When the Seton River was diluted, differences from Kaplan Meier estimates showed Gates Creek sockeye salmon took 12.2 h longer to enter the Seton River, and female fish delayed 4.6 h longer than males (Figure 3.22). There was no support for an effect of Fraser River temperature, gross somatic energy or the number of hours from release to sunset (diel effects) in the Cox Proportional Hazard Model used in the time-to-event analysis (Table 3.7). Again, current management targets of maintaining less than 20% dilution in the Seton River during the Gates Creek sockeye migration appear appropriate. Exceeding 20% dilution levels in the Seton River results in Gates Creek sockeye, especially females, taking longer to complete migration.

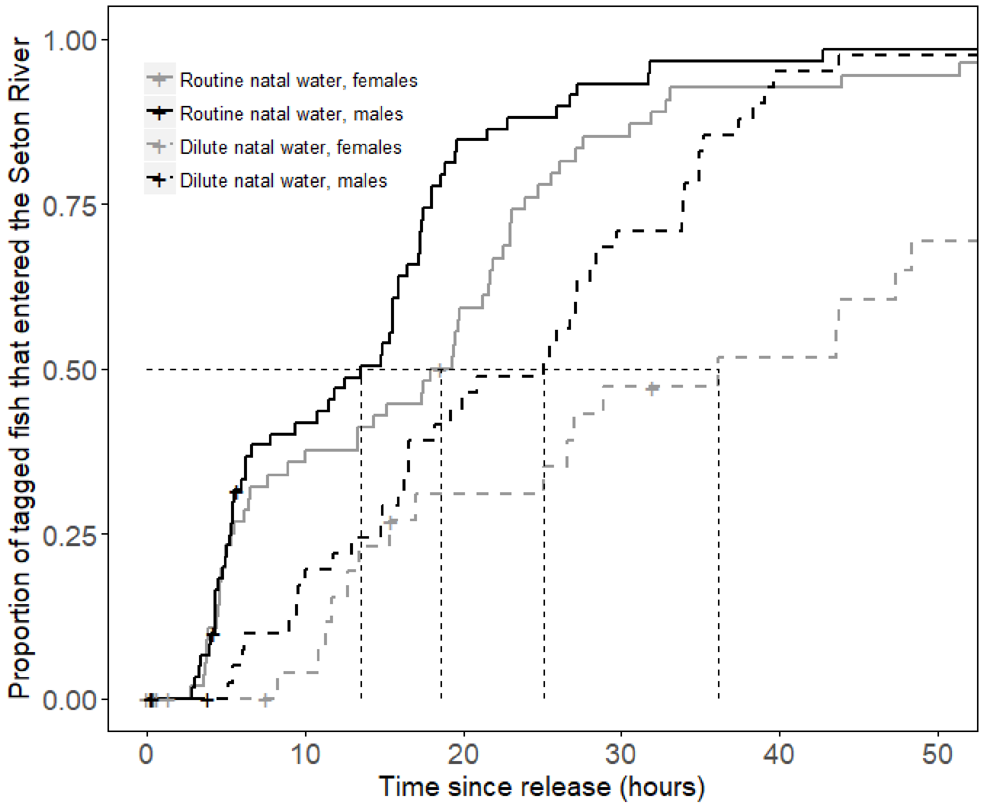

Figure 3.22 **Kaplan-Meir curves depicting the proportion of 193 tagged sockeye entering the Seton River by time since release. Lines represent times when the Seton River was composed of >80% natal water concentration <20% dilution during routine natal water conditions (solid lines). The dilute condition occurs when there was <80% natal water or >20% dilution (dashed lines). Data were separated to show delay in male (black) and female (grey) entry into the Seton River after release. Dashed black lines represent the median delay where half the population of tagged sockeye have entered the Seton River.**

Table 3.7 **Model estimates from time-to-event analysis using a Cox Proportional Hazard Mixed Model indicating how explanatory variables affected the likelihood of 193 tagged sockeye entering the Seton River at any given time interval. Coefficients (coef) are standardized to provide direction and strength of the effect of each variable. Standard error (SE) are also provided as are results of Likelihood Ratio tests of variables. The interaction between the experimental treatment and sex of the fish was not significant (χ^2 = 0.75, p=0.385), and was thus omitted from the final model.**

Explanatory terms	coef (SE)	*Odds Ratio (95% CI)*	X^2	DF	p-value
Natal water condition (dilute)	-1.0 (0.25)	0.4 (0.24, 0.62)	30.2	1	<0.001
Sex (male)	0.6 (0.19)	1.8 (1.26, 2.67)	12.5	1	0.002
Fraser River temperature	-0.1 (0.20)	0.9 (0.61, 1.33)	0.47	1	0.600
Gross somatic energy	-0.2 (0.22)	0.8 (0.52, 1.24)	0.99	1	0.310
Diel effects	-0.0 (0.02)	1.0 (0.95, 1.03)	0.31	1	0.580

3.4.3.4 Relationship Between Migration Time and Seton Generating Station Delay

To determine if natal water released from the Seton Generating Station was the cause of delay in Gates Creek sockeye migration, we examined the correlation between the time it took to enter the Seton River and the time fish spent at the Seton Generating Station. Overall the average time fish spent at the Seton Generating Station increased from 2.1 hours (range = 0 - 17.9 hours, median = 0.6 hours) during routine conditions to 3.7 hours (range = 0 – 13.8 hours, median =2.1 hours) during dilute conditions. However, there was a significant negative interaction between time spent at the generating station and high dilution (p-value = 0.030, Table 3.8). Additionally, as seen in the entry success and migration timing analysis there was a marginally significant interaction (p-value = 0.055, Table 3.8) between dilute conditions and the sex of fish suggesting sex specific responses.

Subsets of the original data set were examined to determine if the effect of time at the generating station on migration time was significant for each sex and under different dilution conditions. Data subsets were used because the main effect of the full model cannot be interpreted when there are significant interactions. The only significant correlation between migration time to the Seton River and time at the Seton Generating Station that remained was during routine conditions. For both sexes, there was a significant positive correlation between time at the generating station and migration time (positive coefficient in Table 3.9) during routine conditions.

Table 3.8 Results from GLMMs testing factors influencing the correlation between time from release of radio-tagged Gates Creek sockeye to their entry into the Seton River and the time these fish spent in the Seton Generating Station tailrace. Interactions between generating station delay and >20% dilution of natal water in the Seton River, and >20% dilution and the sex of fish provide indication of the influence of sex and dilution on time spent at the generating station. When interactions are significant data subsets are used to test main effects. Coefficients (coef) are standardized to provide direction and strength of the effect of each variable. Standard error (SE) are also provided as are results of Likelihood Ratio tests of variables.

Model	Explanatory terms	coef (SE)	X^2	DF	p-value
Full model	Intercept	13.7 (0.69)	42.8	1	<0.001
R^2 = 0.28, n=170	Time at generating station	1.0 (0.35)	8.5	1	0.003
	Natal water condition (dilute)	21.0 (3.92)	28.6	1	<0.001
	Sex (male)	-2.2 (2.57)	0.7	1	0.388
	Gross somatic energy	0.8 (1.14)	0.5	1	0.487
	Time at generating station X Natal water condition (dilute)	-1.2 (0.57)	4.7	1	0.030
	Natal water condition (dilute) x sex	-8.3 (4.31)	3.7	1	0.055

Table 3.9 **Results of GLMM examining the correlation between time from release of radio-tagged Gates Creek sockeye and time spent at the Seton Generating Station. Results of four models are provided from data divided into males and females under routine (<20% dilution) and dilute (>20% dilution) natal water conditions so that estimates of the main effects of terms with significant interactions can be made. A scaled term for Gross Somatic Energy was retained as a covariate and date of release as random effect to partially account for the influence of run timing. Coefficients (coef) are standardized to provide direction and strength of the effect of each variable. Standard error (SE) are also provided as are results of Likelihood Ratio tests of variables.**

Model	Explanatory terms	coef (SE)	X^2	DF	p-value
Male, Routine	Time at generating station	1.0 (0.44)	5.1	1	0.024
R^2 = 0.12, n= 56	Gross somatic energy	-1.0 (1.22)	0.7	1	0.404
Male, Dilute	Time at generating station	0.2 (0.50)	0.1	1	0.722
R^2 = 0.03, n= 41	Gross somatic energy	2.3 (2.05)	1.3	1	0.253
Female, Routine	Time at generating station	1.1 (0.37)	8.5	1	0.004
R^2 = 0.15, n =51	Gross somatic energy	0.2 (1.61)	0.0	1	0.877
Female, Dilute	Time at generating station	-1.8 (1.39)	1.7	1	0.194
R^2 = 0.46, n = 22	Gross somatic energy	0.1 (4.38)	0.0	1	0.979

Despite positive correlation for both sexes under routine conditions, it appears that only males substantially alter the time they spend at the Seton Generating Station in response to changing dilution levels in the Seton River (Figure 3.23A). Male Gates Creek sockeye spent 2.7 hours longer on average at the Seton Generating Station under dilute conditions than under routine conditions, but females spent the same amount of time at the Seton Generation Station under dilute and routine conditions. Time spent at the Seton Generating station was significantly correlated with time from release to Seton River entry (Table 3.10) under routine conditions for both sexes (Figure 3.23B), but not under dilute conditions.

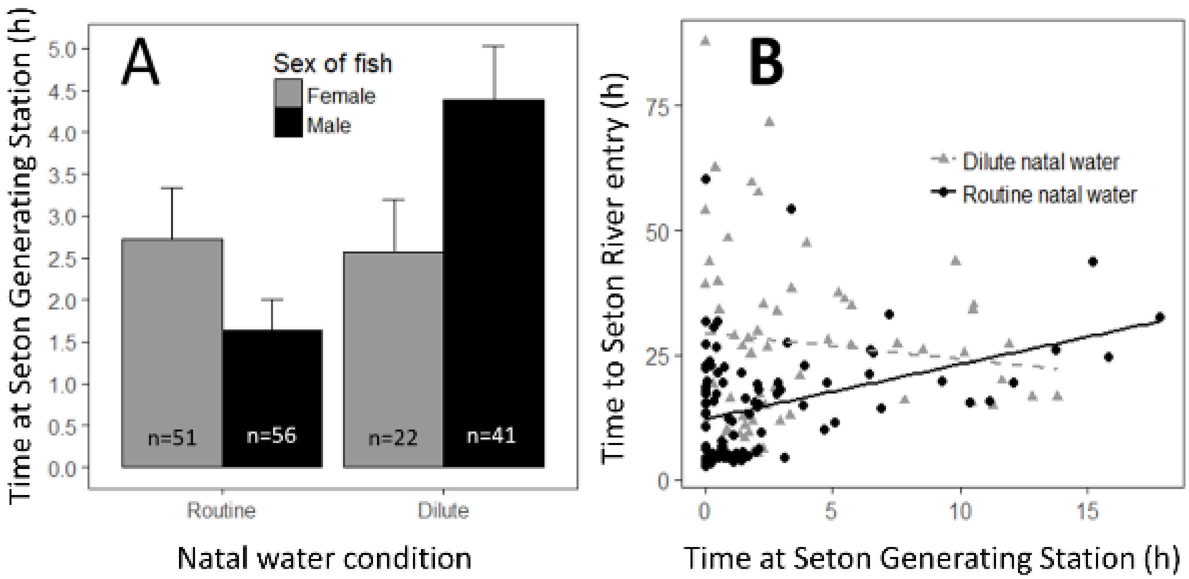

Figure 3.23 **Results from two models showing the number of hours male and female Gates Creek sockeye salmon were detected at the Seton Generating Station under routine and dilute natal water conditions with standard error (panel A) and the influence of delay at the Generating Station on the time it took sockeye to enter the Seton River after release (panel B). Data in panel B are separated to show when the Seton River was composed almost entirely of natal water during routine natal water conditions (grey triangles and dotted line) or was diluted with water from Cayoosh Creek (i.e., dilute natal water conditions; black circles and solid line).**

Table 3.10 **Results of GLMM testing for effects on time from release in the Fraser River to entry into the Seton River (migration time) during routine and dilute natal water conditions. Coefficients (coef) are standardized to provide direction and strength of the effect of each variable. Standard error (SE) are also provided as are results of Likelihood Ratio tests of variables.**

Model	Explanatory terms	coef (SE)	X^2	DF	p-value
Routine Natal Water (<20%), R^2 = 0.15, n= 107	Intercept	13.7 (1.60)	73.5	1	<0.001
	Time at Generating Station	1.1 (0.27)	15.1	1	<0.001
	Sex (male)	-2.7 (2.01)	1.8	1	0.182
	Gross Somatic Energy	-0.4 (1.01)	0.2	1	0.698
Dilute Natal Water Conditions (>20%) R^2 = 0.12, n= 63	Intercept	34.1 (4.1)	70.6	1	<0.001
	Time at Generating Station	-0.1 (0.6)	0.0	1	0.866
	Sex (male)	-9.7 (4.6)	4.4	1	0.036
	Gross Somatic Energy	2.5 (2.3)	1.2	1	0.275

3.4.3.5 Summary of 2015 Gates Creek Dilution Experiment

The overall findings of the 2015 dilution experiment are that when dilution levels in the Seton River fall below the management target (20%), male Gates Creek sockeye will increase delay at the Seton Generating Station, but that this behaviour does not extend migration time to the Seton River. Time spent at the generating station is only correlated with migration time during low routine conditions and the largest impact of high dilution occurs in females, whose behaviour at the generating station remains unchanged but who fail to enter the Seton River in large numbers when dilution targets are exceeded. Female Gates Creek sockeye had longer travel times from release to Seton River entry under dilute conditions as indicated here and by the time-to-event analysis, but they do not increase delay at the generation station. Females Gates Creek sockeye salmon also fail to enter the Seton River much more than males when dilution is above target levels.

The time female Gates Creek sockeye spent at the Generating Station was unrelated to dilution conditions, which differs from the results obtained for Portage Creek sockeye in 3.4.2. It is worth noting, however, that changes in dilution were less dramatic in the Portage Creek sockeye analysis (dilution rarely exceeded the 10% target level for this population). It is possible that other behaviours, such as increased forays or wandering events, could contribute to the observed increase in delay and failure to enter the Seton River under dilute conditions for female Gates Creek sockeye. It is also possible that these fish are spending more time holding in the Fraser River, although our telemetry array does not allow us to test this. Further, natal water concentrations in the Seton River, migration time, and time at the Seton Generating Station are not correlated during dilute natal water conditions for either sex. Current Water Use Plan guidelines aimed at maintaining 80% natal water concertation (<20% dilution) in the Seton River during Gates Creek sockeye migration appear sufficient.

