Cheakamus River Project Water Use Plan

Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

Implementation Year 9

Reference: CMSMON-1B

Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Surveys from 2007-2015, and Chum Fry Production from 2001-2016

Study Period: October 2015 – June 2016

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August 31, 2016

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EXECUTIVE SUMMARY

The Cheakamus River Chum salmon adult escapement monitoring and mainstem spawning groundwater survey, implemented in 2007, and the Chum fry outmigration estimates from the Cheakamus River juvenile salmonid outmigration enumeration monitor, implemented in 2001, are used in conjunction to evaluate the affects of discharge on groundwater upwelling, Chum spawner site selection, incubation conditions and Chum fry production. Egg-to-fry survival rates are used to evaluate the effects of discharge on spawning and incubation. The flow regime implemented in the Water Use Plan in 2006 aimed to increase available spawning habitat for Chum salmon and thus fry production in the Cheakamus River. This study has been evaluating whether the metrics used to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of Chum salmon spawning site selection, and the availability of spawning habitat.

Discharge during Chum spawning affects distribution and redd site selection. At higher minimum discharges (near 25 m^3/s) a larger proportion of spawners utilize the side channels in the upper river. Egg-to-fry survival in these side channels is higher than in the mainstem; thus, when larger numbers of spawners utilize the side channel habitat, upper river productivity increases, as long as side channel carrying capacity is not surpassed. In years of moderate and high escapement when a reduction in the number of fry per spawner is observed and fry productivity decreases in the side channels, discharge rates during the spawning season may be more important for distributing spawners throughout the river to maximize productivity of Chum salmon.

River levels and flow fluctuations prior to and during the Chum spawning window, appear to affect run-timing, upstream migration and egg-to-fry survival. In years of higher flows, Chum spawners have been found moving into higher reaches of the river. In years of low flows, increased pre-spawn mortality has been observed, likely due to increased stress of observed later run timings. Additionally, in low flow years, spawners have been found concentrated in high densities between river kilometer 5.5 and river kilometer 7.0. As a result of high concentrations of Chum spawners in this 1.5 km stretch of mainstem habitat in 2013, carrying capacity was exceeded and egg-to-fry survival in 2013/2014(0.3%) was 1/10th of the 2012/2013 rate (3.6%) when brood escapement was also high. In 2012, increased flow events during the spawning season coincided with high abundances of spawners and a broader distribution of spawners was observed with Chum spawners utilized habitat up to river kilometer 16.5.

The importance of side channel habitats for Chum fry production as a buffer against extreme flow events during spawning and incubation periods was emphasized in 2014/2015 and 2015/2016. Large areas of scour were noted in both years when buried temperature loggers were excavated from potential spawning areas above river kilometer 7.0. The side channel contribution of Chum fry to the total outmigration estimate in the upper river was 92% and 75% in 2015 and 2016, respectively.

In order to assess how discharge has affected mainstem productivity for all years of this study (2007-present), accurate annual egg deposition rates, including fecundity and pre-spawn mortality, need to be determined. After the fourth year of pre-spawn mortality surveys and fecundity evaluations, it is apparent that egg deposition varies both spatially and temporally. After the tenth year of study, fecundity for Years 1-5 of this study can be estimated based on fork length and potentially, age. Additionally, productivity from Tenderfoot Creek will be removed from the 2007/2008-2012/2013 data by using known adult escapement and estimating egg deposition and egg-to-fry survival rates.

Chum salmon are spawning in groundwater upwelling areas of the Cheakamus River and groundwater appears to affect incubation and productivity for spawning Chum. Chum select nest sites based on both hydrological and geophysical features. Whether Chum spawners are selecting sites because of the presence of groundwater or other habitat attributes has not yet been determined. Measuring additional habitat parameters would provide more insight into the features that Chum are selecting for when building redds. One third of females that were radio tagged in the lower river spawned in known groundwater upwelling areas in both 2013 and 2015. However, geophysical habitat data have not been assessed and water depth, water velocity, substrate size and substrate embeddedness are also likely influencing site selection.

Over the past four years, egg-to-fry survival in the side channels has been between 2 and 112 times higher than egg-to-fry survival in mainstem habitat. By comparing peak spawning times to peak fry outmigration times over seven years in the upper river, it appears that the majority of outmigrating fry are emerging from redds with groundwater influence. If Chum salmon are selecting sites because of the presence of groundwater upwelling, groundwater could be included in models along with geophysical habitat characteristics to predict effective spawning areas for Chum salmon.

Additional evaluations of the temperature in the hyporheic zone upstream of the Bailey Bridge (RK 7.0) will provide information on the temperature profiles in the areas classified as effective spawning area that Chum are not consistently utilizing. The connection between the river temperature profiles and discharge pattern can then be further evaluated. Additional data and analysis on distribution trends, monitoring upstream movement patterns on both a fine and course scale would allow for a better understanding of the importance of flow variations for upstream migration and distribution.

The current flow regime was implemented aiming to increase available spawning habitat for Chum salmon and thus, fry production in the Cheakamus River. Since fry monitoring began in 2001, annual fry production has varied greatly. Higher variation has been observed during the Water Use Plan study (CV=0.62) than before the Water Use Plan was impleneted (CV=0.29). Reasons for this could include changes in spawner abundance, distribution patterns and changes in habitat conditions or river discharge. Despite the high variability, an increase of 20% in average annual fry production has been observed under the Water Use Plan flows. The key study goal is the ability to detect a linkage between discharge and a positive change in fry production of 75% or greater as predicted by the modeling work conducted before the Water Use Plan was implemented. At present the observed changes in fry abundance fall short of this level of increase.

ACKNOWLEDGEMENTS

We would like to thank the following people for their cooperation and help over the years:

BC Hydro

Brent Mossop, Ian Dodd, Darin Nishi, Jeff Walker and Alexis Hall

❖

Cheakamus Centre (formerly, the North Vancouver Outdoor School)

Victor Elderton, Carl Halvorson and Jason Fullerton

❖

DFO Tenderfoot Hatchery

Peter Campbell, Brian Klassen and Jordan Uittenbogaard

❖

Squamish First Nations

Randal Lewis, Wylie George and Dustin Billy

❖

InStream Fisheries Research Inc.

Stephanie Lingard, Cole Martin, Dani Ramos,

Todd Moody and Heath Zander

CITATION

C. Fell, C.C. Melville and L.J. Wilson. 2016. Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Groundwater Survey from 2007-2015, and Chum Fry Production from 2001-2016. Cheakamus River Monitoring Program #1B. Technical report for BC Hydro – Coastal Generation. 98 p. + Appendices

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1.0 INTRODUCTION

1.1 Background History of Study

The Water Use Plan (WUP) for the Cheakamus River (BC Hydro 2005) includes a flow regime for the Cheakamus River designed to balance environmental, social and economic values. One of the fundamental objectives of the Cheakamus River WUP is to maximize wild fish populations. As a result, the WUP recommended an operating alternative and associated river flow regime in an attempt to increase productivity of wild fish populations. However, the effects remained uncertain as the updated flow regime, and predicted increases fish productivity, were modeled using assumed relationships between flow, fish habitat and fish production (Marmorek and Parnell 2002). As a result, the Cheakamus WUP Consultative Committee recommended a number of environmental monitoring programs to address the uncertainty in how revised flow regimes would influence wild fish populations.

Cheakamus River Chum salmon were identified during the consultative process as a keystone indicator species. The effect of flow on Chum salmon spawning and incubation was of particular concern. An important recommendation was to establish a link between adult Chum salmon spawner escapement and juvenile outmigration data and use the resultant spawner-fry index (H') as an indicator of flow effects. The potential value of this index was highlighted during an exercise that modeled alternative monitoring designs (Parnell et al. 2003). BC Hydro has monitored Cheakamus River juvenile Chum fry outmigration for the last 16 years (Melville and McCubbing 2000-2013 and Lingard et al. 2014, 2015 and 2016) and an additional year of monitoring is scheduled for 2017 (CMSMON 01A 5 year review, Melville and McCubbing 2012). In addition, an annual Chum salmon spawner escapement study began in 2007 (Troffe and McCubbing 20Fi08, Troffe et al. 2008-2010, McCubbing et al. 2011-2012, Fell et al. 2013, 2014 and 2015) with a tenth year scheduled for fall of 2016 (CMSMON 01B McCubbing et al. 2012). Relationships between adult escapement and juvenile outmigration will be further assessed via data synthesis reports stemming from a nine and ten-year review.

The consultative process also identified the uncertainty in the relationship between river discharge and groundwater upwelling in mainstem spawning areas and how this may affect fish productivity. The flow alternatives established during the consultative process were heavily based on an effective spawning area performance measure for Chum salmon and other salmon. The performance measure was modelled using River 2-D simulations, depth, velocity, substrate preference curves, and redd stranding calculations to identify areas where spawning was likely or unlikely to occur. However, this approach was likely an overestimate of the area of spawning habitat relative to empirical measures and does not predict actual spawning locations (Marmorek and Parnell 2002). Thus, while the model is useful for comparing alternative flows, it does not provide precise measures of spawning habitat. Modeling suggested that lower and more stable flows during the fall relative to the flows under the Interim Flow Agreement (IFA) would provide a larger area suitable for spawning and that these areas would remain wetted during incubation periods thus providing a relatively larger effective spawning area. However, this technique did not incorporate the effect of groundwater on habitat selection by spawning Chum salmon. There was a suggestion within the committee that lower flows during the fall spawning period would result in reduced surface water-to-groundwater exchange and reduced upwelling. This could result in reduced quality of available spawning locations and thus, lower Chum egg-to-fry survival. Concerns were raised that the River 2-D modeling had overestimated suitable spawning areas under low flows. Data collected from 2008 through 2011 supported these concerns finding that Chum salmon select spawning locations in areas with groundwater upwelling and that these are tempered by environmental conditions such as floods. In addition, increased variability in water temperature as a result of warmer upwelling groundwater was detected that could affect fry emergence timing. Additional data on site-specific spawning across a greater range of escapements (in particular, high escapements) are required to assess whether groundwater upwelling areas are critical to fry production.

The Chum adult monitoring program was developed to examine the effects of the WUP flow regime on Chum salmon spawning and incubation in the mainstem of the Cheakamus River and major side channels (BC Hydro 2007). The monitor is composed of two components:

i) Estimating annual escapement of adult Chum salmon in the Cheakamus River
ii) Examining the relation between discharge, groundwater upwelling and the selection of spawning habitat by Chum salmon in the mainstem (BC Hydro 2007)

Data from the Chum adult monitor is used in conjunction with data from the juvenile outmigration monitor (CMSMON -1a) to develop stock-recruitment relationships that is critical for separating effects of spawning escapement from flow-related changes in survival during incubation (Bradford et al. 2005).

“The key management questions are:

1) What is the relation between discharge and Chum salmon spawning site selection and incubation conditions?

2) Do the models used to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of Chum salmon spawning site selection, and the availability of spawning habitat under the WUP?
3) Are there other alternative metrics that better represent Chum salmon spawning habitat?"
(BC Hydro 2007, pg 21)

"The primary null hypotheses (and sub-hypotheses) associated with these management questions are:

H_1: Discharge during the Chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the mainstem

This first hypothesis is general, and the specific hypotheses below will assist in diagnosing some likely reason(s) for any observed patterns.

H_2: Spawning Chum salmon do not select areas of upwelling groundwater for spawning in the mainstem

Hypothesis 2 is being tested by overlaying mapping of Chum salmon spawning distribution at a site with mapping of groundwater upwelling to determine whether Chum salmon spawn more frequently in upwelling areas." (BC Hydro 2007, pgs 21-22)

Mapping of female Chum spawner site selection was conducted in the 2013 and 2015 Chum spawning seasons and will be repeated in the 2016 spawning seasons.

"H_3: Discharge during the Chum salmon spawning and incubation period does not affect the upwelling of groundwater in mainstem spawning areas

This third hypothesis examines the link between discharge and surface-subsurface groundwater exchange.

Appropriate, ecologically based metrics of discharge during the incubation period that will be used to test these hypotheses might include peak discharge or minimum weekly discharge."
(BC Hydro 2007, p. 22)

Since the five-year review, Chum fry data from CMS MON 1A has been reported in the annual CMA MON 1B report. The following management questions from CMS MON 1A are also addressed in this report.

4) "What is the relationship between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River?
5) Does juvenile salmonid production, productivity, or habitat capacity change following implementation of the WUP flow regime?"

(BC Hydro 2007, p.3)

1.2 Study Design

1.2.1 Adult Spawners

There are many challenges when estimating Chum escapement and spawning distribution in the Cheakamus watershed due to its large size and environmental conditions which can make traditional mark-recapture surveys difficult to implement. These challenges include restricted water visibility, considerable downstream movement of spawned-out moribund fish among mainstem spawners and access to some river/channel reaches during high river discharges (Melville and McCubbing 2000; Korman et al. 2002). As a result, traditional visual tag mark recapture approaches that are commonly employed in smaller coastal systems would be difficult and expensive to effectively implement on the Cheakamus River.

Traditional live mark-carcass recapture surveys involve tagging salmon with external tags followed by carcass surveys of all possible spawning grounds. Instead, this monitor uses a passive mark-recapture technique in place of a traditional mark-recapture carcass recovery or visual estimation study methods. This passive tag recovery approach involves the use of fixed location resistivity fish counters to enumerate all fish entering selected side channels, coupled with Passive Integrated Transponder (PIT) scanning tag readers to scan for tags on all fish at these locations. The total number of fish entering each monitored channel and the total number of tagged fish entering each channel is recorded on PIT logging equipment.

One tagging location was used in 2007 and two tagging locations from 2008-2015 (Figure 1). These were combined with three side channel detection locations in a design modeled after Schwarz and Taylor (1998). The original marking site for the 'whole river' estimate (2007 to present), is located in the lower river at river kilometer (RK) 1.5, while the 'upper river' tagging location (2008 to present) occurs at RK 5.5 and provides a more robust estimate of the number of fish that spawn upstream of the mainstem juvenile monitoring site (Rotary Screw Trap (RST); Figure 1). At both sites internal PIT and external Peterson disk tags were applied to adult Chum salmon with subsequent detections of tagged and untagged fish at three upper river side channel complexes with sizable Chum spawning habitat (NVOS and BC Rail side channels and Tenderfoot Creek; Figure 1). In addition, radio tags were gastrically implanted in a subsample of fish from 2007 to 2010 to: 1) determine overall spawner distribution upstream and downstream of the current juvenile outmigration monitoring site; 2) assess post tagging behaviour that may affect estimates; 3) provide information on spawner distribution to assist with mainstem groundwater/spawner evaluations and 4) assist in evaluating spawner residence time during the initial four years of the monitor. In 2013, radio tagging was reinstated in the lower river and a subsample of female Chum salmon have been tagged in subsequent years to: 1) evaluate spawner distribution and 2) determine areas of egg deposition in relation to known groundwater upwelling areas.

1.2.2 Juvenile Outmigration

Prior to the implementation of the new flow order (WUP) in 2006 the Juvenile Outmigration CMSMON - 1a was limited to assessing the total production of juvenile salmon upstream of the RST site (Figure 1). Partitioning of side channel and mainstem production was not included in the initial study design that was implemented in 2000. In 2007, the study was expanded to include population assessments of salmonids from key restoration side channels and further expanded in 2013 to include Tenderfoot Creek. The study revisions were intended to more effectively answer two key management questions:

1. What is the relationship between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River?
2. Does juvenile Chum fry yield or habitat capacity change following the implementation of the WUP flow regime?

The expanded project includes detailed assessments of juvenile salmonid outmigration using estimated counts from mark-recapture studies (BC Hydro 2007).

2.0 METHODS

The methodology for estimating abundance of adult Chum spawners and outmigrating Chum fry has remained relatively consistent throughout the study period (2001-2015). For a more detailed explanation of the methodologies in sections 2.1.1 to 2.1.3 and 2.2 to 2.3 refer to the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey 5 Year Program Review 2007-2011 (McCubbing et al. 2012). Detailed methodologies are provided in Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Groundwater Survey 2001-2013 (Fell et al. 2013) for sections 2.1.4 to 2.1.7 which were added into this study in 2012 after the 5-year review process.

2.1 Adult Spawners

2.1.1 Mark-Recapture

From mid-October through late November Chum salmon were tagged with internal PIT tags and Peterson disk tags at the lower river site (RK 1.5) and upper river site (RK 5.5) on the Cheakamus River. Sex, fork length and visual condition were recorded for all fish captured.

Visual condition was classified as follows:

- Condition 1: fish appeared to have entered the river recently, 'silver' and free of body decay.
- Condition 2: fish exhibited spawning colouration but free of extensive body decay.
- Condition 3: signs of spawning, fin wear, sunken abdomen and extensive body decay.

Tags were only applied to fish with conditions 1 and 2 and condition 3 fish were released untagged. Fish were detected upstream at three locations in the upper river (two side channels, NVOS and BC Rail, and Tenderfoot Creek, Figures 1 and 2). For spawner enumeration and PIT tag detection, the two side channels were set up with full-span fish fences, fitted with Logie 2100C resistivity fish counters and full-duplex PIT tag detection and logging equipment. The detection efficiencies of resistivity counters were assessed using video validation. Recycling/pre-spawn migration behaviour and kelted spawner behaviour was accounted for using the time-stamped PIT antenna data. Spawners that moved upstream and then downstream over the counter array in a period of less than 48 hours were assumed to be re-circulating and were not assumed to have spawned upstream of the counter. Fish that spent > 48 hrs above the counter and then dropped back below were classified as kelts and assumed to have spawned upstream of the counter. The percentage of down counts that were classified as kelts was incorporated into the total channel escapement calculation to ensure all fish that spawned upstream of the counter are enumerated (see methods in McCubbing et al. 2012). At Tenderfoot Creek Chum salmon were enumerated manually by Department and Fisheries and Oceans (DFO) at their fish fence (methodology conceptualized in Figure 3). Spawner detection through resistivity counter monitoring/ trap operations was conducted from October 15 through to December 15.

2.1.2 Escapement Analysis

An abundance estimate for the entire river was derived from the fish tagged at the 'lower river' tagging site and a population estimate for the upper river (above the RST site) was derived from the fish tagged at the 'upper river' tagging site (Figure 1). Tagged fish were recaptured/re-detected at three upstream side channels; the NVOS side channel, the BC Rail side channel and Tenderfoot Creek (Figure 2). From 2007-2013 and in 2015, the total number of fish entering the individual channels was determined using resistivity counters at the NVOS and BC Rail side channels and manual counts were used at the Tenderfoot Creek trap. Pooled Peterson population estimates were calculated using standard mark-recapture methods (Ricker 1975).

In 2014, stream walks were reinstated in the NVOS and BC Rail side channels due to high water events (three flow events greater than 200 m^3/s between October 21st and November 8th at the Water Survey of Canada (WSC) Brackendale Gauge (08GA043)) reducing resistivity counter efficiencies. Stream walks were conducted bi-weekly in conjunction with pre-spawn mortality surveys from mid-October to mid-December. All live fish were counted and all dead fish were counted and then cut in half to ensure they were only enumerated once. The 2014 escapement estimates were calculated using stream walk counts and stream walk efficiencies. Stream walk efficiencies were determined by evaluating previous years of stream walk and counter data (2007-2011). Stream walks were also conducted in 2015 in case high water further affected resistivity counter operations.

Testing of a third resistivity counter channel and a set of directional PIT antennas was conducted at the end of the 2014 season and at the beginning of the 2015 season. In previous years, high wind events have caused an accumulation of leaf litter to build on the upstream side of counter fences resulting in upstream backwatering. This backwatering creates uneven flow across the counters and the counter efficiencies are temporarily reduced. The additional counter channel provided a greater area for water and debris to pass downstream and was anticipated to allow for more laminar flows across all of the counters under fluctuating water conditions. However, after initial tests in 2014 and 2015, the counter efficiency of this additional channel proved to be poor (i.e. overestimating up and down counts 42% and 45%, respectively).

Additionally, the directional movement of PIT tagged spawners was difficult to determine with 6 directional PIT antennas (3 pairs of double antennas). Therefore, the third counter pad and set of directional antennas was removed on the morning of October 22nd, 2015, prior to any large upstream movements of Chum spawners. The NVOS enumeration site reverted to the original design that has been used since 2008 (Figure 4).

During the initial year of enumeration (2007), three channels at the NVOS counter site were open for upstream access and each channel had a counter pad in the middle and one PIT antenna located on the upstream side of the channel. At BC Rail side channel, the counter site was similar to how it has operated since 2008, although, again only an upstream PIT antenna was used. Directional movement of PIT tagged fish was not able to be determined in 2007. Improvements were made to the counter sites in 2008 and since then, the design of the enumeration sites has remained the same with the exception of testing a third channel at NVOS at the end of the 2014 season and early in the 2015 season.

Kelting behaviour has been assessed annually at the NVOS and BC Rail side channels to account for fish that spawn upstream of the counters and then drop back downstream. Using annual PIT tag detections, fish were classified as kelts that spent greater than 48 hours resident in the channel above the fish counter prior to moving downstream. To determine the number of fish that spawn upstream of the counters, the total number of down counts were subtracted from the total number of up counts at each counter site. The down counts were adjusted so that kelts were not removed from the net upstream spawner calculations.

2.1.3 Radio Telemetry

Radio telemetry was conducted from 2007 to 2011 and tags were applied to both male and female Chum to assess spawner distribution and residence time (see McCubbing et al. 2012). Radio telemetry was reinstated again in 2013 to assess spawner distribution and identify locations of egg depositions in relation to known groundwater upwelling areas. In 2013 and 2015, eighty radio tags were installed on female Chum spawners caught at the lower river tagging site throughout the run. In 2014, high flows prevented access to the lower river tagging site so telemetry data was not collected.

Three directional fixed station Lotek W31 radio receivers were installed to detect spawner movement. They were located at the confluence of the Cheakamus and Cheekye rivers (RK 3.2), at the juvenile monitoring RST site (RK 5.5), and 50 m downstream of the Bailey Bridge (RK 7.0) (Figure 1). Mobile tracking was conducted by foot and raft from the Bailey Bridge (RK 7.0) to the Cheakamus and Cheekye confluence (RK 3.2) every two to three days to try and identify precise redd locations. Periodically throughout the season, mobile tracks were also conducted from road’s end (RK 16.5) to the Cheakamus and Squamish Rivers confluence (RK 0) to identify any Chum that may have moved upstream past the Bailey Bridge without detection and any Chum that may have fallen back downstream after tagging at the lower river tagging site.

2.1.4 Fecundity

Fecundity sampling was implemented after the 5-year review in order to develop more accurate egg deposition rates. Since 2012, InStream has been working with Tenderfoot Creek Hatchery DFO staff to sample the fecundity of female Chum salmon caught at the Tenderfoot Creek fence. Females were sampled throughout the run. At the hatchery, when the females were ready to spawn, they were killed and their eggs and ovarian fluid were collected. The ovarian fluid was temporarily drained off the eggs and total egg weight was determined. Then, a subsample was weighed (approximately 20 g) and the eggs in the subsample were manually counted to obtain the individual egg weight. The total number of eggs in each female sampled was estimated by dividing the total egg weight by the weight of an individual egg for that female (Schroder and Ames 2004). To get representation throughout the run, 30 females were sampled for fecundity during each egg take. Mean weighted fecundity for the run was determined by weighting the fecundity at each sampling session proportional to the abundance of females spawned at each session.

Additional information collected from each female included fork length and scale samples to determine if length-fecundity or age-fecundity relationships were present. Recent studies have indicated that the number of eggs per female may be a derivative of both fish age (3 or 4 years) and fish length (Kaev 2000). In addition, summer and fall migrants may have differing egg numbers (Salo 1991) and egg size may vary with body size (Kaev 2000, Salo 1991). Evaluations of these relationships will be presented in the 10-year synthesis report and the most accurate estimates of the annual egg deposition rates used to calculate egg-to-fry survival.

2.1.5 Aging

To evaluate the age of adult Chum spawners, scales have been collected and are being read. The methodology for aging Chum salmon was the same as conducted by Seo et al. (2006), which used the “year-olds” method developed by Salo (1991). This method determines the age by the number of winters from egg to adult. For example, if eggs were deposited in the gravel in the fall of 2007, the fry would emerge in the spring of 2008 and if they returned in the fall of 2012, they would be considered age-5 Chum. The scale would show five periods of slowed growth. The first period of slowed growth is the transition from coastal water to ocean. The next periods of slowed growth are winters and another year is counted at the outer edge of the scale when the salmon returns and completes its lifecycle (Figure 5).

Scale samples have been collected since 2009 during chum tagging in the upper and lower river. From 2012 onward, scale samples were collected at Tenderfoot Creek Hatchery during fecundity sampling. Age analysis of chum salmon for all available years is underway and for the 10-year review. Evaluations of the relationship between age, length and fecundity will be conducted. Additionally, age data will be used to connect brood parents back to their freshwater incubation periods.

2.1.6 Pre-spawn mortality

Pre-spawn mortality surveys were implemented after the 5-year review in order to develop more accurate egg deposition rates. Pre-spawn mortality surveys have been used to assess the percentage of fish that die prior to spawning, partially spawned, or completely spawned out. Pre-spawn mortality surveys have been conducted on the mainstem and side channel habitats of the Cheakamus River from mid-October to the end of November. Mainstem bars were surveyed from road’s ends (RK 16.5) to the Cheakamus/Cheekye confluence (RK 3.2) (Figure 1). Surveyed side channel habitats above the RST site include the NVOS and BC Rail side channels, Tenderfoot Creek and Tenderfoot Pond, and BC Rail mile 49 (BC49) channel (located immediately upstream of the upper river tagging site on river left) (Figure 2).

Spawners were classified into the following categories:

- **spawned-out** = zero to 500 eggs
- **partially spawned** = over 500 loose eggs
- **unspawned** = intact skeins

Staff were familiarized to visually recognize 500 loose eggs (Figure 6). Fish with body cavities that appeared to be compromised, with slices or holes in the body cavity, were not used as part of the sample.

2.1.7 Egg Deposition Rates

Egg deposition rates were calculated using the number of fish classified into each spawner category. Each spawner category was assigned an egg deposition percentage based on average fecundity; spawned-out females deposited 93% of their eggs, partial spawners deposited 43% of their eggs and unspawned females deposited 0% of their eggs.

Egg deposition and retention were calculated using the following equations:

% Eggs Deposited =

$$\left(\frac{(0.93C) + (0.43P) + (0.00U)}{S}\right) \times 100$$

Where:

C = number of complete spawners

P = number of partial spawners

U = number of unspawned females

S = total number of spawners sampled including complete spawners, partial spawners and unspawned females

2.2 Juvenile Outmigrants

2.2.1 Mark-Recapture

Outmigrating juvenile Chum have been marked and recaptured in the mainstem and two main side channels upstream of the RST site (NVOS and BC Rail) since 2000. Fry have been marked and recaptured in Tenderfoot Creek since 2013 (Figures 1 and 2). In the mainstem, outmigrating juveniles were captured annually using Rotary Screw Trap (RSTs). Fyke nets were used to mark and recapture Chum fry in side channels in addition to sampling the number of unmarked Chum fry migrating downstream. When one trapping location was used (i.e. the RSTs and the Tenderfoot Creek fyke net, F10), Chum fry were marked and released upstream to enable recapture in the same trap. A maximum of 2,500 Chum fry were marked daily at each marking location from Monday to Thursday of each week during the sampling period. No marking was conducted from Friday to Sunday.

From 2001 to 2006, the RSTs were operated to capture fry from the last week of February/first week of March to the second week of June. In 2007, the RSTs were operated to capture fry from mid-February (RST installed prior to February 15th) through to the third week of May (strata ending May 21st). From 2008 to 2015, the RSTs were operated to capture fry from mid-February (installed prior to February 15th) to the end of April/beginning of May (last strata ending after April 30th). After the end of April, the RST drums were changed to a larger mesh to enable fishing during higher seasonal flows and the focus of capture changes from outmigrating fry to outmigrating parr and smolts (Appendix A Figures 1A-16A).

In 2016, the RSTs were installed on February 12th. Due to operational flow fluctuations discharges at the Brackendale gauge increased beyond the fishing capabilities of the small mesh RST drum. Therefore, the larger mesh drums were installed on April 12th. As a result, three weeks of fry mark-recapture effort were missed during the 2016 season.

2.2.2 Outmigration Estimate

Outmigration estimates were calculated using a Bayesian spline model described in Bonner (2008), Schwarz et al. (2009) and Bonner and Schwarz (2011). The key features of this model are the use of splines to model the general shape of the run and Bayesian hierarchical methods to share information on catchability and the shape of the spline among time strata. Separate population estimates were calculated for each of the side channels and for Tenderfoot Creek. An upper river estimate was calculated using mark-recapture data from the RSTs. A mainstem and unmonitored side channel estimate was determined by subtracting the side channel and Tenderfoot Creek fish from the upper river estimate.

2.3 Evaluation of H' (Egg-to-fry Survival)

One of the primary goals of this project is to assess the potential relationship between egg-to-fry survival and river discharge. Egg-to-fry survival can be determined for all spawners above the RST or for each individual area (side channel or creek) where the numbers of adults and fry have been independently estimated.

In this case, H' (egg-to-fry survival) was calculated through a number of steps:

1) Estimate spawner abundance (N_t)
2) Estimate the percentage of female spawner in the population (N_{tf})

3) Estimate the numbers of eggs per female (N_{epf})
4) Calculate the percentage of egg deposited per female (N_{ed})
5) Estimate fry production (N_{tfry})
6) Evaluate H’ by dividing the fry outmigration estimates by the egg deposition rates

Thus,

$$H' = (N_t * N_{tf} * N_{epf} * N_{ed}) / N_{tfry}$$

Egg-to-fry survival was determined using the sex ratio of males to females caught at the Tenderfoot trap (Results Section 3.1.3). Female fecundity has been estimated from samples collected at Tenderfoot Creek Hatchery since 2012. Egg deposition rates (2012-2014) were determined from pre-spawn mortality surveys (Results Section 3.1.9 and 3.1.8). For the purpose of comparisons with other literature values of egg-to-fry survival it is important to note that pre-spawn mortality is often not included in egg-to-fry survival estimates. To properly evaluate the impact of flow on egg-to-fry survival it is important to account for pre-spawn mortality to estimate the most precise egg deposition rates.

2.4 Temperatures in Redds

Twenty temperature loggers were deployed during the 2013/2014 and 2014/2015 incubation periods to assess incubation temperatures. This data was used to test the hypothesis that river water temperatures do not differ from water temperatures observed in Chum redds in the hyporheic zone above the Bailey Bridge (RK 7.0). Two sites were selected upstream of the Bailey Bridge. One site was located on bars immediately upstream of the Bailey Bridge (RK 7.0) and the other site was located on bars immediately downstream of road’s end (RK 16.5). At each site 10 simulated egg capsules containing temperature loggers (Onset Tidbit UTBI-001) were deployed on two to three separate bars. Temperature loggers were buried 20 cm deep in suitable bed material and anchored with rebar. Additional data collected included presence of eggs, water depth, dominant and subdominant bed material, average diameter of substrate in the 90th percentile (D_{90}) and water velocity. An additional temperature logger was installed upstream of the NVOS counter site to record surface water temperature in the NVOS side channel complex. Temperature loggers at the RST site (RK 5.5) and suspension bridge site (RK 15.0) were used to collect mainstem river temperatures.

3.0 RESULTS

3.1 Adult Spawners

3.1.1 Mark-Recapture

In 2015, 1,137 Chum salmon were tagged with PIT and Petersen disk tags (Table 1). Over the past seven years of this study (2007-2014) a total of 10,952 Chum salmon have been tagged (range 762-1,907 fish per year). At the lower river tagging site a total of 5,275 Chum salmon have been tagged (range 5-970 fish per year) and 5,629 Chum salmon have been tagged at the upper river tagging site (range 75-1,017 fish per year). In 2015, 396 and 768 Chum were tagged at the lower and upper river tagging sites respectively (Table 1). Fish tagged in the lower river are used to generate the whole river escapement estimate and fish tagged in the upper river are used to generate the upper river escapement estimate.

3.1.2 Fork Length

Significant differences in the mean fork length of female Chum salmon at the upper river tagging site have been observed between years (ANOVA, $p<0.01$). Females tagged in the upper river were significantly smaller in 2011 (704 mm) than all other years (post-hoc t-test, $p<0.01$; Table 2). The size of females in the upper river has ranged from 704 mm in 2011 to 745 mm in 2014. Mean fork length of male Chum salmon at the upper river tagging site is significantly different between years (ANOVA, $p<0.01$). Similar to females, males tagged in 2011 were significantly smaller than all other years (post-hoc t-test, $p<0.001$). Male length in the upper river has ranged from 732 mm in 2011 to 792 mm in 2014 (Table 2).

Significant differences in between mean female fork length of Chum salmon captured at the upper river tagging site and in the Tenderfoot Creek trap have been observed annually (all t-tests, $p<0.001$). The smallest difference between these two locations (20mm) was observed in 2015. The largest difference was in 2014 when Tenderfoot Creek female Chum were on average, 31 mm larger than females at the upper river tagging site. Tenderfoot Creek females were 24 and 29 mm larger than the females captured at the upper river tagging site in 2012 and 2013 respectively.

3.1.3 Sex Ratio

The sex ratio of Chum salmon captured at the Tenderfoot Creek trap has been used to represent the sex ratio of the Chum salmon spawners in the upper river of the Cheakamus for the egg-to-fry survival calculation (Table 3). A lower percentage of female Chum spawners have been captured by tangle net than by the Tenderfoot Creek trap. Large kypes on male spawners increase bias towards male capture when tangle netting and could misrepresent the sex ratio. In 2015, the highest proportion of females (M:F sex ratio of 1.3:1; i.e. 43% females) was observed at the Tenderfoot Creek Trap. Male Chum salmon have always been more abundant than females in this system and the percentage of females captured at the Tenderfoot Creek trap over the course of this study has ranged between 21% and 43% (M:F sex ratios of 3.8:1 and 1.3:1 respectively; Table 3).

3.1.4 Radio Telemetry and Spawner Distribution

Female Chum spawners were radio tagged (79 in 2013 and 83 in 2015) in an attempt to gather detailed data on spawning locations in relation to groundwater upwelling. In 2013, one third (33%, 26 out of 79) of radio tagged females spawned within known groundwater upwelling areas (Moody's bar area, Tenderfoot channel, BC Rail side channel, Upper Upper Paradise in the NVOS side channel complex and BC 49 channel; Figure 7). In 2015, 34% of the radio tagged females (28 out of 83) spawned in known groundwater upwelling areas. In addition, the percentage of radio tagged females that were detected above the RST site (RK 5.5) was 22% and 24% in 2013 and 2015, respectively (Figures 7 and 8).

3.1.5 Fecundity

Thirty females were sampled during each egg take at the Tenderfoot Hatchery. In 2015, fecundity sampling was conducted nine times throughout the run and in total, 234 females were sampled. The mean weighted fecundity for the 2015 run was 3,019 eggs per female. Fecundity ranged from 1,462 to 6,123 eggs per female. The average fecundity of female Chum in 2015 was significantly lower than all other years (all t-tests, $p<0.001$). Average female fecundity in 2012 was significantly higher than all other years (all t-tests, $p<0.015$).

Since fecundity sampling began in 2012, the strongest positive linear relationship between fork length and fecundity was observed in 2015 ($F=163.5$, $p<0.001$). Fork length accounted for 41.3% of the variability in fecundity in 2015 (Figure 9). In 2014, although a significant linear relationship was observed between fork length and fecundity, fork length only accounted for 15.7% of the variability in fecundity (Figure 10). Statistically significant relationships were also observed in 2012 and 2013 with fork length accounting for 22.5% and 38.6% of the variability, respectively (Figures 11 and 12).

3.1.6 Pre-Spawn Mortality

Pre-spawn mortality surveys assess the percentage of fish that die without spawning or only partially spawn and the percentage of females that completely spawn out. Surveys have been conducted on Chum salmon on the mainstem and side channel habitats of the Cheakamus River since 2012. In the mainstem habitat, the highest percentages of spawned out females were observed in 2014 and 2015 at 98.2% and 98.1% spawned out, respectively (Table 4). Significant differences were observed between mainstem pre-spawn mortality in 2012 and 2013 compared to that observed in 2014 and 2015 (Chi-Squared Tests: 2012 and 2014: χ^2=20.2, p<0.001; 2012 and 2015: χ^2=8.6, p=0.003; 2013 and 2014: χ^2=26.4, p<0.001; 2013 and 2015: χ^2=10.6, p=0.001;). In 2012 and 2013, approximately 10% fewer females were completely spawned out (89.0% and 87.1%, respectively; Table 4).