- *A lower proportion of Gates Creek sockeye salmon entered the Seton River when natal water concentrations are below 80% (i.e., dilution levels >20%). This was especially true for female fish, 30% of which did not complete the migration under dilute natal water conditions.*
- *Gates Creek sockeye migration from the Fraser River release site to the Seton River entry took 29% longer when natal water concentration in the Seton River were below 80% (i.e., >20% dilution levels).*
- *The time Gates Creek sockeye spent at the Seton Generating Station was not correlated with time from release to Seton River entry when there was <80% natal water in the Seton river (i.e., >20% dilution levels).*
- *Results from the experimental manipulation natal water concentration (i.e., dilution levels) during Gates Creek sockeye migration support the current Bridge River Water Use Plan dilution targets.*

3.5 Assessment of Injuries in Relation to Seton Generating Station Operations

Gates Creek and Portage Creek sockeye salmon tagged from 2014-2016 and collected as mortalities from the Seton River fish fence were assessed for injuries to determine if any fish were incurring injuries while attempting to swim into the Seton Generating Station. Injuries on individual fish were classified based on injury origin (Figure 3.24) and overall severity (Figure 3.25). In all years, most Gates Creek sockeye were either uninjured or displayed minor injuries (Table 3.11). The proportion of Gates Creek sockeye captured at the Seton River fish fence displaying any level of injury was 63%, 88% and 88% in 2014, 2015 and 2016, respectively (Table 3.11). Moderate or severe injuries, which could be expected to contribute to migratory failure, were present on 21% of tagged fish in 2014, 26% in 2015 and 31% in 2016. By comparison, only 6% of Portage Creek sockeye displayed moderate or severe injuries (2014).

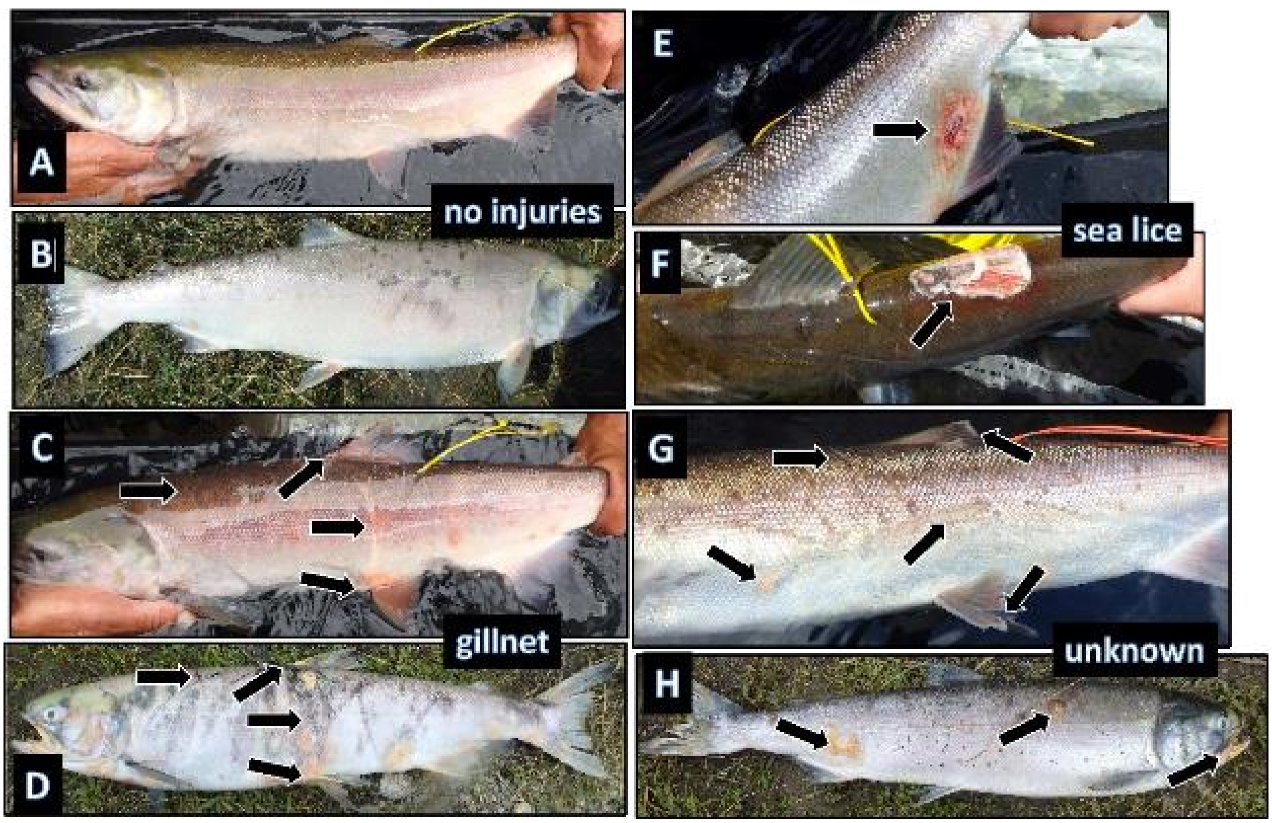

Figure 3.24 **Sockeye salmon with the three most prevalent visible injury categories: gillnet (C,D), sea lice (E,F), and unkown (G,H) and without injury (A,B) photographed during tagging and after recovered dead (from the Seton River fish fence. Arrows in C and D indicate faint gillnet marks posterior to the head, damage to the insertion of the dorsal and pelvic fins, and linear wounds extending between dorsal and pelvic fins. Sea lice scars were commonly found at the base of the anal fin (E) and between the dorsal and adipose fins (F, an extreme example). Injuries with no obvious origin, including descaling, skin damage, and frayed and eroded fins (G and H) were categorized as "unknown".**

Table 3.11 Prevalence of injuries and severity amongst salmon tagged in 2014-2016

Species / Population	Year	Injury Severity			
		Uninjured	Minor	Moderate	Severe
Gates Creek sockeye (*n*=924)	2014	37% (*n*=345)	42% (*n*=387)	12% (*n*=109)	9% (*n*=83)
Gates Creek sockeye (*n*=860)	2015	12% (*n*=105)	62% (*n*=533)	20% (*n*=169)	6% (*n*=53)
Gates Creek sockeye (*n*=752)	2016	12% (*n*=91)	57% (*n*=431)	25% (*n*=184)	6% (*n*=46)
Portage Creek sockeye (*n*=633)	2014	74% (*n*=466)	20% (*n*=124)	3% (*n*=22)	3% (*n*=21)
Coho (*n*=9)	2014	100% (*n*=9)	-	-	-

Gates Creek sockeye injuries were primarily attributable to gillnet entanglement or marine parasites (Table 3.12). The proportion of fish displaying gillnet injuries (Figure 3.24) was approximately equal in 2014, 2015 and 2016.

Table 3.12 The proportion of Gates Creek and Portage Creek sockeye displaying injuries originating from different sources in 2014- 2016

Species / Population	Year	Injury Origin					
		Gillnet	Hook wound	Predator	Sea Lice	Other	Unknown
Gates Creek sockeye (*n*=924)	2014	21% (*n*=193)	8% (*n*=70)	3% (*n*=26)	16% (*n*=148)	2% (*n*=21)	23% (*n*=208)
Gates Creek sockeye (*n*=860)	2015	18% (*n*=153)	1% (*n*=8)	7% (*n*=60)	43% (*n*=366)	1% (*n*=10)	45% (*n*=391)
Gates Creek sockeye (*n*=575)	2016	20% (*n*=113)	<1% (*n*=1)	7% (*n*=40)	43% (*n*=246)	5% (*n*=28)	46% (*n*=263)
Portage Creek sockeye (*n*=633)	2014	2% (*n*=12)	3% (*n*=18)	1% (*n*=8)	2% (*n*=10)	3% (*n*=17)	18% (*n*=111)

A limited number of head injuries were identified on Gates Creek sockeye in 2014 (*n* = 12), 2015 (*n* = 7) and 2016 (*n* = 27). Review of photographs identified some individuals with injuries that may have originated from attempted migration under the Seton River fish fence. However, given the overall low number of head injuries, there is little evidence to suggest that operation of the Seton Generating Station caused injury to salmon in 2014, 2015 or 2016.

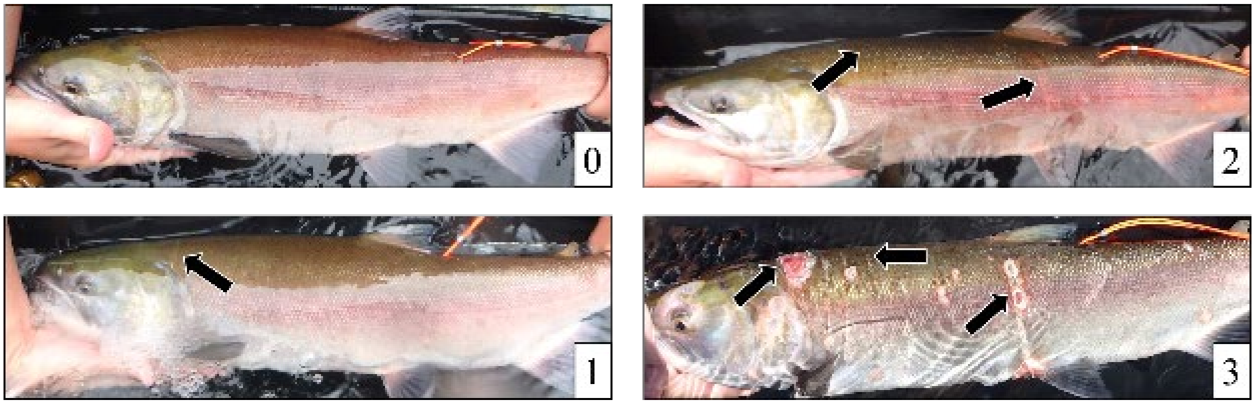

Figure 3.25 **Gates Creek sockeye demonstrating the four levels of gillnet injury severity observed on fish tagged from 2014-2016. Arrows indicate locations where fish became entangled in gillnets and received visible injury. No injury 0, minor injury 1, moderate injury 2, and severe injury 3. Injuries were rated based on depth and number of wounds on each fish.**

- *Prevalence of head injuries in captured Gates Creek and Portage Creek sockeye salmon was low; fish do not appear to be injuring themselves at the Seton Generating Station.*
- *Gillnet and sea lice injuries are the most prevalent and identifiable injuries. Both injuries occur from downstream fisheries or in the marine environment.*

3.6 Effects of Dilution on Pink, Coho, and Chinook Salmon

2) Management Question*: *What are the effects of Seton Generating Station operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

3.6.1 Pink Salmon Water Preference Behavioural Tests

In 2013, pink salmon were tested at 50% dilution of natal water and preferred the dilution mixture to 100% Seton River water. Pink salmon spent a significantly longer amount of time in the arm containing a 50% dilution of natal water (Wilcoxon signed rank test: n = 41, V = 160, p<0.01) (Figure 3.26), and a significantly greater proportion of time (One sample t-test: μ = 0.5, t = 4.3369, p<0.01; Figure 3.27). There was no difference in the number of entrances into each arm (Wilcoxon signed rank test: n = 41, V = 271.5, p = 0.10; Figure 3.28). As a result of this preference for the 50% dilution mixture, no further behavioural tests were undertaken.

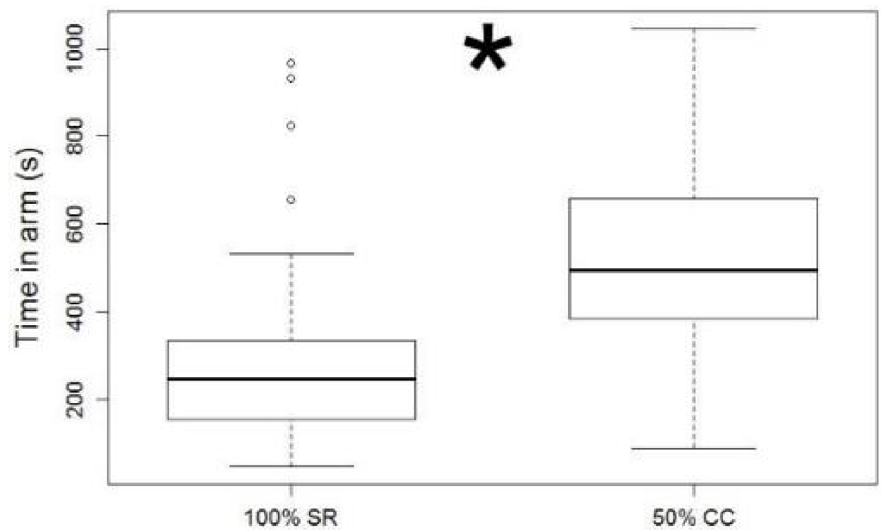

Figure 3.26 **Time spent by pink salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution of natal water. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicated a significant difference.**

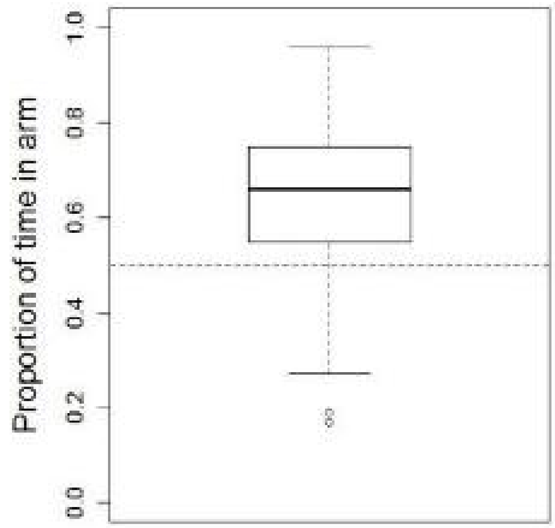

Figure 3.27 **The proportion of time spent by pink salmon in the dilution mixture arm of the Y-Maze during water preference tests. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers.**

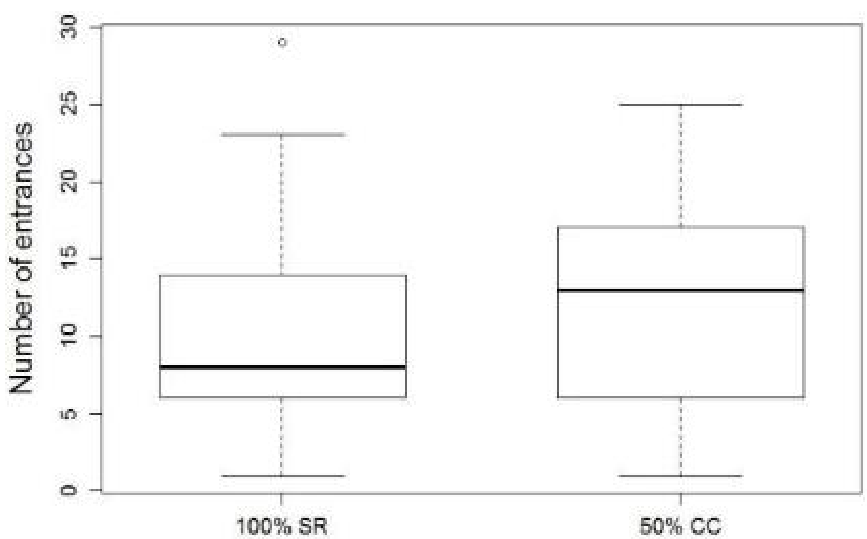

Figure 3.28 **The number of entrances into each arm of the Y-Maze by pink salmon during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution of natal water. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference.**

3.6.2 Observed Movements of Pink Salmon Under Current Operational Dilution Levels

Pink salmon migration in the Seton River begins in late August and finishes in early October, overlapping both Gates and Portage Creek sockeye migrations. Unlike the sockeye populations, which spawn almost exclusively upstream of the Seton Dam, pink salmon spawn throughout the system, with most individuals spawning below the dam in the Seton River. As such, several metrics used to assess sockeye migratory behaviour—including wandering and migration timing measurements—are not as applicable to the pink salmon we studied. Our analyses are thus different than those used to examine the more directed migrations of sockeye salmon. Our analytical objective is to demonstrate that the migration of pink salmon is much less directed in terms of passing the dam than sockeye salmon. Furthermore, pink salmon do not return to the system in even-numbered years, as with all Fraser River pink salmon. As a result, pink salmon were only PIT-tagged (n = 277) and radio-tagged (n = 60) in 2013 so analyses are restricted to just this year.

In 2013, pink salmon migrated through Seton Dam between 09 September and 02 October which is in between Gates Creek and Portage Creek sockeye migration periods. This is relevant to confirm the general migration timing differences among salmon populations in our study. Detections of pink salmon from 2013 suggest that most fish did not travel upstream of the Seton Dam. Only 38.4% of PIT-tagged females (48/125) and 42.0% of PIT-tagged males (60/150) traveled past Seton Dam, and only 9.7% of radio-tagged females (3/31) and 20.7% of radio-tagged males (6/29) traveled past Seton Dam. Thus, most pink salmon stayed below the dam and likely attempted to spawn in the artificial spawning channels or in Cayoosh Creek. Only 36% (120/335) pink salmon released in 2013 were ever detected at the Seton Dam.

During the pink salmon migration, dilution of natal water in the Seton River averaged 9.8%; however, during the peak of migration between 24 September and 29 September dilution of natal water spiked to 20%. When this peak dilution period is removed, the average dilution level experience during the pink migration was 8.2%. This is below the 10% dilution target for Portage Creek sockeye. Just as with sockeye, pink salmon did not make a large number of forays into the tailrace of the Seton Generating Station alone (Figure 3.29, 3.30), yet they still made a higher number of forays per fish (mean per fish 2.1, se = 1.2). These data show pink salmon have less directed migrations and seem to make more forays relative to sockeye. Pink salmon made movements to all telemetry stations below the dam and did not focus on a single station (such as the Seton Generating Station). Individual pink salmon were recorded as visiting each telemetry station 1 to 29 times (Table 3.13).We might expect that if pink salmon were highly influenced by olfactory cues, there should be attraction to the Seton Generating Station and more forays to the tailrace would be expected because of the release of less dilute water there. However, similar to sockeye, pink salmon seem unaffected by water release from the Seton Generating Station. Another consideration is that during the 2013 pink salmon migration there was little dilution of the Seton River. Of the 60 radio-tagged pink salmon released in the Fraser River, only four (7%) were detected at the Seton Generating Station. The males (N = 2) spent an average of 1.6 hours and the females 0.94 hours (N = 2) at the Seton Generating Station. Mean delay of Gates Creek sockeye females was 5.3 h ± 6.4 SE and males 3.4 h ± 3.9 SE, which is much longer than that observed with pink salmon.

Portage Creek sockeye females (mean delay 19.5 h ± 18.5 SE) and males (mean delay 23.4 h ± 27.1 SE) delayed longer still. The time from release to the first detection of pink salmon at the Seton dam was 29 ± 1.65 h (range = 0.8 – 165 h) which was similar to sockeye. In sum, despite dilution being low throughout their migration period, (initially) pink salmon entered the Seton River at very low rates. This aligns with the behavioural data and general overview of pink homing behaviour.

Table 3.13 **Mean and total number of pink salmon forays and mean number of detections per fish with standard errors (se) at monitoring sites below the Seton Dam during 2013. A foray is the number of entries individuals made at each receiver and is used as a measure of attraction to that location.**

Telemetry station	Total # forays	Mean forays per fish (se)	Mean detections per fish (se)
Release Site	140	1.48 (0.071)	203.0 (5.56)
Seton Generating Station	177	2.10 (0.120)	225.0 (1.74)
Seton-Fraser confluence	167	2.14 (0.115)	82.3 (0.745)
Seton Dam	188	1.28 (0.051)	2,179.0 (30.3)

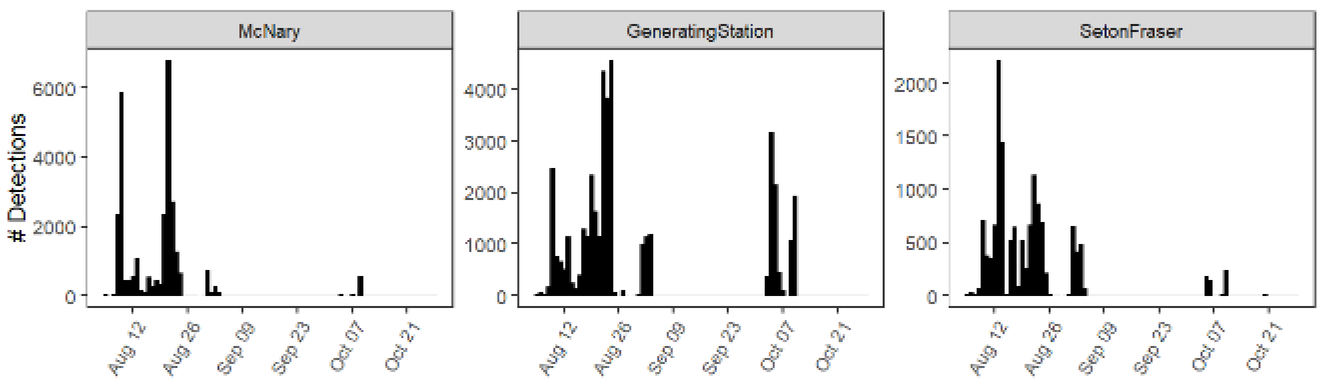

Figure 3.29 **Number of radio-tagged and PIT-tagged pink salmon detections at three telemetry sites shown over time during the 2013 migration.**

- *Preference experiments showed that pink salmon did not prefer pure Seton River water compared to Seton River water that was diluted with Cayoosh Creek by 50%.*
- *Behaviour observations showed no attraction to the Seton Generating Station by pink salmon at dilution levels in the Seton River of 10% (90% Seton River water). These are the same levels as dilution management targets for Portage Creek sockeye.*
- *Few pink salmon (~30%) passed Seton Dam to spawn, most made many movements in the lower Seton River and eventually spawned below the dam.*

3.6.3 Expected Influence of Dilution on Coho and Chinook Salmon

Due to low numbers of Chinook and coho salmon encountered at our capture site in the Seton River, we were unable to tag any Chinook salmon, and tagged only a limited number of coho salmon. Nevertheless, we can make inferences about the potential effect of Seton Generating Station and dilution operations on Chinook and coho salmon migration based on knowledge of olfactory abilities and observations from the small number of tagged coho salmon. Both species have fall migrations and thus should experience dilution levels similar to Portage Creek sockeye salmon.

Sensory impairment studies have determined that, similar to sockeye and pink salmon, Chinook and coho salmon rely on olfaction as they navigate to their spawning grounds (Wisby and Hasler 1954; Groves et al. 1968; Rehnberg et al. 1985). Electrophysiological research, in which the electrical response of the olfactory nerve is monitored after administering an odour to the fish's peripheral olfactory organ (i.e., rosette), indicates Chinook and coho recognize the odour of their natal stream as adults (Oshima et al. 1969a). Furthermore, coho salmon were used as a model species in the first studies of olfactory navigation to demonstrate olfactory imprinting (Hasler and Scholz 1983), which has since been proven in other Pacific salmon species. Injection of memory-blocking agents in Chinook salmon inhibits their response to natal water (Oshima et al. 1969b), suggesting they also imprint on natal odours.

As with sockeye, the olfactory system of Chinook and coho salmon is extremely sensitive. Both species respond to their natal water when they are diluted by 90% (Hara et al. 1965; Ueda et al. 1967), indicating a high level of sensitivity to natal water odours. By comparison, sockeye salmon are also sensitive to natal water odours; alterations to natal water concentration in 10% increments elicited differential responses in sockeye in our water preference experiments. Coho salmon can also detect amino acids—believed to be an important directional cue in the natal water of returning salmon (Ueda et al. 2011)—at concentrations that are comparable to the detection range of sockeye. Hara (1972) tested the responses of coho and sockeye to three amino acids and found the detection threshold for each amino acid is 10^{-6} M for both species. Other studies on coho salmon have identified detection thresholds for amino acids centred around this concentration, ranging from 10^{-4} M to 10^{-9} M depending on the specific amino acid (Rehnberg et al. 1985; Rehnberg & Schreck 1986; Quinn and Hara 1986).

The low sample size of tagged coho salmon (7 radio tags and 2 PIT in 2014), combined with the fact that they all experienced the same dilution levels, made it difficult to assess the effects of Generating Station operation on their migration through the system. One of the radio-tagged coho salmon was never detected after release. Of the remaining six, the amount of delay at the Seton Generating Station tailrace was 1.5 ± 0.3 h. This is substantially shorter than the amount of time co-migrating Portage Creek sockeye delayed, which was 22.8 ± 2.4 h and 33.8 ± 8.6 h for individuals that successfully and unsuccessfully migrated to the Seton Dam, respectively. None of the coho salmon made more than two forays into the tailrace. Furthermore, five of the six individuals entered the Seton River, and four of them passed the dam. The dilution was 9% throughout the period these fish were tracked, which sits below the target value suggested for Portage Creek sockeye. Coho salmon co-migrate with Portage Creek sockeye through the Seton River during the fall, and it therefore appears that the target dilution for Portage Creek sockeye would similarly not cause substantial delay for coho salmon at the Seton Generating Station tailrace.

Chinook salmon have a run timing that is similar to that of coho and Portage Creek sockeye, and therefore experience similar dilution levels. Their migration rate is similar to that of other Pacific salmon species (Keefer et al., 2004), and, given their similar sensitivities to olfactory cues, they are likely to act like coho salmon when passing the Seton Generating Station tailrace. Although no Chinook salmon were captured and tagged, evidence from the other species suggest that dilution levels that remain below the target set for Portage Creek sockeye should not cause substantial delay at the Seton Generating Station tailrace for Chinook salmon.

Together, the limited telemetry results, the relative olfactory sensitivities of coho and Chinook salmon, and the life histories of these species in the Seton-Anderson system suggest that operational guidelines recommended for sockeye are sufficient in mitigating the effects of Seton Generating Station operations on coho and Chinook migrations.

- *Coho and Chinook salmon return numbers were exceptionally low during the research project, preventing direct observation of the effect of dilution on their migration behaviour*
- *Coho and Chinook salmon have similar olfactory sensitivities to natal water as sockeye salmon, and guidelines for sockeye salmon in the Seton-Anderson systems are expected to be sufficient for coho, and Chinook salmon*

3.7 Seton Dam Operations and Fish Passage

<u>Management Questions</u>
3) Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?
3a) What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

Seton Dam was operated according to normal BC Hydro procedures throughout monitoring in 2013 and in 2015. Water was released from the fish water release gate and Siphon 1 during the Gates Creek sockeye migration period, and the fish water release gate during the Portage Creek sockeye migration period. Behaviour and passage of Gates Creek sockeye, Portage Creek sockeye and pink salmon were examined during these normal operations in 2013. Portage Creek sockeye were examined again during routine conditions in 2014, and Gates Creek sockeye were examined again during routine conditions in 2015. Changes to water release siphons from Seton Dam occurred in 2014 and again in 2016 to test if an alternative water release from Siphon 4 could improve passage and post-passage survival of Gates Creek sockeye. Alternative water releases were only tested during the Gates Creek sockeye migration period because alternative operations outside of this period would exceed the Seton Dam target hydrograph. Portage Creek sockeye experience a different flow regime wherein only the fish water release gate is operating and thus similar experimental approaches to test the effect on dam operation on Portage Creek sockeye were not possible.

Much of the early research on the alternative flow scenario has been published in Burnett et al. (2014a), Burnett et al. (2014b), Burnett et al. (2017) or is being prepared for publication (for 2016 data). Therefore, the sections below adopt the analyses of each of these peer-reviewed published manuscripts. These studies examined the physiological and behavioural components of Seton Dam passage and tracked post-passage survival upstream of the dam to spawning grounds.

3.7.1 Seton Dam Passage Under Routine Operations

Gates Creek and Portage Creek sockeye passage of Seton Dam was studied from 2013 to 2016 and from 2013 to 2014, respectively. Normal BC Hydro operations occurred during the entire 2013 and 2015 migrations. Normal operations also occurred during the Portage Creek sockeye migration in 2014.

Flow conditions at Seton Dam during the Gates Creek sockeye migration vary over time within years. Here we describe the differences between routine and alternative water releases. Gates Creek sockeye typically migrate during two distinct discharge and flow conditions over the course of their month-long migration period. Declining discharge is achieved through either reducing conveyance structure discharge or switching to conveyance structures with different total discharge volume. To meet the target hydrograph for Seton Dam (BC Hydro 2012) discharge is normally decreased during the Gates Creek sockeye migration in mid-August from ~26 $m^3 \cdot s^{-1}$ to 21 $m^3 \cdot s^{-1}$ via a reduction in the fish water release gate. In 2015, however, conveyance structure use was fixed throughout the Gates Creek sockeye migration period with approximately 21 $m^3 \cdot s^{-1}$ released from the fish water release gate and Siphon 1.

3.7.1.1 Passage of Gates Creek Sockeye

There were some differences in attraction efficiency, passage efficiency or entrance delay in Gates Creek sockeye tagged with different transmitter types and handling procedures (Table 3.14).

Table 3.14 Passage success of acoustic- radio-, and PIT tagged Gates Creek sockeye at Seton Dam in 2013 and 2015. Fish were released either at the capture fence or downstream on the west or east side of the Fraser River (DSW or DSE). Data from 2014 and 2016 are reported in subsequent sections when water release trials where undertaken. See Section 3.7.2 for a discussion relating to the impacts tag type, handling, and location of release.