Significant differences in pre-spawn mortality between the side channel and mainstem habitats were observed in all years (Chi-Squared Tests: 2012: χ^2=27.9, p<0.001; 2013: χ^2=151.4, p <0.001; 2014: χ^2=27.9, p<0.001; 2015: χ^2=27.9, p=0.002). Lower percentages of females appear to completely spawn out in the side channel habitats compared to mainstem habitats. Similar to trends observed in the mainstem, in all of the side channel habitats combined, the percentage of spawned out females was highest in 2014 and 2015 at 91.7% and 88.9%, respectively (Table 4). The lowest percentage of spawned out females in all of the side channel habitats combined was observed in 2013 (64.5%; Table 4).

Among the individual side channels, the lowest percentages of spawned out females were observed in the BC Rail side channel in 2012 and 2013 (45.0% and 37.1% spawned out, respectively). A small sample size in 2012 (N=40) prevented statistical comparisons to other years. However, there was a significant difference between pre-spawn mortality in 2013 compared to that observed in both 2014 and 2015 (Chi-Squared Tests: 2013 and 2014: χ^2=198.0, p<0.001; 2013 and 2015: χ^2=148.7, p<0.001) (Table 5). The percentage of spawned out females in the BC 49 side channel has ranged between 68.1% and 95.0% in 2013 and 2014, respectively. Significant differences in pre-spawn mortality in the BC 49 side channel were observed between 2012, 2013 and 2014 (Chi-Squared Tests: 2012 and 2013: χ^2=11.0, p<0.001; 2012 and 2014: χ^2=24.9, p<0.001; 2013 and 2014: χ^2=67.1, p<0.001). Unlike the trend of low pre-spawn mortality observed in the mainstem and other side channels in 2014 and 2015, pre-spawn mortality observed in 2015 in the BC 49 side channel was significantly higher than in 2014 (Chi-Squared Tests: 2014 and 2015: χ^2=22.5, p<0.001) and 17.2% more females completely spawned out in 2014 compared to 2015 (Table 5). Pre-spawn mortality in 2015 was not significantly different than 2012 or 2013.

In the NVOS side channel complex, on average, 85.1% of females spawned out completely. This has ranged from a low of 73.6% in 2013 to a high of 91.0% in 2014 (Table 5). Moribund females are most frequently identified in the Kisutch, Upper Paradise and Upper Upper Paradise channels of the NVOS side channel complex. The Kisutch and Upper Upper Paradise channels are both groundwater fed channels (Figure 1). Among these three most commonly used channels, annual pre-spawn mortality has been significantly lower in the Upper Upper Paradise channel compared to the Kisutch channel in 2012, 2013 and 2015 (Chi-Squared Tests: 2012: χ^2=11.4, p<0.001; 2013: χ^2=28.8, p<0.001; 2014: χ^2=4.96, p<0.001). No difference was observed in 2014 when pre-spawn mortality was very low. The percentage of spawned out females in the Kisutch channel has ranged from 55.0% in 2013 to 90.4% in 2014 (Table 6). The percentage of spawned out females in the Upper Upper Paradise channel has ranged from a low of 81.0% in 2013 to a high of 95.5% in 2014 (Table 6).

3.1.7 Egg Deposition Rates

Area-specific egg deposition rates were calculated for the mainstem and monitored side channel habitats to be used in the egg-to-fry survival calculations. In both 2014 and 2015, mainstem egg deposition rates were high at 92.1% and 91.7%, respectively (Table 7). The 2014 and 2015 mainstem egg deposition rates were between 5% and 6.5% higher than in 2012 and 2013. Relatively high egg deposition rates were also observed in the BC Rail side channel, the NVOS side channel complex and Tenderfoot Creek in 2014 and 2015. Egg deposition rates in the BC Rail side channel in 2013 were 26.0% and 26.9% lower than in 2014 and 2015, respectively (Table 7). Pre-spawn mortality surveys only assessed the tail end of the 2012 Chum run in the BC Rail side channel, therefore, 2012 egg deposition rates were not comparable to other years. Average annual side channel egg deposition rates were used for the egg-to-fry survival calculation for the 2012 year.

In the NVOS side channel complex, in 2012, 2014 and 2015, egg deposition rates were between 6.7% and 8.9% higher than egg deposition rates in 2013 (Table 7). The average egg deposition rate for the NVOS side channel complex was 87.0% in 2015. Within the channel complex, egg deposition rates varied among channels, ranging from 75.3% to 89.1%. The highest variation in egg deposition rates occurred in the Kisutch channel ranging from a low 70.1% in 2013 to a high of 87.5% in 2014 (Table 7).

In the Tenderfoot Creek and Pond, egg deposition rates in 2014 and 2015 were 16.1% and 13.5% higher than egg deposition rates in 2013, respectively (Table 7). Pre-spawn mortality was not assessed at Tenderfoot Creek and Pond in 2012. Therefore, average egg deposition rates for all side channels combined was used to calculate egg-to-fry survival for Tenderfoot Creek (Table 7).

In 2015, the lowest egg deposition rate in side channel habitats was observed in the BC 49 side channel (81.9%; Table 7). The 2015 egg deposition rates in the BC 49 side channel were 8.6% lower than the 2014 egg deposition rate (90.5%) and 1.9% lower than the 2012 egg deposition rate (83.8%). Similar to all other habitats surveyed on the Cheakamus River, egg deposition rates were lowest in the BC 49 side channel in 2013 when the egg deposition rate was 76.1% (Table 7).

3.1.8 Kelt Behaviour

Kelting behaviour was assessed at the NVOS and BC Rail enumeration sites using PIT detections. Fish that spent greater than 48 hours resident in the channel above the fish counter prior to a directional downstream outmigration were classified as kelts. From 2007-2013 and again in 2015, the total down counts removed from the total up counts on the fish counters at each site was scaled so that kelts were not removed from the net upstream spawner calculations. In 2015, the percentage of spawners that moved downstream past the NVOS and BC Rail PIT readers and counters after successfully spawning was similar to the average over the previous 8 years. In the NVOS side channel complex, 21% of spawners were estimated to have kelted (M:F ratio 9:1) and 15% were estimated to have kelted at the BC Rail side channel (M:F ratio 1:1) (Table 8).

3.1.9 Validation of Counters

Video validation has been conducted at both side channel counter sites annually and counts have been adjusted to estimate the actual number of spawners moving up and down over each counter. Counter efficiency has varied annually with fish abundances, river discharge and site configuration. At the beginning of the 2015 season, three channels were run. Channel 1 and channel 2, two narrow channels on either side of the channel have been utilized since 2007. Channel 3, a large channel in the middle, was tested until October 22nd. Channel 3 was removed because it was overestimating down and up counts by 42% and 43% respectively. It was also complicating the ability to determine directional movement of PIT tagged fish. Prior to October 22nd, only 6% of the entire run (410 Chum salmon) migrated through the

NVOS counter site. NVOS counter efficiencies were among the highest recorded following the removal of the third channel. Channel 1 was slightly more efficient than channel 2. Up counts in channel 1 were only overestimated by 2% and down counts by 3% (Table 9). In channel 2, up counts were only over estimated by 1% and down counts by 6%. In 2015, the BC Rail counter only missed 10% of up migrating salmon and 13% of the salmon moving downstream. Compared to the past 7 years when video validation was reflective of the entire run, the 2015 counter efficiency was 2nd highest (Table 9).

3.2 Escapement Estimates

3.2.1 Adult Spawners

3.2.1.1 Upper River Estimate

Upper river estimates were derived from marking at the upper river tagging site (Figure 1) and recapturing/re-detecting them at three upstream locations (the NVOS side channel, BC Rail side channel and Tenderfoot Creek; Figure 2) (Section 2.1.2). In 2015, the adult Chum escapement estimate in the upper river (above the RST site at RK 5.5) was 69,974 spawners (Table 10). The estimate was 5 times greater than the lowest upper river escapement estimate in 2010 (12,827) and 39% of the highest upper river escapement estimate in 2013 (180,669). In 2015, 35% of the Chum returning to the Cheakamus River spawned in the upper river (Figure 13). The distribution of spawners between the upper and lower river in 2015 was similar to the distributions observed from 2011 to 2013 when between 40% and 43% of spawners utilized the upper river habitat areas. A distributional shift appears to have occurred over the last nine years (excluding 2009 due backwatering changing habitat conditions). Since 2011 (excluding 2014 due to no distribution data available), a higher proportion of returning Chum spawners have been observed in the upper river (Figure 13).

Prior to the 2009 Cheekye Creek washout, 16% and 20% of the population used the upper river habitat for spawning in 2007 and 2008, respectively (Figure 13). In the year of Cheekye Creek washout (2009), Chum distribution was heavily weighted in the upper river. A higher than average percentage of total spawners (64%) utilized the upper river habitat in 2009 (Figure 13) after a summer storm event resulted in the backwatering of a substantial area of spawning habitat above the Cheekye confluence for some 1.5 km upstream (Figure 1). This new backwatered area included Moody's bar, as area which had previously been observed as a reach of high Chum spawner density based on visual and radio tag observations. The loss of suitable habitat in 2009 likely influenced a large number of spawners to move farther upstream. In the following year (2010), the distribution trend from 2007 and 2008 continued and 15% of spawners utilized the upper river spawning area (Figure 13).

In 2010, the escapement of Chum salmon to the upper river (12,827 spawners) was the lowest recorded since monitoring began in 2007 (Table 10). High upper river escapement was estimated in 2009, 2012 and 2013, with maximum escapement reaching 180,669 spawners in 2013 (Table 10; Figures 13 and 14). In 2012, the upper river estimate of Chum spawners in the Cheakamus River was 132,128 Chum salmon. Notably in 2009, a large upper river spawner abundance of 105,540 Chum salmon was also observed but in this case, this was the result of a change in the distribution of spawners, not of a particularly high Chum salmon spawner return to the Cheakamus River.

During years of higher escapement (> 100,000 Chum salmon in the upper river), greater numbers of salmon were enumerated at the upstream monitoring sites (BC Rail side channel and Tenderfoot Creek). However, distribution trends above the Bailey Bridge (RK 7.0) and to road's end (RK 16.5) have not been consistent (Tables 10 and 11). In 2012, a large return of Chum was estimated and during pre-spawn mortality surveys, Chum salmon were recorded spawning as high upstream as river kilometer 16.5 in the mainstem. However, in 2013, when the upper river escapement estimate was the highest over the past 9 years, few fish were visually observed and present to be assessed for pre-spawn mortality above the Bailey Bridge and none were assessed as far upstream as river kilometer 16.5 (i.e. in 2012, 98 female Chum were surveyed between RK 11.3 and 16.5 while in 2013, no females were present in this area to be surveyed). In 2009, pre-spawn mortality surveys were not conducted so no presence or absence data of spawners upstream of the Bailey Bridge was recorded. Although, anecdotal information indicates that few Chum spawners were visually observed above the Bailey Bridge, even though, over a hundred thousand fish returned to the upper river.

In 2009, prior to and during the peak spawning time for Chum salmon (late October to mid-November), multiple one to two-day increased flow events (> 60 m^3/s at Brackendale gauge) occurred in the Cheakamus River (Table 12; Figure 15). An eight and a half day (October 29th to November 6th) increased flow event (>25 m^3/s at Brackendale Gauge) occurred prior to and during peak spawning in 2012 (Table 12; Figure 16). In 2013, discharge at Brackendale gauge prior to and during peak spawning remained below 25 m^3/s and there were only two days during peak spawning when average daily discharge was greater than 20 m^3/s (Table 12; Figure 17).

Three high flow events occurred in 2014 in the three-week period between October 21st and November 10th. Discharge at Brackendale gauge peaked at 363 m^3/s during the first high flow event, 350 m^3/s during the second high flow event and 287 m^3/s during the third high flow event (Figure 18). Flows during the spawning season stabilized after November 11th. Chum escapement was moderate in the upper river in 2014 (52,202 Chum spawners). Due to the high flows, it was not possible to thoroughly assess spawner distribution during peak spawning periods though pre-spawn mortality surveys. However, a full river float was conducted on November 13th, 2014 to evaluate pre-spawn mortality and a total of 22 females were assessed between road's end (RK 16.5) and the Cheekye Confluence (RK 3.0) and 1 female was assessed between the suspension bridge (RK 15.0) and road's end (RK 16.5).

Discharge during the 2015 spawning season remained relatively stable from October 15th-30th. A three-and-a-half-day increased flow event (>25 m^3/s at Brackendale gauge) maxing out at 40 m^3/s occurred from October 30th to November 2nd (Figure 19). During peak spawning (November 1st to 15th) another two 2-3-day increased flow events occurred with maximum hourly discharges of 68 and 82 m^3/s at Brackendale gauge (Figure 19). During this relatively moderate escapement year (69,974), few fish were observed above the Bailey Bridge (i.e. no moribund female Chum spawners were present to be assessed above the Bailey Bridge during pre-spawn mortality surveys).

3.2.1.2 Whole River Estimate

From 2007 to 2013 and in 2015, whole river Chum salmon spawner estimates were derived from marking at the lower river tagging site (Figure 1) and recapturing/re-detecting them at three upstream locations (NVOS side channel, BC Rail side channel and Tenderfoot Creek; Figure 2) (Section 2.1.2). In 2015, the whole river escapement estimate for Chum salmon in the Cheakamus River was 199,165 spawners (Table 10; Figure 14). The 2015 escapement estimate was average when compared to the previous eight years. A whole river Pooled Peterson Estimate for Chum salmon could not be calculated in 2014 due to high water affecting safe access to the lower river fishing grounds. However, assuming that the proportion of Chum salmon that spawned in the upper river was similar to what was observed in the previous three years (average 41%; Figure 13), a moderate 2014 whole river escapement estimate can be approximated at 127,330 Chum salmon (Table 10; Figure 14).

The highest Chum salmon escapement estimates over the nine years of monitoring were observed in 2012 and 2013. Whole river escapements were 327,804 and 468,511 Chum salmon in 2012 and 2013, respectively (Table 10; Figure 14). A large escapement of Chum salmon spawners also returned to the Cheakamus River in 2007 when a whole river estimate was 267,574 Chum salmon (Table 10 and Figure 15). Chum returns to the Cheakamus River were the lowest over the 9 study years in 2010 and 2011 with whole river estimates of 85,461 and 73,377 Chum salmon, respectively. In 2008 and 2009, the returns were moderate in the time series, estimated as 117,780 and 165,318, respectively (Table 10; Figure 14).

3.2.1.3 Side Channel Estimates

Side channel escapement estimates were based on resistivity counts at the NVOS side channel and the BC Rail side channel and manual counts at Tenderfoot Creek fish fence (Figure 2). BC Rail side channel and Tenderfoot Creek are both groundwater fed channels, as are the most selected areas for Chum spawning within the groundwater and surface water fed NVOS side channel complex (Kisutch and Upper Upper Paradise channels). The number of spawners returning to side channel habitats to spawn is strongly correlated (R=0.96) with the total number of upper river spawners (Figure 20; Tables 10 and 11).

The proportion of upper river spawners utilizing all the monitored side channels (by comparing resistivity counts in NVOS and BC Rail and manual counts at Tenderfoot Creek fence to upper river PPE) has varied over the study period. In 2015, 15.3% of upper river spawners (10,677 Chum spawners) selected the monitored side channel habitats; 9.4% (6,544) spawning in the NVOS side channel complex, 2.8% (1,994) spawning in the BC Rail side channel and 3.1% (2,139) spawning in Tenderfoot Creek (Table 11; Figure 21). Similar proportional distributions among the monitored side channel habitats were observed in 2009, 2011 and 2015. In all three of these years, minimum discharge during peak spawning was below 19 m^3/s at Brackendale gauge (Table 12; Appendix B)

In 2014, prior to the first large rainfall event which began increasing discharges in the Cheakamus River watershed on October 20th, both Tenderfoot Creek and BC Rail side channel were disconnected from the mainstem due to low flows in these side channels. There were no inflows from Tenderfoot Pond to Tenderfoot Creek until October 22nd-23rd when discharge in the mainstem had increased and access was restored. The proportion of upper river Chum spawners that utilized the BC Rail side channel in 2014 (2.9%) was slightly higher than average from the previous eight years (2.5%). However, a lower than average proportion of upper river spawners (2014: 2.5%; 2007-2013 average: 4.7%) was enumerated at the Tenderfoot fish fence. However, two high flow events (lasting 1-2 days) during the season (October 29th and November 1st) did, prevent the trap from holding fish back. During these high flow events, spawners were able to pass upstream without being enumerated.

In 2012, low numbers of spawners (683 Chum salmon) were found in the BC Rail side channel, despite a high escapement of spawners returning to the upper river and other side channel habitats (Table 11). Prior to the 2012 spawning season, a habitat restoration project had been undertaken to improve access to Tenderfoot Creek which altered access to the BC Rail side channel. Large escapements into Tenderfoot Creek occurred 2012 and 2013, following the habitat restoration. Escapement into Tenderfoot Creek in 2012 and 2013 was 5,419 spawners (3.9% of upper river spawners) and 7,643 spawners (3.9% of upper river spawners), respectively. BC Rail escapement improved in 2013, with 3,331 spawners using the BC Rail side channel (Table 11).

The percentage of upper river Chum spawners that utilized the side channel habitats has ranged from 10% to 33% (mean 17%, Figure 21). A strong-moderate positive correlation exists (R=0.69) between the percentage of side channel spawners and minimum discharge during peak spawning (November 1st to November 15th) (Figure 22). When minimum discharge was between 15 m^3/s and 20 m^3/s, on average 13% of spawners utilized side channel habitats; however, when minimum discharge was greater than 24 m^3/s, the average percentage of spawners that utilized side channel habitats was 24% (Figure 22). When the 2007 and 2014 data was removed, due to differences in the methodologies used to generate abundance estimates for the upper river and side channels (Section 2.1.2), a stronger correlation between the percentage of side channel spawners and minimum discharge during peak spawning was observed (R=0.83) (Figure 23).

Including all nine years of distribution data (2007-2015), a strong positive correlation exists (R=0.74) between the proportion of spawners utilizing the groundwater and surface water fed NVOS side channel complex and minimum discharge during peak spawning (Figure 24). An even stronger positive correlation (R=0.86) exists when the 2007 and 2014 data are excluded (Figure 25). The largest proportion of spawners that utilized the NVOS side channel complex occurred in 2010 when minimum discharge during peak spawning was 24.3 m^3/s (Table 12; Appendix B. Table 11B). In 2010, upper river escapement was low (12,827 Chum spawners) and 21% of upper rivers spawners utilized side channel habitats (Table 11; Figures 22 and 23). The majority of the side channel spawners (16% of upper river spawners), spawned within the NVOS side channel complex and very few were enumerated at the BC Rail side channel or Tenderfoot Creek (Figures 24 and 25).

Moderate positive correlations exist between the proportion of spawners utilizing the BC Rail side channel and minimum discharge during peak spawning (2007-2015: R=0.58; 2008-2013 and 2015: R=0.66; Figures 26 and 27). Low to moderate positive correlations exist between the proportion of spawners utilizing Tenderfoot Creek and minimum discharge during peak spawning (2007-2015: R=0.37; 2008-2013 and 2015: R=0.54; Figure 28 and 29). In 2008, the largest proportion of spawners were estimated in both of these upstream monitored side channel habitats. Fourteen percent of upper river spawners (3,309 Chum salmon) utilized Tenderfoot Creek and 5% of upper river spawners (1,279 Chum salmon) utilized the BC Rail side channel (Table 11) With exception to 2008, on average 3% of upper river spawners utilized Tenderfoot Creek. Minimum discharge during peak spawning was 24.6 m^3/s in 2008 (Table 12; Figures 26-29). In 2008, discharge at Brackendale gauge was high during the first week of peak spawning. Three high flow events peaked between November 2nd and 13th at average discharges between 80 and 130 m^3/s (Table 12 and Appendix B. Table 9B).

3.2.2 Outmigrant Fry

Chum fry production has been monitored on the Cheakamus River at the RST site (RK 5.5) since 2001 and during this period, peak run-timing (the day when 50% of the enumerated Chum fry population past the RST site) has ranged between the 83rd and 113th Julian Day (Appendix A. Figures 1A-16A). The earliest outmigration date occurred in 2015 when 50% of the chum fry population outmigrated on the 83rd Julian day. This was a week earlier than any other year. This early outmigration coincided with high 2014 flows early in the spawning season. The second earliest peak outmigration also occurred under the WUP, (in 2011) and 50% of chum fry outmigrated by the 90th Julian day, which also coincided with two high flow events (> 70m^2/s) early in the spawning season in 2010. The latest peak outmigration occurred pre-WUP in 2003 on the 113th Julian day. The year prior, discharge early in the spawning season was the lowest of the past fifteen years. The average daily discharge from October 15th to November 6th, 2002 was 10.9 m^3/s (range 10.0 to 12.5 m^3/s) (Appendix B. Figure 3B).

The Bayesian Time-Stratified Population Analysis System (BTSPAS) estimates for Chum fry until April 12th, 2016 was 2,320,266 (Table 13). Using the 2008-2015 data, the estimated proportion of Chum fry that outmigrated during the last three strata that were missed due to high flows was 23.4% (12.0% in strata 10, 11.3% in strata 11 and 0.1% in strata 12). Therefore, an estimated total of 708,763 Chum fry were missed during this period resulting in an estimated total of 3,029,030 Chum fry that outmigrated past the RST site in 2016 (Figure 29).

Estimated fry production has varied from a low of 1,685,668 in 2001 to a high of 10,795,444 in 2013 (Table 13; Figure 29). The average annual fry production pre-WUP was 3,795,110 Chum fry per year. Average annual fry production under the WUP is 4,466,867 Chum fry per year. This represents an increase in average annual fry production of 20% since the introduction of the WUP. It is important to mention that fry production was less than the pre-WUP average in five of the ten WUP years.

Additionally, out of the 6 lowest Chum fry outmigration years, 5 have occurred WUP. Higher variance in annual fry production has been observed during the WUP flows than pre-WUP (coefficient of variation for annual fry production pre-WUP: 0.29 and WUP: 0.62).

Estimates of Chum fry production have also been derived annually for the BC Rail and NVOS side channels from 2008 to present. In the NVOS side channel complex the annual estimates have ranged from a low of 557,908 Chum fry in 2011 to a high of 2,428,254 Chum fry in 2013 (Table 14). In 2016, the NVOS side channel complex outmigration estimate was 1,222,215 Chum fry. In the BC Rail side channel, the annual estimates have ranged from a low of 23,022 Chum fry in 2011 to a high of Chum fry in 649,368 in 2015. The 2016 Chum fry estimate for the BC Rail side channel was 546,574.

From 2008 to 2016, combined fry production from NVOS and BC Rail side channels represented between 27% and 92% of the annual total production above the RST site (Figure 29). In 2016, fry production from these two channels constituted 58% of the total yield. In 2015, after multiple large flow events during peak spawning and incubation periods, combined fry production from NVOS and BC Rail side channels made up 92% of the total fry production above the RSTs (Figure 29).

In 2016, the outmigration estimate for Tenderfoot Creek was the lowest estimate since monitoring began in 2013 (503,509 Chum fry; Table 14). The 2016 Tenderfoot Creek estimate constituted 17% of the upper river fry outmigration estimate (Figure 29). An outmigration estimate of Chum fry from Tenderfoot Creek was not possible due to low capture rates in 2015. Tenderfoot Creek contributed 26% and 42% of the total yield in the upper river in 2013 and 2014, respectively (Figure 29).

In 2016, 17% of the total fry production upstream of the RSTs came from mainstem (Figure 29). It was not possible to remove the Tenderfoot Creek fry production from the mainstem estimate in 2015 but the combined proportional contribution from Tenderfoot Creek and the mainstem was the lowest recorded over the previous nine years (8%). The percentage of Chum fry produced in the mainstem was 26% and 42% in 2013 and 2014, respectively (Figure 29).

3.3 Juvenile Outmigrant Bio-sampling

Mean Chum fry fork length from 2001 to 2016 was 39 mm (Table 15). An analysis of variance juvenile of fork length from 2001 to 2016 revealed a significant difference among years (ANOVA: F=60.34, p<0.001). The mean size of juvenile Chum was significantly larger pre-WUP (average 39.4 mm) than

WUP (average 38.2 mm) (F-Test: two-sample for variances, $F=2.30$, $p<0.001$; t-Test: unequal variances, $p<0.001$).

3.4 Index of Productivity H', (Egg-to-fry Survival)

Egg-to-fry survival, H', was calculated based on the estimated number of spawners for each area, the sex ratio of Chum captured in the Tenderfoot Creek trap, the fecundity of females sampled at Tenderfoot Creek Hatchery and area specific egg deposition rates based on pre-spawn mortality surveys. For comparisons to other research, pre-spawn mortality is not included. For the entire area above the RSTs and without accounting for site-specific pre-spawn mortality, egg-to-fry survival was 3.3% in 2016 (Table 16). The 2015 egg-to-fry survival estimate was similar at 3.1%. Over the previous four years (2013-2016) the egg-to-fry survival estimate for the upper river was lowest in 2014 (1.6%) and highest in 2013 (5.7%). Accounting for pre-spawn mortality, egg-to-fry survival in the mainstem was 1.1% in 2016, 0.3% in 2014 and 3.6% in 2013. The 2015 egg-to-fry estimate accounting for pre-spawn mortality was 0.3% but included escapement from Tenderfoot Creek so is not comparable (Table 16).

Two high mainstem flow events occurred during the 2015/2016 incubation periods. The first occurred from December 2nd-4th, 2015 during which discharge at the Brackendale gauge peaked at 218 m^3/s. The second occurred from January 28th-31st, 2016 during which discharge at the Brackendale gauge peaked at 336 m^3/s (Appendix B. Figures 10B and 11B). Similarly, there were also multiple high flow events during the 2014 spawning season and 2014/2015 incubation periods. Notable flow events that occurred during the incubation period occurred from December 9th-12th, 2014 during which discharge at the Brackendale gauge peaked at 457 m^3/s and from February 6th-9th, 2015 during which discharge peaked at 411 m^3/s (Appendix B. Figures 15B and 16B). Details on discharge events during the spawning seasons are described in Section 3.2.1.1.

Egg-to-fry survival was calculated independently for the NVOS side channel complex, the BC Rail side channel and Tenderfoot Creek upstream of the fish fence. Similar egg-to-fry survival rates (accounting for pre-spawn mortality) were observed in the NVOS side channel complex in 2014/2015 and 2015/2016, 17.9% and 16.5%, respectively (Table 16). In the NVOS side channel complex egg-to-fry survival was 2 times higher in 2012/2013 (23.1%) than in 2013/2014 (11.8%) The highest egg-to-fry survival rates in all the side channel habitats (NVOS side channel, BC Rail side channel and Tenderfoot Creek) were observed in 2012/2013 and the lowest were observed in 2013/2014(Table 16).

Strong pre-spawn mortality data was not available for the 2012/13 data from BC Rail side channel and Tenderfoot Creek. Therefore, the following annual comparisons do not include pre-spawn morality.

In the BC Rail side channel, relatively moderate egg-to-fry survival estimates were observed in 2015/2016 (21.1%) and 2014/2015 (33.6%; Table 16). Although, the 2014/2015 egg-to-fry survival rate was 37% higher than the 2015/2016 rate. The egg-to-fry survival rate in 2015/2016 was 57% lower than 2012/2013 rate (49.0%) and 4.1 times higher than 2013/2014 rate (5.1%). In Tenderfoot Creek, upstream of the fish trap, egg-to-fry survival was relatively moderate in 2015/16 at 34.3%. No egg-to-fry survival estimate is available for Tenderfoot Creek in 2015 due to low capture rates. Maximum and minimum egg-to-fry survival estimates were 45.5% and 20.5% in 2012/2013 and 2013/2014, respectively (Table 16).

3.5 Spawner-Recruit Relationships

In all the areas above the RSTs, the relationship between the number of spawners and the number of recruits (outmigrating Chum fry) appears to follow a polynomial curve (Figure 33). Data from the past, three years (spawning/incubation periods: 2013/2014, 2014/2015 and 2015/2016) all fall below the curve (Figure 33). High densities of adult spawners were observed between RK 5.5 and 7.0 in 2013 and the lowest number of fry (23 fry) were produced per spawner in the spring of 2014. Large discharge events occurred during peak spawning in 2014 and during the 2014-2015 and 2015-2016 incubation periods. The numbers of fry produced per adult spawner from the 2014 and 2015 brood years were the lowest observed at 39 and 43, respectively. Adult spawners from 2012 produced the highest escapement of fry (82 fry per spawner) when spawners were distributed from river kilometer 3.0 to as high as river kilometer 16.5.

Fry production was highest in the NVOS side channel complex in 2010 and 2013 after 9,357 and 8,859 spawners returned to the areas in the previous falls, respectively (Tables 11 and 14; Figure 34). Higher spawner densities in 2013 (13,213) resulted in reduced survivorship and lower fry productivity in 2014. In 2013/2014, the lowest number of fry per spawner was observed (126 fry per spawner). Minimum and maximum values ranged from 126 to 445 fry per spawner in 2013/2014 and 2007/2008, respectively. In 2007/2008, 2008/2009, 2010/2011 and 2011/2012, Chum escapement was below 3,500 spawners and total fry production was under 1,000,000. In 2015/2016, 187 fry were produced per spawner (Table 11 and 14; Figure 34).

The minimum and maximum number of fry per spawner in the BC Rail side channel has ranged 63 to 673 fry per spawner in 2010/2011 and 2012/2013, respectively (Table 11 and 14; Figure 35). In 2015/2016, 274 fry were produced per spawner. Reduced survivorship and lower productivity were observed in both 2013/2014 and 2009/2010 when over 3,000 Chum spawners utilized the side channel habitat. The number of fry produced per spawner in 2009/2010 and 2013/2014 was 83 and 69, respectively. The lowest number of fry per spawner (63) was observed in 2010/2011 when the lowest escapement of spawners was observed the previous fall (367). Low escapement in 2011 (713 Chum spawners) also resulted in a relatively low number of fry per spawner (130). In 2007/2008, 2008/2009, and 2012/2013, the number of fry produced per spawner was relatively high at 300, 306 and 673 fry per spawner, respectively (Table 11 and 14; Figure 35).

3.6 Incubation Temperature

Of the twenty temperature loggers that were implanted in redds upstream of the Bailey Bridge (RK 7.0) on January 5th, 2016, six remained in the gravel until May1st. Four temperature loggers were recovered on the bars upstream of the Bailey Bridge (RK 7.0) and two were recovered at road's end (RK 16.5). On February 10th, three temperature loggers were recovered at road's end, however, they were no longer buried in the redds so data was discarded. The remaining temperature loggers were excavated during high water events that occurred from January 28th-31st during which discharge at the Brackendale gauge peaked at 336 m^3/s (Appendix B. Figures 10B and 11B).

Data from temperature loggers buried in suitable spawning habitat upstream of the Bailey Bridge was compared to data from temperature loggers at the RST site, located approximately 2 km downstream. Mean temperature in spawning habitat upstream of the Bailey Bridge (4.4 ˚C) was significantly lower (t-test: $p<0.001$) than mean river temperatures at the RST site (4.7 ˚C). There was no significant difference in temperature variability between the two locations in January. However, significantly higher variability in temperatures were observed at the RST site in February, March and April (all F-tests: $p<0.01$). Data from the two redd temperature loggers on bars just downstream of road's end did not give consistent results.

Using data from 2007 to 2014, average incubation temperature in redds was approximated by comparing peak migrations times of returning Chum spawners to outmigrating fry. The Julian day when 50% of Chum spawners had passed over the NVOS counter pads was used to indicate peak Chum spawning. The Julian day when 50% of Chum fry had outmigrated downstream past the RSTs was used to indicate peak Chum fry outmigration. Chum salmon require 850-900 accumulated thermal units to emerge from the gravel (Cheakamus Centre Hatchery data and Tenderfoot Hatchery data). The average number of thermal units accumulated daily was 5.6-6.0º C (Table 17). Average temperature in redds is approximately 1.5-2ºC warmer than the river temperature (Table 17).

4.0 DISCUSSION

The primary goal of this monitor is to examine the effects of the WUP flow regime on Chum spawning and incubations conditions in the mainstem of the Cheakamus River and major side channels. In order to determine whether or not discharge affects the productivity of Chum salmon in the Cheakamus River, total escapement of adult and juvenile Chum, distribution of adult Chum spawners and egg deposition rates are required. Total egg deposition data can then be linked with fry production data (Melville and McCubbing 2012, Bonner and Schwartz 2012) to determine spatial egg-to-fry survival rates. In the area upstream of the juvenile outmigration monitoring site (RK 5.5), monitoring of adult Chum salmon is conducted in the mainstem, two major side channels and a tributary (BC Rail and NVOS spawning channels, and Tenderfoot Creek). The number of eggs per spawner are utilized as a measure of productivity and compared to discharge regimes during spawning and incubation periods under the WUP. The effects of WUP discharge regimes and annual flow events on spawner distribution (i.e. effects on spawning habitat availability) and spawning and incubation periods.

Chum spawning in the Cheakamus River falls into three main locations for this study: below the RST juvenile monitoring site, above the RST site (mainstem) and in the side channels above the RST site. As data is only produced on fry production from above the RST site, total river escapement data is only useful as a general indicator of fish abundance and stock health. Over the nine years of enumeration, a large range in escapement has been observed in the whole river from a high of 442,228 Chum salmon to a low of 73,377 Chum salmon. High escapement was estimated in 2007, 2012 and 2013. In 2010 and 2011, escapement was relatively low. Escapement was moderate in 2008, 2009, 2014 and 2015. Note that these comparisons were based on the whole river Pooled Petersen Estimate (PPE) for all years, except 2014 when the whole river escapement was estimated based on the upper river PPE and the three previous year’s distribution data (2011-2013).

With four years of data (2012-2015), it is apparent that female fecundity varies annually in this watershed. In 2015, fecundity was significantly lower than all other years (all t-tests, $p<0.001$) and in 2012, female fecundity was significantly higher (all t-tests, $p<0.015$) than all other years and significant positive relationships between length and fecundity have occurred in all years. This relationship will be used to estimate fecundity during years when fecundity sampling was not conducted (2007-2011). Additionally, annual fecundity estimates can be adjusted based on the differences observed between the fork length of fish captured at the upper river tagging site and the fork length of fish sampled at Tenderfoot Creek. The variability in fecundity described by fork length has ranged from 15.7% in 2014 to 41.3% in 2015.

Annual variance in age cohorts could help explain this variability, as significant differences in population age structure have been observed among years. A stronger relationship between length and fecundity occurred in 2014 with age 4 spawners (length describing 35.1% of the variability in fecundity) (Fell et al. 2015). Recent publications have indicated that egg-per-female fecundity may be dependent on fish age (3 or 4 years) and fish length (Kaev 2000). Length, weight and fecundity have also been liked to run size (Volobuev 2000). Further age analysis will help determine whether a significant relationship exists between age, length and fecundity. If deemed valuable, additional age structure relationships can be developed for Years 1-5 from archived scale samples.

Pre-spawn mortality surveys conducted since 2012 have revealed that egg deposition varies both spatially and temporally in both mainstem and side channel habitats. The highest egg deposition rates were observed in 2014 which coincided with high flows early in the spawning season and low to moderate spawning densities. High egg deposition rates were also observed in 2015 when flows increased > 25 m^3/s for 3.5 days prior to peak spawning and spawner abundance was moderate. Higher spawner densities in 2013 and 2012 may have contributed to pre-spawn mortality. The highest pre-spawn mortality occurred in 2013 when the maximum spawner densities were observed in side channel habitats. Additionally, low early season flows (< 25 m^3/s at Brackendale) in 2013 may have been a stressor and delayed upstream movement of fish.