Metric	2013			2015	
	Acoustic	Radio	PIT	Radio	PIT
Release Site	Fence Seton	DSE/DSW	Fence	DSW	Fence
Attraction Efficiency	83% (45/54)	74% (114/155)	82% (311/379)	100% (180/180)	97% (445/457)
Entrance Delay*	10.8 ± 1.4 h (0.1-58.4 h)	8.8 ± 1.3 h (0.1-80.3 h)	28.3 ± 1.4 h (0.5-161.0 h)	7.6 ± 0.6 h (2.0 – 50.4 h)	13.3±0.9 h (0.9-196.0 h)
Passage Efficiency	98% (44/45)	95% (108/114)	94% (292/311)	99% (178/180)	99% (441/445)
Overall Success	81% (44/54)	70% (108/155)	77% (292/379)	99% (178/180)	97% (441/457)

In 2013, acoustic accelerometers in Gates Creek sockeye allowed for measurements of swimming activity and estimates of anaerobic muscle recruitment (which powers swimming at speeds exceeding the critical swimming speeds, i.e., burst swimming). Burst swimming was required to reach the fishway entrance (Figure 3.31) and pass the dam (Figure 3.32A; Table 3.15). Anaerobic recruitment, maximum Seton River temperature, and sex formed the top-ranked dam passage model, explaining 50% of the variation in the data after accounting for capture location. Capture location (fishway vs fence), anaerobic recruitment, sex, and maximum temperature had similar effect sizes. Fish that experienced higher flows (26.2 $m^3 \cdot s^{-1}$) showed higher anaerobic recruitment near the fishway entrance (Figure 3.33B). Individuals that traversed the high flows multiple times used more anaerobic effort compared to fish that made fewer crossings of the tailrace.

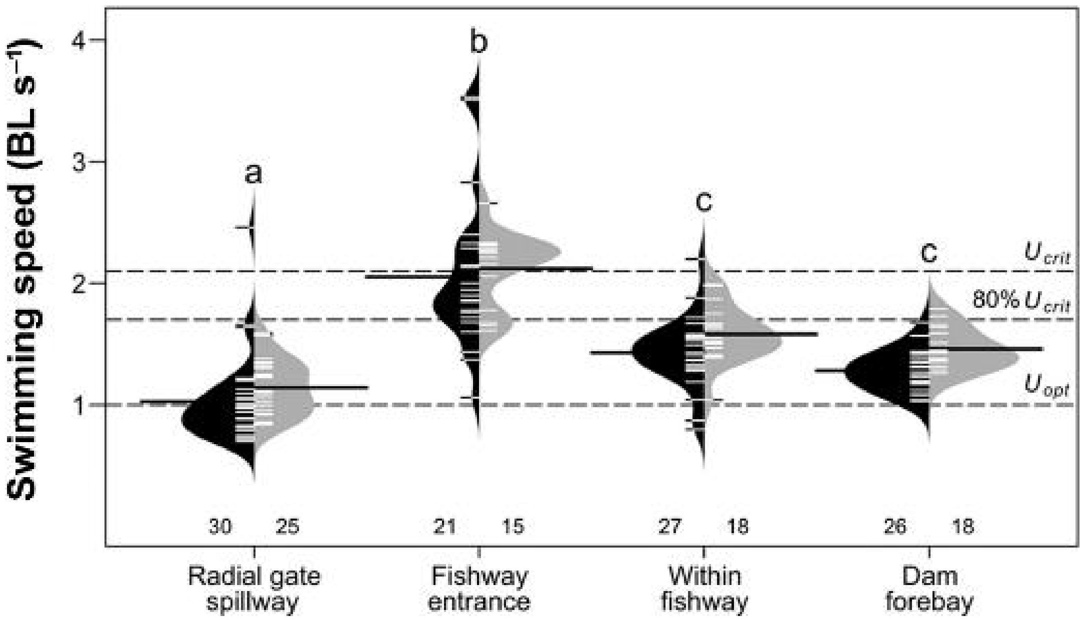

Figure 3.30 **Distribution plot (black horizontal lines = means) comparing the swimming speed (body lengths per second [BL s^{-1}]) of male (black) and female (gray) Gates Creek sockeye in the radial gate spillway, surrounding the fishway entrance, within the fishway, and in the dam forebay in 2013. Shaded areas depict the estimated density of the distribution of individual swimming speed values (white horizontal lines). Optimal (U_{opt}; 1.0 BL·s^{-1}) and critical (U_{crit}; 2.1 BL·s^{-1}) swimming speeds are shown as dashed horizontal lines; the swimming speed at which anaerobic muscle fibers start to be recruited (80% U_{crit}) is also shown. Sample sizes (*n*) are presented below each distribution, and lowercase letters represent significant differences ($P < 0.05$) from one-way ANOVA and Tukey post hoc tests.**

Individuals that were naïve of the fishway relied more on anaerobic recruitment near the fishway entrance compared to fishway-non-naive individuals. Flows from Siphon 1, sex, and tailrace crossings formed the top-ranked anaerobic recruitment model, explaining 46% of the variation in the data after accounting for capture location (Table 3.15). Swimming at their critical swimming speeds (U_{crit}; 2.1 BL·s^{-1}), fish swam significantly faster in the fishway entrance area compared to all other areas of the tailrace (one-way ANOVA, $F = 70.94$, $df = 3$, $P < 2 \times 10^{-16}$). Fish swam faster within the fishway and in the dam forebay compared to when delaying in the radial gate spillway. Four females swam at 80% U_{crit} while in the fishway entrance area, while 11 other females swam consistently above U_{crit}.

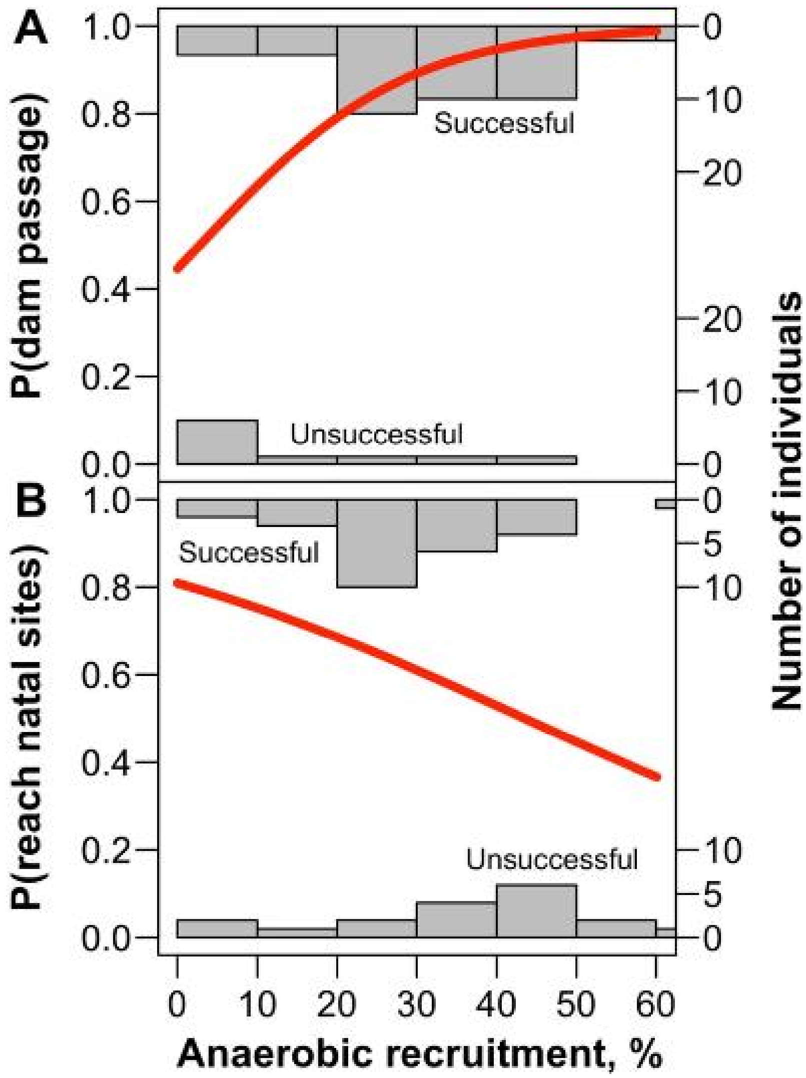

Figure 3.31 **Predicted probability of Gates Creek sockeye passing Seton Dam (*A*; *n* = 54) and reaching natal spawning streams (*B*; *n* = 44) in 2013, visualized by fitting a logistic regression to the anaerobic recruitment of successful and unsuccessful migrants.**

Table 3.15 Model selection statistics for generalized linear models predicting dam passage (A), anaerobic recruitment in areas of high flow below Seton Dam (B), tailrace crossings (C), and the ability of acoustic-tagged Gates Creek sockeye to reach natal spawning streams (D) in 2013

Response variable and model	Log likelihood	AIC_c	ΔAIC_c	w_i	*D*
A. Dam passage:					
Sex + maximum temperature + anaerobic recruitment	−12.97	37.20	.00	.12	50
Sex + maximum temperature	−14.29	37.40	.21	.10	45
Sex + anaerobic recruitment	−14.30	37.40	.23	.10	45
B. Anaerobic recruitment:					
Sex + siphon 1 + tailrace crossings	−212.02	437.80	.00	.48	46
Sex + siphon 1 + tailrace crossings + maximum temperature	−212.01	440.50	2.63	.13	46
Sex + siphon 1 + tailrace crossings + tailrace delay	−212.02	440.50	2.64	.13	46
C. Tailrace crossings:					
Sex + anaerobic recruitment	−62.51	133.80	.00	.14	25
Sex + anaerobic recruitment + tailrace delay	−61.67	134.60	.77	.10	30
Sex + tailrace delay	−62.95	134.70	.89	.09	22
D. Reach spawning grounds:					
Anaerobic recruitment + siphon 1	−18.73	46.50	.00	.14	37
Anaerobic recruitment + siphon 1 + tailrace crossings	−17.65	46.90	.38	.11	41
Anaerobic recruitment + siphon 1 + sex	−18.07	47.70	1.23	.07	39

Note: ΔAIC_c represents the difference in AIC_c values between model *I* and the top-ranked candidate model. Models are ranked from lowest to highest ΔAIC_c (highest to lowest w_i); all top-ranked candidate models had a ΔAIC_c of 0. *D* represents the percentage of deviance explained by a generalized linear model. Capture location was included in all models as a fixed factor.

Individuals that used more anaerobic effort near the fishway entrance were less likely to reach spawning grounds compared to fish that swam more conservatively (Figure 3.32B). Anaerobic recruitment had an equal but opposite effect on fish reaching spawning grounds as capture location. Anaerobic recruitment affected the ability of dam-successful migrants to reach Gates Creek, explaining 30% of the variation in the data after accounting for capture location. Fishway-naive individuals were 154% ($e^{5.04}$; Figure 3.33D) more likely to complete their freshwater migration after passing Seton Dam compared to fishway-non-naive individuals. Forty-four percent (8/18) of the fish that failed to reach natal spawning streams after passing the dam died in Seton Lake; all other individuals (56%; 10/18) migrated to within 4 km of Gates Creek but perished in Anderson Lake prior to spawning.

While capture location influenced post-passage survival, it was evident that migration at Seton Dam under normal operations was stressful for Gates Creek sockeye, even for those captured at the fence site. High swimming speeds and high levels of anaerobic recruitment near the fishway entrance appeared to contribute to reduced post-passage survival. This finding led to follow up studies in 2014 and 2016 that examined the effects of an alternate water release strategy at Seton Dam on Gates Creek sockeye passage and post-passage survival.

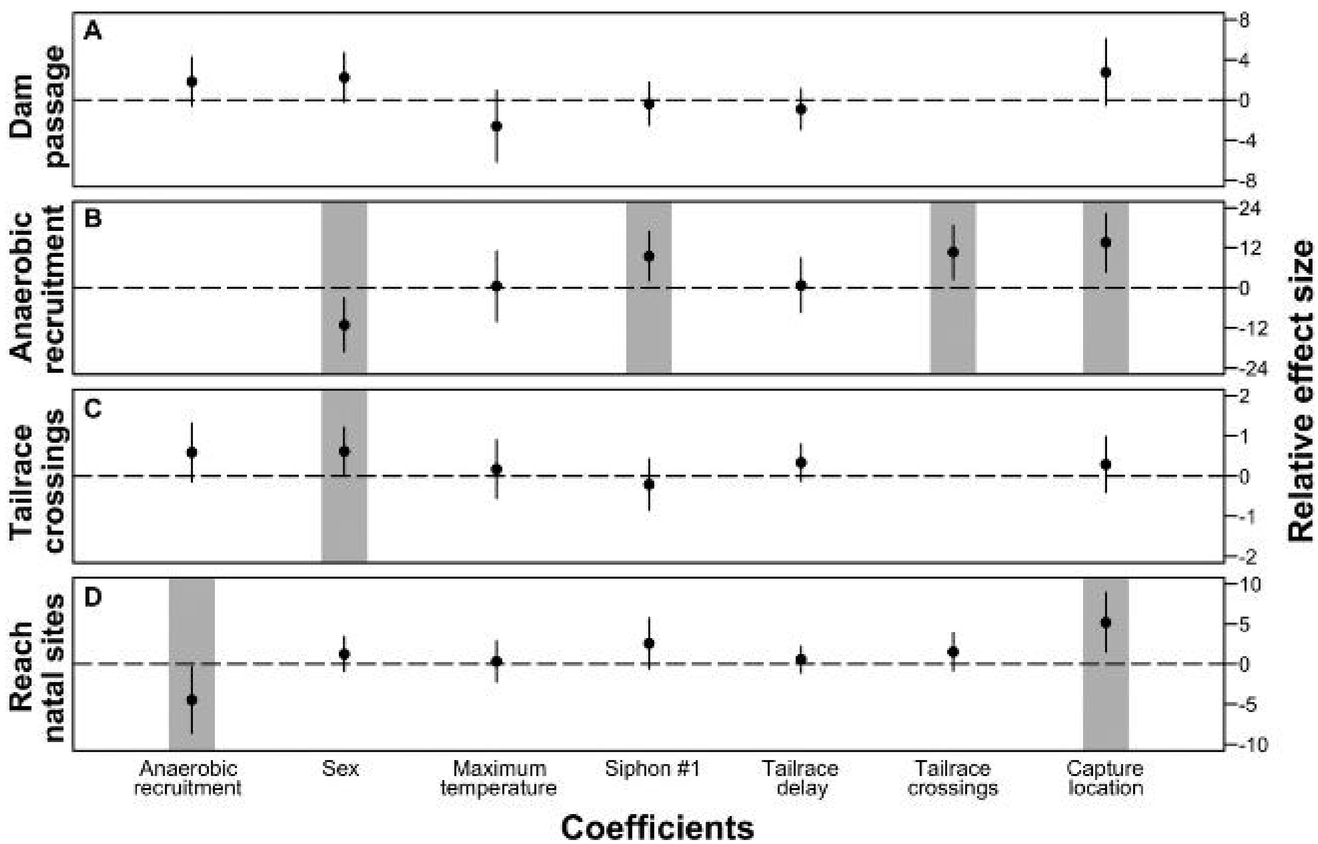

Figure 3.32 **Model-averaged standardized coefficients for models describing dam passage (A), anaerobic recruitment in areas of high flow below Seton Dam (B), tailrace crossings (C), and the ability of Gates Creek sockeye to reach natal spawning streams (D). Coefficients have been highlighted in gray if the error bars (representing 95% confidence intervals) do not cross 0. Capture location was included in all models as a fixed factor and has been included to show its relative effect on the response variables. Note the different secondary Y-axes scales.**

3.7.1.2 Passage of Portage Creek Sockeye

Tagged Portage Creek sockeye experienced one flow scenario in 2013 (15.0 $m^3 \cdot s^{-1}$) and one in 2014 (14.5 $m^3 \cdot s^{-1}$) as Seton Dam discharge was adjusted prior to and after the Portage Creek sockeye migration period in each year. Temperatures during releases were 13.1 - 14.2°C in 2013 and 13.9 - 16.6°C in 2014. These temperatures are likely within the range of optimal temperatures for Portage Creek sockeye (optimal temperature for Weaver Creek sockeye, another Fraser River late-run population, is 14.5°C).

Passage success of Portage Creek sockeye was high in 2013 - 2014 (Table 3.17). Attraction efficiency was lower for acoustic-tagged fish, probably due the small sample size of this release group. Entrance delay was lowest for radio-tagged fish released in the Fraser River, with increased delay observed for fence-released acoustic and PIT-tagged fish. Entrance delay for radio-tagged fish did not differ in 2013 and 2014. For all radio-tagged Portage Creek sockeye released downstream in the Fraser River, including those not detected in the tailrace, passage success was 86% (*n* = 162/189). Dam arrival could not be confirmed for PIT-tagged fish released downstream; however, passage success for this group was 94% (*n* = 180/192). Overall passage success for all Portage Creek sockeye released in 2014 was 88% (*n* = 557/634).

Table 3.16 Radio, acoustic, and PIT-tagged Portage Creek sockeye passage at Seton Dam in 2013 and 2014

Variable	2013	2014		
	Radio	Radio	Acoustic	PIT
Release Site	DSW	DSW	Fence	Fence
Attraction Efficiency	95% (21/22)	98% (163/167)	80% (8/10)	95% (229/241)
Entrance Delay (h)	12.6 ± 2.9 (0.2 - 42.8)	14.9 ± 2.2 (0.1 - 74.0)	26.9 ± 8.5 (2.5 - 74.0)	27.5 ± 2.7 (0.6 - 352.0)
Passage Efficiency	95% (20/21)	99% (162/163)	100% (8/8)	98% (225/229)
Overall Success	91% (20/22)	97% (162/167)	80% (8/10)	93% (225/241)

*Entrance delay is mean ± SE. Discharge was 15.0 $m^3\ s^{-1}$ (2013) and 14.5 $m^3\ s^{-1}$ (2014).

Swimming speeds (mean ± SE) of acoustic-tagged Portage Creek sockeye within the fishway entrance area (1.72 ± 0.07 $BL \cdot s^{-1}$) and the fishway (1.66 ± 0.12 $BL \cdot s^{-1}$) were significantly greater than swimming speeds in the radial gate spillway (1.02 ± 0.07 $BL \cdot s^{-1}$) or Seton Dam forebay (1.35 ± 0.07 $BL \cdot s^{-1}$) (One-way ANOVA: F = 15.48, df = 3, $p<0.001$). Critical swimming speeds are unknown for Portage Creek sockeye; however, swimming speeds in the fishway entrance exceeded 80% of the critical swimming speed for Gates Creek sockeye. Overall, swimming speeds approximated those observed for Gates Creek sockeye in 2013 and 2014. Swimming speeds in body lengths per second ($BL\ s^{-1}$) were calculated according to the methods in 2013. For swimming speed calculations, optimal swimming speed was 1 $BL \cdot s^{-1}$ and critical swimming speed was 2.10 $BL \cdot s^{-1}$.

Survival to spawning grounds was determined for radio-tagged and acoustic-tagged Portage Creek sockeye. Survival data is unavailable for PIT-tagged fish because a PIT antenna could not be installed in Portage Creek. As there was a low likelihood of recovering tags in Portage Creek, no tag recovery efforts were made, and spawning success could not be assessed. Portage Creek sockeye were not tagged in 2015 due to low abundance and co-migrating pink salmon.

Post-passage survival of radio-tagged Portage Creek sockeye in 2014 was double that observed in 2013. In 2013, post-passage survival to spawning grounds from Seton Dam for radio-tagged fish was 36%, although sample sizes were low in 2013 (n = 22). Low post-passage survival of acoustic-tagged fish in 2014 (Table 3.18) may also be due to a low sample size and/or lower detection efficiency at one station and could account for the difference in survival of acoustic- and radio-tagged Portage Creek sockeye following Seton Dam passage. Post-passage survival did not differ for males and females. Post-passage survival of radio-tagged Portage Creek sockeye was 72% (n = 116/162) in 2014. Mortality primarily occurred in Seton Lake. Likewise, 43% of acoustic-tagged Portage Creek sockeye that passed Seton Dam (3/7) survived to spawning grounds in 2014. Similar patterns were seen with Gates Creek sockeye in 2014.

Table 3.17 Survival of Portage Creek sockeye salmon following Seton Dam passage in 2014

Release Site / Tag Type	Post-Passage Survival		
	Male	**Female**	**Combined**
Fraser River West			
Radio-tagged	72% (63/87)	71% (53/75)	72% (116/162)
Upper Seton River			
Acoustic-tagged	40% (2/5)	50% (1/2)	43% (3/7)

3.7.1.3 Passage of Pink Salmon

In 2013, 340 pink salmon were captured at the fish fence just downstream of the Seton Dam. Of these fish, 276 were PIT-tagged (128 females, 150 males) and 60 were radio-tagged (30 females, 28 males). Tagged pink salmon experienced discharges of 24.6 to 29.5 $m^3 \cdot s^{-1}$ from 20 August to 16 September when discharge was primarily from Siphon 1, and 17.4 to 18.7 $m^3 \cdot s^{-1}$ from 17 September to 21 September when discharge was primarily from the fish water release gate. Temperatures during releases were 13.8 – 19.8°C. PIT tagged fish were released at the fish fence, but radio-tagged fish were transported downstream and released in the Fraser River; 30 on the west side of the Fraser and 28 on the east side of the river. A larger portion of PIT tagged fish passed upstream the Seton Dam; however, most of the fish remained below Seton Dam. PIT-tagged fish received minimal handling and were released at the fish fence rather than downstream in the Fraser River, but still less than half of these fish passed Seton Dam and almost none traveled to Gates Creek.

Attraction efficiency, passage efficiency and overall passage success of pink salmon was substantially lower than that of both Gates Creek and Portage Creek sockeye. Mean entrance times (i.e., entrance delay) was much longer than in sockeye (Table 3.19). These numbers appear representative of what would be expected for pink salmon. The differences between pink and sockeye salmon arise because of the differences in the extent of directed migration in the two species. A large number of pink salmon spawn downstream of Seton Dam in many different locations, including the Seton spawning channels, and thus pink salmon do not have the strong attraction and passage propensity to move upstream of Seton Dam as seen in Gates and Portage sockeye salmon.

Table 3.18 Dam passage rates for radio-tagged and PIT-tagged pink salmon passage at Seton Dam in 2013

		Radio-tagged	PIT-tagged
Release Location		**Fraser River**	**Fence**
Attraction Efficiency	Female	10% (3/31)	38% (48/125)
	Male	21% (6/29)	42% (63/125)
Entrance Delay (h)	Female	32 ± 2.8	24 ± 2.2
	Male	42 ± 5.1	31 ± 2.8
Passage Efficiency	Female	67% (2/3)	73% (35/48)
	Male	67% (4/6)	83% (52/63)
Overall Success	Female	6% (2/31)	28% (35/125)
	Male	14% (6/29)	35% (52/150)

- *Attraction and Passage efficiency of Seton Dam is high for Gates Creek and Portage Creek sockeye salmon under the routine operations.*
- *Passage efficiency for pink salmon is relatively low, which likely reflects the tendency for pink salmon to spawn downstream of the dam.*
- *High flows in the tailrace and near the fishway entrance necessitated swimming that surpassed critical swimming speeds and were associated with increased anaerobic metabolic costs in Gates Creek sockeye salmon. Individuals with greater anaerobic swimming during passage had poorer survival to spawning grounds.*

3.7.2 Review of Gates Creek Sockeye Passage of Seton Dam Over Multiple Years

This section summarizes data collected on Gates Creek sockeye passage at Seton Dam, as this population has a robust dataset that covers numerous years, including years prior to the start of this project. Two major comparisons can be made: 1) a comparison of passage across multiple years, which enables us to summarize the overall passage success of Gates Creek sockeye at the Seton Dam, and 2) a comparison of passage using different tag types and release locations, which allows us to better understand how these factors, which varied amongst different studies within this project, might influence passage results.

To compare passage success across multiple years, Gates Creek sockeye released at the Upper Seton River were compared (Table 3.20, Figure 3.34). Because these fish were released close to the Seton Dam, they had to recover from tagging in the dam tailrace, which resulted in increased delay times. However, their minimal handling (in comparison to radio-tagged fish) and consistent treatment allows for them to be used to study passage time and post-passage survival. Fish transported to the Fraser River for release to test dilution issues were not included in this comparison. Past studies in 2005 and 2007 used similar tagging and handling methods and are included in this comparison, although radio tags were used in 2005 and acoustic tags were used in 2007. In these two years, as well as 2012 and a portion of 2013, fish were captured from the Seton Dam fish ladder, rather than in the Seton River. In 2015 and 2016, Gates Creek sockeye were not tagged with acoustic transmitters; therefore, PIT-tag fish were used for comparison, as the release site was the same as for acoustic-tagged fish in 2013 - 2014. The effect of blood sampling and tag burden could cause some effects compared to PIT tagging; therefore, PIT tag approaches should be considered the gold standard when assessing attraction, passage, and survival.

Nearly all PIT-tagged Gates Creek sockeye released in 2015 and 2016 successfully located and ascended the Seton Dam fish ladder. The proportion of PIT-tagged fish that successfully located the Seton Dam fishway during these years was comparable to acoustic-tagged fish in 2014, and greater than all study years prior to 2014 (Table 3.20). In 2005, 2007, 2012 and the first half of 2013, sockeye were captured from the top pool of the Seton Dam fishway and transported to the Seton River for release. The transportation process, which is stressful for fish may have contributed to the lower attraction efficiencies. The effect of transport on passage was measured in 2014, when Gates Creek sockeye were captured at the Seton River fence site, transported in a truck, and released back at the capture site (Casselman et al. 2015). Although survival to spawning grounds was lower in this group than in fish that were not transported, passage success was not affected. In addition, the 2013 Gates Creek run experienced abnormally high temperatures that may have negatively affected passage success.

Overall, these data indicate that attraction efficiency and passage efficiency of Gates Creek sockeye at the Seton Dam was high. Overall passage success of PIT-tagged Gates Creek sockeye in 2015 - 2016, which experienced the least amount of handling (no transportation, minimal handling e.g. blood sampling during tagging) are the closest representative of salmon naturally migrating through Seton Dam, suggesting the migration success of healthy, untagged Gates Creek sockeye through Seton Dam is >95%.

Table 3.19 Passage success of Gates Creek sockeye at Seton Dam in 2005 (radio tags), 2007 (acoustic tags), 2012 - 2014 (acoustic), and 2015 - 2016 (PIT tags)

Variable	2005[a]	2007[b]	2012	2013	2014	2015	2016
Attraction efficiency	77% (23/30)	86% (44/51)	69% (18/26)	83% (45/54)	98% (44/45)	97% (445/457)	98% (425/433)
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)	12.9±1.6 h (0.7-50.9 h)	13.3±0.9 h (0.9-196.0 h)	11.0± 0.7 (0.5-68.8 h)
Passage efficiency	100% (23/23)	93% (41/44)	89% (16/18)	98% (44/45)	98% (43/44)	99% (441/445)	100% (424/425)
Overall success	77% (23/30)	80% (41/51)	62% (16/26)	81% (44/54)	96% (43/45)	97% (441/457)	98% (425/433)

*Entrance delay is mean ± S.E. Data from [a]Pon et al. (2006) and [b]Roscoe and Hinch (2008).

To answer all the management questions in this project, different tag types and release locations were necessary, which could influence passage success and entrance delay. Indeed, passage success and entrance delay for Gates Creek sockeye differed between release locations and with different tag types (Table 3.21). Acoustic-tagged fish released from the Upper Seton River site delayed longer in the Seton Dam tailrace than radio-tagged fish that migrated to Seton Dam following release in the Fraser River. Given that the downstream detection range of the Seton Dam acoustic and radio telemetry arrays was equal, differences are likely due to acoustic-tagged fish recovering in the tailrace post-tagging. Entrance delay of PIT-tagged fish, calculated from the time of release at the Upper Seton River site, was also longer than radio-tagged fish in 2014 (9.1 ± 0.5 h; n = 510), 2015 (13.3 ± 0.9 h; n = 445) and 2016 (10.8 ± 0.5 h; n = 433). However, the entrance delay of downstream released PIT-tagged fish, estimated in 2016 using an antenna installed on the Seton River fish fence, was comparable to radio-tagged fish. These data suggest that across years downstream released radio-tagged fish may be most representative of Gates Creek sockeye migration delay at Seton Dam. However, downstream migration conditions may also contribute to the reduced passage success of radio-tagged fish as compared to acoustic-tagged, as both Seton River and Fraser River temperatures were elevated in 2013 when the passage success of radio-tagged fish was lower than acoustic-tagged fish.

Table 3.20 Passage success of Gates Creek sockeye at Seton Dam released at different sites and tagged using different telemetry devices from 2013 – 2016.

Metric	2013		2014		2015	2016		
	Acoustic	Radio	Acoustic	Radio	Radio	Radio	PIT	
Release location	Fence	DSW	Fence	DSW	DSW	DSW	Fence	DSW
Attraction efficiency	83% (45/54)	74% (114/155)	98% (44/45)	98% (143/146)	100% (180/180)	87% (98/113)	98% (425/433)	88% (90/102)
Entrance delay (h)*	10.8 ± 1.4	8.8 ± 1.3	12.9 ± 1.6	8.3 ± 1.3	7.6 ± 0.6	5.0 ±0.8	10.8 ± 0.5	3.8 ± 0.4
Passage efficiency	98% (44/45)	95% (108/114)	98% (43/44)	100% (143/146)	99% (178/180)	98% (96/98)	100% (424/425)	99% (89/90)
Overall success	81% (44/54)	70% (108/155)	96% (43/45)	98% (143/146)	99% (178/180)	85% (96/113)	98% (425/433)	87% (90/102)

*Entrance delay is mean ± SE. Entrance delay is the time difference between first detection in the Seton Dam tailrace and first detection at the fishway entrance. Sample sizes for entrance delay of radio-tagged sizes were: *n*=99 (2013); *n*=117 (2014); *n*=180 (2015); *n=113 (2016).*

- *Fishway attraction at Seton Dam has been consistently good over multiple years (>74%), while fishway passage has been exceptionally high (> 95%). Earlier estimates were likely lower than actual values due to capture location and handling/transport effects*
- *During the latter years of this study, when handling was minimized to represent naturally migrating salmon, overall passage success was high (> 95%)*

3.7.3 Seton Dam Passage Under Alternative Operations

To determine the effect of Seton Dam operations on attraction efficiency, passage, and post-passage survival of fish, Seton Dam water release during Gates Creek sockeye migration was altered in 2014, and again in 2016 to reduce flows near the fishway entrance. Briefly, alternative dam operation trials were completed in 2014 and 2016. Water release was altered by changing release from Siphon 1 to Siphon 4. Detailed physiological measurements were made in 2014, and much of that work is presented in Burnett et al. (2017). Since the 2014 work had only a single water release trial it was impossible to isolate the influence of run timing and temperature on post-passage survival in this year and so the experiment was repeated in 2016 with only PIT tagged fish. Despite these shortcomings, the 2014 trial succeeded in providing detailed physiological and behaviour measurements on Gates Creek sockeye. This allowed a better understand how the operation of Seton Dam conveyance structures affected Gates Creek sockeye passage success. In 2016 the water release trials were repeated, altering water release operations at Seton Dam with two trials each of routine and alternative flow scenarios. This allowed the isolation of run timing and temperature effects.