Factors that have been linked to higher egg retention and pre-spawn mortality include temperature, time of freshwater entry and density dependence (Kolski 1975, Schroder 1981). Additional factors may include fish stranding, disease, lack of passage at culverts or dams and low water conditions (Wild Fish Conservancy 2008). If possible, the assessment of pre-spawn mortality rates in Years 6-10 will be used to help derive estimates for Years 1-5 when pre-spawn mortality surveys were not conducted. Current egg-to-fry survival data are provisional at this time.

Egg-to-fry survival in side channel habitats is higher than in the mainstem. Distribution of spawners into these habitats is correlated with spawner density (R=0.96) and minimum discharge during peak spawning (all years combined: R=0.74; 2008-2013 and 2015: R=0.86). When minimum flows during peak spawning increased (>25 m^3/s), a larger proportion of upper river Chum spawners utilized side channel habitats. Higher overall discharges in the river increase flows in the flow-through NVOS channel which may draw a larger proportion of spawners into the channel. Increased discharge in the mainstem also provides better access into the groundwater-fed BC Rail side channel. In years of low to moderate escapement in the upper river, these side channel habitats are particularly important for fry productivity for the upper river due to higher egg-to-fry survival. Additional years of data at higher flows, particularly with minimum flows are set between 20 m^3/s and 25 m^3/s, would provide more certainty on this relationship.

It is possible that the NVOS and BC Rail side channel habitats reach and even surpass their habitat carrying capacity when escapement into the upper river is moderate to high. During years of high spawning escapement, reduced numbers of fry per spawner were observed and fry production decreased compared to years of moderate spawner densities. The habitat restoration conducted in 2012 to improve access to Tenderfoot Creek appears to have improved access to the BC Rail side channel. Further evaluations will be conducted on habitat carrying capacity and relationships between density dependent and independent factors during the 10-year program review.

During years of high escapement in the upper river, discharge rates during the spawning season appear to be an important determinant of spawner distributions. Discharge during the 2013 spawning season was low and a large number of upper river Chum salmon (180,669) spawned between the Bailey Bridge (RK 7) and the RST site (RK 5.5). Egg-to-fry survival in 2013/2014 was very low. In comparison, higher flows occurred in 2012 and 2014 prior to and during peak spawning periods and fish were observed farther upstream. Egg-to-fry survival was 10 times higher in 2012/2013 than 2013/2014. High flow events early in the season appear to have helped distribute these fish throughout the river and as a result, increase egg-to-fry survival. Hunter (1959) noted that stream discharge was an important factor in controlling the upstream movement of Chum salmon in coastal British Columbia streams. Augmented flow increases could potentially be used in the Cheakamus River to aid in the distribution of spawning salmon.

The timing and speed of upstream migrating salmon can be affected by river flow, water temperature, photoperiod and turbidity (Banks 1969 and Jonsson 1991). Telzlaff et al. (2005) found a complex relationship between hydrological variability and upstream movement of adult Atlantic salmon spawners in late October to mid-November. In years with regular flow pulses, the timing of freshwater entry of females was more distributed and fish were found more evenly distributed in the stream. In years when discharge prior to spawning remained low, entry of spawners into streams was delayed and spawning was focussed in the lower reaches of the stream. In years of low flows, even minor flow increases were sufficient enough to cause fish to move upstream (Telzlaff et al. 2005). Additional years of directed radio telemetry observations on female fish will provide us with a better understanding of the effects of discharge on distribution and upstream movement of female spawners.

High flow events may aid in spawner distribution but they also create challenges for incubating salmon eggs. The majority of temperature loggers buried in redds during the 2014/2015 incubation period and the 2015/2016 incubation period were scoured out. The magnitude and frequency of these high flow events appears to have a large impact on egg-to-fry survival in the mainstem. The importance of side channel habitats for Chum fry production as a buffer against these extreme events has been emphasized over the past two years. Enhancing side channel habitat by cleaning out the accumulation of sand, silt and debris could increase productivity upstream of the RSTs, especially during years when high flow events occur.

Including estimates of fecundity and pre-spawn mortality into the study design have enabled superior egg deposition estimates and egg-to-fry survival estimates. Mainstem egg-to-fry survival rates in 2013/2014 and 2014/2015 were very low at 0.2% and 0.3%, respectively (without accounting for pre-spawn mortality). These low rates were likely the result of high spawner densities (2013/14) and high discharges (2014/15). Egg-to-fry survival rates in 2012/2013 were 10-15 times higher than these years but still low (3.1%) compared to other coastal rivers. A broader distribution of the abundance of spawners in 2012 appears to have improved egg-to-fry survival. High discharge also appears to have had substantial effects in 2015/2016, although to a lesser extent. Egg-to-fry survival in the mainstem in 2015/2016 was 3.3 times higher than in 2014/2015 (1.0%).

It is apparent that Chum salmon egg-to-fry survival rates in the Cheakamus are highly variable among habitat types. Compared to other research on Chum salmon on the west coast, egg-to-fry survival in all areas (mainstem and side channels) combined upstream of the RSTs has been low over the past four years. Parker (1962) observed a broad range of survivorship in Chum salmon, 1-22% from 14 years of sample data on Hooknose Creek, BC. Bradford (1995) reported average Chum egg-to-fry survival rate of 7-9%. Estimates from the Fraser River over 19 years of monitoring have ranged between 6% and 35% (Beacham and Starr 1982).

Further monitoring and analysis will help establish the temporal and spatial trends in egg-to-fry survival and explore how they may be affected by discharge. With additional years of data collection, the linkages between discharge and pre-spawn mortality could be further evaluated and flows could be managed to try and prevent higher pre-spawn mortality. More data and analysis on distribution trends, monitoring upstream movement patterns on both a fine and course scale would allow for a better understanding of the importance of flow variations for upstream migration and distribution. Where and in what density fish spawn, will affect egg deposition densities and egg-to-fry survival rates and thus, fry production.

Spawning timing in conjunction with incubation temperatures are the primary factors regulating the timing of Chum fry outmigration. There does appear to be a relationship between river discharges early in the Chum spawning season and the corresponding peak outmigration dates for fry. Early fry outmigration dates were associated with high discharges early in the spawning season the previous year and late outmigration dates were associated with low flows early in the spawning season the previous year.

Using upstream movement of spawners at NVOS and outmigration timing of Chum fry in the mainstem as an indication of peak spawning and peak fry outmigration (from brood year 2008-2013), the average incubation temperature in redds was 1.5 to 2.0º C warmer than the temperatures in the river (RST site). This indicates that the majority of outmigrating fry were emerging from redds with groundwater influence. Preliminary results from a small number (4) of temperature loggers in redds upstream of the Bailey Bridge indicate that although temperatures in the upstream redds are less variable than the river temperature at the RST site, the incubation temperatures are lower than the river temperatures downstream. The redd temperature monitoring will be repeated in 2016/2017 and the additional data will inform on the incubation conditions upstream of the Bailey Bridge (RK 7.0). The results will be presented in the 10-year synthesis report.

Chum fry outmigration estimates for the mainstem indicate that Chum fry production has varied greatly from year to year since 2001. Comparisons of variation pre-WUP (CV=0.29) and WUP (CV=0.62) indicate that there has been higher annual variation since the WUP was implemented. This could be a result of changes in spawner abundance, distribution patterns, changes in habitat conditions or river discharge fluctuations (e.g., the influence of the Cheekye Creek washout in 2009). Despite the high variability, average annual fry production has increased 20% under the WUP flow regime. A key study goal is the ability to detect a linkage between discharge and a positive change in fry production of 75% or greater as predicted by the modeling work pre-WUP (Marmorek and Parnell 2002). At present the observed changes in fry abundance fall well short of this level.

It is important to recognize that by using averages as a measure of success data resolution is lost. The average total fry production under the WUP is strongly skewed because of two years of high Chum fry outmigration estimates (i.e. in 2013 when 10.8M Chum fry outmigrated and in 2010 when 7.3M Chum fry outmigrated). Therefore, it is important to also understand how much variation there is in the data. Total fry production in 50% of the WUP years has been less than the pre-WUP average and total fry production in 70% of the WUP years has been less than the WUP average. Additionally, without the adult escapement data in the pre-WUP years, it is not possible to determine whether there changes in variation and abundance are related to discharge patterns or if these changes are the result of changes in adult spawner abundances.

The body size of juvenile Chum was significantly larger pre-WUP (average 39.4 mm) than during the WUP (average 38.2 mm) ($p<0.001$). Further evaluations of fry size will be conducted on the significant difference observed among years from (2000-2016) and reported in the 10-year review report. Size of alevin and fry is influenced by both egg size and incubation temperature (Beacham and Murray 1986 and 1987, Weatherley and Gill 1995). Beacham and Murray (1987) found a change in incubation temperature from 4 to 8ºC corresponded with a 2 mm increase in fry length. Water temperature pre-WUP was significantly higher than WUP, although, this was based on very limited temperature data (2001 and 2005) (McCubbing et al. 2012). In addition, egg size data is absent prior to 2012. WUP evaluations of the relationships among river temperature, discharge, egg size and fry length will be further evaluated during the synthesis.

4.1 Management Questions

4.1.1 What is the relation between discharge and Chum salmon spawning site selection and incubation conditions?

There appears to be a correlation between side channel spawner distribution and minimum discharge. When minimum discharge was near 25 m^3/s, a larger proportion of spawners utilized side channel habitats (particularly NVOS side channel habitat). Egg-to-fry survival in side channel habitats is higher than in the mainstem and it appears that increased spawner density in side channels could increase upper river productivity as long as side channel carrying capacity is not surpassed. Additional years of higher minimum flows (>20 m^3/s) would provide more insight into the relationships between discharge and spawner distribution in both side channel and mainstem habitats.

4.1.2 Do the models developed during the WUP to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of Chum salmon spawning site selection, and the availability of spawning habitat?

A large area of habitat upstream of the Bailey Bridge (RK 7.0) was classified as effective spawning area in the original model. Chum spawners have only been observed utilizing this area in large numbers in one year (2012). This was a year with high spawner abundance but higher numbers of Chum spawners returned in 2013 and spawners were not distributed as far upstream. Differences in spawner distribution could be related to discharges during spawning seasons. In 2012, the average discharge was higher than in 2013, which could have drawn Chum spawners farther upstream. With an additional year of radio-telemetry and pre-spawn mortality data this hypothesis could be further evaluated. Further evaluation of the temperature in redds upstream of the Bailey Bridge (RK 7.0) would also provide insight into the quality of upper river spawning areas.

4.1.3 Are there other alternative metrics that better represent Chum salmon spawning habitat?

Groundwater appears to be an important determinant of effective spawning habitat for Chum salmon and groundwater upwelling is present in many spawning areas utilized by Chum salmon. During pre-spawn mortality surveys, Chum spawners have been found to concentrate in the groundwater-fed side channels and in the mainstem, high concentrations of spawners are observed in known groundwater upwelling areas. However, additional evaluations are required to be able to definitively say that Chum spawners are selecting for groundwater in the Cheakamus River (see Null Hypothesis 4.2.2 and Recommendation 5.8).

To test if redds in the mainstem were influenced by groundwater upwelling, temperature loggers were buried in the hyporheic zone within redds at Moody's Bar and at the Gauge pool in 2010 (upper river tagging site) and compared to two independent stilling wells recording water temperature (Figure 1) (McCubbing et al. 2011). River water temperatures had high daily and weekly variation over the egg incubation period from lows near 0.5° C during early January and late February to highs of over 5° C in December and mid-February 2011. The majority of redds had significantly less daily temperature variation and were 3-5^0 C warmer than the surface water. Most temperature loggers recorded temperatures between 5 and 8^0 C after late December (McCubbing et al. 2011). By calculating the average temperature required to accumulate 850-900 ATUs from peak spawning to peak fry outmigration (using 6 years of data from 2008/2009-2013/2014), it appears that the majority of outmigrating fry were emerging from redds with groundwater influence.

Assessments of temperature in the hyporheic zone in the spawning areas upstream of the Bailey Bridge (RK 7.0) conducted in 2014/2015 and 2015/2016, indicate that in most months river water temperatures were more variable than temperatures in the hyporheic zone 2 km upstream. Mean temperatures in redds upstream were cooler than mean river temperatures at the RST site. Additional, temperature data collected in 2016/2017 could provide more information on the temperature profiles of the river and help further assess the influence of groundwater on the temperature profile.

4.1.4 What is the relationship between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River?

Discharge affects the distribution of spawners. At higher minimum discharges (near 25 m^3/s), a larger proportion of spawners utilized side channel habitats. Side channel habitats are more productive than mainstem habitats. In 2014/2015 and 2015/2016, when mainstem conditions were affected by high water events, side channel habitats produced 92% and 75% of the total Chum fry yield in the upper river, respectively. Increasing the number of side channel spawners increases upper river productivity as long as side channel carrying capacity is not surpassed. These theories will continue to be evaluated during the 9yr synthesis and with an additional year of data collected in 2016/17. Additional years of higher minimum flows (>20 m^3/s) would provide more insight into the relationships between discharge and distribution in both habitat types.

The upstream distribution of spawners also affects productivity above the RST site. In years of high escapement and low flows, large numbers of Chum spawners do not distribute upstream past the Bailey Bridge (RK 7.0). High densities of spawners in the 1.5 km stretch of the mainstem above the RSTs resulted in low egg-to-fry survival and low productivity in 2013/2014 from exceed carrying capacity. In contrast, there were higher flows during peak spawning in 2012 and the large escapement of spawners that returned to the upper river distributed from the RST site (RK 5.5) up to Road’s End (RK 16.5). The highest outmigration of fry over the 15 years of this study occurred in spring of 2013 and egg-to-fry survival in 2012/2013 was 10 times higher than in 2013/2014.

Increased pre-spawn mortality and lower egg deposition rates have been associated with delayed access to spawning grounds. This was evident in 2013 when pre-spawn mortality was the highest and corresponded with stable flows at Brackendale gauge (between 20 m^3/s and 25 m^3/s). In 2015, pre-spawn mortality was 10% lower when a three-and-a-half-day increased flow event increased flows at Brackendale gauge up to 40 m^3/s. By understanding the requirements of salmonids, operational flow increases could be utilized to draw fish into the river and improve access in low flow years, potentially decreasing pre-spawn mortality. Operational flows could also potentially be used to promote spawner distribution in the river system.

4.1.5 Does juvenile Chum fry yield or habitat capacity change following implementation of the WUP flow regime?

A positive change in fry production of 75% or greater was predicted by the modeling work that was conducted. To date, a 20% increase in average annual fry production has been observed. There has been higher variance in Chum fry production observed since the implementation of the WUP (pre-WUP variance: 29%, WUP variance: 62%). WUP there have been some very productive years (> 10 million Chum fry). However, fry production in 50% of the WUP years have been less than the pre-WUP average.

4.2 Null Hypotheses (and sub-hypotheses)

4.2.1 H_1: Discharge during the Chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the mainstem

In order to thoroughly test this hypothesis, the number of fry per spawner in the mainstem must be determined. Prior to 2012, RST mainstem fry production estimates included Tenderfoot Creek fry data. Since the 5-year review process in 2012, the productivity of Tenderfoot Creek has been evaluated and its contribution has ranged from 17% to 42% of the total yield above the RST site. Estimates of productivity from Tenderfoot for Year 1 to 5 will be determined using the known adult escapement above the Tenderfoot Creek fish fence operated by the Tenderfoot Creek Hatchery staff and removed from the mainstem fry production estimates.

The fecundity evaluations at Tenderfoot Hatchery and pre-spawn mortality surveys in the mainstem and side channel habitats have shown that egg deposition varies both temporally and spatially. Further evaluations of these variables will aid in the development of accurate egg-to-fry survival rates for Years 6-10 and help estimate deposition rates for Years 1-5.

4.2.2 H_2: Spawning Chum salmon do not select areas of upwelling groundwater for spawning in the mainstem

Possibly Reject. Current evidence suggests this hypothesis may be incorrect, however, further research is required to definitively say whether or not Chum are selecting redd sites for upwelling groundwater or if other habitat attributes or a combination of habitat attributes make sites more favourable. Additional habitat attributes (substrate size, substrate embeddedness, water depth and water velocity) should be measured in conjunction with temperature evaluations and selected and non-selected sites should be compared.

The evaluations conducted by burring temperature loggers in spawning areas (in 2009 and 2010) have revealed that groundwater is present in areas of the Cheakamus River. Temperature logger evaluations of redd temperatures at Moody's bar area revealed a significant presence of groundwater upwelling. Groundwater influence was also evident in some areas on the bar upstream of the RST site (upper river tagging site). The majority of the areas where temperature loggers were buried (in 2009 and 2010) and Chum eggs were present there was some degree of groundwater influence (McCubbing et al. 2011; see Section 4.1.3 for more details).

In 2013 and 2015, one third of radio tagged females spawned in known groundwater upwelling areas (Moody's bar area, BC 49 channel, Upper Upper Paradise channel, BC Rail side channel and Tenderfoot Creek). Additional years of radio tagging female Chum spawners would provide more insight into site selection by female spawners and their selection of groundwater upwelling areas. Further monitoring and evaluations of temperatures in the hyporheic zone upstream of the Bailey Bridge (RK 7.0) in 2016 will provide information on the temperature profiles in this area classified as effective spawning area.

4.2.3 H_3: Discharge during the Chum salmon spawning and incubation period does not affect the upwelling of groundwater in the mainstem spawning areas

Reject. Discharge patterns in the Cheakamus River can affect incubation condition in redds with groundwater upwelling. Evaluations conducted in 2009 (Troffe et al. 2009) revealed that high flow events (> 350 m^3/s) can push colder surface water down into redds and temporarily reduce the influence of upwelling groundwater. The effects of smaller increased flow events (50-100 m^3/s) were also observed in the temperature profile of some redds at Moody's bar (Troffe et al. 2009). Further evaluations on the influences of temperature in 2016 will provide more insight into the relationship between discharge and groundwater upwelling, particularly in reaches upstream of the Bailey Bridge.

Additional evaluation using a minipiezometers could also be conducted to further assess the groundwater-stream water exchange in selected and non-selecting spawning areas. Measurements under different flow conditions could help evaluate the influence of stream flow on hydraulic conductivity.

5.0 Recommendations

5.1 Temperature Loggers above Bailey Bridge (RK 7.0)

To determine if there is a groundwater influence upstream of the Bailey Bridge, temperature loggers should be buried in spawning gravel upstream of the Bailey Bridge at the end of the 2016 spawning season, through incubation and emergence in 2017. Temperature loggers should also be installed at these sites to record river temperatures. The areas upstream of the Bailey Bridge were initially identified by the model as suitable spawning habitat. However, Chum spawners do not frequently utilize this habitat. If Chum salmon are keying into groundwater upwelling areas and there is no groundwater influence upstream, this could explain why they are not selecting this habitat.

5.2 Comparing Selected and Non-Selected Spawning Sites

To determine whether or not Chum spawners are selecting groundwater upwelling areas over areas without groundwater upwelling, habitat attributes (including substrate size, substrate embeddedness, water depth and velocity and red temperate) of selected and non-selected sites should be measured and compared. The presence of groundwater in redd sites does appear to be an important factor for incubation, although, radio telemetry had shown that only 30% of spawners select known groundwater upwelling areas. By comparing habitat attributes of selected and non-selected site, we an focus on finer-scale details to determine what draws spawners to specific areas. This assessment would also aid in identifying areas for enhancement as well as areas that may be classified as available spawning habitat that are not consistently utilized.

5.3 Using Groundwater to Model Effective Spawning Habitat for Chum salmon

If Chum salmon are determined to select groundwater upwelling areas (Recommendation 5.2), groundwater could be included in the models to predict available spawning habitat for Chum salmon in the Cheakamus River. Further evaluation of the temperature in the hyporheic zone upstream of the Bailey Bridge (RK 7.0) will provide information on the temperature profiles in the areas of the Cheakamus River that were classified as effective spawning area that Chum are not consistently utilizing. The connection between the river temperature profiles and discharge pattern can then be further evaluated. Additional data and analysis on distribution trends, monitoring upstream movement patterns on both a fine and course scale would allow for a better understanding of the importance of flow variations for upstream migration and distribution.

5.4 Additional Years of Chum Escapement and Distribution at Higher Minimum Flows

Evaluations of spawner distribution should be conducted with minimum flows set between 20 m^3/s and 25 m^3/s. Additional years of distribution and escapement data would provide more certainty in our understanding of the relationships between minimum flows, site selection and reproductive success of Chum salmon. Linkages between minimum flows and the proportion of spawners utilizing side channel habitats indicate that higher minimum flows (set at 25 m^3/s during peak spawning) could potentially increase productivity of Chum salmon, particularly when adult escapement is low to moderate.

5.5 Additional Years of Chum Distribution and Escapement under Different Flow Variations

Additional years of detailed radio telemetry should be conducted during the spawning season to observe movement trends of Chum spawners in relation to flow fluctuations. By monitoring Chum spawner upstream movement on a finer scale (every 24-48hrs) as they move from the lower river (RK 1.5) to their final nest sites and relating movement patterns to discharge, the importance of flow fluctuations could be evaluated. Increased flow events prior to and during early peak spawning have coincided with a broader distribution of Chum spawners within the anadromous section of the Cheakamus River. In years of high escapement particularly, this broader distribution of spawners appears to increase productivity. Additional years of radio tagging Chum spawners under varied flow regimes is warranted.

Coupled with escapement data of adult Chum spawners and outmigrating Chum fry abundances (Recommendation 5.6) the connectivity between discharge and egg-to-fry survival could also be further evaluated. With additional years of data and more replications of flow variations, we would be able to gain a better understanding of how flow pulses aid in the distribution of spawners and affect their site selection and the reproductive success of Chum salmon in the mainstem of the Cheakamus River.

Additionally, the connectivity between flow variation and the timing of river entry could also be further evaluated. Delayed river entry has coincided with low flows and increased pre-spawn mortality. Increased stress on spawners can reduce their ability to spawn successfully.

5.6 Additional Years of Chum Fry Data Collection

High early season flows during Chum adult upstream migration and early spawning have been associated with early peak outmigration timing of Chum fry. Low flows throughout the Chum spawning season have been associated with late outmigration of Chum fry in the following spring. Additional years of both Chum adult data collection (Recommendation 5.5) and Chum fry data would allow us to develop a better understanding of how in-stream flows affect the run-timing and peak spawning of adult Chum salmon and the peak emergence and run-timing their progeny.

5.7 Side Channel Habitat Enhancement

Enhancement of side channel habitat along the Cheakamus River could be conducted by cleaning out the accumulated sand, silt and debris. Cleaning of the side channels would likely increase channel productivity. Side channel restoration projects on the Cheakamus River began in the late 1970s with goals to enhance spawning areas for Chum, Pink and later Coho (Melville 2003). Multiple channels were constructed from 1979 onward but it appears that these channels do not have the hydrological properties to be able to flush out sand, silt and debris as it accumulates. Therefore, over time the spawning habitats have been degraded in many areas. Side channel habitats are refuges for spawning salmon and egg-to-fry survival remains higher in the side channel habitats when unfavourable conditions in the mainstem reduce survival of incubating eggs (eg. winter storm events that result in high flows during the incubation period).

6.0 TABLES

Table 1. Numbers and distribution of PIT tags applied to Chum salmon adults on the Cheakamus River, 2007-2015.

Year	Total # Fish Tagged	Lower River Tagging Site				Upper River Tagging Site			
		Totals	Males	Females	% Females	Totals	Males	Females	% Females
2007	870	795	349	446	56%	75*	45	30	40%
2008	951	569	328	241	42%	382	252	130	34%
2009	762	391	224	165	42%	371	261	110	30%
2010	914	537	334	204	38%	377	292	85	23%
2011	1,890	970	766	204	21%	920	763	157	17%
2012	1,517	722	379	343	48%	795	587	208	26%
2013	1,907	890	515	375	42%	1,017	795	222	22%
2014	1,005	5*	4	1	20%	1,000	730	270	27%
2015	1,137	396	202	194	49%	768	586	182	24%

* small sample size

Table 2. Mean fork length ± standard deviation (mm) of tagged adult Chum salmon at the lower river tagging site and the upper river tagging site, Cheakamus River 2007-2015.

Year	Lower River Tagging Site		Upper River Tagging Site	
	Female	Male	Female	Male
2007	750 ± 40	802 ± 42	Sample size too small	
2008	718 ± 43	765 ± 52	720 ± 43	760 ± 52
2009	720 ± 33	765 ± 45	729 ± 30	760 ± 45
2010	729 ± 42	765 ± 49	732 ± 41	768 ± 58
2011	702 ± 35	728 ± 46	704 ± 33	732 ± 47
2012	726 ± 37	778 ± 52	739 ± 43	785 ± 49
2013	719 ± 34	764 ± 45	721 ± 35	774 ± 47
2014	Sample size too small		745 ± 40	792 ± 47
2015	705 ± 39	734 ± 54	719 ± 35	758 ± 57

Table 3. Percentages of females, Male:Female (M:F) sex ratio and total number (N) of Chum spawners captured by tangle netting at the upper river tagging site on the Cheakamus River and at the Tenderfoot Creek fish fence (operated by DFO) 2007-2015.

Year	Upper River Tagging Site			Tenderfoot Fish Fence		
	% Females	M:F Sex Ratio	N	% Females	M:F Sex Ratio	N
2007	40%	1.5:1	75*	23%	3.3:1	1557
2008	34%	1.9:1	382	36%	1.8:1	3308
2009	30%	2.3:1	371	38%	1.6:1	2935
2010	23%	3.3:1	377	23%	3.3:1	293
2011	17%	4.9:1	920	21%	3.9:1	690
2012	26%	2.8:1	795	40%	1.5:1	5396
2013	22%	3.5:1	1017	41%	1.4:1	7643
2014	27%	2.7:1	999	38%	1.6:1	1329
2015	24%	3.2:1	768	43%	1.3:1	2139

*small sample size

Table 4. The number (N) and percentage of spawned out female Chum salmon in each habitat type surveyed on the Cheakamus River in 2012-2015.

Location	2012		2013		2014		2015	
	N	Spawned Out	N	Spawned Out	N	Spawned Out	N	Spawned Out
Mainstem Habitat	602	89.0%	744	87.1%	342	98.2%	108	98.1%
Side Channel Habitat	773	82.9%	1775	64.5%	1383	91.7%	1077	88.9%

Table 5. The number (N) and percentage of spawned out female Chum salmon in each surveyed side channel on the Cheakamus River 2012-2015.

Side Channel Location	2012		2013		2014		2015	
	N	Spawned Out	N	Spawned Out	N	Spawned Out	N	Spawned Out
BC 49 side channel	262	81.7%	339	68.1%	300	95.0%	72	77.8%
BC Rail side channel	40	45.0%	268	37.1%	375	88.3%	213	90.1%
Tenderfoot Creek and Pond	Not surveyed		292	66.4%	105	98.1%	56	92.9%
NVOS side channels	458	86.7%	810	73.6%	603	91.0%	736	89.3%

Table 6. The number (N) and percentage of spawned out female Chum salmon in the NVOS side channel complex from 2012 to 2015.

NVOS Side Channel Location	2012		2013		2014		2015	
	N	Spawned Out	N	Spawned Out	N	Spawned Out	N	Spawned Out
Baby Gorbushca	41	82.9%	10	60.0%	7	100.0%	26	92.3%
Big Gorbushca	0	-	52	55.8%	11	100.0%	55	70.9%
Kisutch	123	77.2%	100	55.0%	115	90.4%	141	84.4%
Sues	41	90.2%	65	76.9%	50	74.0%	83	94.0%
Upper Paradise	151	90.1%	231	74.0%	222	90.5%	296	92.6%
Upper Upper Paradise	102	93.1%	352	81.0%	198	95.5%	135	91.1%

Table 7. The percentage of eggs deposited by female Chum salmon by area in the Cheakamus River from 2012 to 2015.

Location	Eggs Deposited			
	2012	2013	2014	2015
Mainstem Habitat	**86.7 %**	**85.6 %**	**92.1 %**	**91.7%**
Side Channel Habitats	**84.4 %**	**74.8 %**	**88.8 %**	**87.0%**
BC 49 side channel	83.8 %	76.1 %	90.5 %	81.9%
BC Rail side channel	65.5 %*	61.2 %	87.1 %	88.1%
Tenderfoot Creek	Not surveyed*	75.9 %	92.0 %	89.4%
NVOS side channel complex	86.2 %	79.5 %	88.4 %	87.0%

* egg deposition rate for all side channel habitats used

Table 8. Percentage of PIT tagged fish that kelted, total number of PIT tagged spawners in channel and portion of PIT tagged male and female spawners that kelted in the side channels from 2007 to 2015.

NVOS	% Kelts	Total	PIT Tagged Kelts			BC Rail	% Kelts	Total	PIT Tagged Kelts	
			Males	Females					Males	Females
2007	31%*					**2007**	13%*			
2008	38%	82				**2008**	10%	41		
2009	53%	49	26	0		**2009**	16%	25	2	1
2010	11%	53	5	1		**2010**	14%	14	1	1
2011	22%	130	26	2		**2011**	13%	40	5	0
2012	20%	54	9	2		**2012**	17%	18	1	2
2013	14%	110	12	3		**2013**	4%	28	1	0
2014	16%	75	10	2		**2014**	10%	30	3	0
2015	21%	98	18	2		**2015**	15%	13	1	1
PIT Tagged Kelt Total (98)			88	10		**PIT Tagged Kelt Total (17)**			13	4
Average Kelts			25%			**Average Kelts**			12%	

*averaged from 2008-2011

Note: In 2015, in total 21 Chum kelted. The sex was unknown for one fish.

Table 9. Resistivity fish counter efficiency based on video validation for the NVOS side channel complex and BC Rail side channel from 2007 to 2015.

NVOS				BC Rail		
Year	**Up**	**Down**		**Year**	**Up**	**Down**
2007	96%	99%		**2007**	No video	
2008	72%	84%		**2008**	100%	95%
2009	85%*	74%*		**2009**	68%*	52%*
2010	71%	68%		**2010**	75%	78%
2011	68%	69%		**2011**	66%	78%
2012	49%**	75%**		**2012**	80%	71%
2013	74%	101%		**2013**	77%	77%
2014	High water			**2014**	87%*	104%*
2015	104%	101%		**2015**	90%	87%

*at normal flows

**large range in counter efficiency

Note: 2015 efficiencies at NVOS reflective of the period from Oct 22nd-Nov 3rd, 2015.

Table 10. Pooled Petersen Estimates (PPE) of Chum salmon spawner abundance for the Cheakamus River upstream of the RST site and for the full river, 2007-2015 with 95% confidence limits (CL).

	PPE	95% CL		PPE	95% CL	
Year	**Upper River**	**Lower CL**	**Upper CL**	**Total River**	**Lower CL**	**Upper CL**
2007	42,011	22,506	75,020	267,574	163,234	431,396
2008	24,058	20,206	28,369	117,780	86,066	160,776
2009	105,540	81,235	136,954	165,318	120,309	226,566
2010	12,827	10,002	16,434	85,461	51,453	139,344
2011	29,041	24,610	34,264	73,377	56,861	94,590
2012	132,128	107,619	162,149	310,295	223,712	429,106
2013	180,669	152,853	213,506	442,448	335,124	583,255
2014	52,202	44,998	60,554	127,330*	no PPE available	
2015	69,974	58,443	83,758	199,165	131,459	299,331

Note: The 2014 whole river estimate is not a PPE but an estimate of escapement based on the upper river estimate and the previous three years of proportional distribution data (i.e. on average 41% upper river).

Table 11. Estimates of the number of Chum salmon spawner utilizing NVOS and BC Rail spawning channels, and Tenderfoot Creek, 2007-2015.

	Year								
Location	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
BC Rail side channel	522	1,279	3,243	367	754	683	3,331	1,523	1,994
Tenderfoot Creek	1,555	3,309	3,003	293	713	5,396	7,643	1,329	2,139
NVOS side channel	2,170	3,263	9,357	2,048	2,915	8,859	13,213	6,169	6,544
Total Channels	4,247	7,851	15,603	2,708	4,382	14,961	24,187	9,021	10,677

Table 12. Discharge (m^3/s) during peak Chum spawning on the Cheakamus River (November 1st to November 15th) from 2007 to 2015.

Date	2007	2008	2009	2010	2011	2012	2013	2014	2015
01-Nov	20.4	31.1	49.1	57.9	23.3	54.9	17.8	171.0	34.6
02-Nov	18.6	67.4	23.0	49.3	17.6	42.3	18.6	104.0	24.3
03-Nov	18.7	92.1	19.0	33.2	16.7	79.9	16.7	50.0	19.9
04-Nov	24.1	28.9	20.1	30.1	16.0	80.9	15.9	136.0	16.4
05-Nov	20.7	25.5	31.2	48.5	15.9	70.9	16.0	62.9	14.2
06-Nov	19.0	25.2	43.0	96.5	16.5	32.4	16.5	163.0	14.6
07-Nov	19.4	24.6	32.2	101.0	16.8	21.2	21.5	227.0	52.2
08-Nov	19.3	70.5	27.5	74.7	16.3	17.9	18.0	101.0	34.4
09-Nov	38.9	118.0	44.9	44.8	16.5	16.6	15.1	68.3	20.9
10-Nov	46.7	91.7	34.2	28.9	21.4	17.3	15.3	45.4	17.1
11-Nov	35.2	33.8	28.6	27.4	22.3	17.3	15.4	30.8	20.7
12-Nov	71.5	56.1	22.2	26.2	19.7	16.9	18.7	28.1	38.7
13-Nov	39.8	67.2	29.3	25.2	17.0	16.5	20.3	26.8	64.2
14-Nov	28.6	36.6	71.2	24.3	16.1	16.1	16.5	25.9	36.3
15-Nov	38.1	26.0	50.3	25.1	16.4	16.1	16.6	24.9	26.4
Average	**30.6**	**53.0**	**35.1**	**46.2**	**17.9**	**34.5**	**17.3**	**84.3**	**29.0**
Minimum	**18.6**	**24.6**	**19.0**	**24.3**	**15.9**	**16.1**	**15.1**	**24.9**	**14.2**
Maximum	**71.5**	**118.0**	**71.2**	**101.0**	**23.3**	**80.9**	**21.5**	**227.0**	**64.2**
Median	**24.1**	**36.6**	**31.2**	**33.2**	**16.7**	**17.9**	**16.6**	**62.9**	**24.3**

Table 13. Number of juvenile Chum caught, marked and recaptured at the rotary screw trap on the Cheakamus River from 2001-2016 and Bayesian Time-Stratified Population Analysis System (BTSPAS) population estimates with upper and lower confidence limits (CL), standard deviation (SD) and coefficient of variation (CV). Bold = WUP estimates.

Coefficient of Variation > 0.3 = Poor precision.

Year	Total Caught	Total Marked	Total Recap	BTSPAS Estimate	95% CL		SD	CV
					Upper CL	Lower CL		
2001	122,044	43,520	3,557	1,685,668	1,798,406	1,595,828	52,172	0.03
2002	105,221	23,685	1,101	4,173,706	4,836,441	3,642,305	311,447	0.07
2003	50,143	11,537	181	4,501,682	6,620,388	3,335,970	898,827	0.20
2004	126,216	63,006	2,775	3,699,539	4,001,317	3,461,175	138,533	0.04
2005	174,469	62,312	4,425	4,101,706	5,073,701	3,548,635	654,281	0.16
2006	355,391	94,235	7,998	4,608,359	4,751,038	4,477,697	69,200	0.02
2007	**382,087**	**82,802**	**6,746**	**5,842,755**	**6,097,001**	**5,618,684**	**121,051**	**0.02**
2008	**81,115**	**35,469**	**1,878**	**3,806,330**	**5,014,920**	**3,261,866**	**497,455**	**0.13**
2009	**283,383**	**48,382**	**6,759**	**3,024,765**	**3,329,535**	**2,793,071**	**136,382**	**0.05**
2010	**366,185**	**94,647**	**10,102**	**7,264,443**	**7,825,972**	**6,735,949**	**280,858**	**0.04**
2011	**188,897**	**59,734**	**7,718**	**1,882,688**	**1,973,763**	**1,804,029**	**43,817**	**0.02**
2012	**186,073**	**42,369**	**4,350**	**2,760,670**	**2,913,866**	**2,619,252**	**74,013**	**0.03**
2013	**897,121**	**92,212**	**10,165**	**10,795,444**	**11,077,880**	**10,521,160**	**143,849**	**0.01**
2014	**402,910**	**88,537**	**10,301**	**4,207,889**	**4,303,532**	**4,115,233**	**48,069**	**0.01**
2015	**332,573**	**70,931**	**11,849**	**2,054,657**	**2,094,276**	**2,016,513**	**19,934**	**0.01**
2016	**231,496**	**60,642**	**8,176**	**2,320,266**	**2,425,998**	**2,224,994**	**50,959**	**0.02**

Note: The 2016 BTSPAS estimate only include data from February 12th to April 12th. Approximately, 23.4% of the run outmigrated in the last three weeks of April.

Table 14. Chum Fry Production on the Cheakamus River upstream of the RST site 2008-2016.

BTSPAS Estimate of Chum Fry Abundance					
Year	**All Chum Fry Above RST Site**	**Mainstem**	**Tenderfoot Creek**	**NVOS Side Channels**	**BC Rail Side Channels**
2008	**3,806,330**	2,684,494	not assessed 2008-2012	965,096	156,740
2009	**3,024,766**	1,709,022		924,726	391,018
2010	**7,264,444**	5,008,836		1,986,853	268,755
2011	**1,882,689**	1,301,759		557,908	23,022
2012	**2,760,670**	1,994,304		668,231	98,135
2013	**10,795,444**	5,053,570*	2,854,058	2,428,254	459,562
2014	**4,207,889**	529,632*	1,787,587	1,662,267	228,403
2015	**2,054,657**	164,961	poor estimate	1,240,328	649,368
2016	**3,029,030**	756,732	503,509	1,222,215	546,574

* Tenderfoot Creek estimate removed
(all other Mainstem estimates include Tenderfoot Creek)

Note: The 2016 estimate was derived using the BTSPAS estimate from mark-recapture conducted from February 12th – April 12th and then 23.4% to account for the proportion of the missed due to operational flow increases.

Table 15. Summary of mean Chum fry lengths (mm) 2001-2015 from the Cheakamus River. Bold = WUP.

Year	N	Mean (mm)	Range
2001	352	40	31-50
2002	414	39	30-53
2003	276	41	33-55
2004	223	39	32-50
2005	200	39	31-55
2006	224	39	30-54
2007	**425**	**38**	**30-54**
2008	**459**	**39**	**31-49**
2009	**400**	**39**	**34-57**
2010	**400**	**38**	**31-48**
2011	**465**	**39**	**35-45**
2012	**405**	**37**	**30-41**
2013	**448**	**38**	**27-42**
2014	**373**	**38**	**31-49**
2015	**527**	**39**	**28-50**
2016	**274***	**38**	**34-42**

Table 16. Egg-to-fry survival by habitat area from 2012/13 to 2015/16 (with and without accounting for site-specific egg deposition rates from pre-spawn mortality (PSM) surveys).

Location	Egg-to-fry Survival				Egg-to-fry Survival - without PSM			
	2012/13	2013/14	2014/15	2015/16	2012/13	2013/14	2014/15	2015/16
All area above RST					5.7%	1.6%	3.1%	3.3%
Mainstem above RST	3.6%	0.3%	0.3%	1.1%	3.1%	0.2%	0.3%	1.0%
NVOS Side Channel	23.1%	11.8%	17.9%	16.5%	19.9%	9.4%	15.9%	14.4%
BC Rail Side Channel	58.0%	8.3%	37.5%	24.0%	49.0%	5.1%	33.6%	21.1%
Tenderfoot Creek Natural Spawners	53.9%	27.0%		38.4%	45.5%	20.5%		34.3%

Table 17. Annual redd incubation and river temperatures (2007-2013).

	Julian Day			Average Daily Redd Temperature (ºC)		Average Daily River Temperature (ºC)
Spawner Year	**Peak Chum Spawning**	**Peak Fry Outmigration**	**Days of Incubation**	**850 ATU**	**900 ATU**	**(at RST site)**
2007	313	104	156	5.4	5.8	4.2*
2008	312	93	146	5.8	6.2	3.6**
2009	310	91	146	5.8	6.2	4.5
2010	305	90	150	5.7	6.0	3.9
2011	313	98	150	5.7	6.0	3.8
2012	303	94	156	5.4	5.8	4.6
2013	313	103	155	5.5	5.8	4.1
Average	**310**	**96**	**151**	**5.6**	**6.0**	**4.1**

* missing 3 weeks of temperature data in December 2007

** missing one week of temperature data in March 2009

7.0 FIGURES

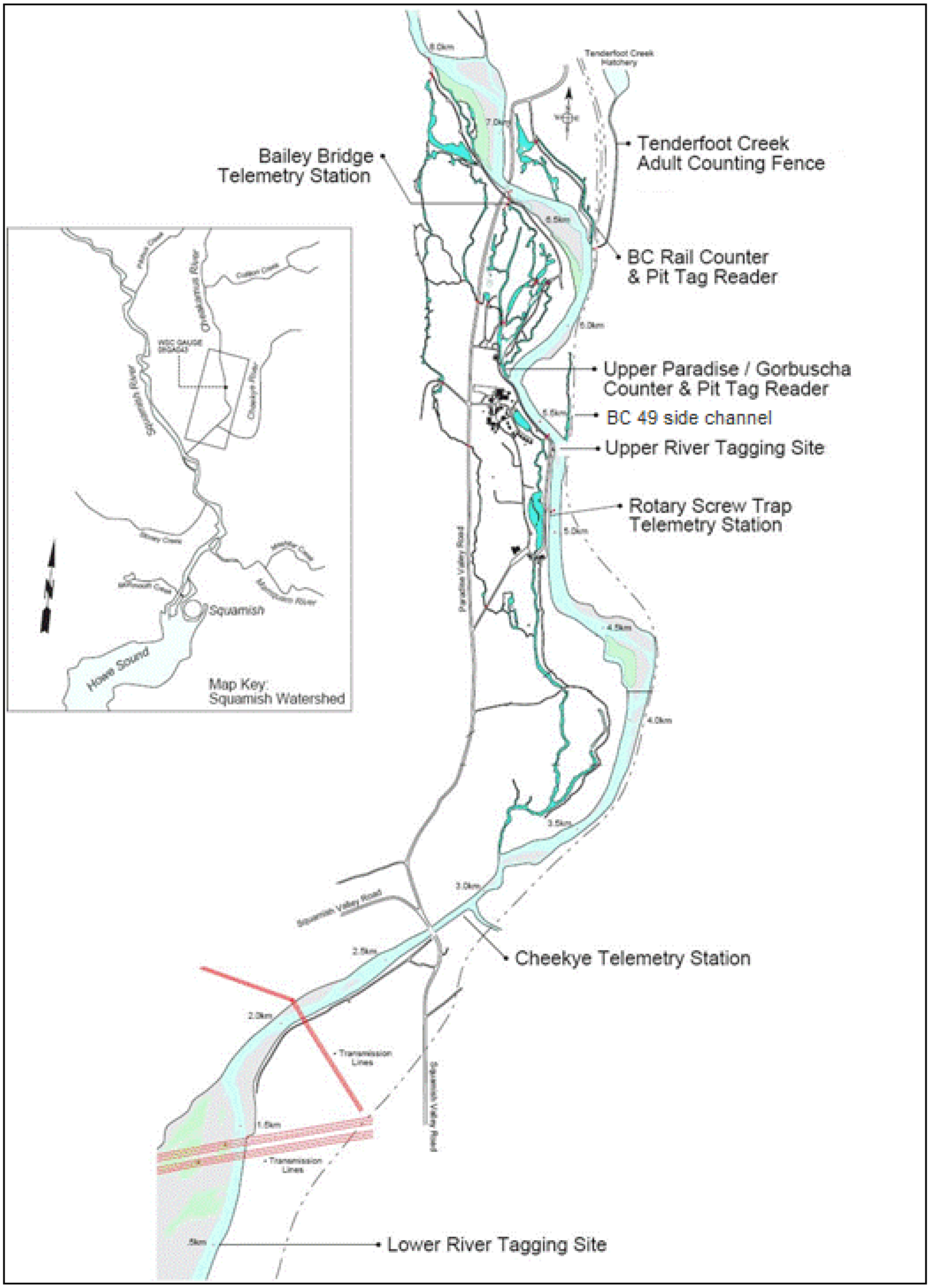

Figure 1: Study area for Cheakamus River Chum salmon escapement monitoring (River KM 0.5-8.0).

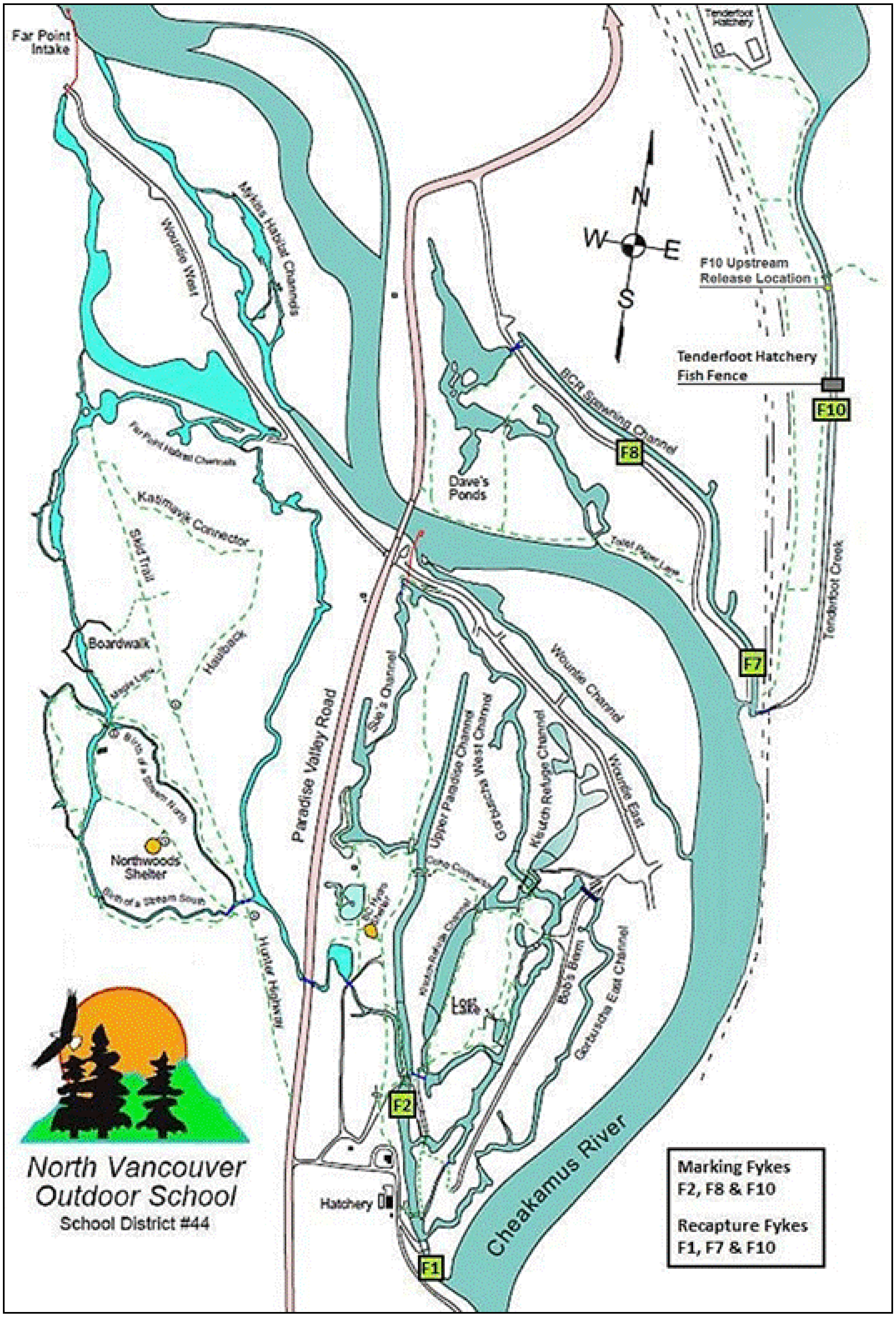

Figure 2. Site map showing the marking and recapture fyke net trap locations and the network of side channels upstream of the RST site (Figure 1).

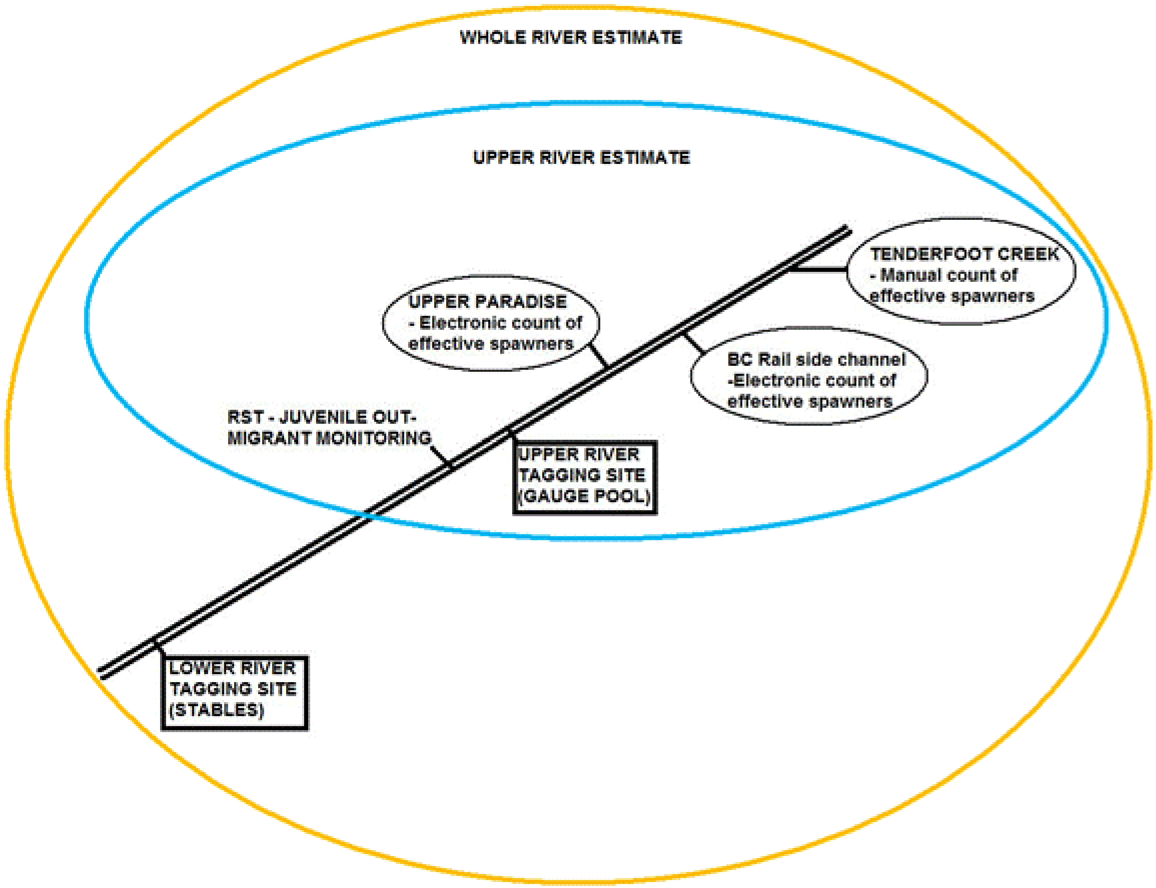

Figure 3. Conceptual diagram of the Cheakamus River Chum salmon spawner enumeration monitor illustrating the spatial relationship of tagging and monitoring locations. Whole river (yellow ellipse), Upper river (blue ellipse), and individual side channel (black ellipses) spawner estimates are highlighted.

Figure 4. Downstream photo of the NVOS enumeration site showing the design used from 2008-2015 with two channels containing one resistivity counter pad in the centre and two directional antennas (one upstream and one downstream).

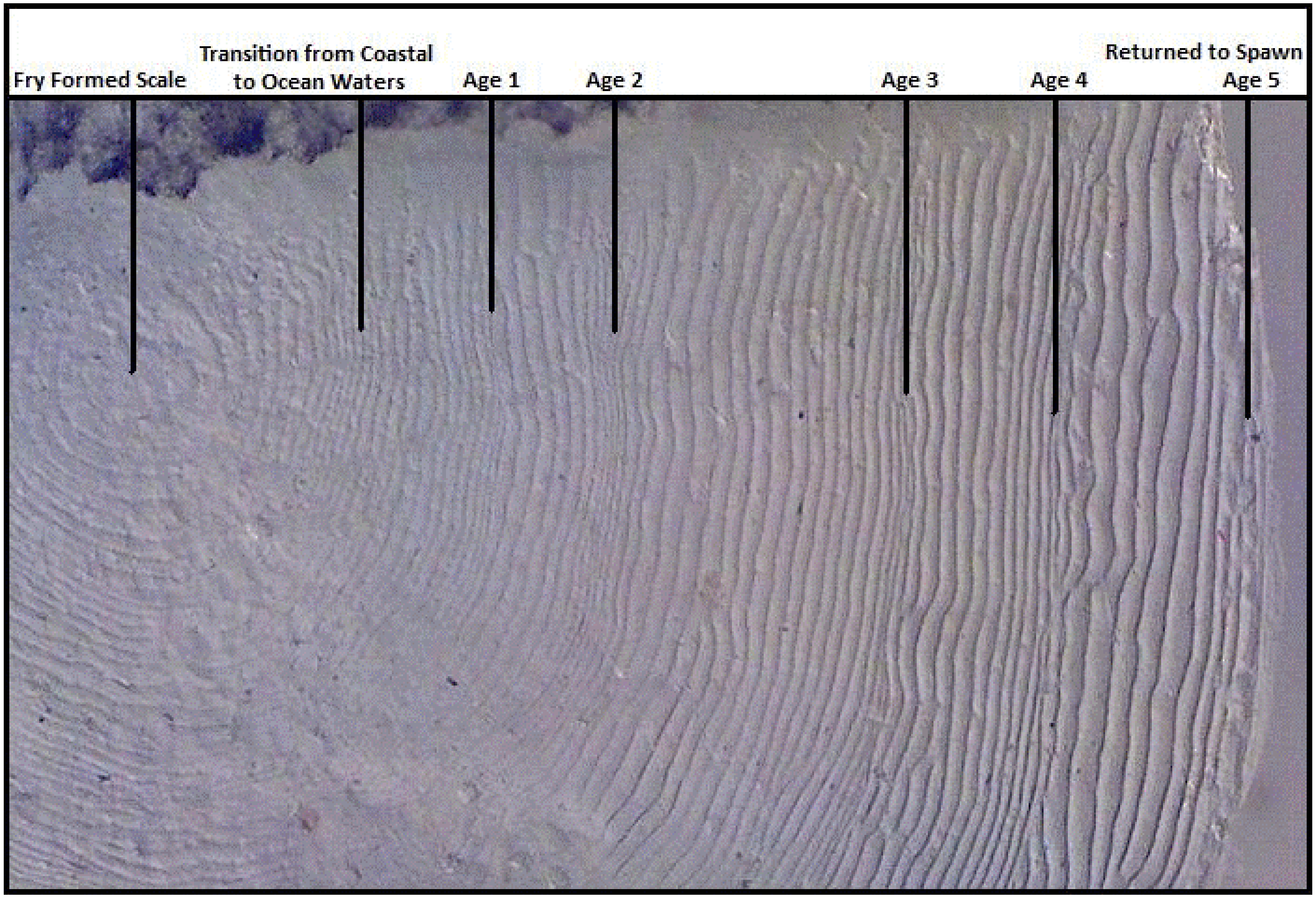

Figure 5. Magnified Chum scale (200x) showing periods of slowed growth during the transition from coastal to ocean waters and winter periods at age 1,2,3,4, and returning to spawn at age 5.

Figure 6. An example of what 500 eggs looks like for differentiating between the pre-spawn mortality classifications of spawned-out (zero to 500 loose eggs) and partially spawned (over 500 loose eggs) female Chum.

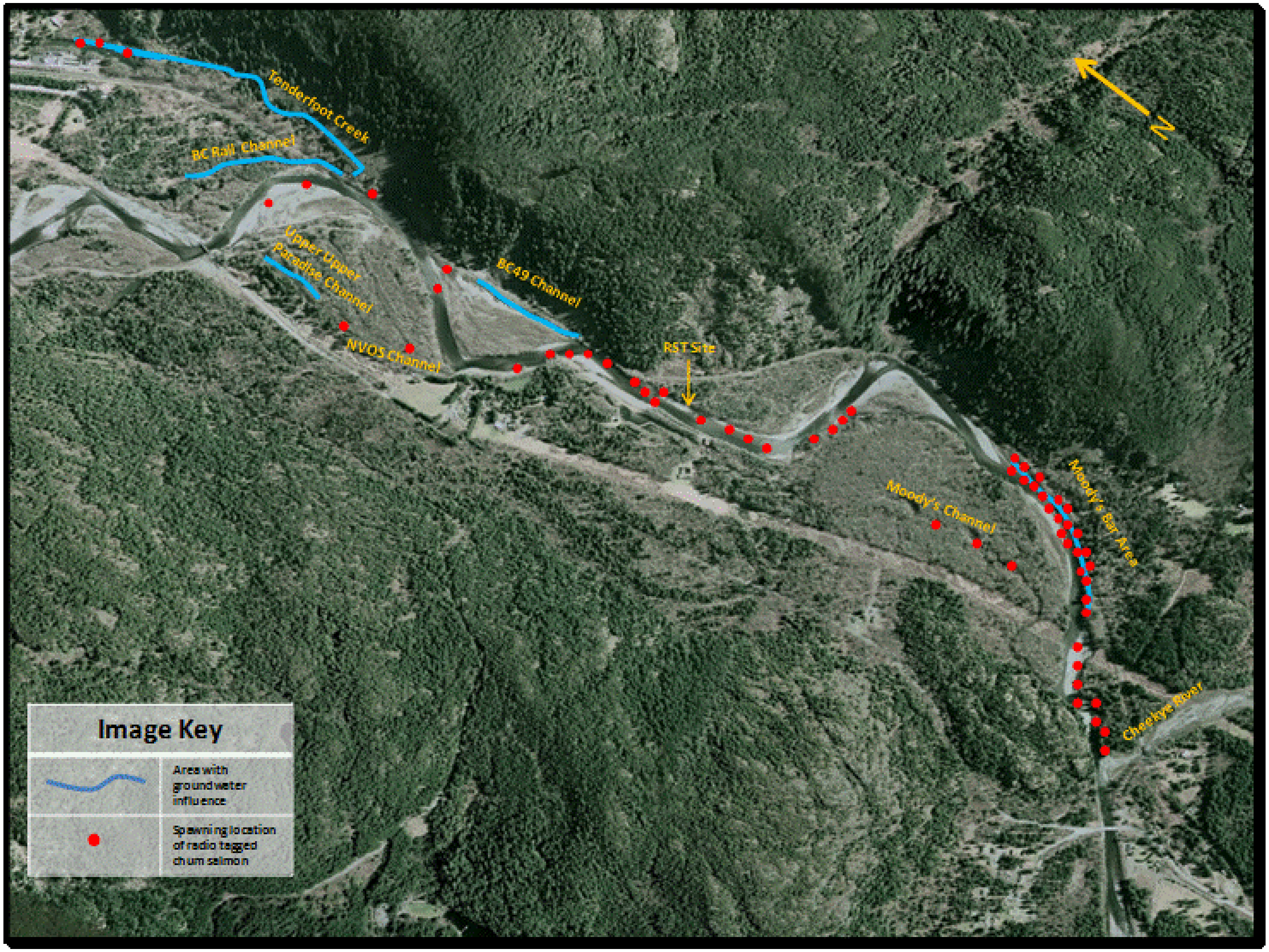

Figure 7. Spawning locations of radio tagged female Chum salmon in 2013 and areas with groundwater influence.

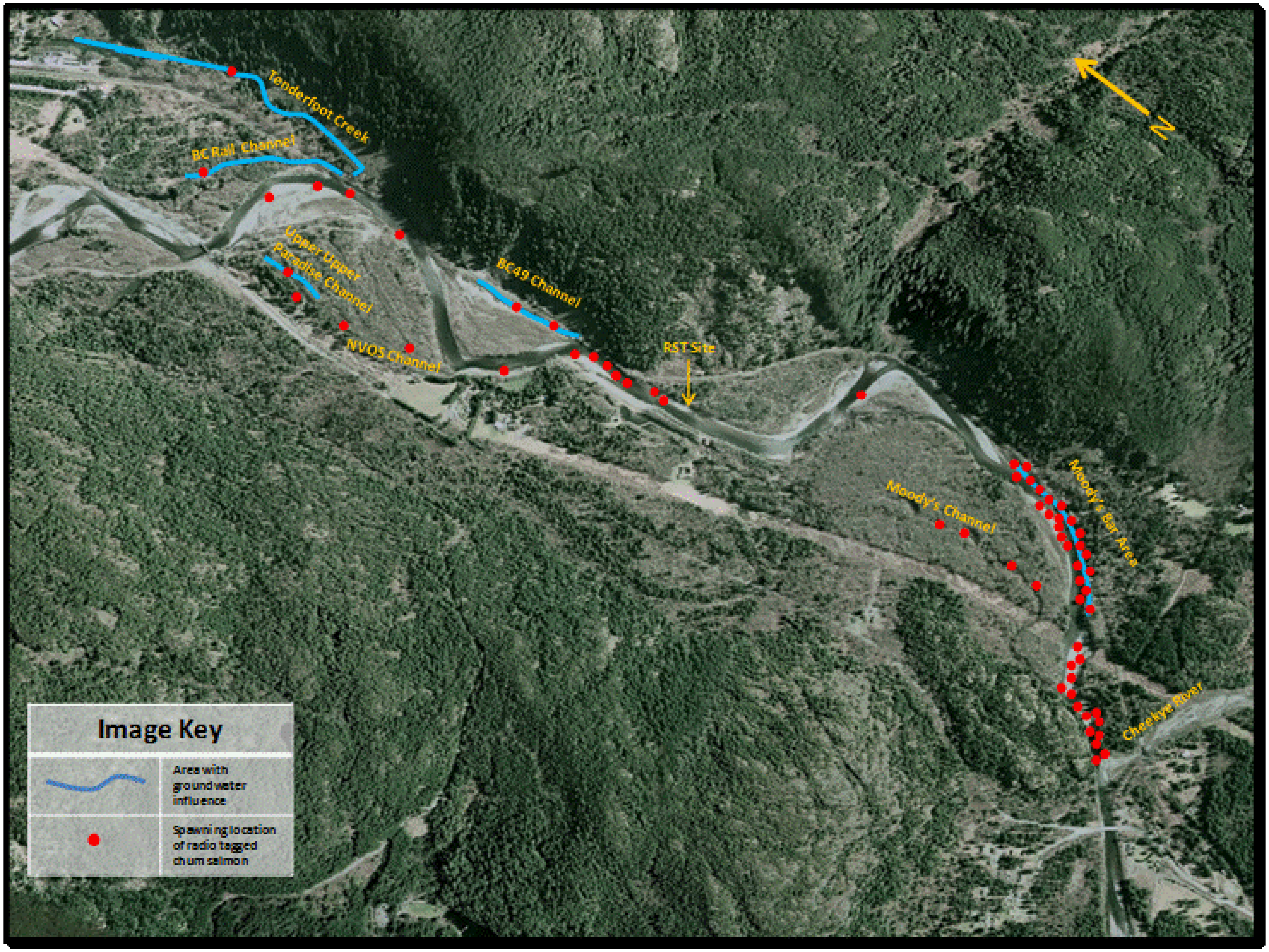

Figure 8. Spawning locations of radio tagged female Chum salmon in 2015 and areas with groundwater influence.

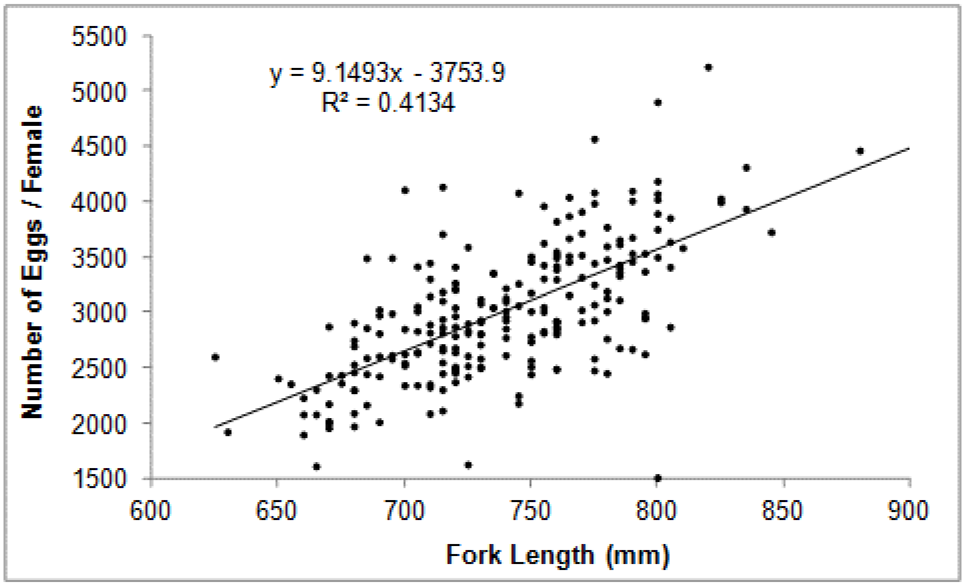

Figure 9. Annual female fecundity vs. fork length (mm) from Tenderfoot Creek, 2015.

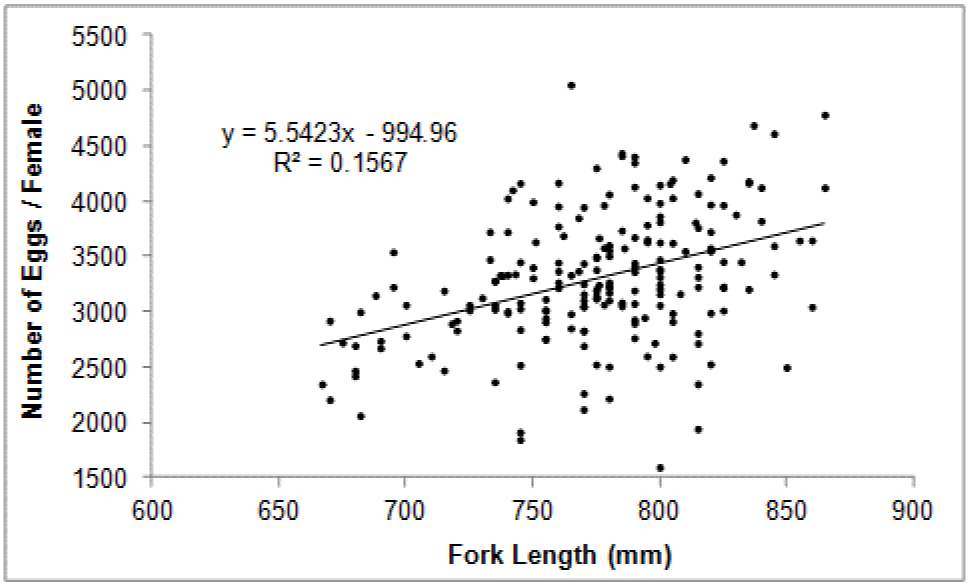

Figure 10. Annual female fecundity vs. fork length (mm) from Tenderfoot Creek, 2014.

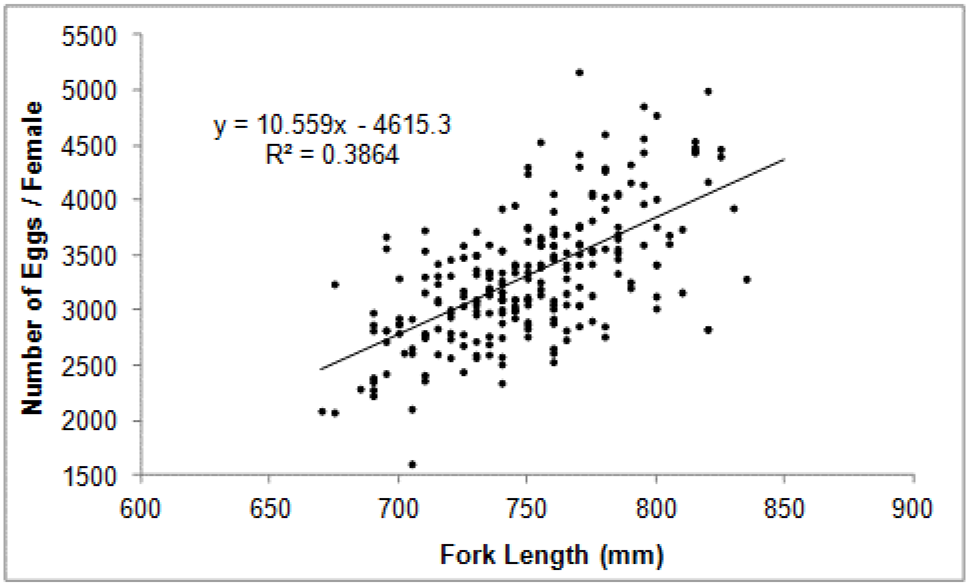

Figure 11. Annual female fecundity vs. fork length (mm) from Tenderfoot Creek, 2013.

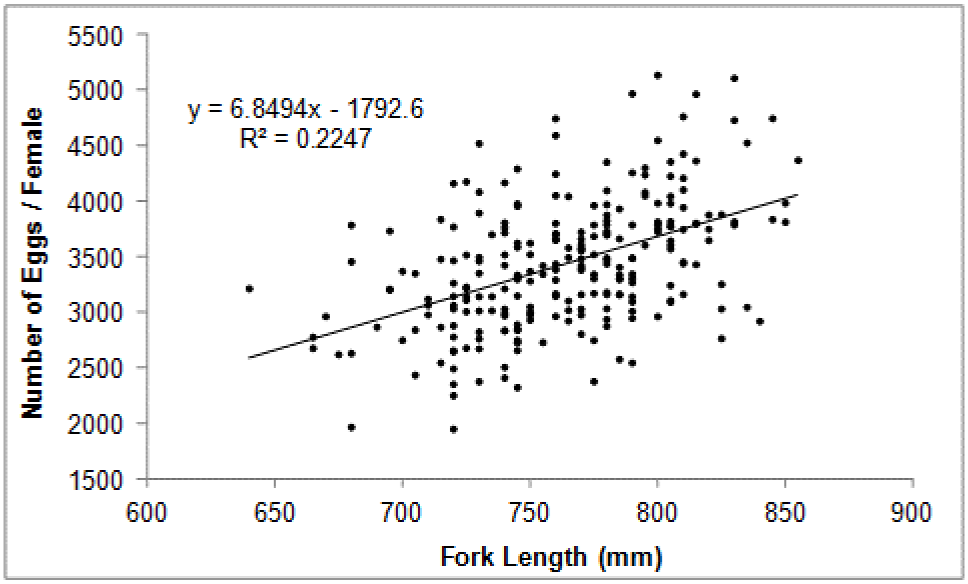

Figure 12. Annual female fecundity vs. fork length (mm from Tenderfoot Creek, 2012.

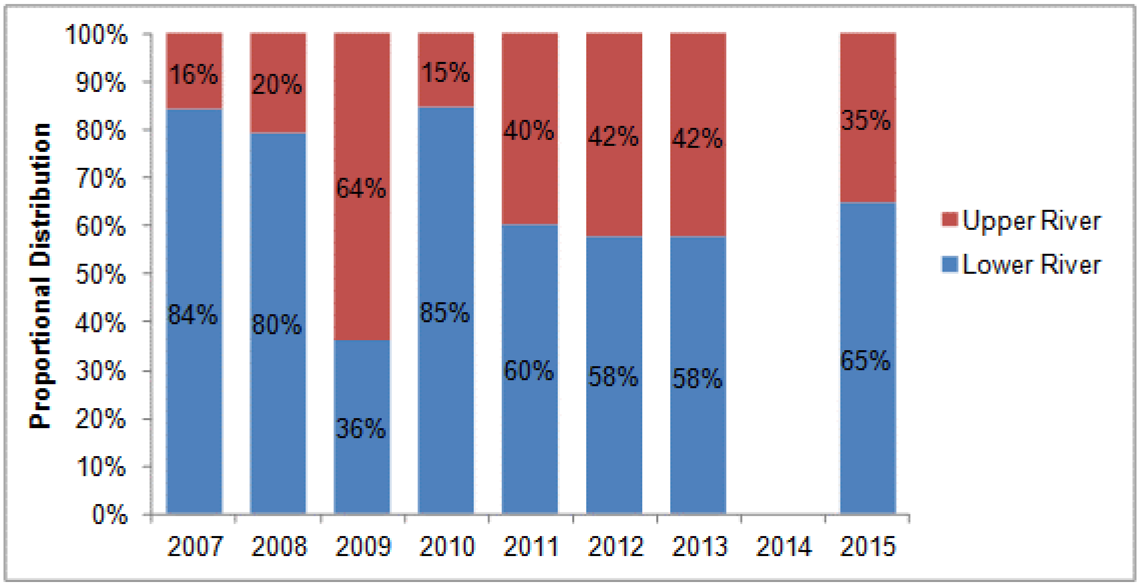

Figure 13. Distribution of Chum spawners in upper and lower river habitat areas from 2007 to 2013 and 2015.