In 2016, the Seton Dam water release experiment carried out in 2014 was repeated during the Gates Creek sockeye migration period. The water release experiments in 2014 and 2016 had different objectives. In 2014, there was poor understanding of how fish would respond to alternative water release from Siphon 4. In that year, extensive acoustic tagging was combined with detailed flow measurements in the tailrace to develop an understanding of the migration environment that fish experience, how this may influence their physiology, and how changes to dam water release locations (i.e., release from Siphon 1 versus Siphon 4) could affect dam passage and survival to spawning grounds. In 2014 there was only a single one-week period when the water release was switched from Siphon 1 to Siphon 4. This trial was successful (Burnett et al. 2014a; Burnett et al. 2014b; Burnett et al. 2017) in showing that survival to spawning grounds could be enhanced by modifying dam water release locations. In 2016, the water release trials were repeated to confirm the 2014 findings, but this time focused on a much larger sample of Gates Creek sockeye but only with PIT-tags and no acoustic transmitters. During the 2016 trials, water release was switched from Siphon 1 to Siphon 4 twice, alternating weekly between each water release. Focusing the 2016 trial on a larger number of fish without acoustic tags, while ensuring that fish at different points in the migration experienced both routine and alternative water releases, allowed for isolation of the effects on run timing on passage and spawning success.

3.7.3.1 Passage Success In 2014

Dam passage was 7% higher for acoustic-tagged and 9% higher for PIT-tagged Gates Creek sockeye under the alternative flow condition. Both male and female PIT-tagged fish showed increased passage success under alternative flows (8% and 10% increases, respectively). Under the alternative flow condition, acoustic-tagged sockeye exhibited significantly more tailrace crossings (Mann–Whitney U-test, $p = 0.001$) and spent significantly more time below the dam. Fish that experienced the routine flow condition spent significantly more time in the dam forebay following dam passage (Mann–Whitney U-test, $p = 0.001$. Anaerobic recruitment in the dam tailrace did not differ between the two flow conditions

(Mann–Whitney U-test, p = 0.350). Under the two flow conditions, no significant differences were found when comparing the swimming speed of acoustic fish in the radial gate spillway (Mann–Whitney U-test, p = 0.404), near the fishway entrance (p = 0.516), within the fishway (p = 0.447), and in the dam forebay (p = 0.357) (Figure 3.35).

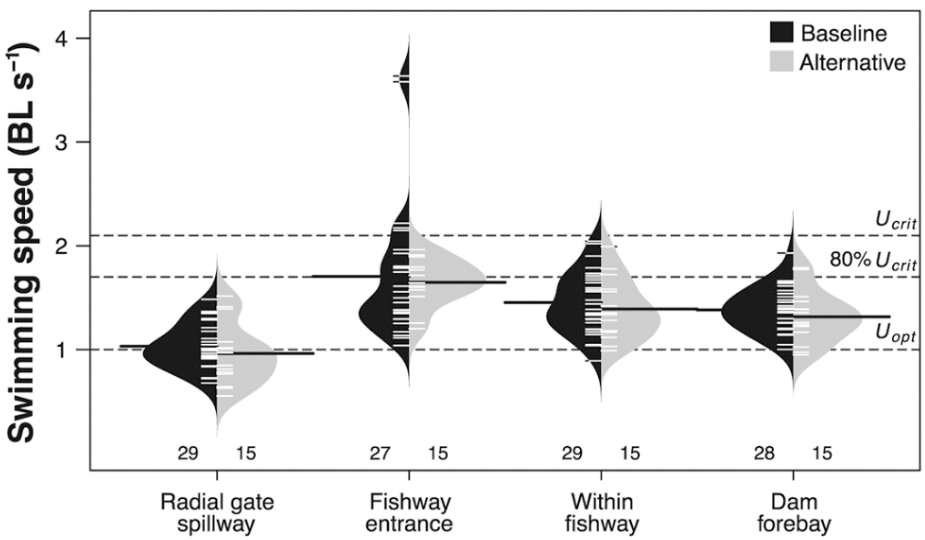

Figure 3.33 **Swimming speed (BL s^{-1}) of acoustic-tagged sockeye under the routine (baseline, black) and alternative flow conditions (grey) in the radial gate spillway, surrounding the fishway entrance, within the fishway and dam forebay. Shaded distributions depict the estimated density of the distribution of individual swimming speed values (white horizontal lines; mean black horizontal line). Optimal (U_{opt}; 1.0 BL s^{-1}) and critical (U_{crit}; 2.1 BL s^{-1}) swimming speeds (Lee et al., 2003a) are shown as dashed horizontal lines; the swimming speed at which anaerobic muscle fibers are recruited (80% U_{crit}) is also shown. Sample sizes (n) are presented below each distribution. No statistical differences ($p > 0.05$; Mann–Whitney U-tests) were detected between the two flow conditions at the four sites.**

3.7.3.2 Post-Passage Survival In 2014

In 2014, post-passage survival to spawning grounds was 52% higher for acoustic-tagged (Table 3.22) and 7% higher for PIT-tagged sockeye under the alternative flow scenario. Both male and female PIT-tagged fish showed increased survival to spawning grounds under alternative flows (12% and 4% increases, respectively). A 7% higher estimate of post-passage survival to spawning grounds for PIT- tagged fish under alternative flows assisted approximately 557 additional fish in reaching spawning grounds in 2014 (Burnett et al. 2017). Survival from release to spawning grounds was 55% higher for acoustic-tagged and 14% higher for PIT-tagged fish under the alternative flow scenario.

Table 3.21 Seton Dam passage success and apparent survival to spawning grounds for Gates Creek sockeye during routine and alternative flow scenarios in 2014

	Routine	Alternative
Acoustic-tag releases (Upper Seton River)		
Dam passage	93% (28/30)	100% (15/15)
Post-passage survival	48% (13/27)	100% (15/15)
Overall survival	45% (13/29)	100% (15/15)
PIT-tag releases (Upper Seton River)		
Dam passage	89% (344/388)	98%* (199/204)
Post-passage survival	81% (279/344)	88% (176/199)
Overall survival	72% (279/388)	86%* (176/204)
Radio-tag releases (Fraser River West)		
Dam passage	98% (102/104)	98% (41/42)
Post-passage survival	76% (78/102)	80% (33/41)
Overall survival	75% (78/104)	79% (33/42)

3.7.3.1 Environmental Conditions In 2014

Fraser River water temperature, run timing, and water release scenarios may have influenced passage success and post-passage survival, but it was not possible to disentangle their effects. The only methods that provides some insight is to repeat trials with years and present migrating fish with different water releases at different points during the migration. Gates Creek sockeye exposed to alternative flows (09 August to 18 August 2014) experienced significantly higher water temperatures ($t_{1099} = -28.1$, $p < 0.001$) and discharges ($t_{4229} = -86.4$, $p < 0.001$) in the Fraser River compared with fish exposed to baseline flows

(20 August to 15 September 2014; Figure 3.36). Fish exposed to alternative flows experienced water temperatures in the Fraser River consistently higher (range: 17.8–20.5 °C) than the thermal optimal for aerobic scope for this population (i.e. >17.5 °C; Lee et al., 2003b). Higher temperatures generally led to lower dam passage (Figure 3.37; Table 3.23), and passage may have been even higher under alternative flows had temperatures in the Fraser River been closer to their thermal optimum. Exposure to sub-optimal conditions may have similarly had a negative effect on post-passage survival.

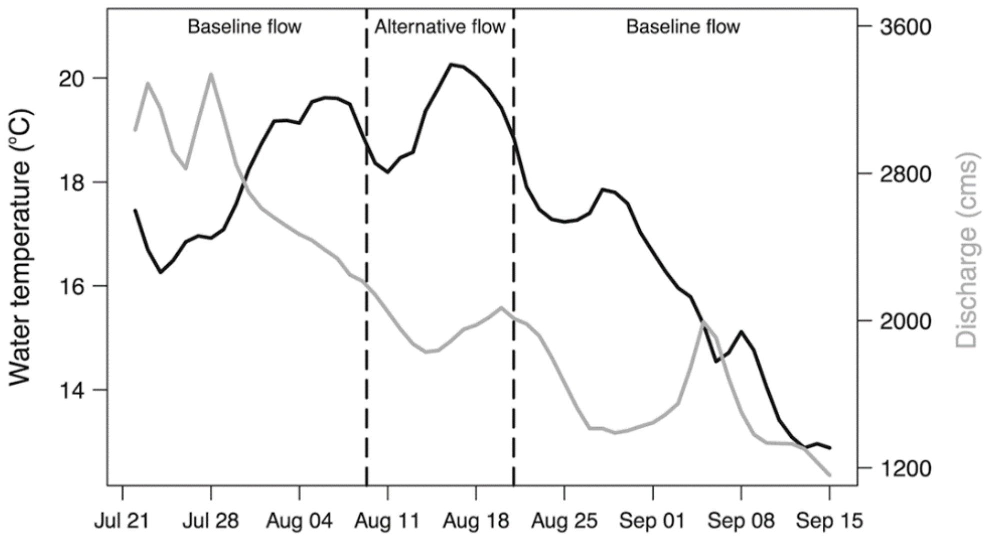

Figure 3.34 **Mean daily Fraser River water temperature (black) and discharge (grey) at Texas Creek (10 km downstream from Seton River) throughout the 2014 study period. Vertical lines denote the date that flow conditions were changed. Baselines flows labeled on the figure are equivalent to routine flows.**

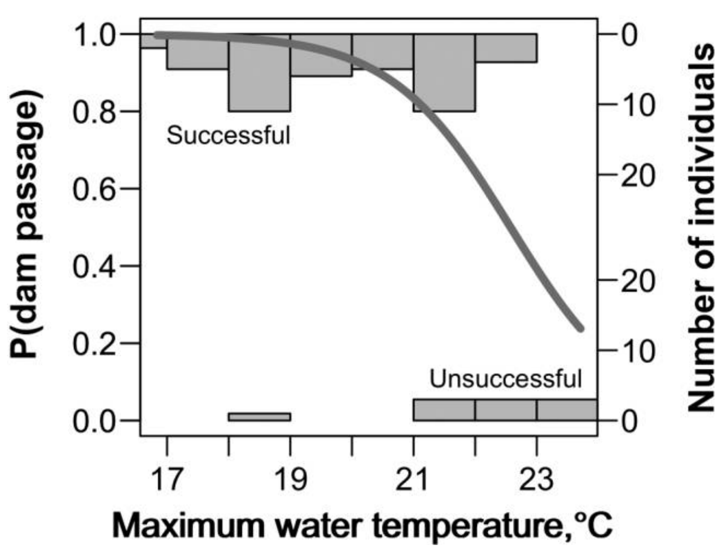

Figure 3.35 **Predicted probability of Gates Creek sockeye passage of the Seton Dam, visualized by fitting a logistic regression to the maximum Seton River temperature successful and unsuccessful fish experienced while directly below the dam.**

Table 3.22 Model selection statistics for generalized linear models predicting dam passage (A), anaerobic recruitment in areas of high flow below Seton Dam (B), tailrace crossings (C), and the ability of acoustic tagged Gates Creek sockeye to reach natal spawning streams (D) in 2014.

Response variable and model	Log likelihood	AICc	DAICc	*wi*	*D*
A. Dam passage					
Sex + maximum temperature + anaerobic recruitment	-12.97	37.20	0.00	0.12	50
Sex + maximum temperature	-14.29	37.40	0.21	0.10	45
Sex + anaerobic recruitment	-14.30	37.40	0.23	0.10	45
B. Anaerobic recruitment					
Sex + siphon 1 + tailrace crossings	-212.02	437.80	0.00	0.48	46
Sex + siphon 1 + tailrace crossings + maximum temperature	-212.01	440.50	2.63	0.13	46
Sex + siphon 1 + tailrace crossings + tailrace delay	-212.02	440.50	2.64	0.13	46
C. Tailrace crossings					
Sex + anaerobic recruitment	-62.51	133.80	0.00	0.14	25
Sex + anaerobic recruitment + tailrace delay	-61.67	134.60	0.77	0.10	30
Sex + tailrace delay	-62.95	134.70	0.89	0.09	22
D. Reach natal sites					
Anaerobic recruitment + siphon 1	-18.73	46.50	0.00	0.14	37
Anaerobic recruitment + siphon 1 + tailrace crossings	-17.65	46.90	0.38	0.11	41
Anaerobic recruitment + siphon 1 + sex	-18.07	47.70	1.23	0.07	39

Note: DAICc represents the difference in AICc values between model *i* and the top-ranked candidate model. Models are ranked from lowest to highest DAICc (highest to lowest *wi*); all top-ranked candidate models had a DAICc of 0. *D* represents the percentage of deviance explained by a generalized linear model. Capture location was included in all models as a fixed factor.

3.7.3.2 Passage Success In 2016

In 2016, assessments of post-passage survival of Gates Creek sockeye were completed by having two periods of routine (release from Siphon 1) and alternative (release from Siphon 4) water release. If both routine and alternative water release scenarios are not attempted at both the beginning and end of the migration period, any effect of water release could be attributed to temperature effects and not dam operations. Thus, the 2016 study was initiated to ensure passage and post-passage survival improvements were from dam operations and not confounded by run timing or temperature.

Results in 2016 followed the same trend as those obtained in 2014 in that overall passage success was higher during alternative flows, entrance delay was longer during alternative flows, and post-passage survival was higher under alterative flows (Table 3.24). As in 2014, PIT-tagged fish in 2016 passed Seton Dam faster under routine rather than alternative flows (Cox Proportional Hazard Model Chi = 52.5 p

<0.001; Figure 3.38). Fish rarely passed Seton Dam at night and this can be visualized as an extended plateau in passage probabilities seen in the time-to-event analysis (Figure 3.38). This could have been partially an artifact of the timing of fish release which was typically in the afternoon. Overall passage times averaged 8.4 h (SE = 0.41) and ranged from 1.0 to 58.8 hours for some fish. Passage times for fish during alternative flows was about 2.5 hours longer.