Note: In 2014, only an upper river estimate was derived due to high flow conditions in the Cheakamus disrupting fishing opportunities.

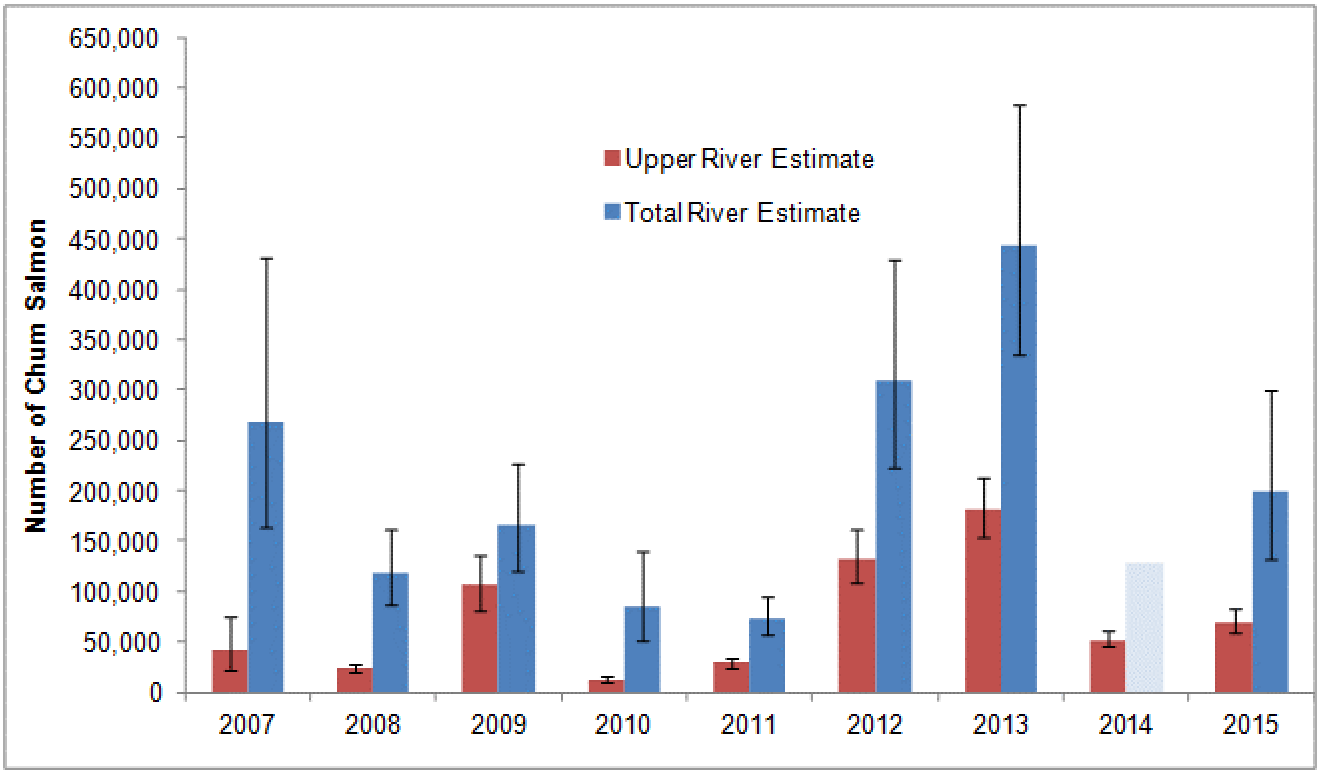

Figure 14. Pooled Petersen Estimates of Chum spawner escapement for the upper portion and whole river of the Cheakamus River with 95% confidence limits from 2007-2015.

Note: In 2014, the total river estimate of Chum escapement was derived from the upper river estimate and the proportional distribution pattern observed from 2011-2013 (41% upper river spawners).

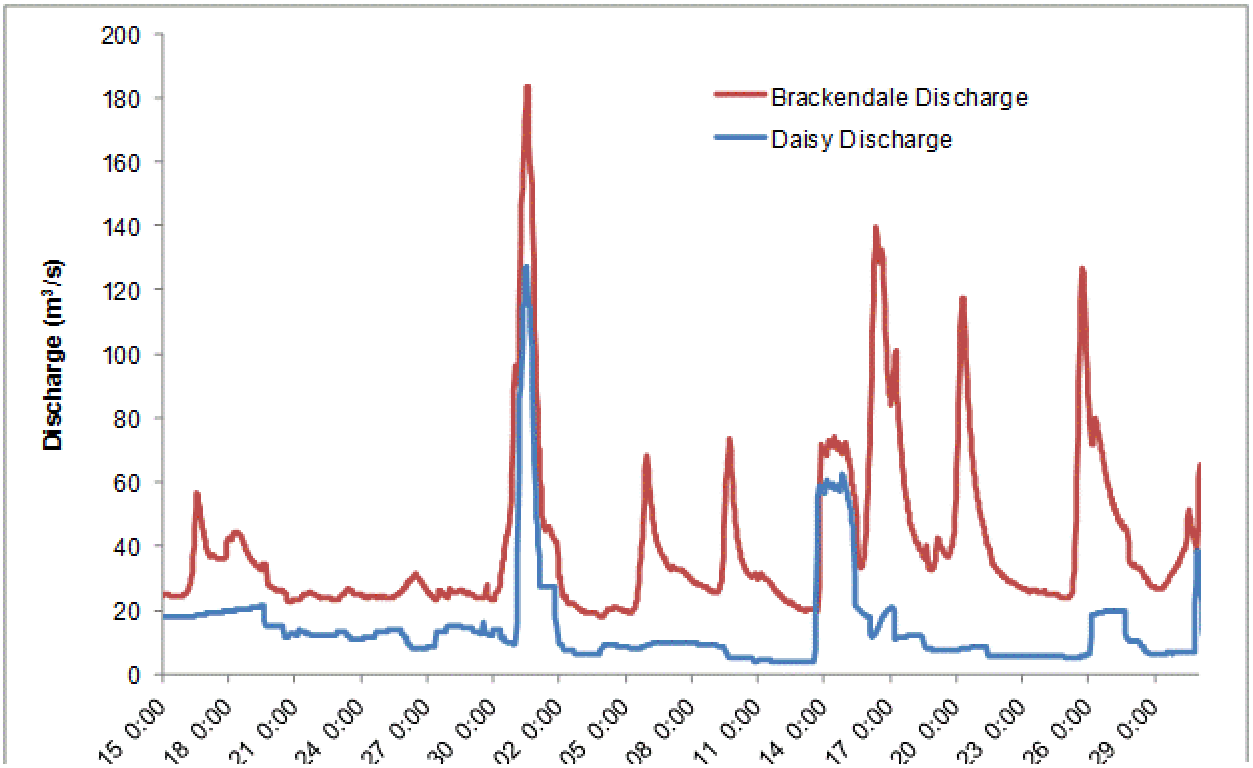

Figure 15. Average hourly discharge at the Brackendale gauge during Chum spawning and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2009.

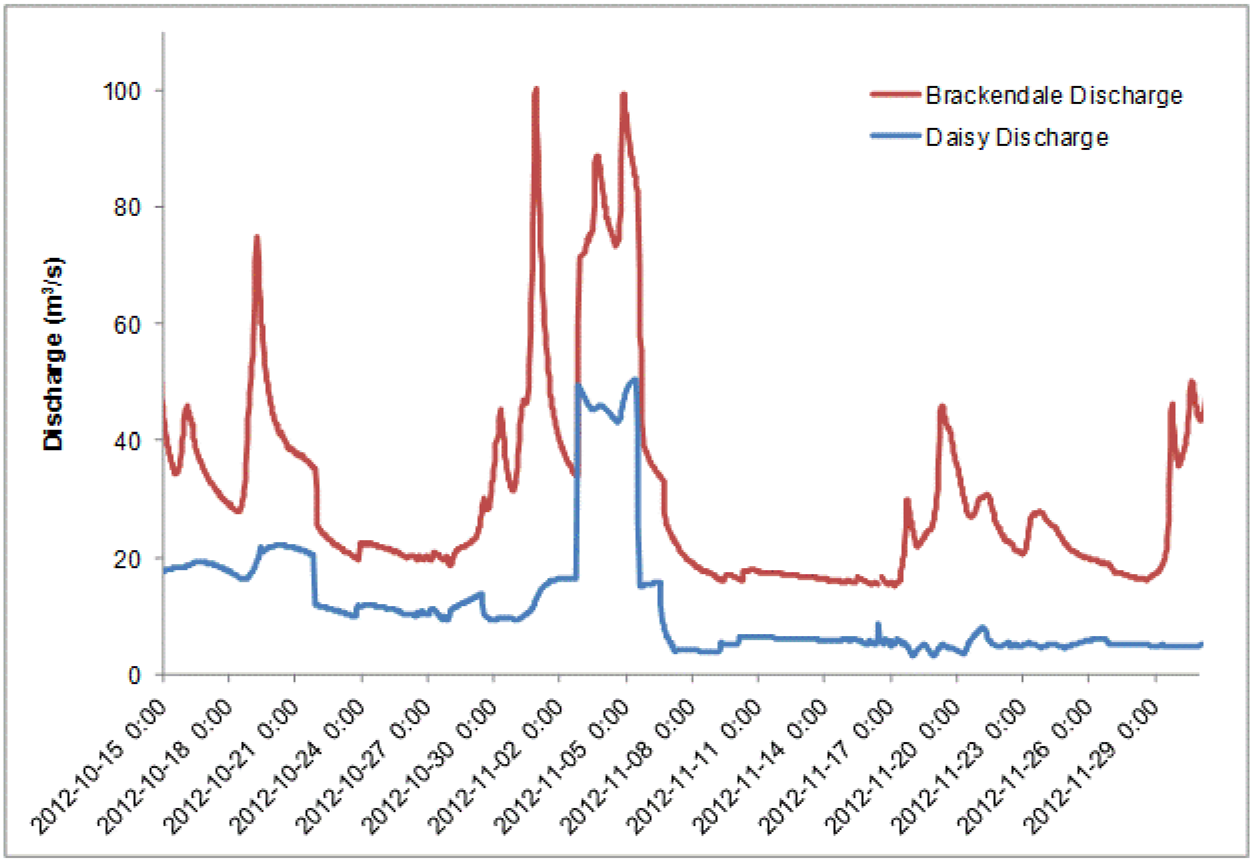

Figure 16. Average hourly discharge during Chum spawning at the Brackendale gauge and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2012.

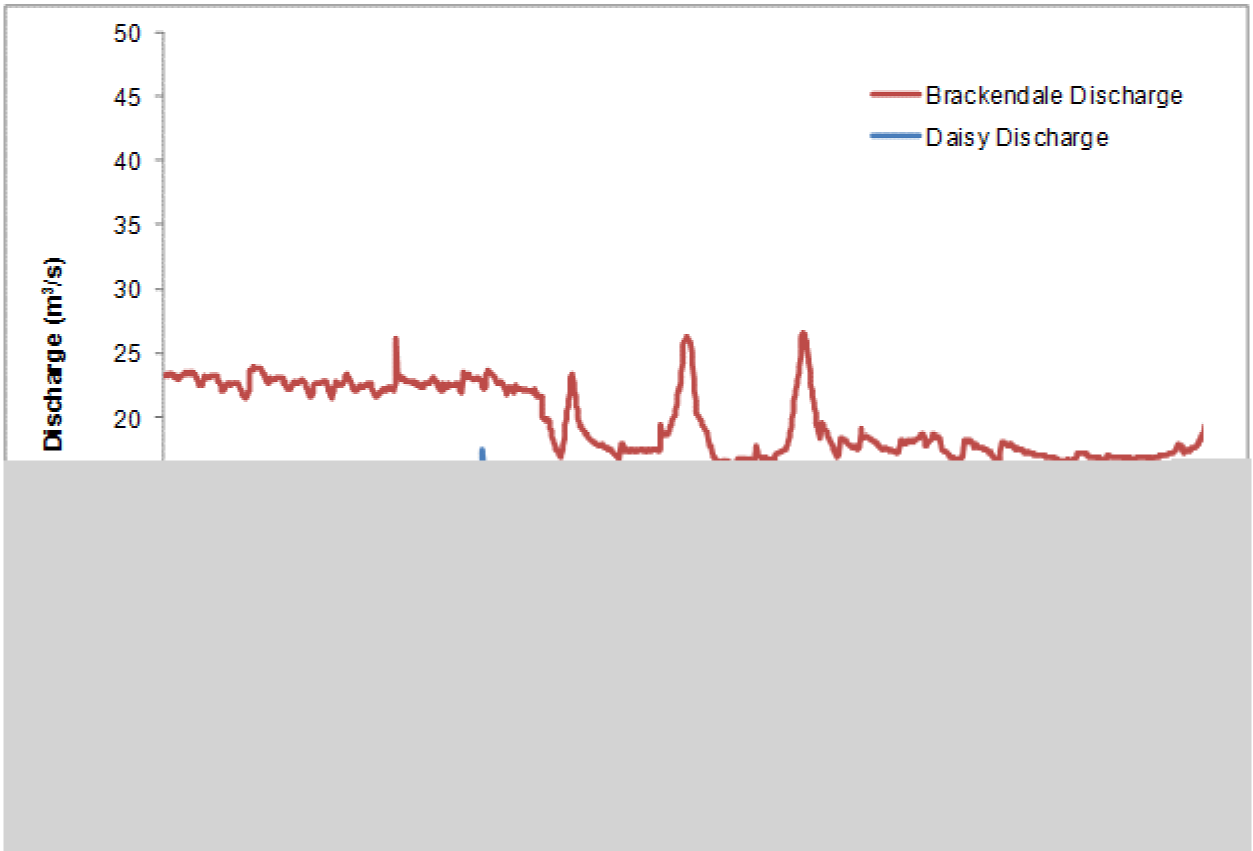

Figure 17 Average hourly discharge during Chum spawning at the Brackendale gauge and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2013.

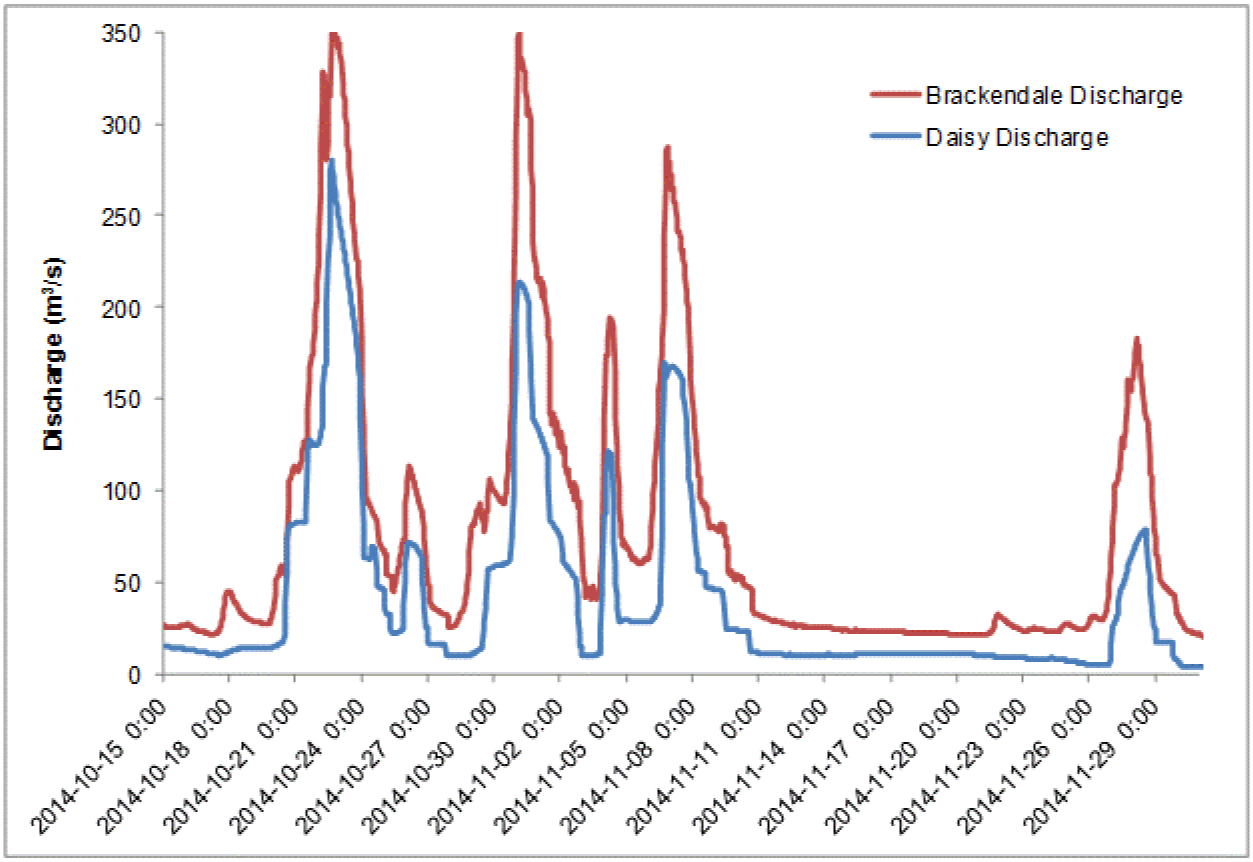

Figure 18. Average hourly discharge during Chum spawning at the Brackendale gauge and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2014.

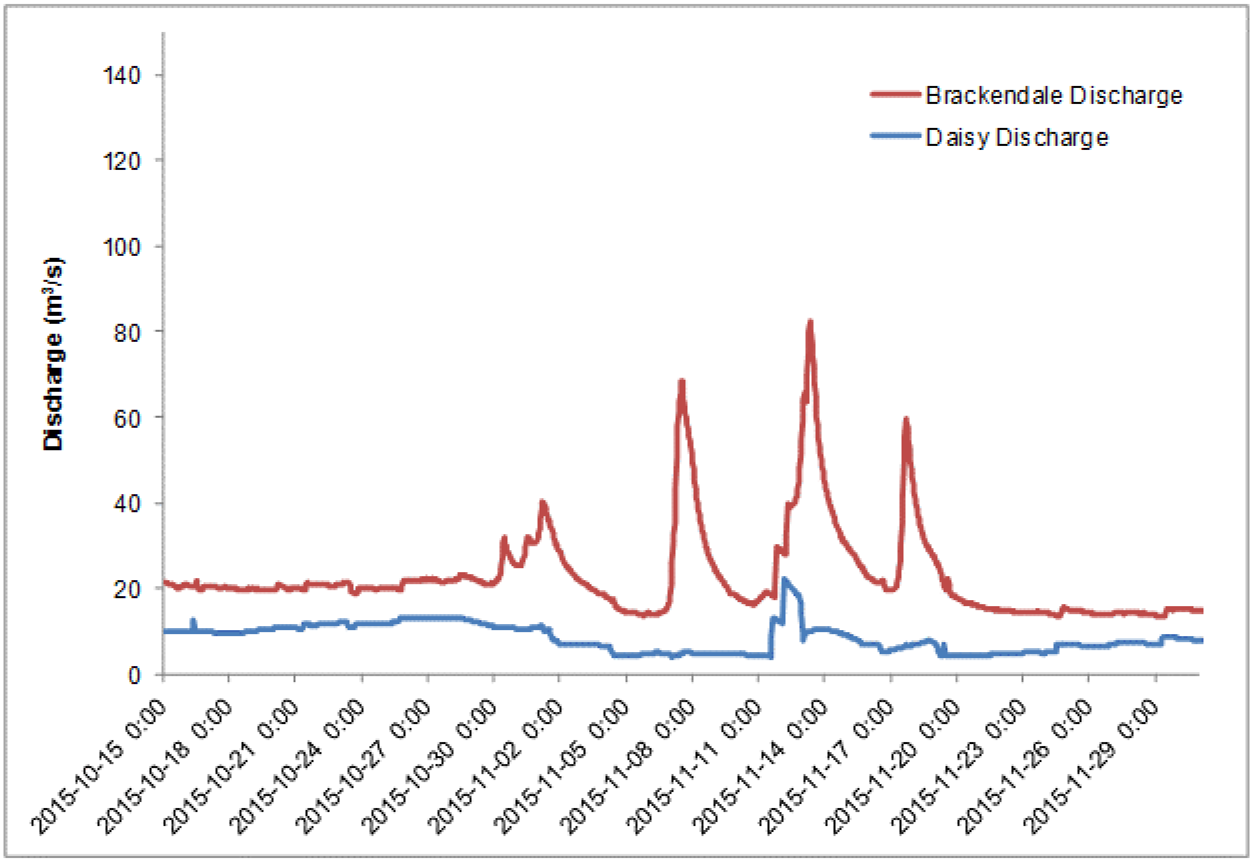

Figure 19. Average hourly discharge during Chum spawning at the Brackendale gauge and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2015.

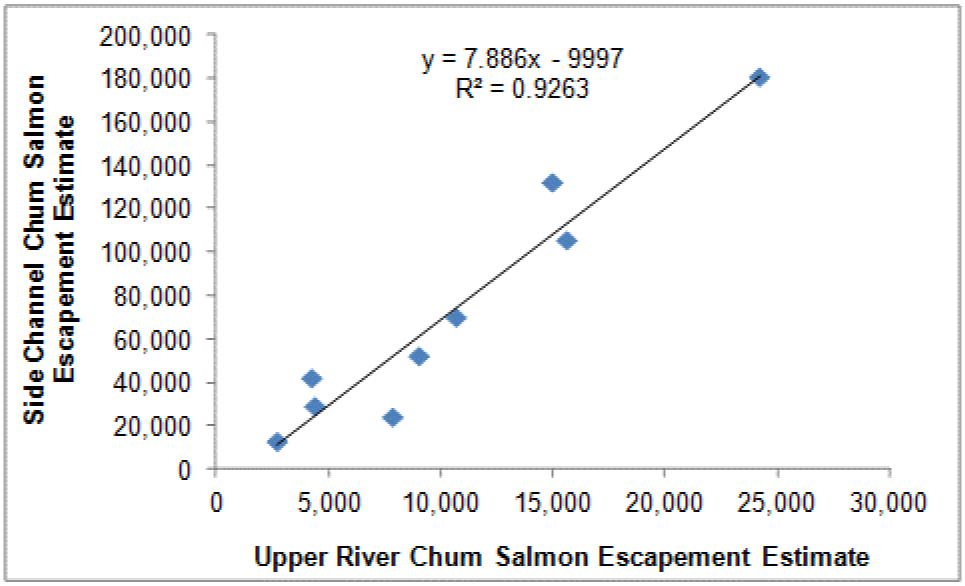

Figure 20. The relationship between the number of side channel Chum salmon spawners and the number of upper river Chum salmon spawners (2007-2015).

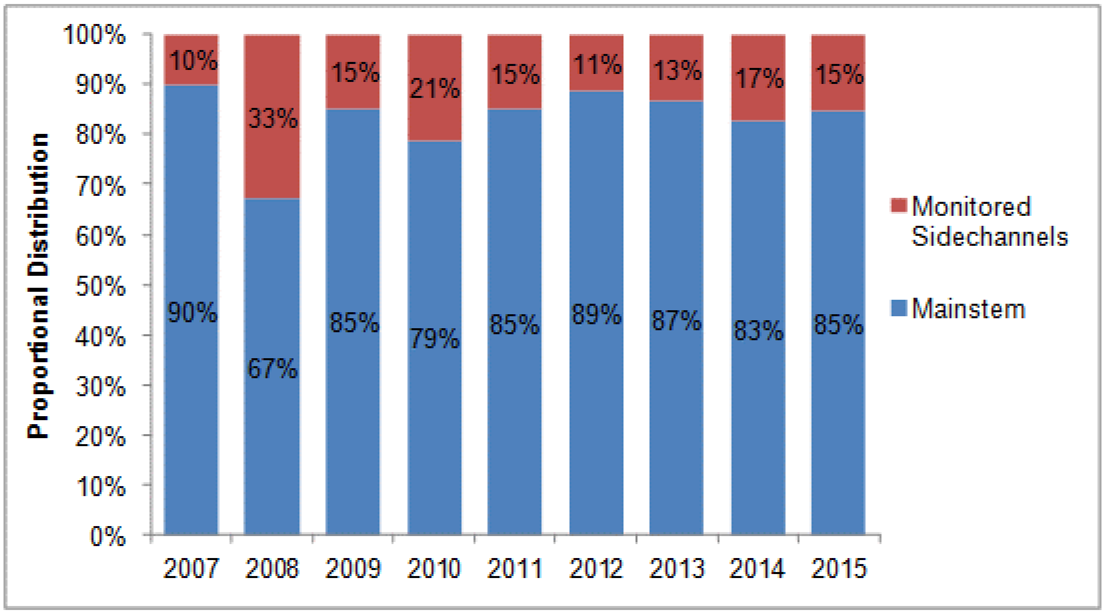

Figure 21. The proportion of upper river Chum spawners utilizing monitored side channel habitats and those utilizing the mainstem and unmonitored side channel habitats (2007 to 2015).

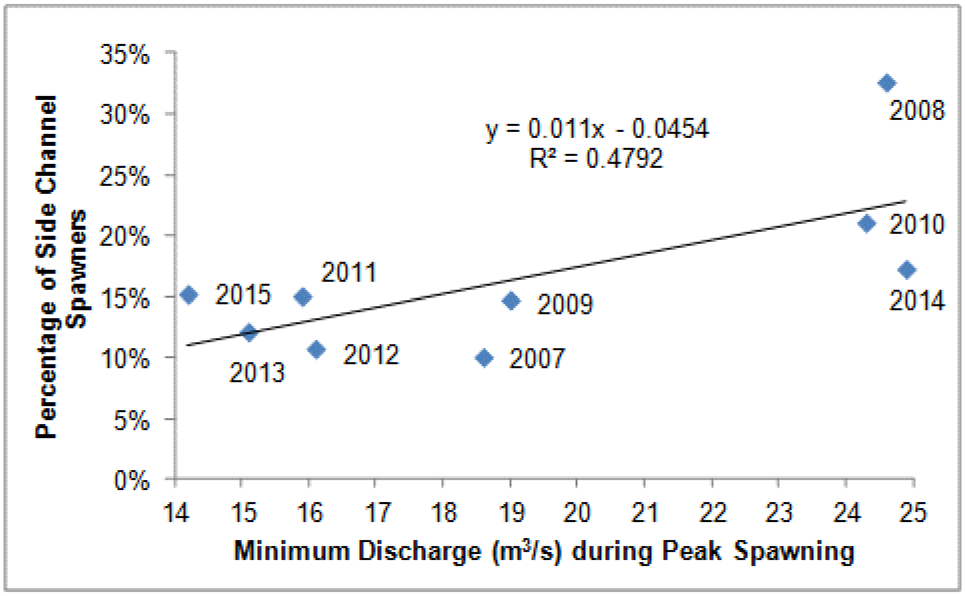

Figure 22. The relationship between the percentage of side channel spawners and the minimum discharge during peak spawning (2007-2015).

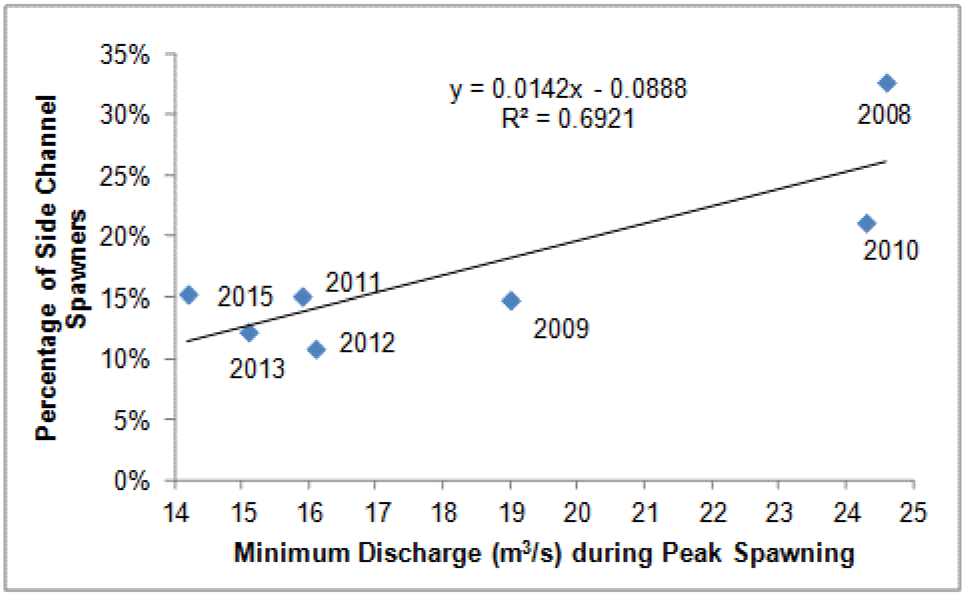

Figure 23. The relationship between the percentage of side channel spawners and the minimum discharge during peak spawning.

Note: Data from 2008-2013 and 2015 (excluding 2007 and 2014 data)

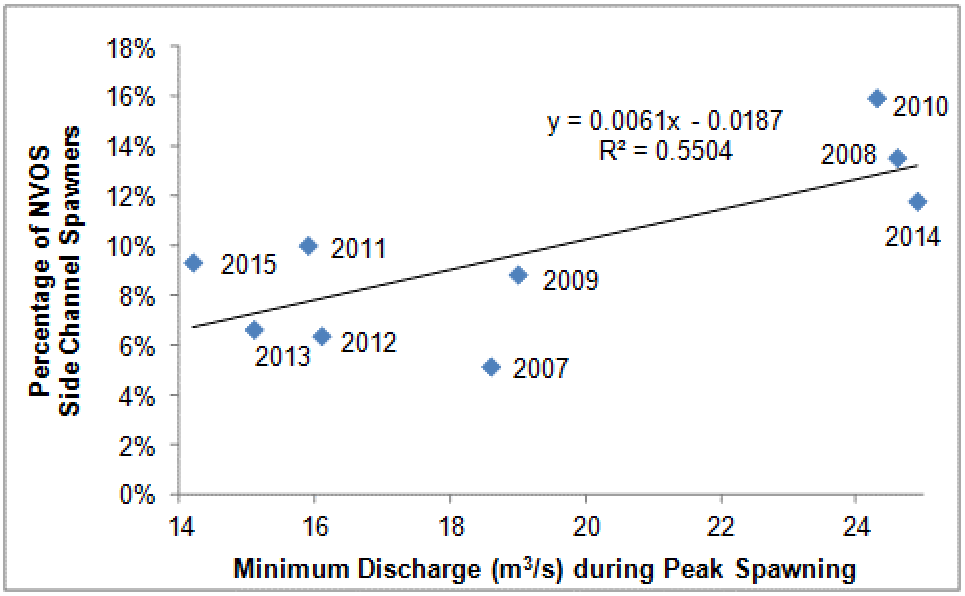

Figure 24. The relationship between the percentage of NVOS side channel spawners and the minimum discharge during peak spawning (2007-2015).

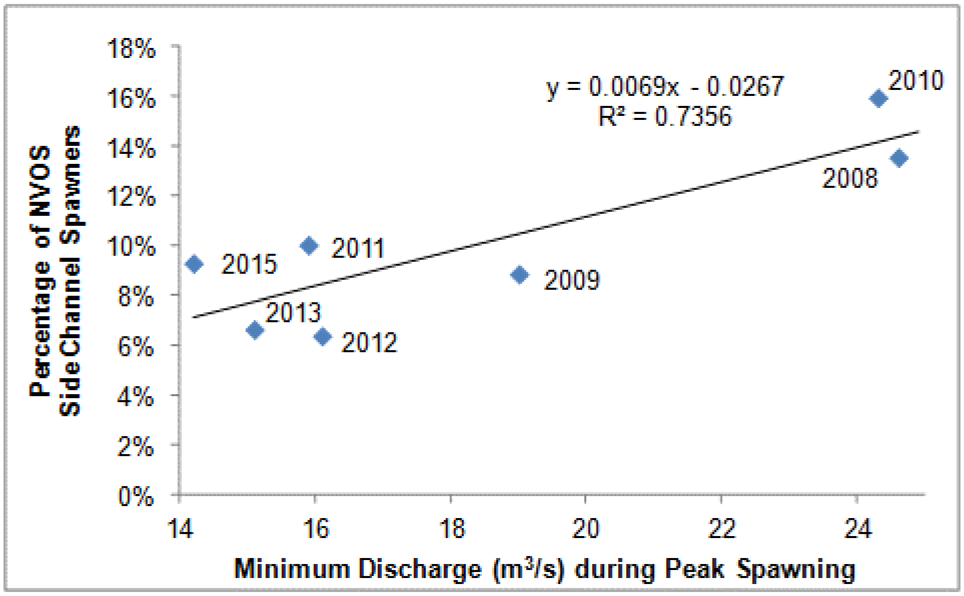

Figure 25. The relationship between the percentage of BC Rail side channel spawners and the minimum discharge during peak spawning.

Note: Data from 2008-2013 and 2015 (excluding 2007 and 2014 data)

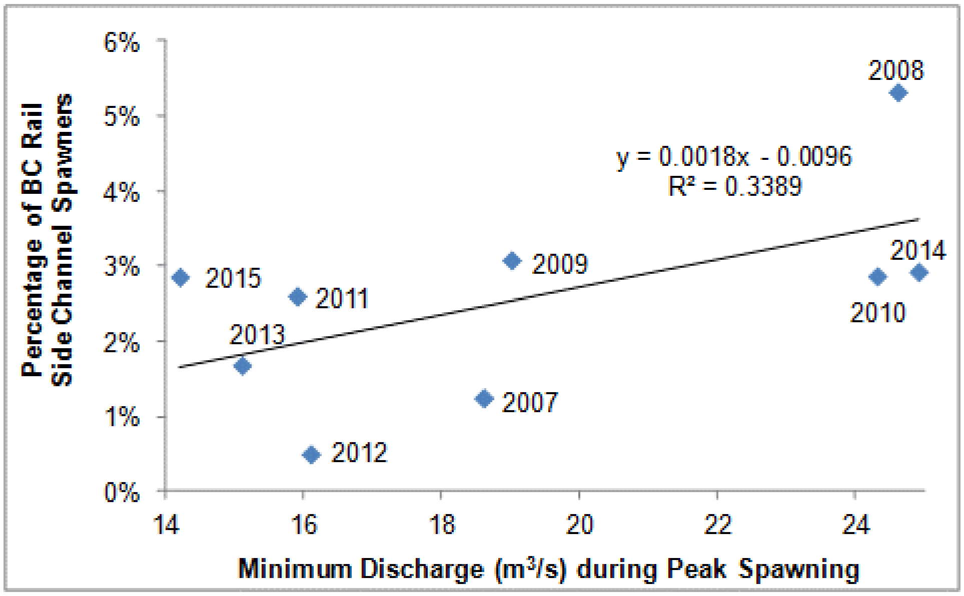

Figure 26. The relationship between the percentage of BC Rail side channel spawners and the minimum discharge during peak spawning (2007-2015).

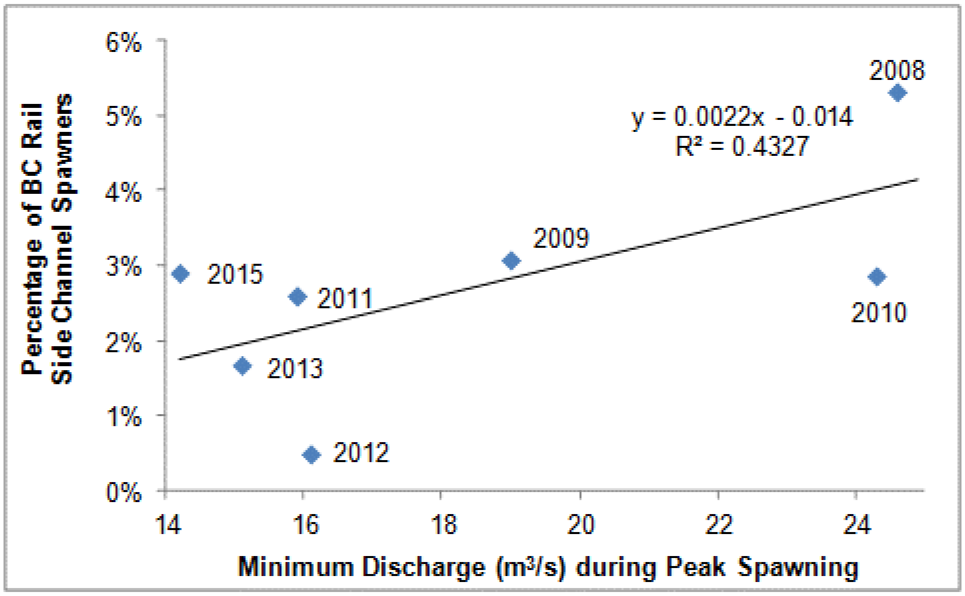

Figure 27. The relationship between the percentage of BC Rail side channel spawners and the minimum discharge during peak spawning.

Note: Data from 2008-2013 and 2015 (excluding 2007 and 2014 data)

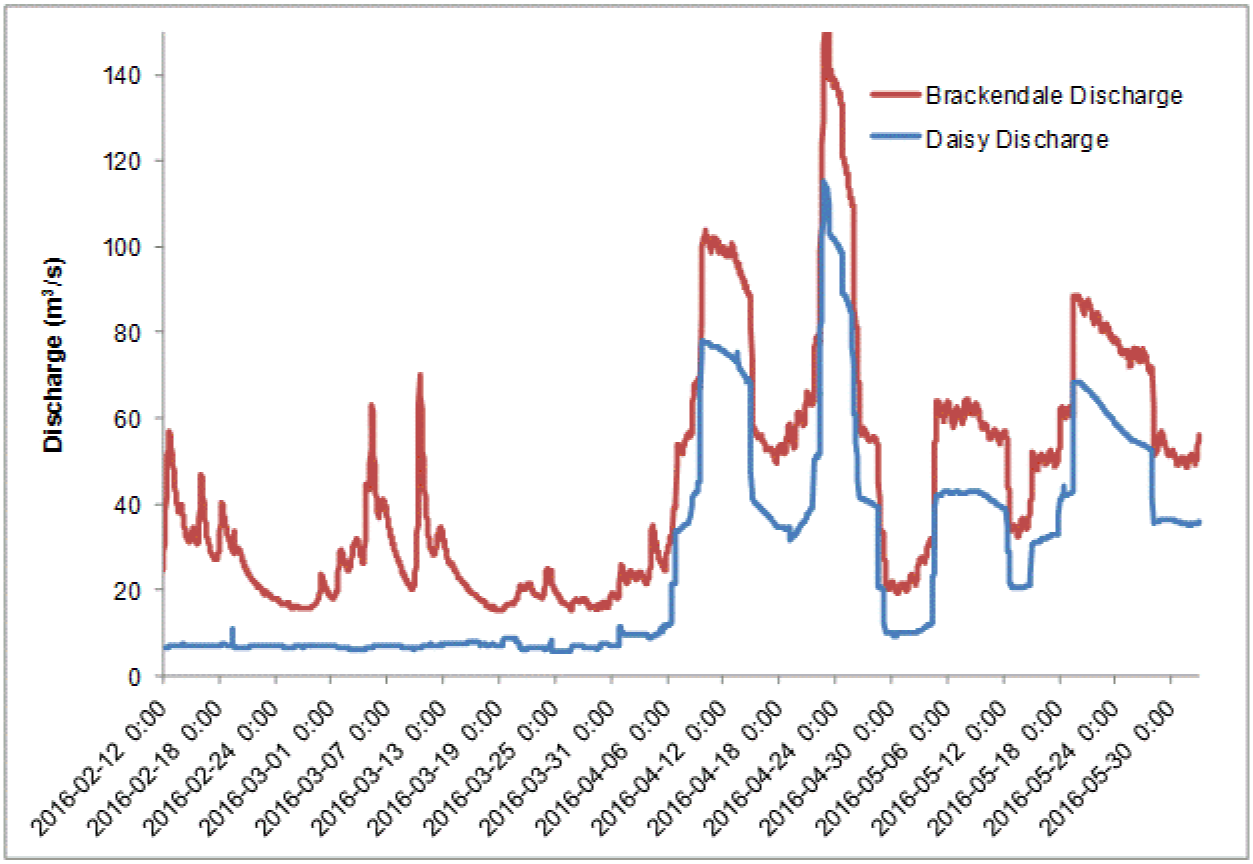

Figure 28. Average hourly discharge during juvenile salmonid outmigration at the Brackendale gauge and average hourly flow releases from the Daisy Lake Dam in the Cheakamus River in 2016.

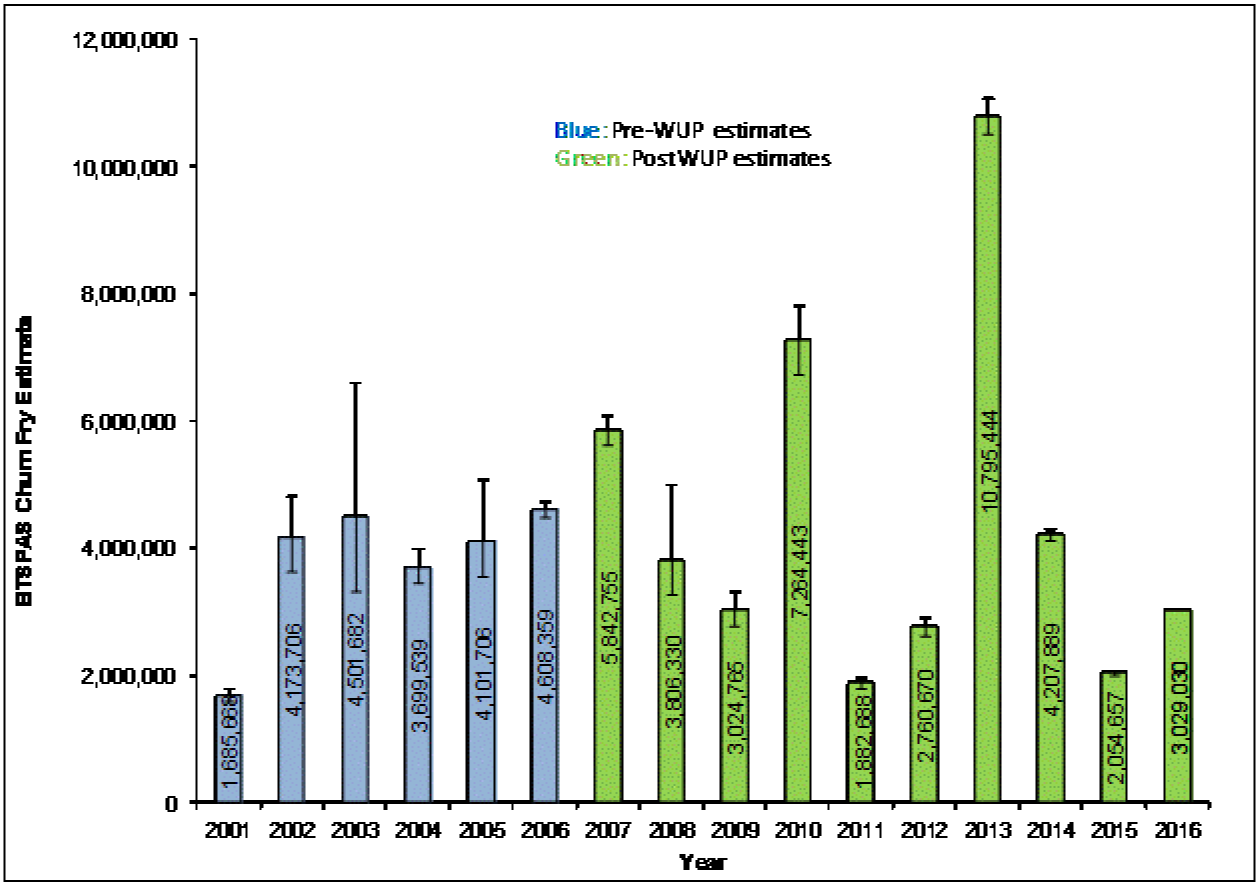

Figure 29. Bayesian Time-Stratified Population Analysis System (BTSPAS) Estimate of Chum fry outmigrating from upstream of the Rotary Screw Traps on the Cheakamus River from 2001-2015 including 95% confidence limits and the 2016 estimate.

Note: The 2016 estimate was derived using the BTSPAS estimate from mark-recapture conducted from February 12th – April 12th and then adding 23.4% to account for the proportion the run missed due to operational flow increases.

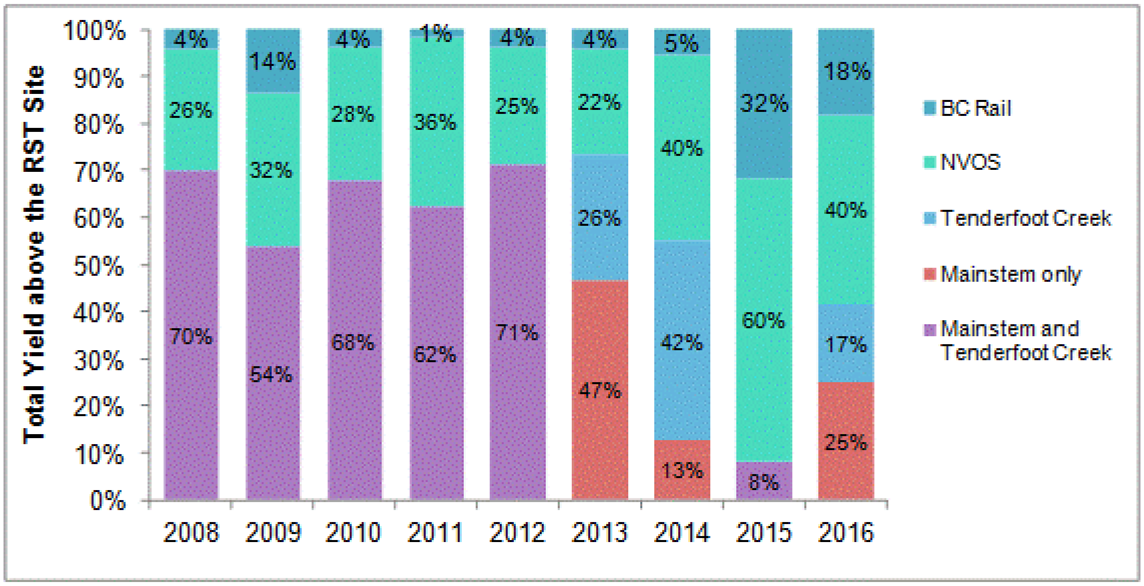

Figure 30. Yield of Chum fry from the mainstem habitat, NVOS and BC Rail side channels, and Tenderfoot Creek in the Cheakamus River 2008-2016.

Note: Tenderfoot Creek data separated from the mainstem in 2013, 2014 and 2016

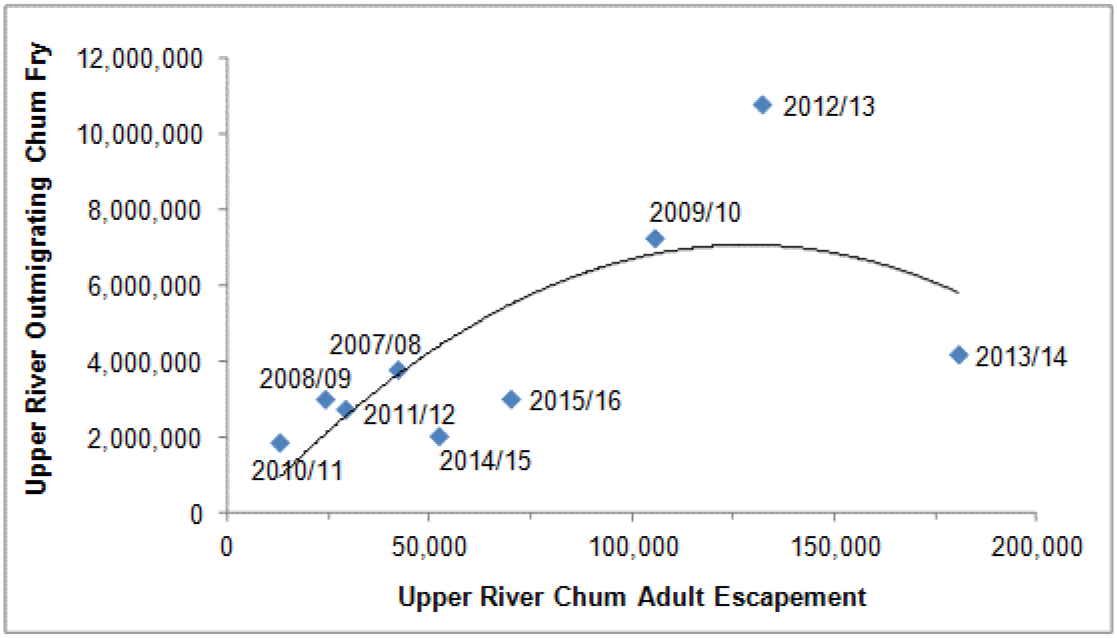

Figure 31. The spawner-recruit curve for the upper river from brood years (2007 to 2015) and outmigration years (2008 to 2016).

Note: Years indicating brood year/fry outmigration year

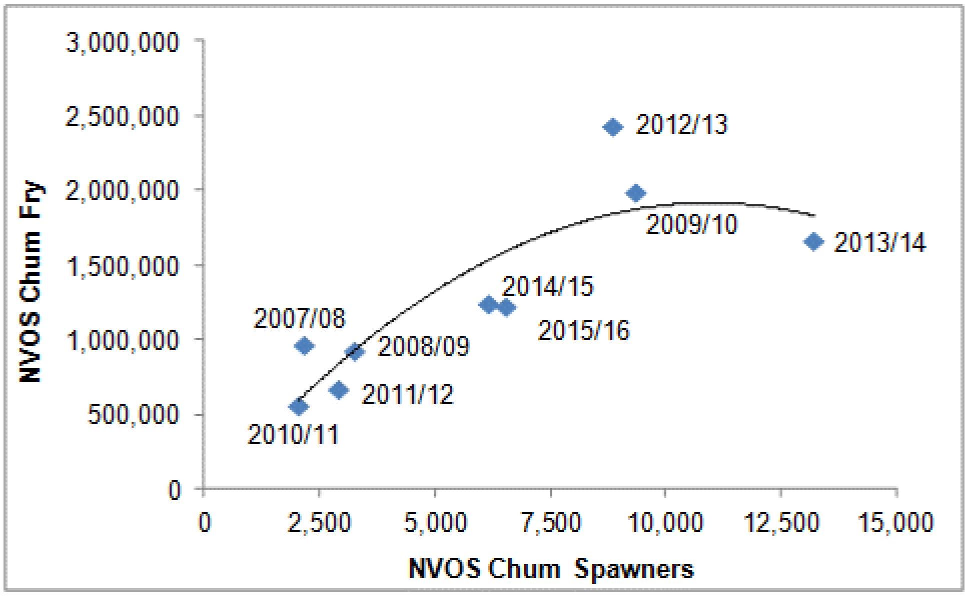

Figure 32. The spawner-recruit curve for the NVOS side channel from brood years (2007 to 2015) and outmigration years (2008 to 2016).

Note: Years indicating brood year/fry outmigration year

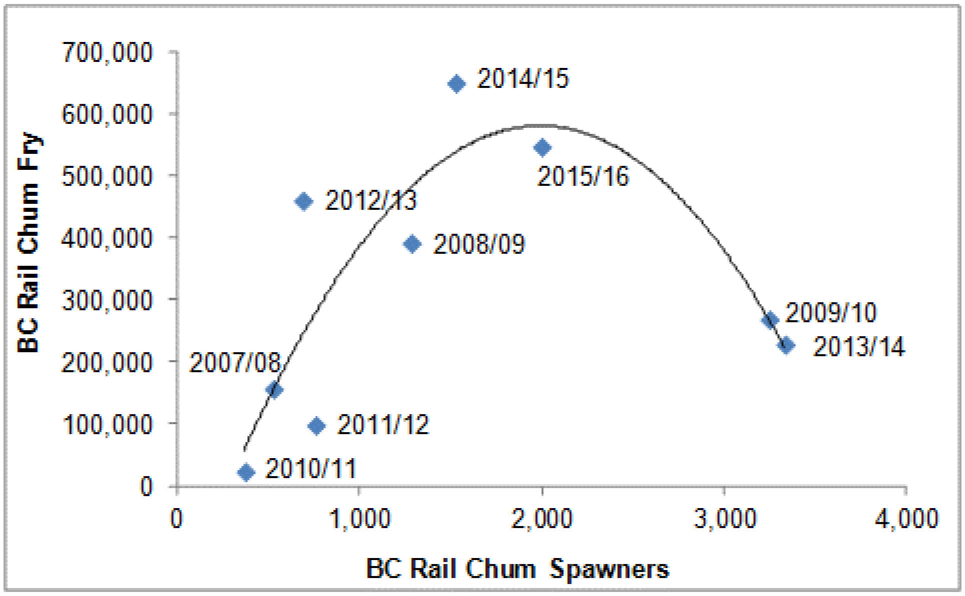

Figure 33. The spawner-recruit curve for the BC rail side channel from brood years (2007 to 2015) and outmigration years (2008 to 2016).

Note: Years indicating brood year/fry outmigration year

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APPENDIX A. Supplemental Data

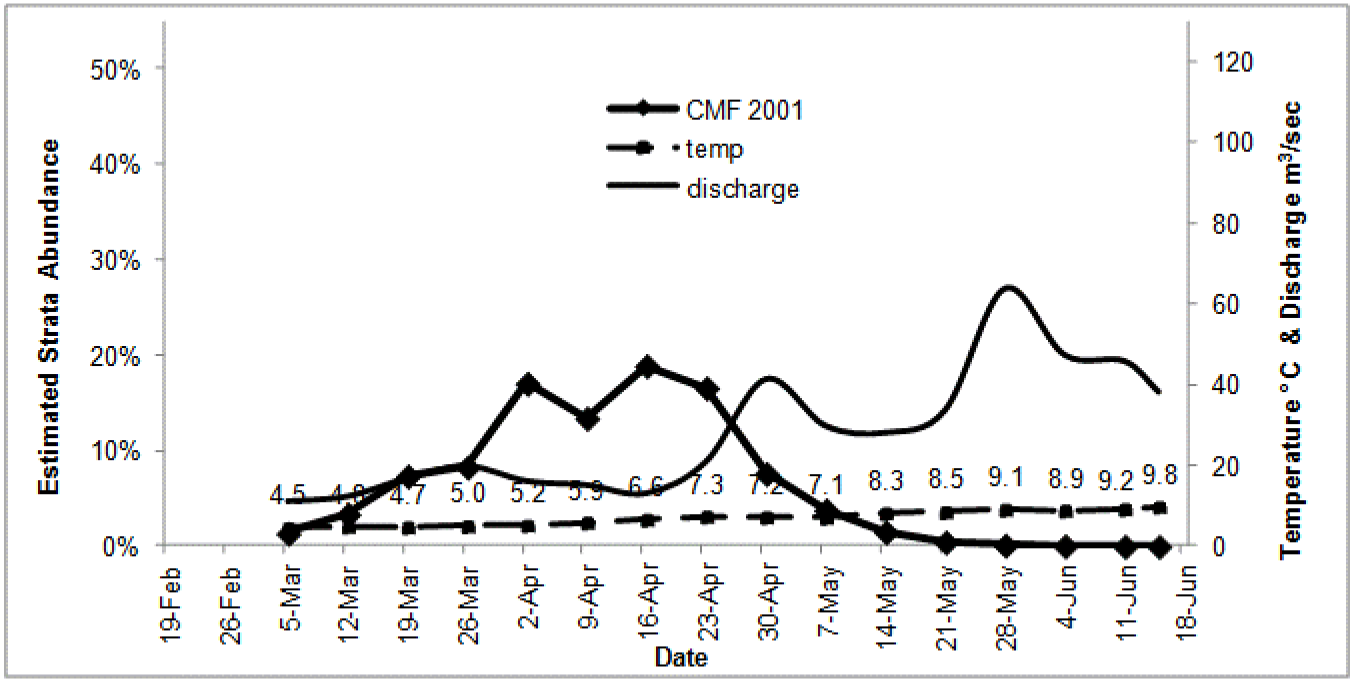

Figure 1A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2001 (Pre-WUP).

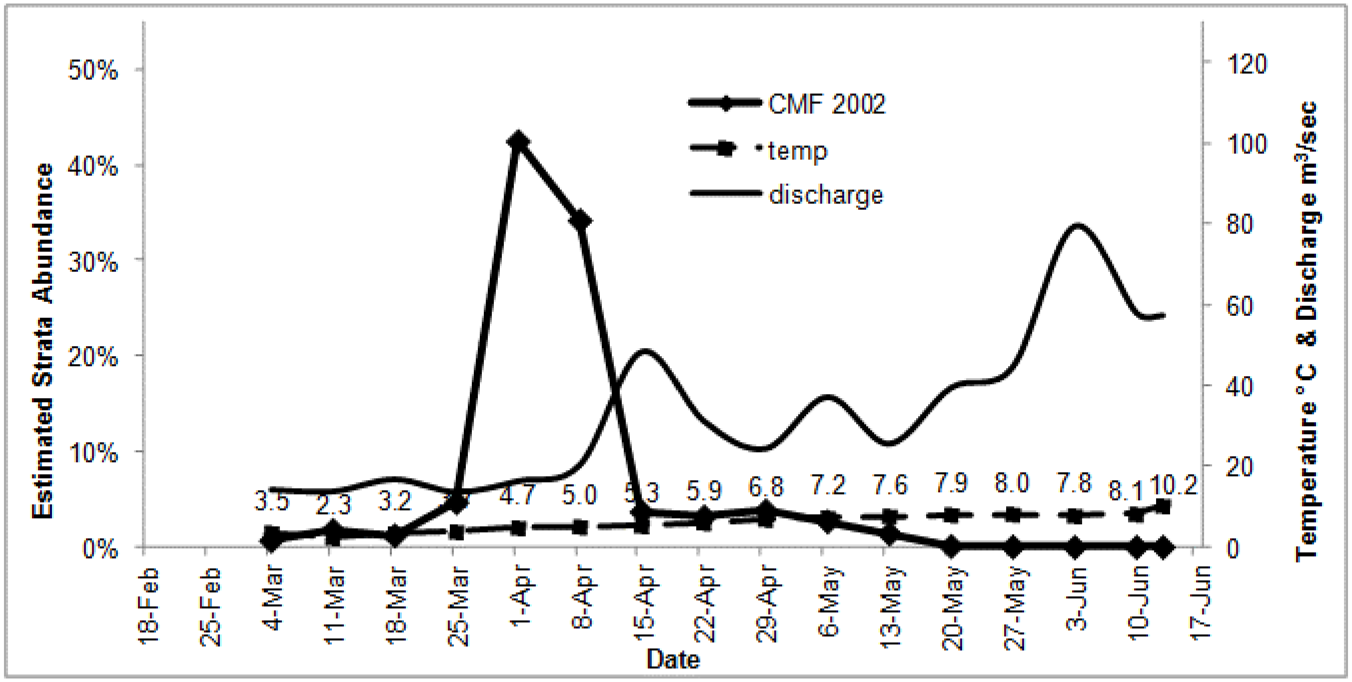

Figure 2A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2002 (Pre-WUP).

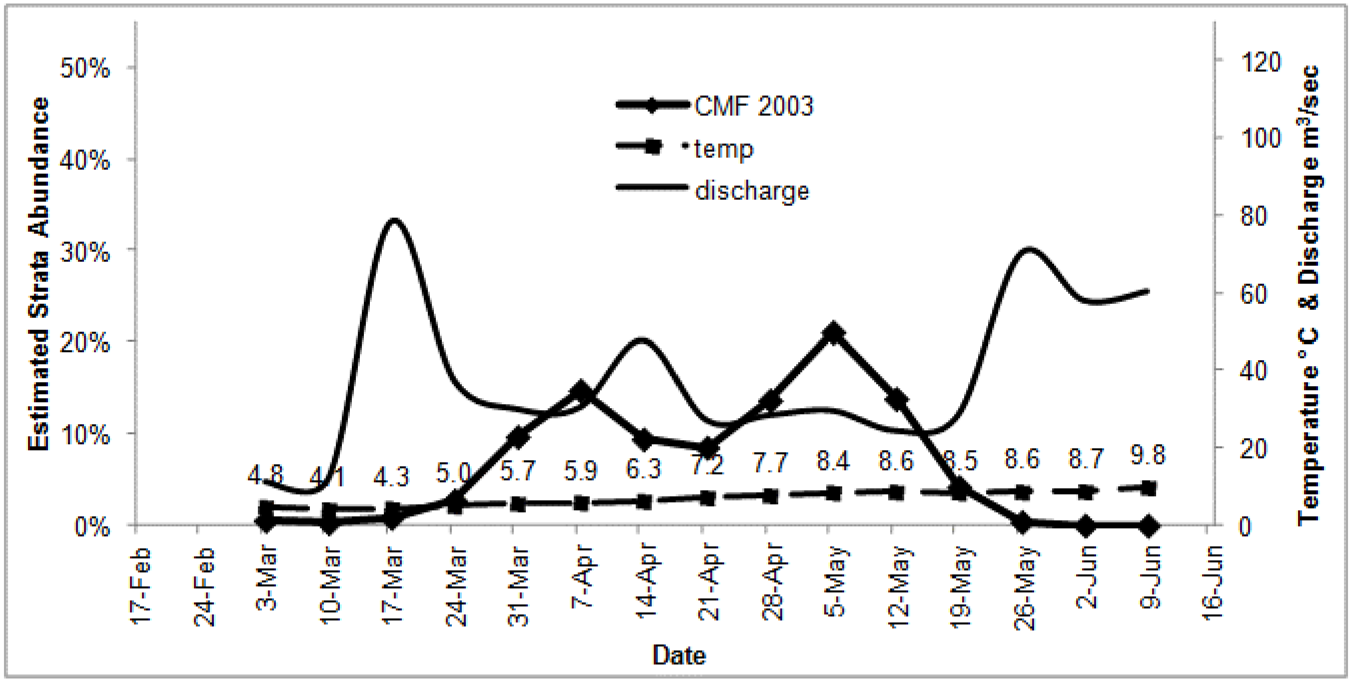

Figure 3A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2003 (Pre-WUP).

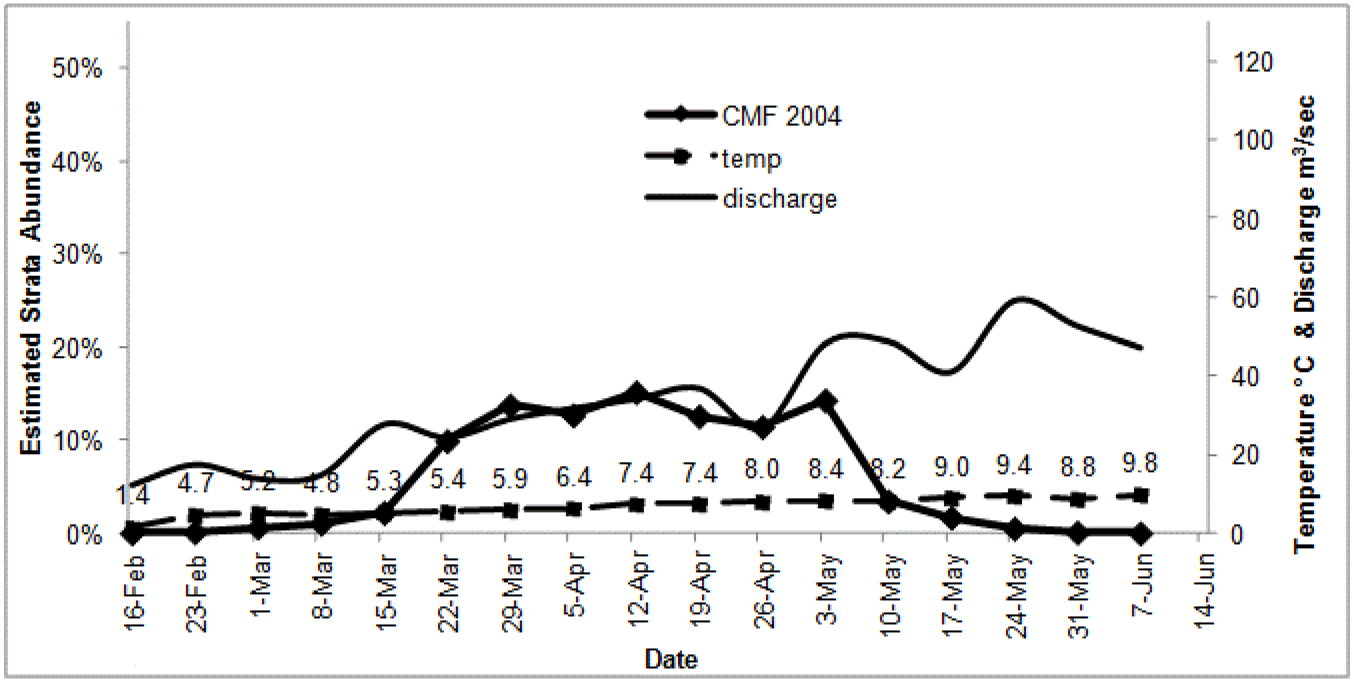

Figure 4A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2004 (Pre-WUP).

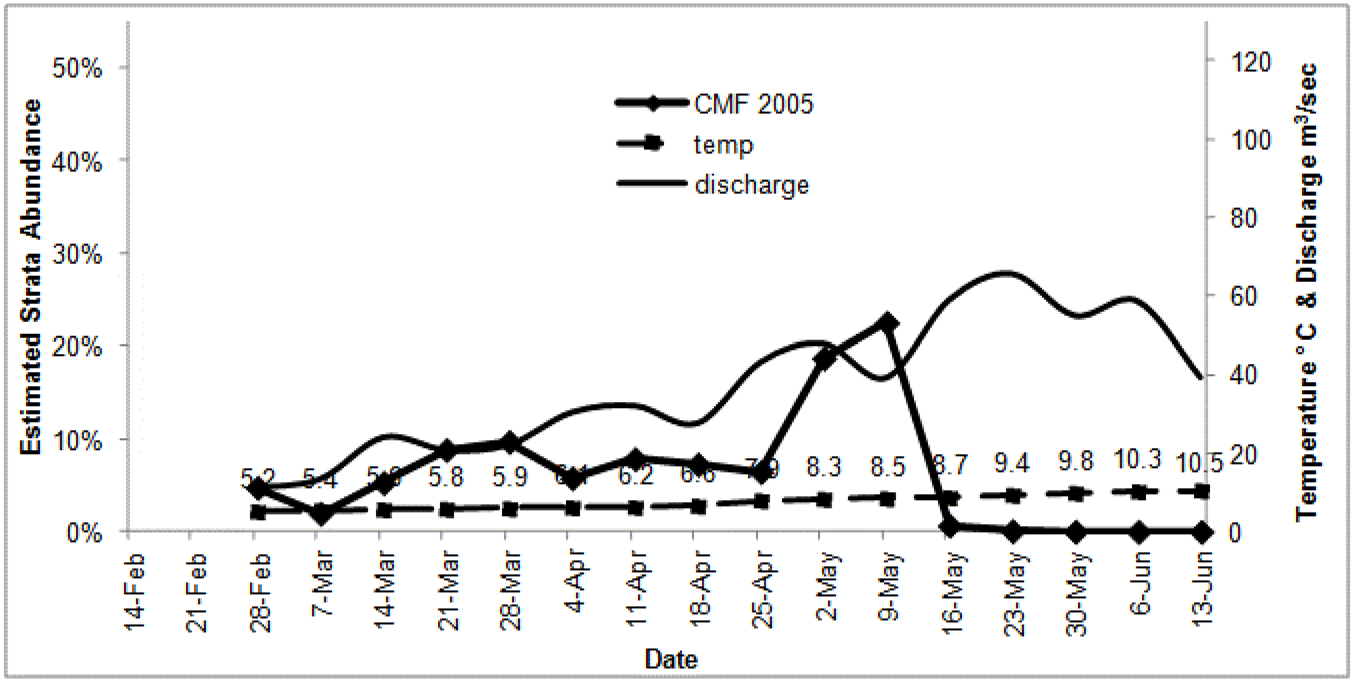

Figure 5A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2005 (Pre-WUP).

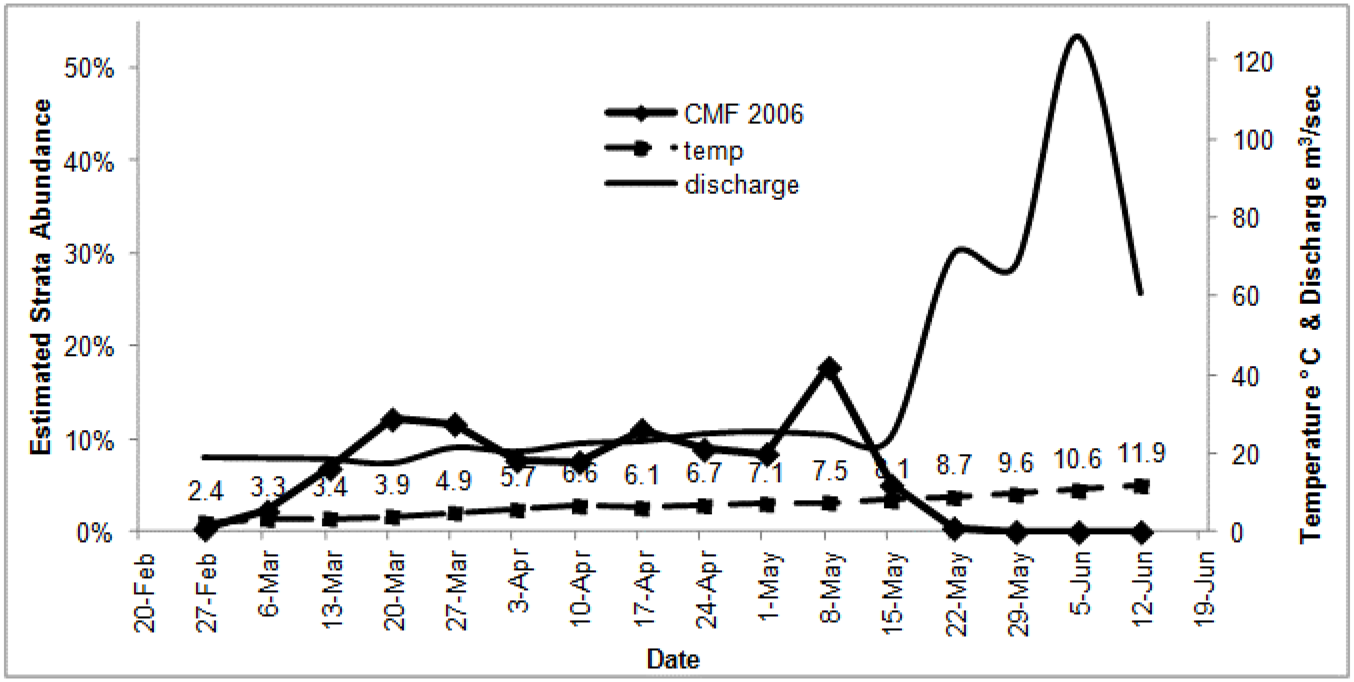

Figure 6A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2006 (WUP).