Table 3.23 **Dam passage metrics for PIT tagged Gates Creek sockeye at the Seton Dam from 2016 under either routine operations where water was released from Siphon 1 or during alternative operations where water was released from Siphon 4. Entrance delay is mean ± S.E.**

	Routine	Alternative
Attraction efficiency	98% (187/191)	98% (238/242)
Entrance delay (h)	8.0 ± 0.6	12.5 ± 0.8
Passage efficiency	100% (187/187)	99% (237/238)
Overall passage success	98% (187/191)	98% (237/242)
Success to spawning grounds	70% (131/187)	84% (201/238)
Overall passage and success to spawning grounds	69% (131/191)	83% (201/242)

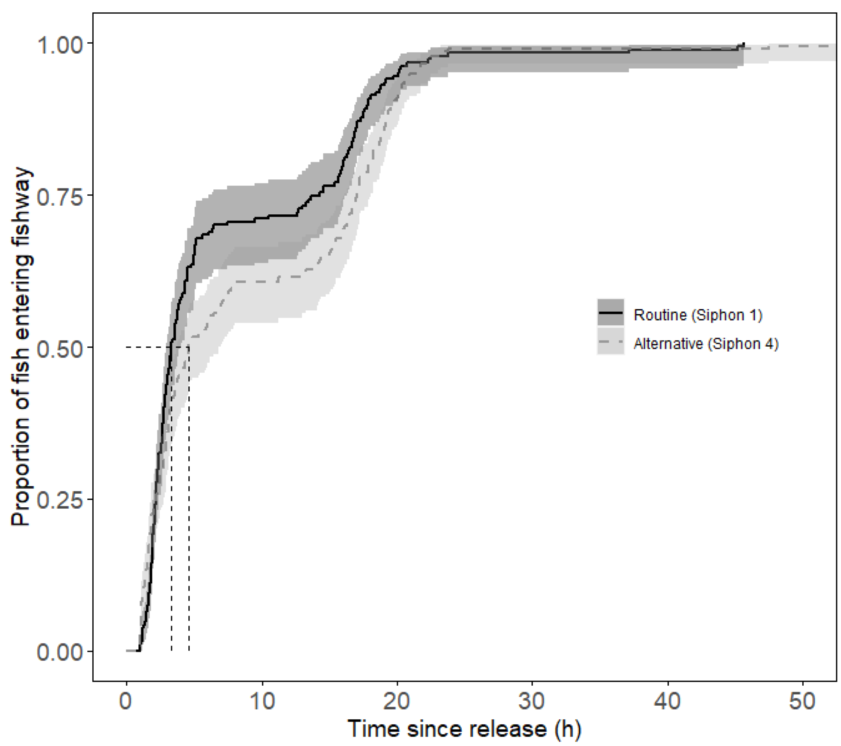

Figure 3.36 **Time-to-event curves for entrance of Gates Creek sockeye into the fishway at Seton Dam during routine (black solid line) and alternative water releases (grey dotted line). The point where half the fish have entered the fishway is indicated with a dotted line. Ribbons represent 95% confidence intervals on the estimates.**

3.7.3.3 Post-Passage Survival In 2016

Post-passage survival of fish that delayed longer at the dam under alternative flows was improved, in contrast to Caudill et al. (2007). In 2016, almost all PIT-tagged fish passed Seton Dam. Under routine water release from Siphon 1, 95% of PIT-tagged Gates Creek sockeye passed the dam. Under the alternative water release from Siphon 4, 99% passed the dam. This was similar to the trends seen in 2014 Gates Creek sockeye released under alternative water release scenarios. However, PIT-tagged Gates Creek released under alterative water release scenarios had better survival to spawning grounds (LR Test, Chi = 9.3, p = 0.002) in 2016. Post-passage survival, from the top of the fishway to Gates Creek increased by 16% with alternative water release, in 2014 this increase was 7%. This increase was attributed to the reduced burst swimming required by sockeye to enter the fishway when water is released from Siphon 4. Water release from Siphon 1 requires more burst swimming and some fish cannot recover from this extra effort and complete migration. In 2016, overall survival improvements in Gates Creek sockeye of the alternative water release scenario were 20%, in 2014 overall survival of PIT-tagged fish improved by 14%.

- *Gate Creek sockeye salmon delayed longer downstream of Seton Dam under the alternative flow scenario but swimming effort to enter the fishway was reduced.*
- *Increased post-passage survival under the alternate flow scenario was likely associated with reduced burst swimming during Seton Dam passage, as fish spent more time in the Seton Dam forebay following passage under routine flows, presumably recovering from anaerobic stress.*
- *Water release from Siphon 4 has a limited effect on attraction and passage of fish; however, it does result in an up to 20% improvement in Gates Creek sockeye survival to spawning grounds than water release from Siphon 1.*

4 DISCUSSION

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 Creek dilution in Seton River.

3. To identify operating strategies that will mitigate impacts to upstream migration.

To meet the objectives, a series of management questions and hypotheses were developed and directly addressed with a capture, tagging, and monitoring program from 2012 to 2016, inclusive. The management questions sought to answer how dam operations influence salmon migratory and spawning success in the Seton-Anderson watershed. They are:

1a. 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 populations?

1b. How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

2. 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?

3a. Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3b. What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

We specifically address these management questions by discussing the how the research presented above relates to each management question.

<u>**Management Question 1a**</u>**: 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 populations?**

Previous studies of salmon migration in the Seton-Anderson watershed (Andrew and Geen 1958, Fretwell 1989) suggested negative effects of the dilution of Seton River with water from Cayoosh Creek on the migratory behaviour of returning sockeye. Specifically, these studies found evidence that salmon may spend more time in the Seton Generating Station tailrace, and that operations upstream may influence the amount of time spent in the tailrace. These previous studies helped set current management targets for dilution at the Seton Dam.

Streamside behavioural choice experiments were done 2013 and 2014 and revealed that both Gates Creek and Portage Creek sockeye populations prefer undiluted Seton Lake water to water that is diluted above certain threshold levels (see Section 3.4.1). Undiluted Seton Lake water is the water released through the Seton Generating Station.

The experimentally determined thresholds for dilution from BRGMON-14 align with both previous studies on dilution effects (Andrew and Geen 1958, Fretwell 1989) and the targets in the Bridge River Water Use Plan—20% dilution for Gates Creek sockeye and 10% dilution for Portage Creek sockeye (BC Hydro 2012). When given the choice of undiluted Seton Lake water and Seton Lake water diluted to or below these threshold levels in the stream-side experiments, both Gates and Portage Creek sockeye did not exhibit any preference. Thus, results from streamside behavioural choice experiments confirm previous concerns that when the Seton River is diluted beyond threshold levels, migrants will have stronger attraction to their preferred water flowing from the Seton Generating Station tailrace.

Management Questions 1b: How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

Observation of fish movements with radio-tagging and telemetry supported the findings of the streamside behavioural choice experiments, further demonstrating that dilution can influence migration behavior. Sockeye were observed spending time in the Seton Generating Station tailrace (see Section 3.4.2), confirming the observations made in earlier studies (Fretwell 1989). Although the water in the tailrace can be cooler than the Fraser River, there was little indication that the holding behaviour of sockeye was influenced by temperature differences, suggesting the behaviour was primarily driven by an attraction to natal olfactory cues. For Portage Creek sockeye, dilution had a strong effect on the frequency of forays into the tailrace, delay in the tailrace, and wandering between the tailrace and the mouth of the Seton River (see Section 3.5). Portage Creek sockeye also spent longer in the Fraser River than Gates Creek sockeye and delayed when natal water concentration in the Seton River was low (i.e., dilution levels >10%). An effect of dilution on forays, delay and wandering was not found in Gates Creek sockeye. However, following from the stream-side behavioural choice experiments (see Section 3.4.1), Gates Creek sockeye appear less sensitive to moderately low levels of dilution (i.e., their dilution threshold is twice as high as that of Portage Creek sockeye), and dilution levels during observational field studies in 2013 and 2014 were well below the 20% threshold during most of the observations of Gates Creek sockeye migration.

The experimental manipulation of dilution levels in the Seton River during the Gates Creek run in 2015 allowed for an assessment of migratory behaviour under a prolonged period of elevated dilution that exceeded the 20% target. Under these conditions, there was a reduction in entry success into the Seton River and migrants took longer to enter the river. There was also a differential response in entry success between sexes, with males more likely to be successful at completing migration under the diluted conditions. The cause of this difference remains unclear but what is clear is that for Gates Creek sockeye females take longer to complete migration and more females fail to complete migration when dilution of natal water in the Seton River is over the 20% target. Experimental manipulation of dilution of natal water in the Seton River supports previous research, stream-side experiments, and observational studies – dilution beyond the 20% target in the Bridge River Water Use Plan can negatively impact Gates Creek sockeye migration. Similar results could occur with Portage Creek sockeye but at the lower dilution target (10%) outlined in the Bridge River Water Use Plan.

Gates Creek sockeye appear to not sustain injuries at the Seton Generating Station as previously thought, but instead are typically injured escaping from downstream net fisheries in the Fraser River and from other downstream factors. During a period of closure of the Cayoosh Creek diversion tunnel—and subsequent increase in the dilution of the Seton River—a high frequency of head injuries was found in returning salmon (Anonymous 1976). These injuries were thought to occur when fish attempted to swim into the Seton Generating Station. Previous trials showed that when water in Cayoosh Creek was once again diverted to Seton Lake, and dilution in the Seton River thereby reduced, the frequency of head injuries decreased (Fretwell and Hamilton 1983). However, a detailed analysis of injuries in sockeye conducted during this project, including the examination of over 3500 Gates Creek and Portage sockeye, confirmed that head injuries from attempted migration at the Seton Generating Station were infrequent, including during periods of high dilution.

Dilution of the Seton River with water from Cayoosh Creek does affect the migratory behaviour of Gates Creek and Portage Creek sockeye, including delay at the Seton Generating Station tailrace, and these effects are significant at dilution levels that exceed the previously established targets of 20% for Gates Creek sockeye and 10% for Portage Creek sockeye populations. It appears that current management thresholds for dilution of natal water in the Seton River are enough to mitigate delays in Gates and Portage Creek sockeye, and that there is a relationship between dilution and both delay and success of upstream migration of Gates Creek sockeye at dilution levels >20%. Similar results should occur with Portage Creek sockeye when dilution of natal water in the Seton River is >10%.

The results from BRGMON-14 support previous management objectives for dilution outlined in the Bridge River Water Use Plan; suggest that Gates Creek sockeye become sensitive at >20% dilution of natal water in the Seton River and Portage Creek Sockeye become sensitive at >10% dilution of natal water in the Seton River; and that injuries sustain by Gates Creek sockeye are more likely to arise from gill net fisheries in the Fraser River than from attempts to migrate up the Seton Generation Canal. BRGMON-14 results provide support for the following alternative hypotheses:

> *H_{1A}: Gates Creek sockeye upstream migration is significantly delayed when the Cayoosh Creek dilution exceeds 20%.*
>
> *H_{2A}: Portage Creek sockeye upstream migration is significantly delayed when the Cayoosh Creek dilution exceeds 10%.*
>
> *H_{3A}: There is a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.*
>
> *H_{4A}: There is a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.*

<u>Management Question 2</u>: 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?

Controlled, streamside behavioural tests of pink salmon suggest they are not influenced by the dilution of Seton River (see Section 3.6.1). When tested with pure Seton Lake water and a 50% dilution mixture, pink salmon did not show a preference for either water source. Dilution of natal water in the Seton River rarely if ever reaches a 50% dilution during salmon migration. A lack of preference to even this exceptionally high level of dilution suggests that pink salmon in this area are less responsive, and therefore less sensitive, to olfactory cues than Gates Creek or Portage Creek sockeye. Observations of fish in the river using telemetry showed that pink salmon do not make forays into the Seton Generating Station tailrace as frequently as sockeye, do not make the same directed movements to well defined spawning grounds as sockeye, and most spawn below the Seton Dam (see Section 3.6.2). This lends further support to the conclusion that dilution of the Seton River has limited influence on the migratory behaviour of pink salmon. These findings support the management alternative hypothesis:

H_{5A}: There is no significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure

Chinook and coho are expected to behave similarly to sockeye in terms of their responses to olfactory cues (see Section 3.6.3). BRGMON-14 did not capture Chinook or many coho - both species only occurred in small numbers in the Seton-Anderson watershed. A review of the behaviour of Chinook and coho in other systems shows these species have similar olfactory sensitivities as sockeye and respond similarly to natal water concentrations. Like sockeye salmon but unlike pink salmon, these species also home to their natal sites with a high degree of fidelity (Keefer and Caudill 2015). Dilution of the Seton River is therefore expected to influence Chinook and coho that spawn above the dam.

The behaviours observed in sockeye, including forays into the Seton Generating Station tailrace, longer migration timings, failure to complete migration, and wandering are expected to occur in both Chinook and coho. Chinook and coho could be compared to Portage Creek sockeye since they migrate at the same time in the fall. A small number of coho that were radio-tagged and tracked during BRGMON-14 made fewer forays into the generation station tailrace and delayed entry to the Seton River substantially less than did Portage Creek sockeye. It therefore appears that although coho should be influenced by Seton River dilution, the current operational guidelines set for the co-migrating Portage Creek sockeye population (<10% dilution of natal water) is likely sufficient in mitigating any adverse effects. From literature reviews, we expect Chinook and coho to respond in a similar manner to Portage Creek sockeye but only have limited field data support the following alternative hypotheses for Chinook and coho:

H_{6A}: There is no significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure

H_{7A}: There is no significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.

<u>Management Question 3</u>: Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

The attraction and passage efficiencies at the Seton Dam of Gates Creek sockeye was found to be consistently high (>90%) with almost all fish passing the dam (see Section 3.7.1). Both attraction efficiency and passage for sockeye remained high under routine and alternative flow scenarios (see Section 3.7.2). Attraction and passage efficiencies have been consistently high across all years of Gates Creek sockeye studies (>90% for all tag types). The attraction efficiency for Portage Creek sockeye tagged with either radio- or PIT-tags was extremely high (> 95% when released at the fence). Lower passage of radio-tagged fish could occur because these fish were transported and released downstream in the Fraser River. Water release trials of 2014 and 2016 demonstrate that Seton Dam and fishway operation has only small effects on attraction and passage of Gates and Portage Creek sockeye.

The low passage efficiencies in pink salmon likely reflect differences in the life history and homing behaviour of this species in comparison to sockeye. Pink salmon have a lower affinity for their natal streams and tend to stray more frequently into other tributaries (Keefer and Caudill 2015) and are less responsive to the odor of their natal streams (Yamamoto et al. 2008). Pink salmon only return to the Seton River in high abundance in odd years (2013 and 2015 during BRGMON-14) and the timing of their return means they co-migrate with Gates and Portage Creek sockeye. Most pink salmon currently spawn downstream of the Seton Dam, few in the present study (~35%) passed the dam, and they do not respond to natal cues like sockeye (see Section 3.7.1). Pink salmon would therefore not be expected to respond as strongly to migratory cues present in the discharge of the dam and are less likely to pass the dam. Therefore, it's unsurprising that the attraction efficiency of pink salmon that reached Seton Dam was low (15% for radio-tagged fish transported and released in the Fraser River and 44% for PIT-tagged fish(released at the fence) relative to Gates Creek and Portage Creek sockeye. However, for pink salmon attracted to the dam, passage efficiency remained relatively high (66% for radio-tagged fish but only 9 individuals attempted to pass the fishway: 77% for PIT-tagged fish in 2013). Given the relatively low numbers of pink salmon that attempt to pass the dam, Seton Dam operations likely have only a small effect on the population.

Attraction and passage efficiencies of coho and Chinook at the Seton Dam could not be assessed due to difficulty in capturing these species (described in Section 3.3). Different species of Pacific Salmon are believed to have similar passage abilities (Bunt et al. 2012; Noonan et al. 2012), however, and there is no reason to believe that Chinook and coho migrating to spawning grounds upstream of Seton Dam would exhibit passage efficiencies that significantly differ from those of Gates or Portage Creek sockeye. Coho can also spawn below Seton Dam, and these fish are not affected by passage issues.

<u>Management Question 3a</u>: What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

Post-passage survival to spawning grounds of Gates Creek sockeye was affected by Seton Dam conveyance structure use. Post-passage survival of Gates Creek sockeye under routine (water release from Siphon 1) and alternative water release (water release from Siphon 4) scenarios were revealed by water release trials in 2014 and 2016 (see Section 3.7.3). In 2014, attraction efficiency and passage efficiency were high under both the routine and alternate conditions, although passage efficiency was slightly higher but took 6.2 hours longer under alternate water release. (Burnett et al. 2014). However, there was a pronounced difference in post-passage survival to spawning grounds between routine and alternative water release scenarios with two times longer recovery times from dam passage and 10% higher mortality under routine water release scenarios (Burnett et al. 2014). These results support changing dam operations to release water from Siphon 4 rather than Siphon 1 during the Gates Creek sockeye migration to increase the number of fish able to complete migration and spawn.

The monitoring focus of the 2014 and 2016 alternative flow trials were different. Water release trials in 2014 provided detailed physiological mechanisms for how behaviour during both water release scenarios, however, because only a single period of release from Siphon 1 occurred it was impossible to decipher the effects of run timing and water temperature from the effects of water release during the 2014 trial. The 2016 trial confirmed the post-passage survival results determined in 2014 and provided detailed estimates of post-passage survival rates using the relatively non-invasive PIT-tagging. It used two periods of alternative water release from Siphon 4 to isolate the effects of run timing and temperature on post-passage survival.

Studies in 2014 found Gates Creek sockeye must perform more burst swimming during discharge from Siphon 1 during the routine conditions than during the alternative discharge conditions. The increased burst swimming requirements during dam passage under siphon 1 resulted in higher mortality once fish passed the dam and before being able to spawn. Water release from Siphon 1 created a large area of highly turbulent water downstream of the entrance to the fishway. Discharge from Siphon 4 during the alternative conditions moved the primary area of discharge approximately 10 m away from the fishway entrance and created a narrower band of high turbulence. Under the alternate conditions, there was also a reverse flow field downstream of the fishway entrance, along the fishway wall, that served as a refuge. Under both conditions, fish were observed staging near the tailrace in a large vortex on the northern bank of the river and would cross through the areas of high turbulence to arrive at the fishway entrance. Most fish made multiple crossings before entering the fishway. During alternative water release conditions Gates Creek sockeye spent more time in the tailrace but did not require as many or as intense bouts of burst swimming to pass the dam. To enter the fishway, Gates sockeye did not have to swim with maximum effort for as long during the alternative water release. This reduced effort translated into increases survival of sockeye post-passage and thus more fish that completed their migration to spawning grounds. Fish experiencing routine conditions incurred a greater oxygen debt, which necessitated a longer recover period and likely contributed to increased post-passage mortality. Sockeye that consume more oxygen accumulate greater excess post-exercise oxygen costs (EPOC; Lee et al. 2003) and require more time to restore tissue and cellular oxygen levels. From the 2014 trials, the reduced physiological effort required by Gates Creek sockeye, combined with the increase in entrance time of the alternative water release, suggests dam operations should release water from Siphon 4 during the Gates Creek sockeye migration. The 2016 results, with a larger number of PIT tagged fish and replication of water release treatments, confirmed this result.

Water is not released from Siphon 1 during the Portage Creek migration, and therefore altering the release of water to a siphon further from the fishway (as for Gates Creek sockeye) does not apply to this population. It is possible that a different form of operational change might affect post-passage survival of Portage Creek sockeye, however any expected benefit would likely be less significant than in the Gates Creek population for two reasons: 1) the Portage Creek population has a shorter post-passage migration to spawning grounds that is less physiologically demanding; and 2) water temperatures during the Portage Creek migration are cooler than during the Gates Creek migration, and burst swimming in cooler waters is associated with lower oxygen consumption (Lee et al. 2003b). This suggests that at least in 2014 that Gates sockeye were able to pass Seton Dam, but up to 25% died soon after likely because of excessive burst swimming required to pass the dam. Portage Creek sockeye are therefore expected to accumulate lower oxygen debt under the routine conditions as they navigate to the fishway entrance through cooler waters and lower flows (relative to the Gates Creek population) and have a shorter post-passage migration distance.

Fraser River sockeye have population-specific thermal tolerance ranges that reflect historic river temperatures, and migration outside their range can lead to the collapse of metabolic and cardiac scope, and mortality (Eliason et al. 2011). Portage Creek sockeye experienced >50% *en route* mortality in over half of the brood years from 1995 - 2010 (Hinch et al. 2012). High post-passage and pre-spawning mortality may therefore occur in early migrants in the Portage Creek population regardless of Seton Dam release patterns, although mortality could be exacerbated by a sub-optimal release strategy. Portage Creek sockeye migrants returning during the normal historic return period may benefit from the alternative release scenario if discharge could be kept low. However, any early component the Portage Creek run would already experience significant thermal stress and would not be expected to respond in the same manner as Gates Creek sockeye.

Our results demonstrate that attraction efficiency and passage efficiency of sockeye salmon at the Seton Dam remains high under the current, routine operational conditions as well as under an alternative operational condition. As such, the results from BRGMON-14 do not support the following alternative hypotheses:

> *H_{8A}: Operation of Seton Dam and fishway affects attraction to the fishway*
>
> *$H_{9A:}$ Operation of Seton Dam and fishway affects passage efficiency at the fishway*

However, operation of the Seton Dam did affect post-passage survival of Gates Creek sockeye, with higher survival rates in salmon experiencing an alternate water release, in which water was discharged through Siphon 4 rather than Siphon 1. Water release from other Siphons 2, 3 or 5 could have a similar effect as water release from Siphon 4 as they would move turbulent flows away from the fishway entrance like flows from Siphon 4 did. However, as we did not specifically examine water releases from these siphons, we cannot specifically comment on effects of their use to salmon migration. Portage Creek sockeye may benefit, possibly to a lesser degree, from an alternate water release strategy as we demonstrated for Gates Creek sockeye, but we did not specifically examine this in the field program.

5 CONCLUSION

The Seton-Anderson watershed poses a complex migration route for returning adult salmon, a route made more complicated by hydroelectric infrastructure. Through a combination of controlled behavioural tests, telemetry, and *in situ* experiments BRGMON-14 has provided an extensive examination of the influence of changes in local hydroelectric dam operations on salmon migration through this system. BRGMON-14 data confirms that the dilution of natal water in the Seton River with water originating from Cayoosh Creek influences migration behaviour, particularly in the Fraser River. The results support the efficacy of the current dilution targets derived by the IPSFC in mitigating delays associated with dilution of natal water in the Seton River during Gates Creek and Portage Creek sockeye migrations. Pink salmon are not as sensitive to natal water cues as sockeye and our results suggest they are less sensitive to changes in dilution. BRGMON-14 was not able to telemetry track many coho or any Chinoook salmon, so were not able to directly examine the impact of dilution or Seton Generating Station operations on coho or Chinook. However, information from reviewing the scientific literature suggests that current dilution objectives for co-migrating Portage Creek sockeye are generally appropriate for these two species.

BRGMON-14 also demonstrates while passage and attraction efficiency remain high at Seton Dam when water is released from either Siphon 1 or Siphon 4, there are post-passage survival consequences for Gates Creek sockeye that can be mitigated with alternative (Siphon 4) water release scenarios. Restrictions on discharge during the Portage Creek sockeye run prevented detailed investigations on the influence of alternative water release scenarios on this population. It is possible that late-run Portage Creek sockeye would respond differently than the early-run Gates Creek population to alternative discharge patterns. For pink salmon it appears that dam operation does not have a large impact, since most pink salmon spawn below the dam.

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7 APPENDIX I

List of deliverable other than this report arising from BRGMON-14 including peer-reviewed scientific articles, Thesis and Dissertations, Highly Qualified Personnel, and Articles in preparation.

7.1 Peer-reviewed Journal Articles Arising from BRGMON-14

Bass, A.L., Hinch, S.G., Casselman, M.T., Patterson, D.A., Bett, N.N., Burnett, N.J., and Middleton C.T. (2018). Visible gill net injuries predict migration and spawning failure in adult sockeye salmon. Transactions of the American Fisheries Society. 147(6): 1085-1099.

Bett, N.N., Hinch, S.G., and Casselman, M.T. (2018). Effects of natal water dilution in a regulated river on the migration of Pacific salmon. River Research and Applications. 34(9): 1151-1157.

Bett, N.N., Hinch, S.G., Burnett, N.J., Donaldson, M.R., and Naman, S.M. (2017). Causes and consequences of straying into small populations of Pacific salmon. Fisheries. 42(4):220-230.

Bett, N., Yun, S.S., Hinch, S.G. (2016). Behavioural responses of Pacific salmon to chemical disturbances cues during the spawning migration. Behavioural Processes. 132:76-84.

Bett N.N., Hinch, S.G. (2016). Olfactory navigation during spawning migrations: A review and introduction of the Hierarchical Navigation Hypothesis. Biological Reviews. 91(3):728-759.

Bett, N.N., and Hinch, S.G. (2015). Attraction of migrating adult sockeye salmon to conspecifics in the absence of natal chemical cues. Behavioural Ecology. 26(4):1180-1187.

Burnett, N.J., Hinch, S.G., Braun, D.C., Casselman, M.T., Middleton, C.T., Wilson, S.M., Cooke, S.J. (2014) Burst swimming in areas of high flow: delayed consequences of anaerobiosis in wild adult sockeye salmon. Physiological and Biochemical Zoology. 87(5):587-598.

Burnett, N.J., Hinch, S.G., Donaldson, M.R., Furey, N.B., Patterson, D.A., Roscoe, D.W., Cooke, S.J. (2014) Alterations to dam-spill discharge influence sex-specific activity, behaviour and passage success of migrating adult sockeye salmon. Ecohydrology. 7(4):1094-1104.

Burnett, N.J., Hinch, S.G., Bett, N.N., Braun, D.C., Casselman, M.T., Cooke, S.J., Gelchu, A., Lingard, S., Middleton, C.T., Minke-Martin, V., and White, C.F.H. (2017). Reducing carryover effects on the migration and spawning success of sockeye salmon through a management experiment of dam flows. River Research and Applications. 33:3-15.

Drenner, S.M., W.L. Harrower, M.T. Casselman, N.N. Bett, A.L. Bass, C.T. Middleton, S.G. Hinch. (2018). Whole-river manipulation of olfactory cues affects upstream migration of sockeye salmon. Fisheries Management and Ecology. 25(6): 488-500.

Kanigan, A.M., Hinch, S.G., Bass, A.L., Harrower, W.L. (2019). Gill-net fishing effort predicts physical injuries on sockeye salmon captured near spawning grounds. North American Journal of Fisheries Management. 39(3): 441-451.

Middleton, C.T., Hinch, S.G., Martins, E.G., Braun, D.C., Patterson, D.A., Burnett, N.J., Minke-Martin, V., Casselman, M.T., Gelchu, A. (2018). Effects of natal water concentration and temperature on the behaviour of up-river migrating sockeye salmon. Canadian Journal of Fisheries and Aquatic Sciences. 75(12): 2375-2389.

Minke-Martin, V., Hinch, S.G, Braun, D.C., Burnett, N.J., Casselman, M.T., Eliason, E.J., and Middleton, C.T. (2018). Physiological condition and migratory experience affect fitness-related outcomes in adult female sockeye salmon. Ecology of Freshwater Fish. 27(1): 296-309.

7.2 Thesis and Dissertations Arising from BRGMON-14

Bass, A. (2018) Fisheries gear and biological context drive fishing-related incidental mortality in Pacific salmon spawning migrations. PhD Dissertation. University of British Columbia, Vancouver. BC

Bett, N.N. (2016) Responses of Pacific salmon to pheromones, natal water, and disturbance cues during the spawning migration. PhD Dissertation. University of British Columbia, Vancouver. BC

Middleton, C.T. (2016) The cumulative effects of physiology, temperature, and natal water cues on the migration behaviour and survival of adult sockeye salmon during passage through the Seton River hydroelectric system, British Columbia. MSc. Thesis University of British Columbia, Vancouver. BC.

Minke-Martin, V. (2016) Thermal behaviour, survival, and reproductive success of adult Gates Creek sockeye salmon (Oncorhynchus nerka). MSc. Thesis University of British Columbia, Vancouver. BC.

Burnett, N.J. (2014) Evaluating the effects of dam-altered flow regimes on the swimming activity, behaviour and survival of adult sockeye salmon (Oncorhynchus nerka). MSc. Carleton University, Ottawa. ON.

7.3 Highly Qualified Persons (HQP) that Received Training on BRGMON-14

Avaleen Adolph – St’át'imc Eco Resources

Arthur Bass – University of British Columbia

Nolan Bett – University of British Columbia

Douglas Braun – University of British Columbia

Nicholas Burnett – University of British Columbia

Jennifer Carter – Simon Fraser University

Matthew Casselman – University of British Columbia

Matthew Drenner – University of British Columbia

William Harrower – University of British Columbia

Jessica Hopkins – St'át'imc Eco Resources

Allison James – St'át'imc Eco Resources

Melanie Kuzyk – University of British Columbia

Roxx Ledoux – St'át'imc Eco Resources

Andrew Lotto – University of British Columbia

Collin Middleton – University of British Columbia

Venessa Minke-Martin – University of British Columbia

Wesley Payne – St'át'imc Eco Resources

Yu Qian – University of Alberta

Carson White – University of British Columbia

Wenming Zhang – University of Alberta

7.4 Press Articles

UBC Press Release:

http://news.ubc.ca/2014/08/21/salmon-forced-to-sprint-less-likely-to-survive-migration-2/

Vancouver Sun:
http://www.vancouversun.com/health/Sprinting+sockeye+dying+from+heart+attacks/10136996/story.html

Science Daily:

https://www.sciencedaily.com/releases/2014/08/140820183938.htm