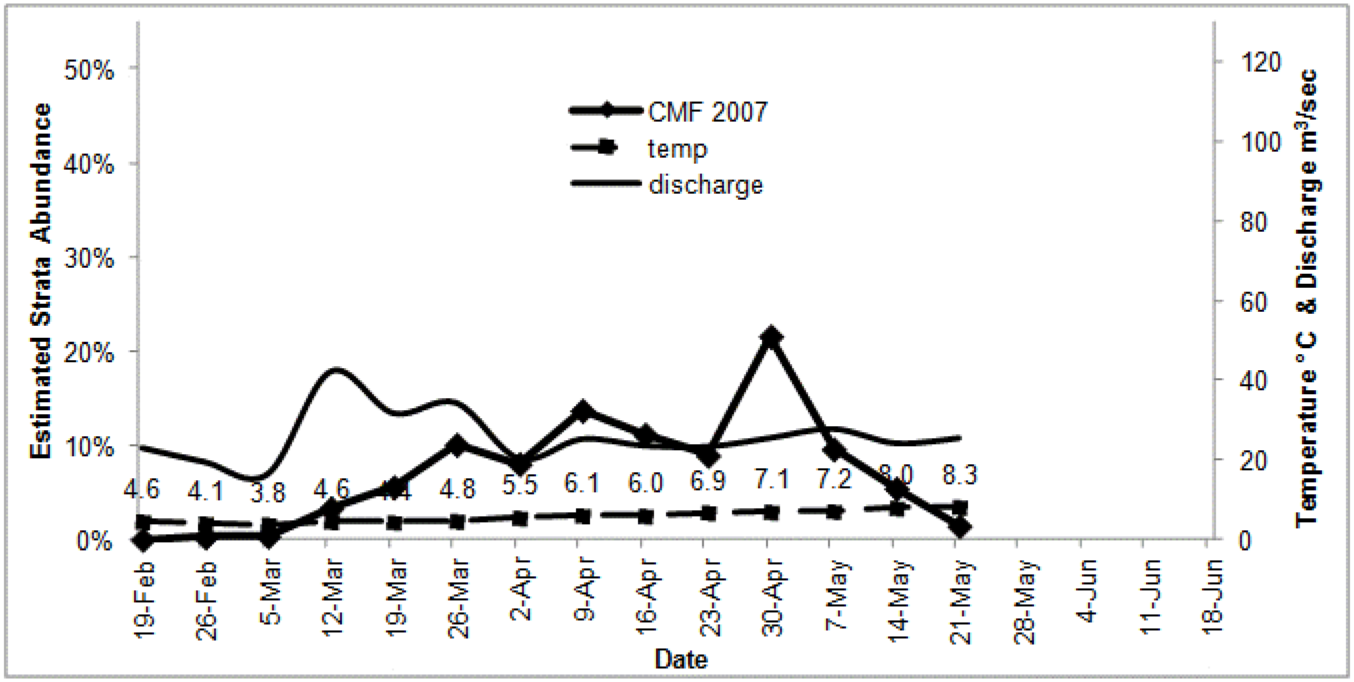

Figure 7A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2007 (WUP).

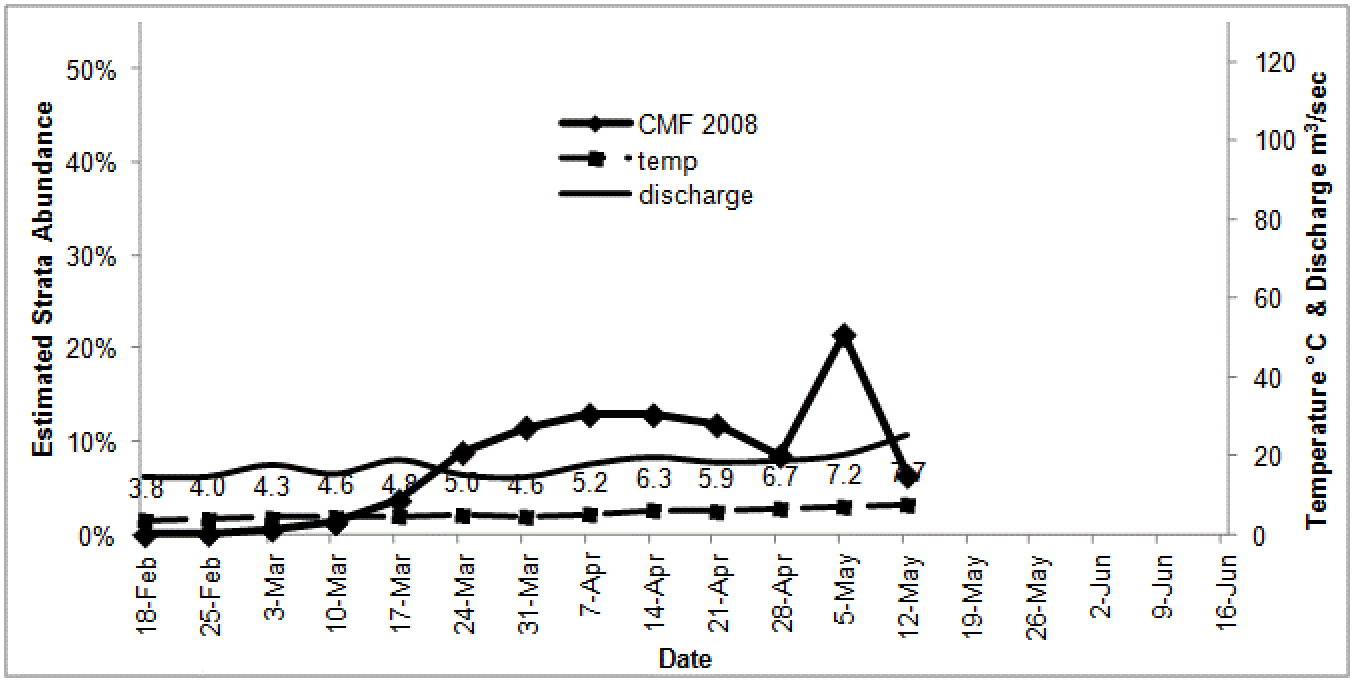

Figure 8A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2008 (WUP).

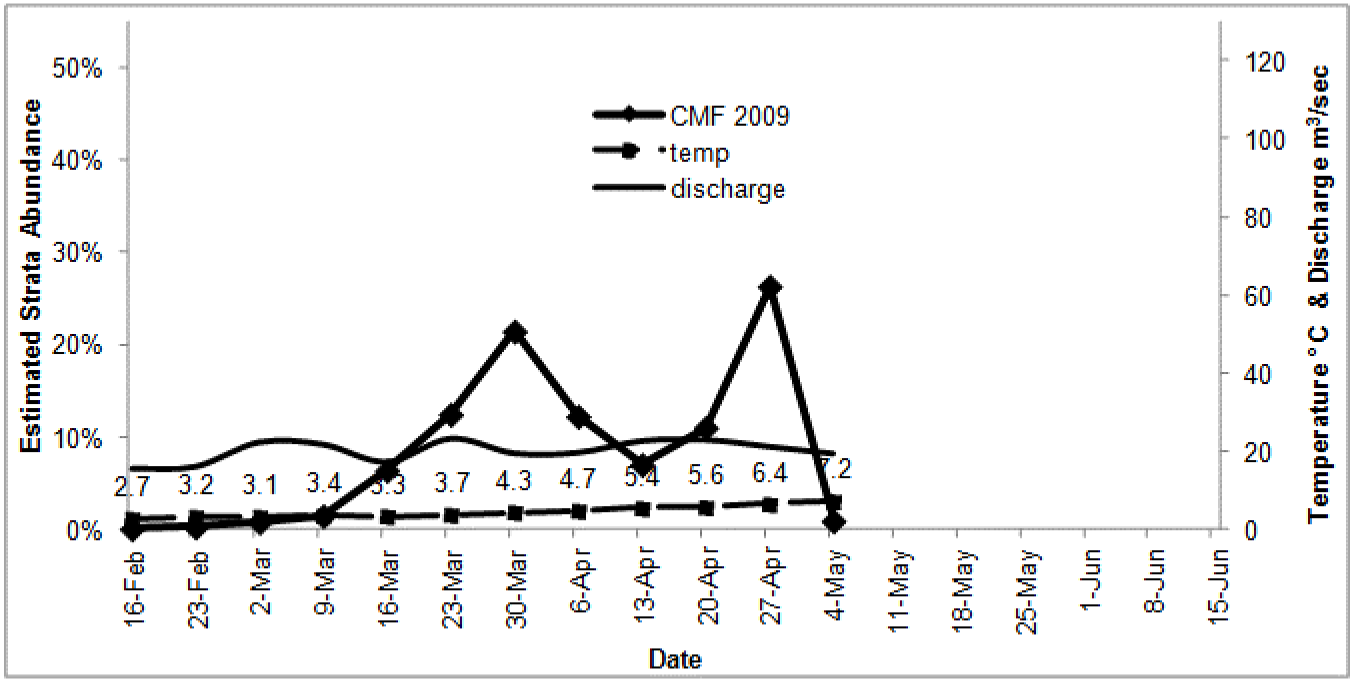

Figure 9A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2009 (WUP).

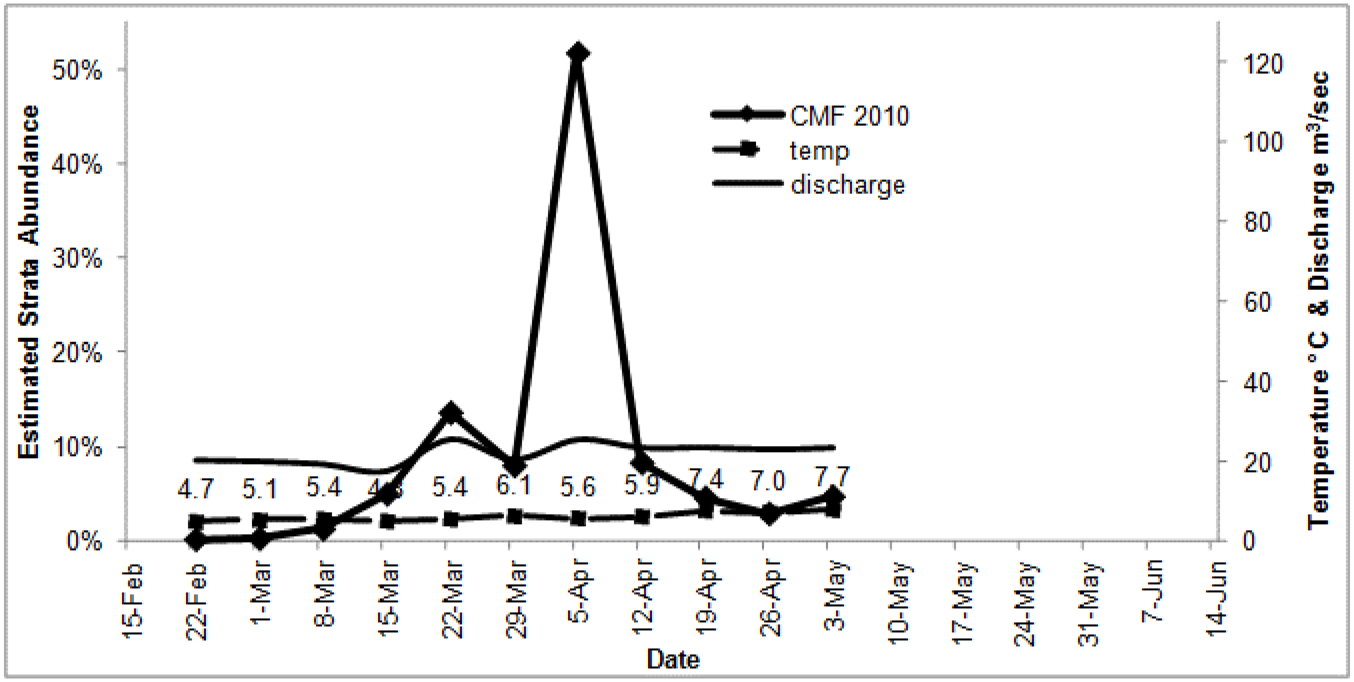

Figure 10A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2010 (WUP).

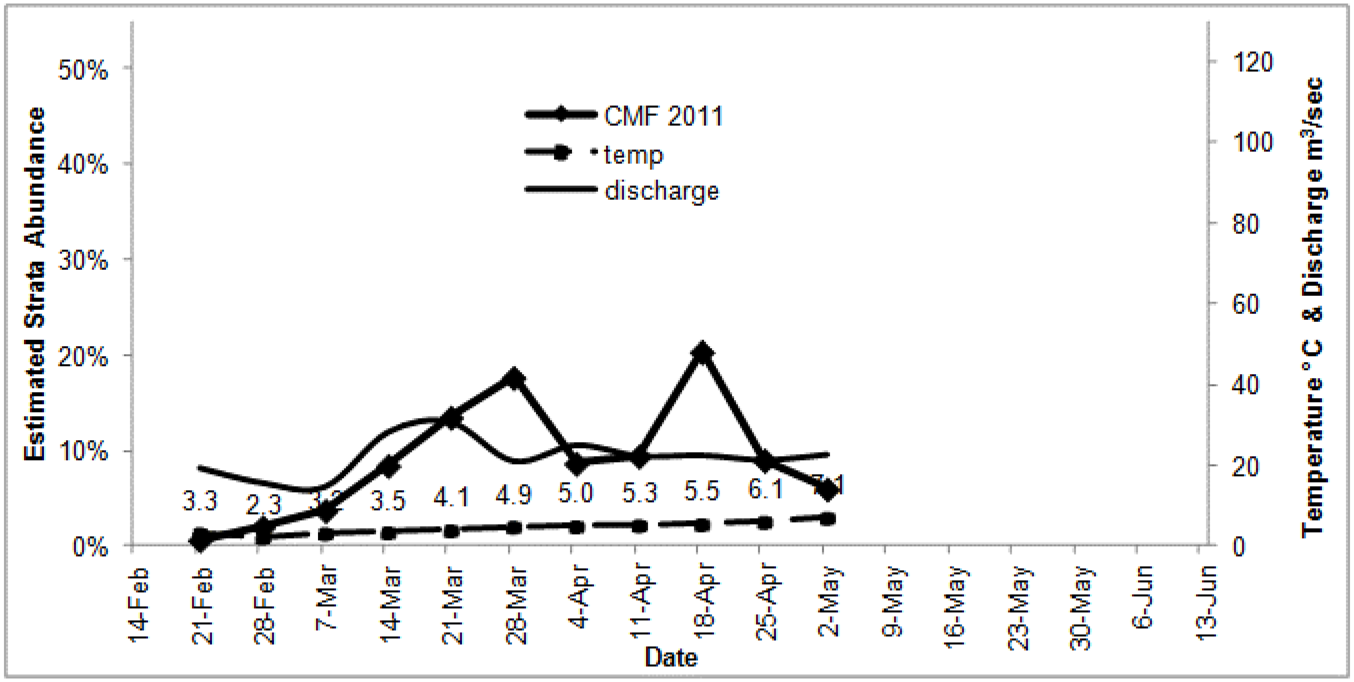

Figure 11A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2011 (WUP).

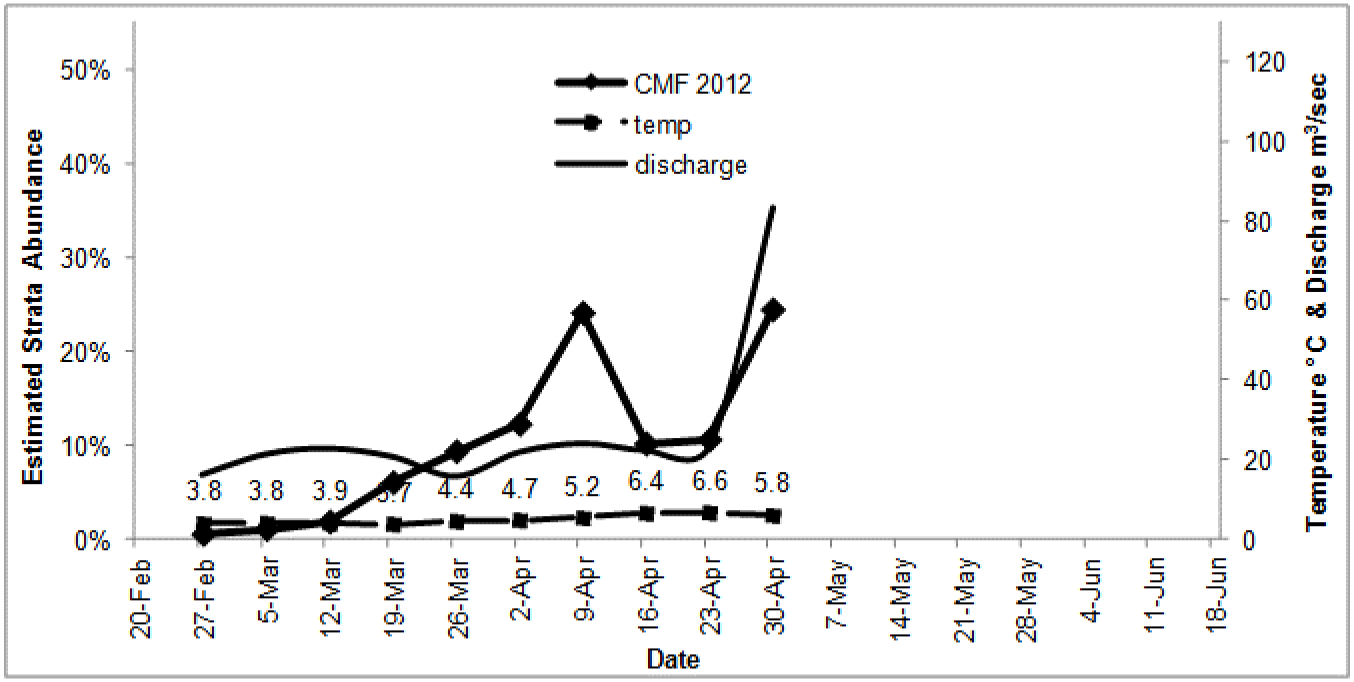

Figure 12A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2012 (WUP).

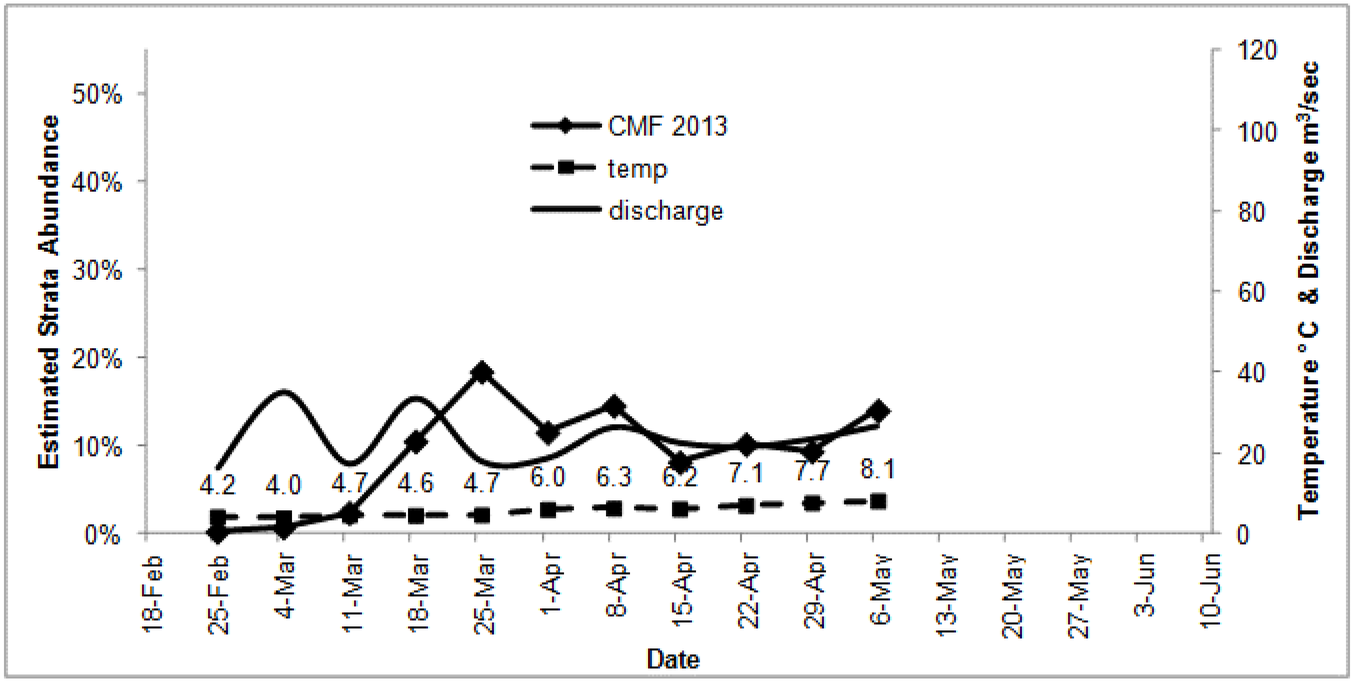

Figure 13A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2013 (WUP).

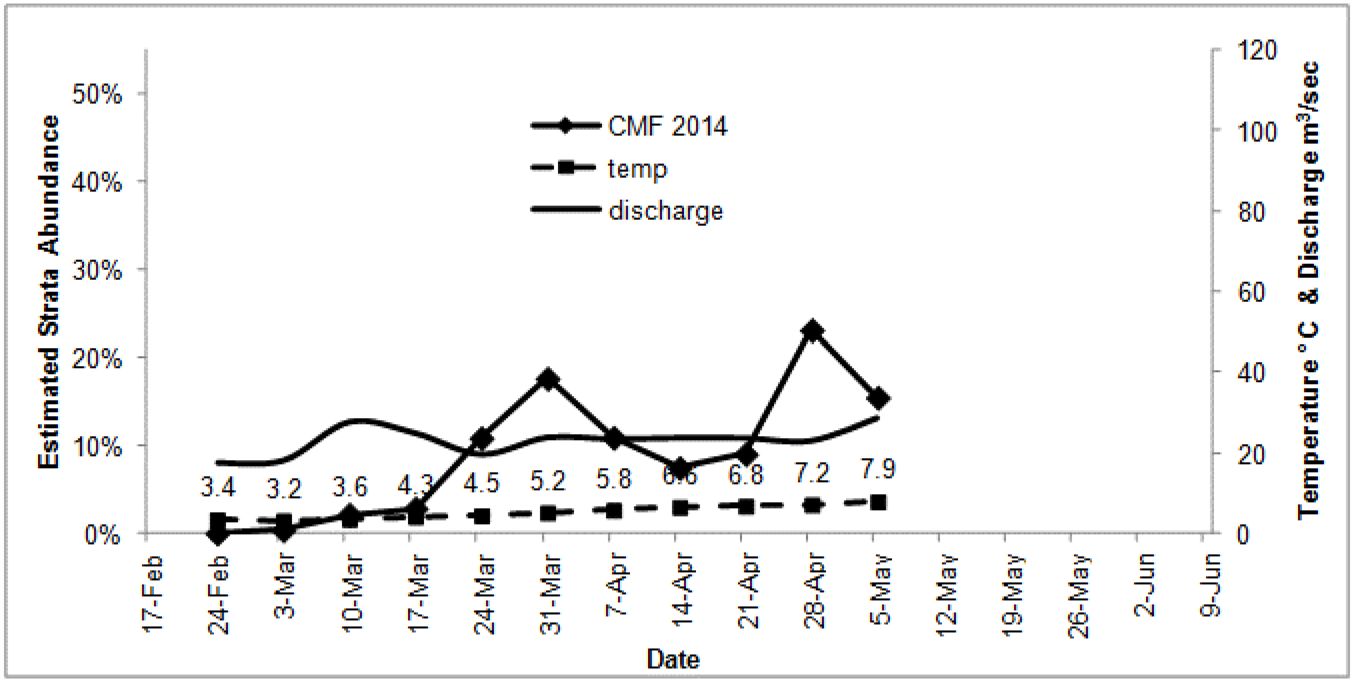

Figure 14A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2014 (WUP).

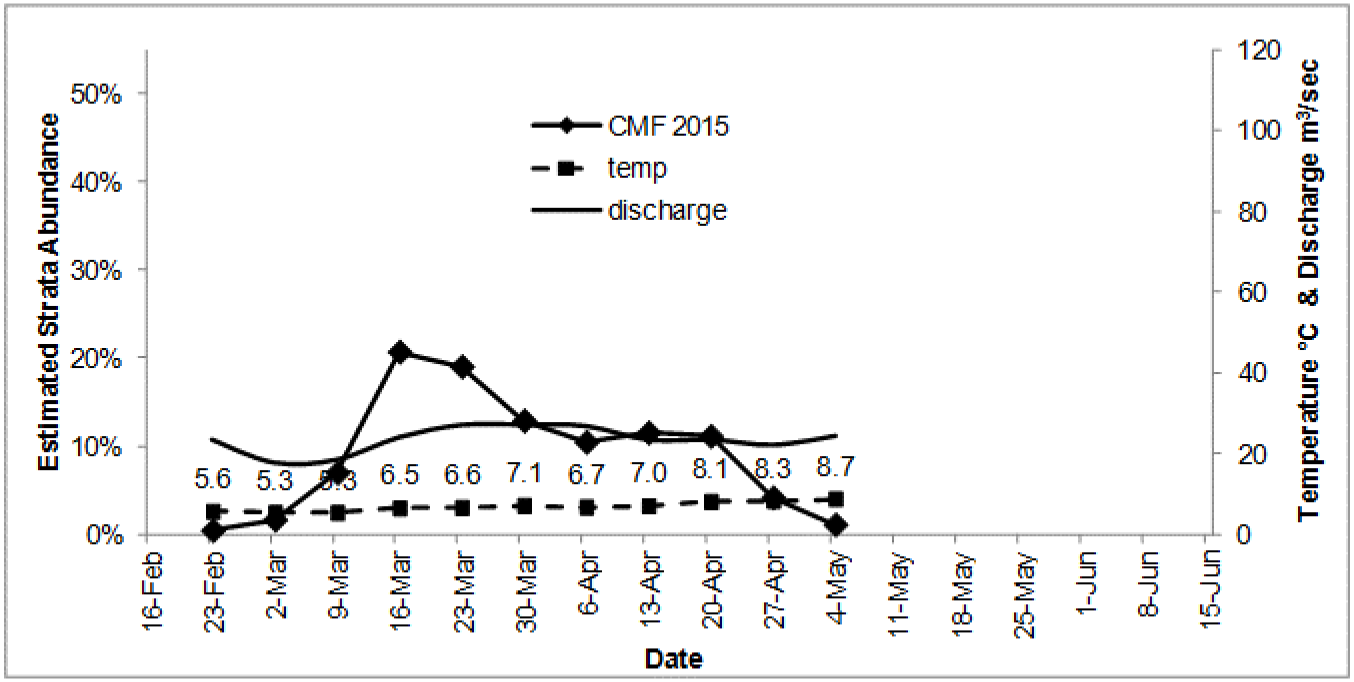

Figure 15A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2015 (WUP).

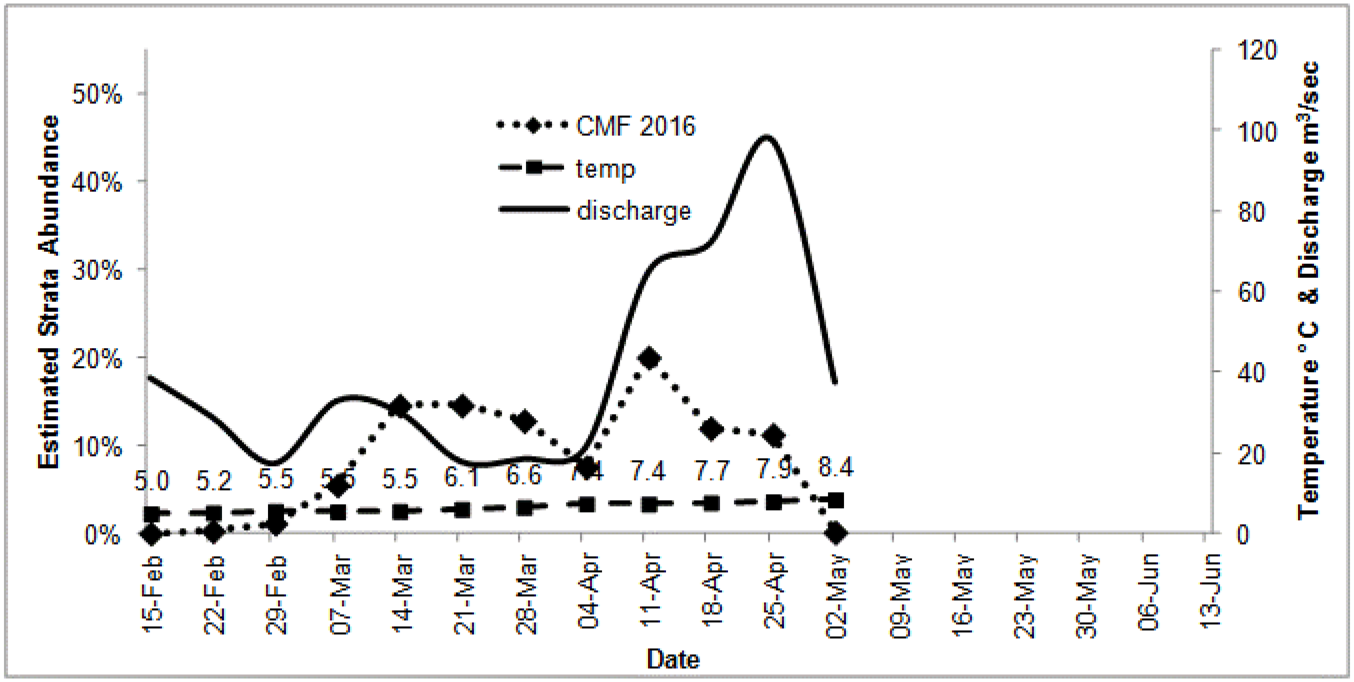

Figure 16A. Weekly abundance estimates of Chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2016 (WUP).

Note: Fishing was not possible during last three strata of 2016. Therefore, Chum escapement for Chum fry in the last three strata were estimated based on the proportion of Chum outmigrating in the last three strata in 2009-2015. Then the strata abundances were estimated for the entire run using the weekly escapement estimates.

APPENDIX B. Cheakamus Discharge Data

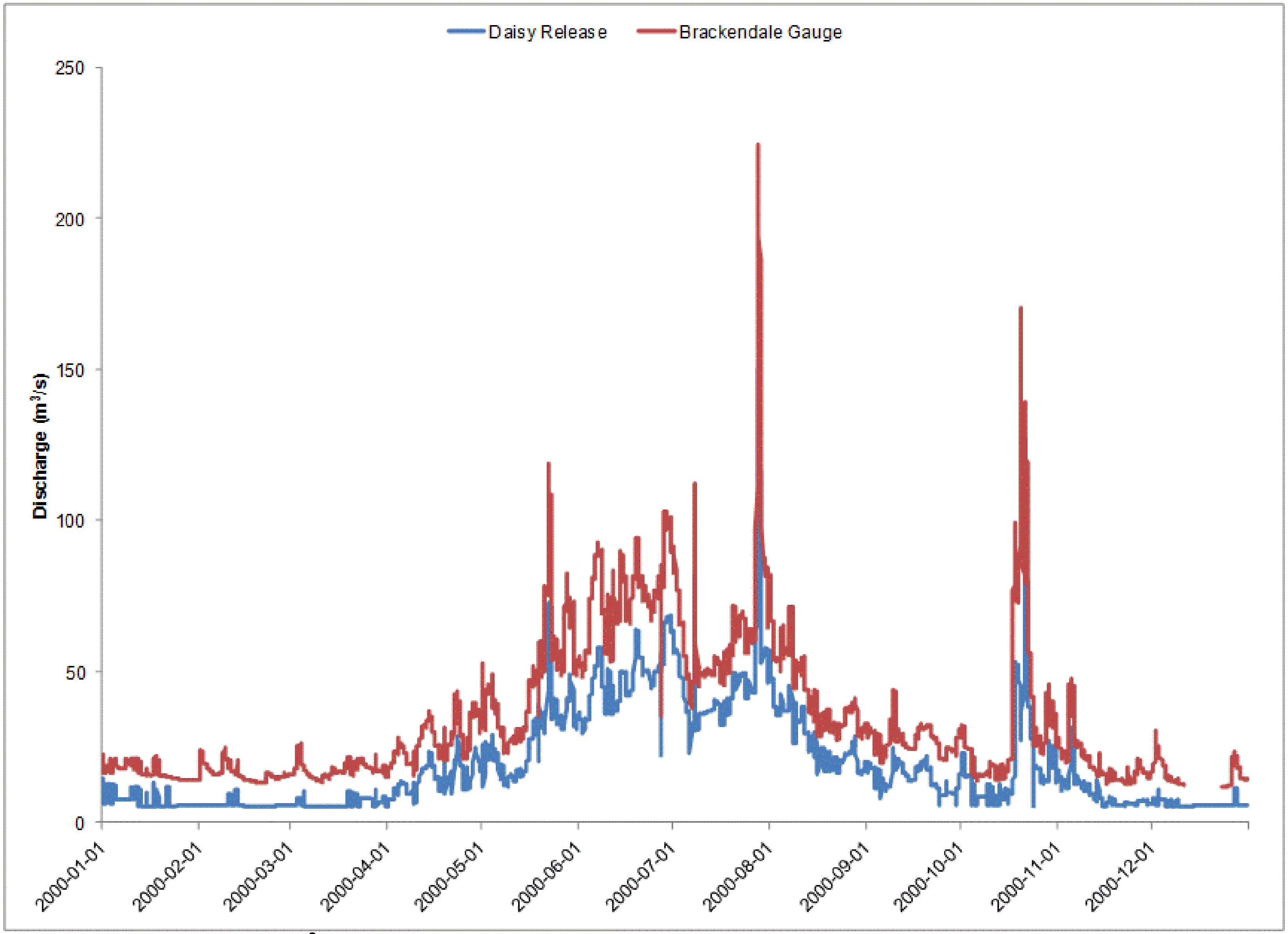

Figure 1B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2000.

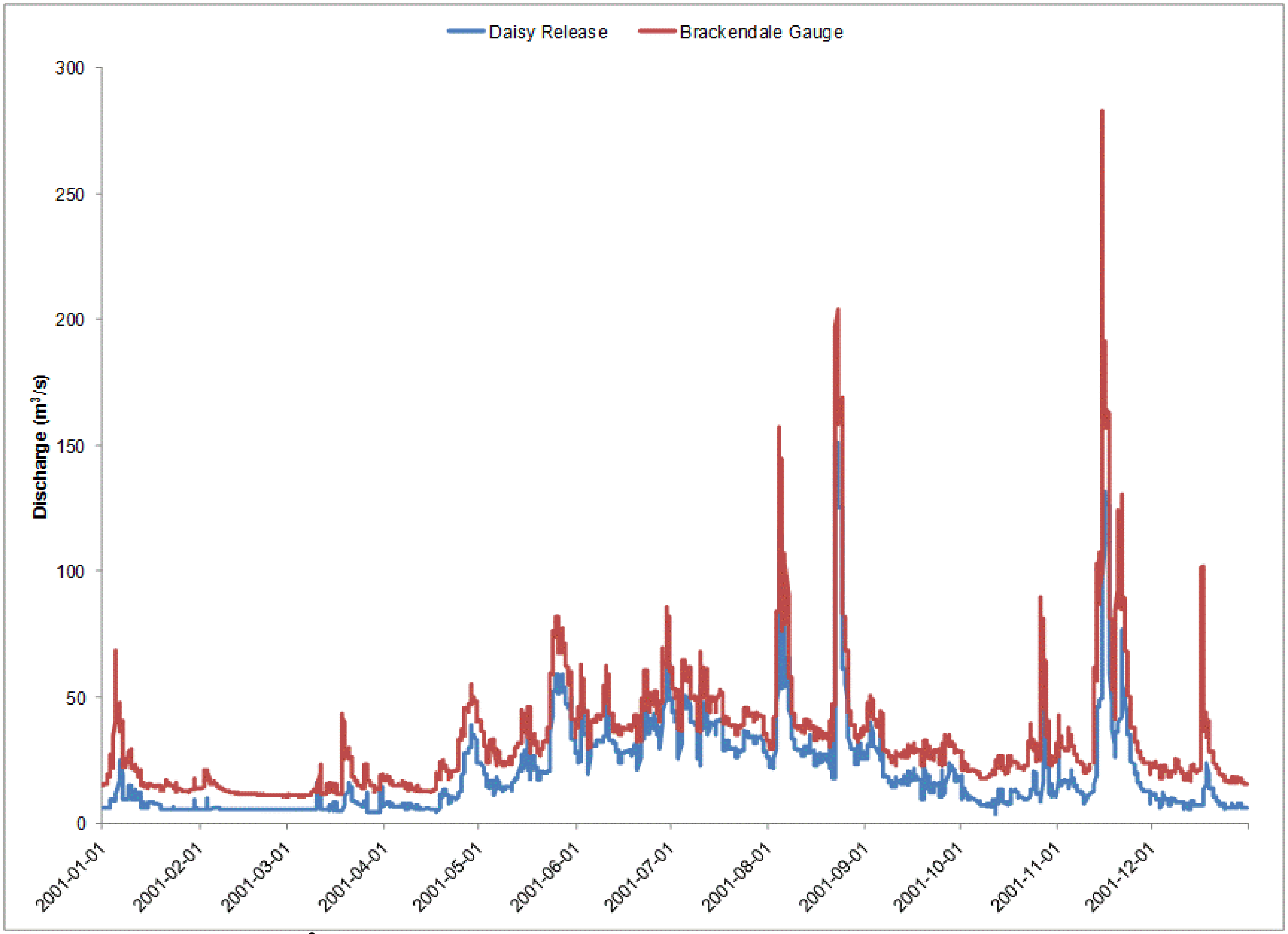

Figure 2B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2001.

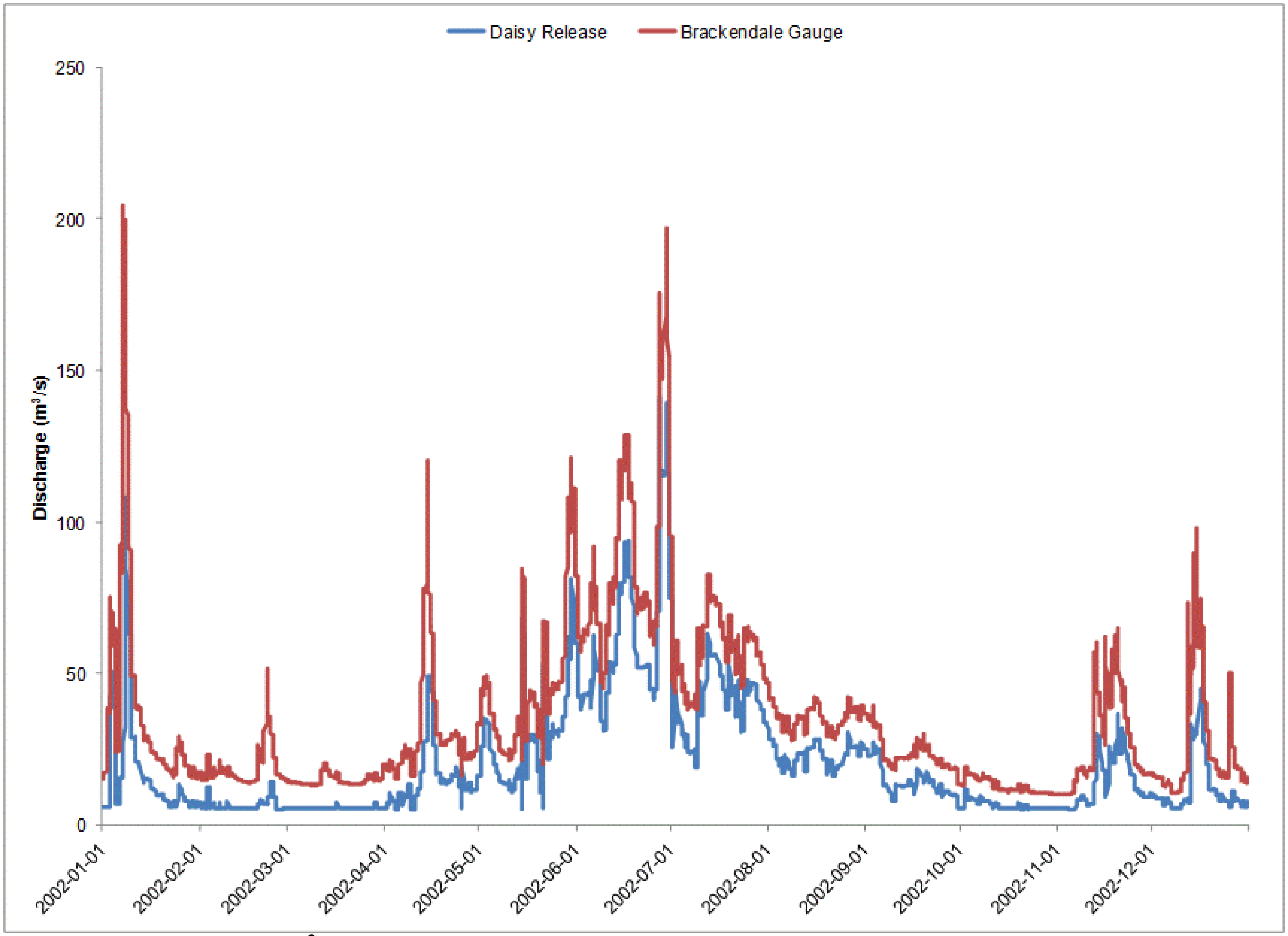

Figure 3B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2002.

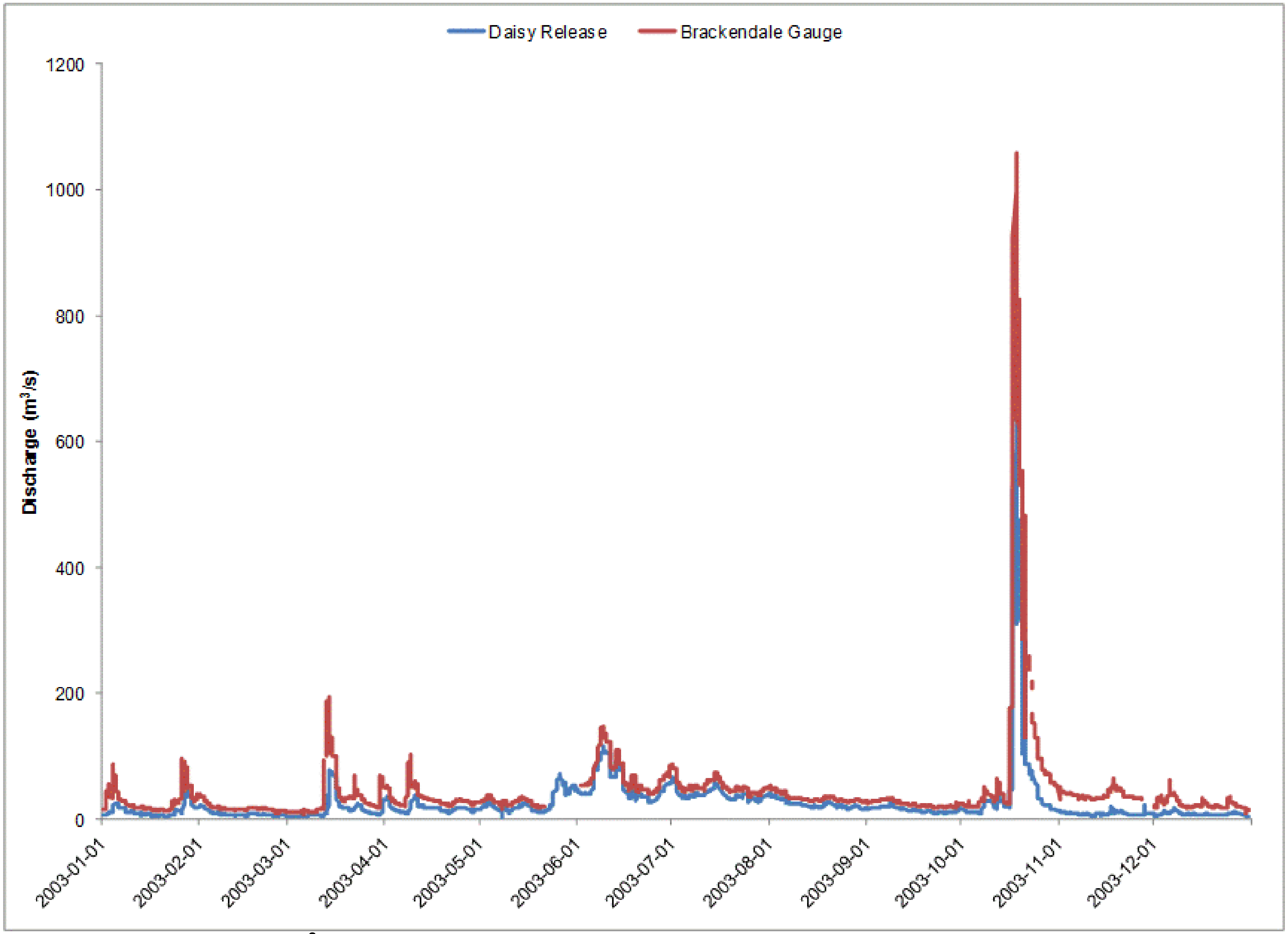

Figure 4B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2003.

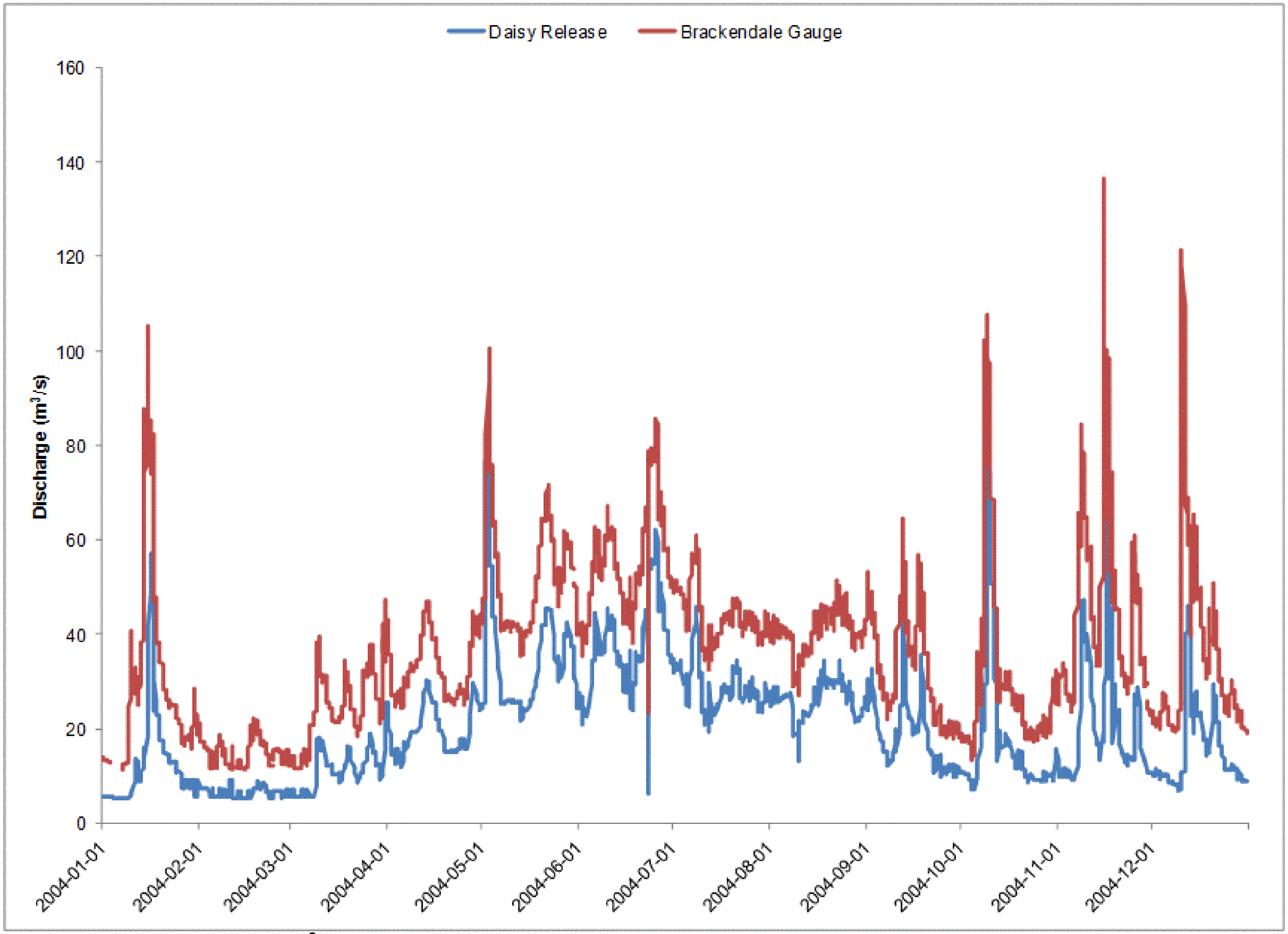

Figure 5B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2004.

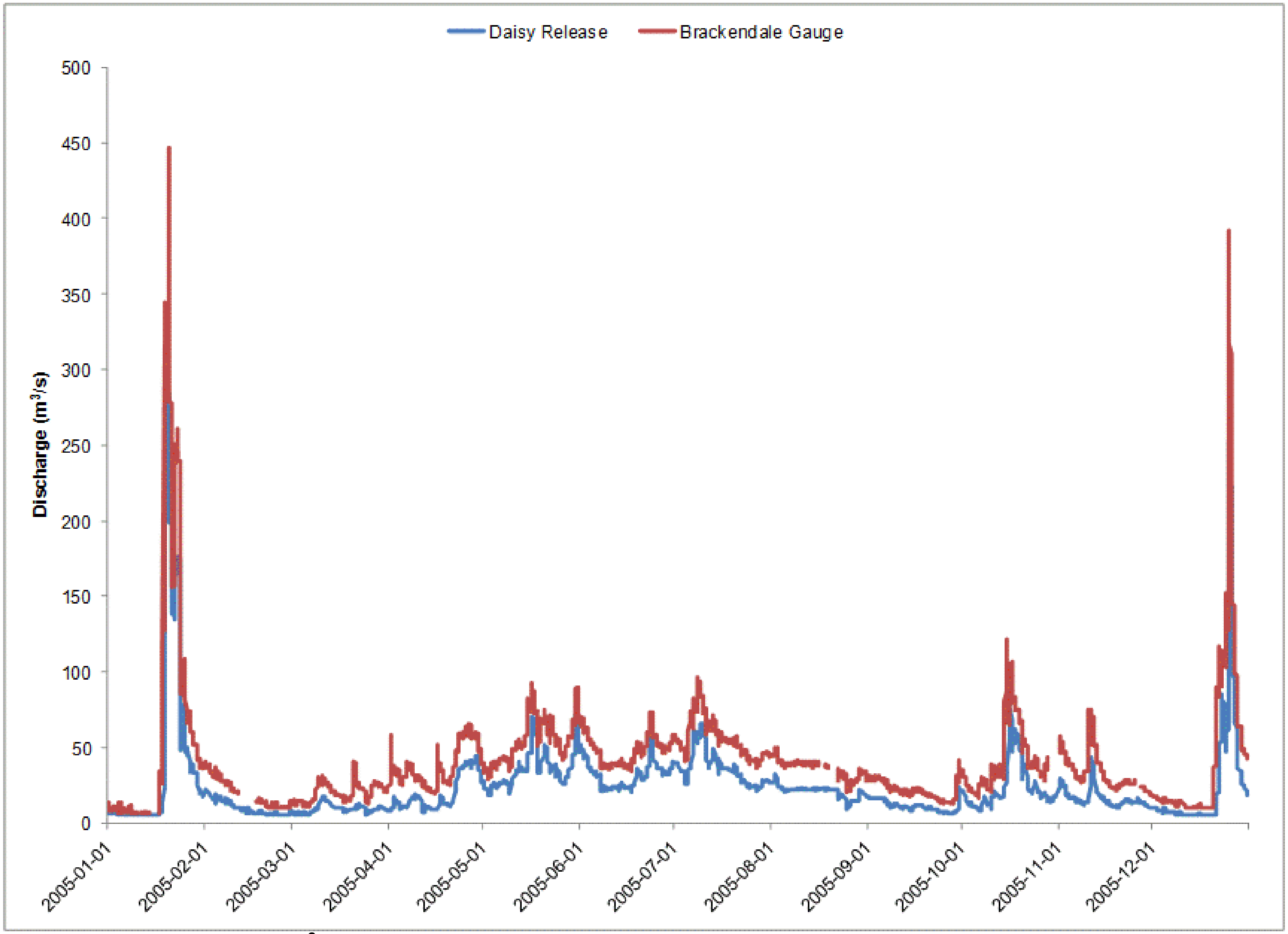

Figure 6B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2005.

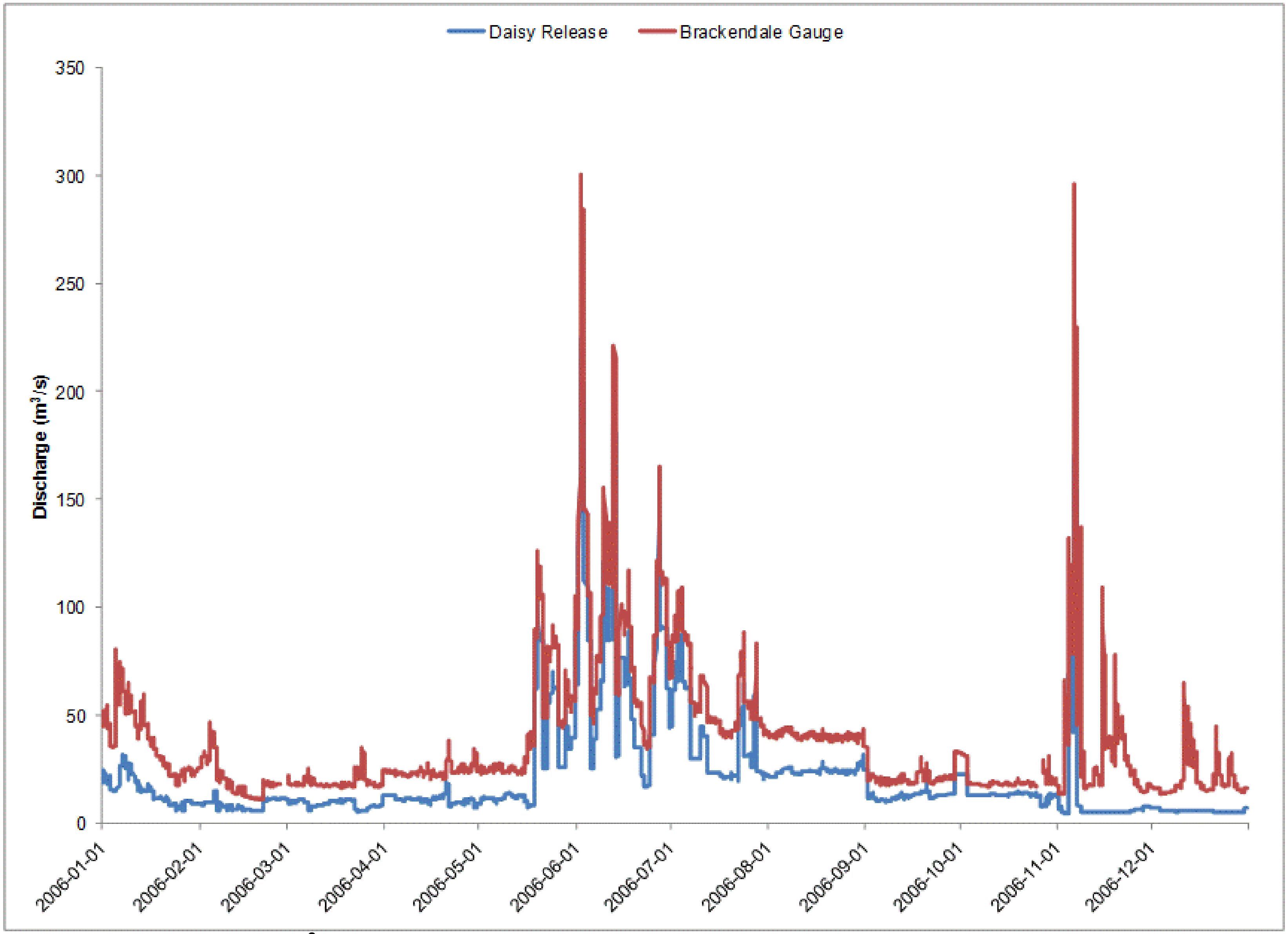

Figure 7B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2006.

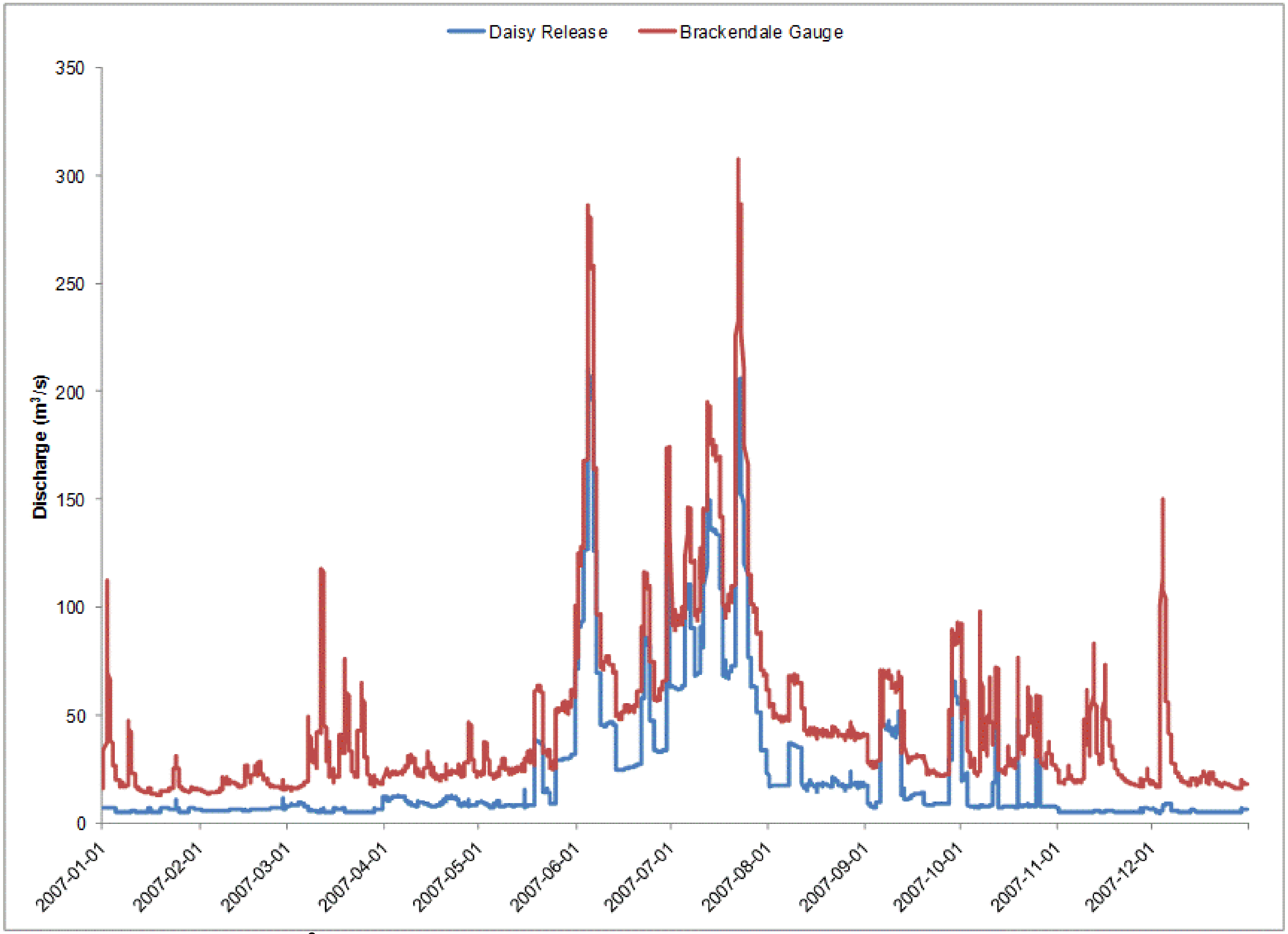

Figure 8B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2007.

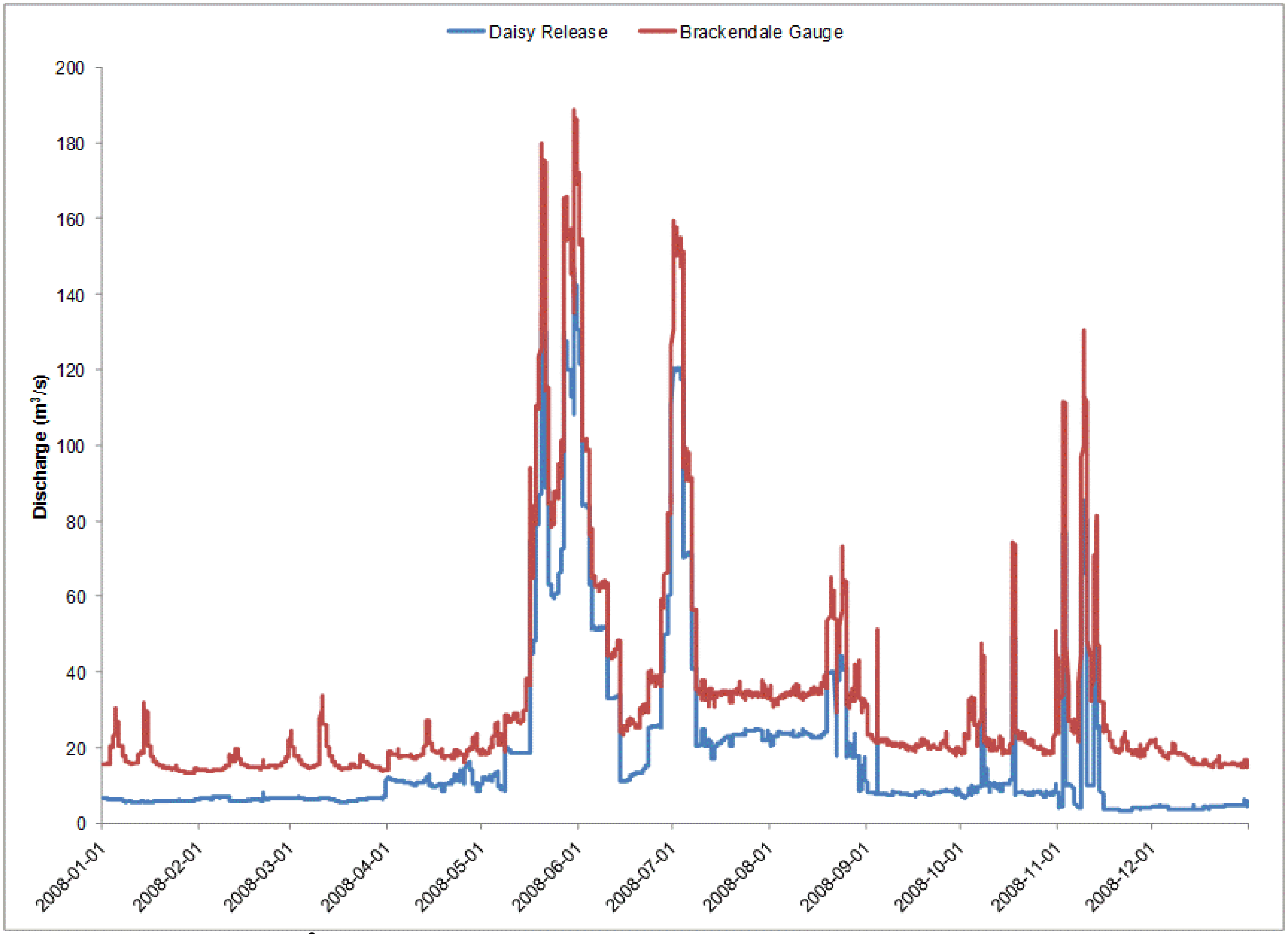

Figure 9B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2008.

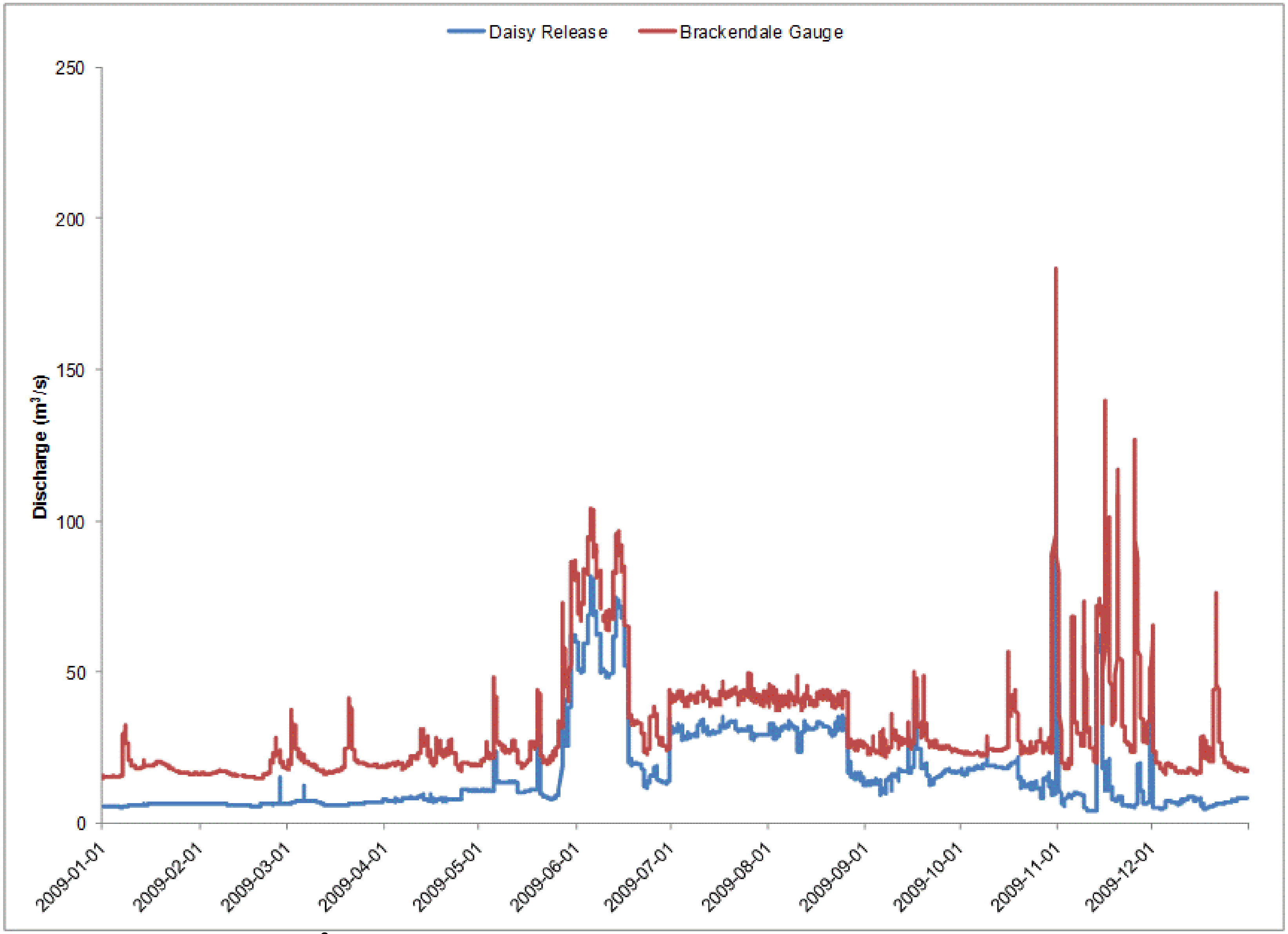

Figure 10B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2009.

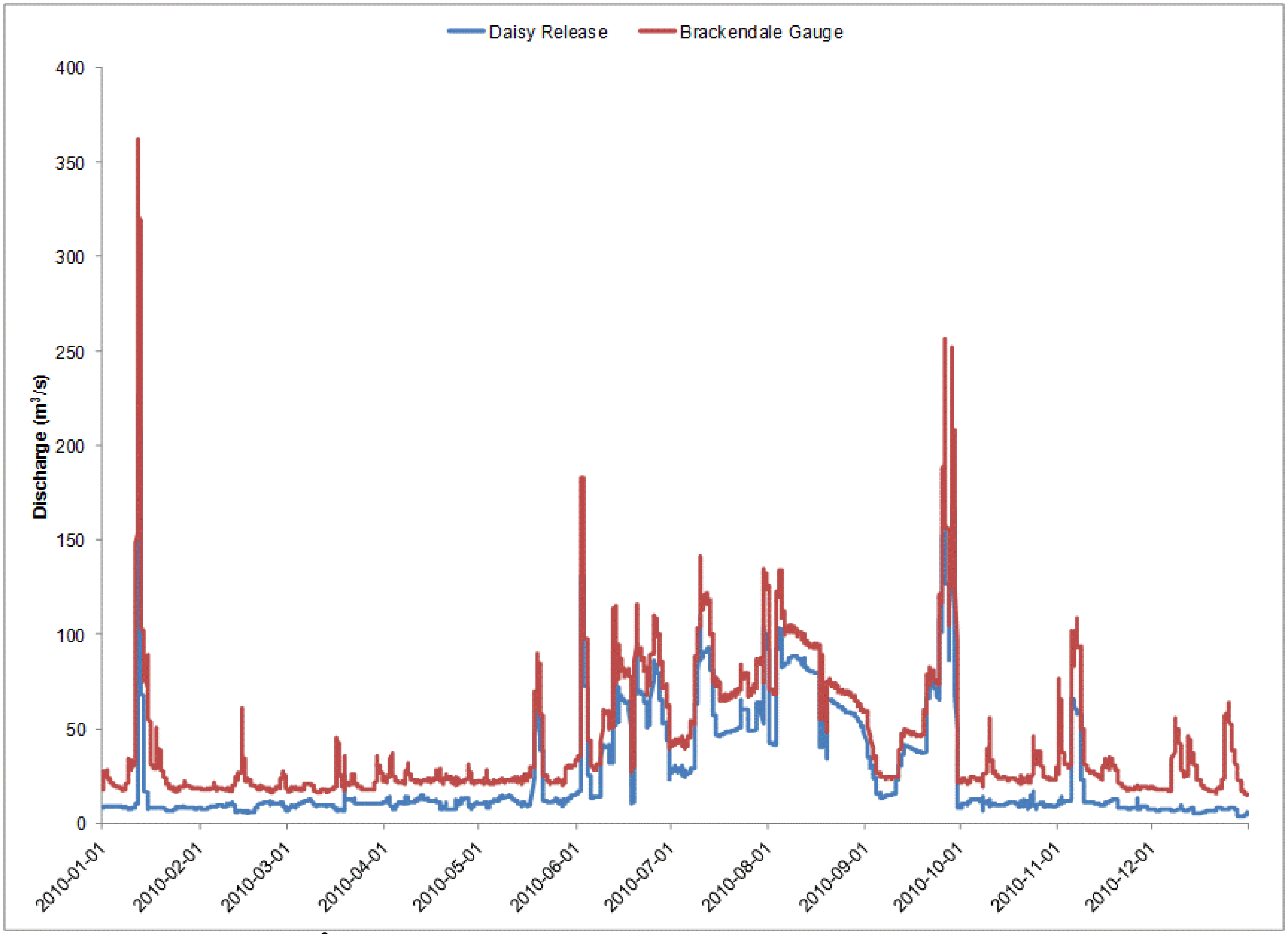

Figure 11B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2010.

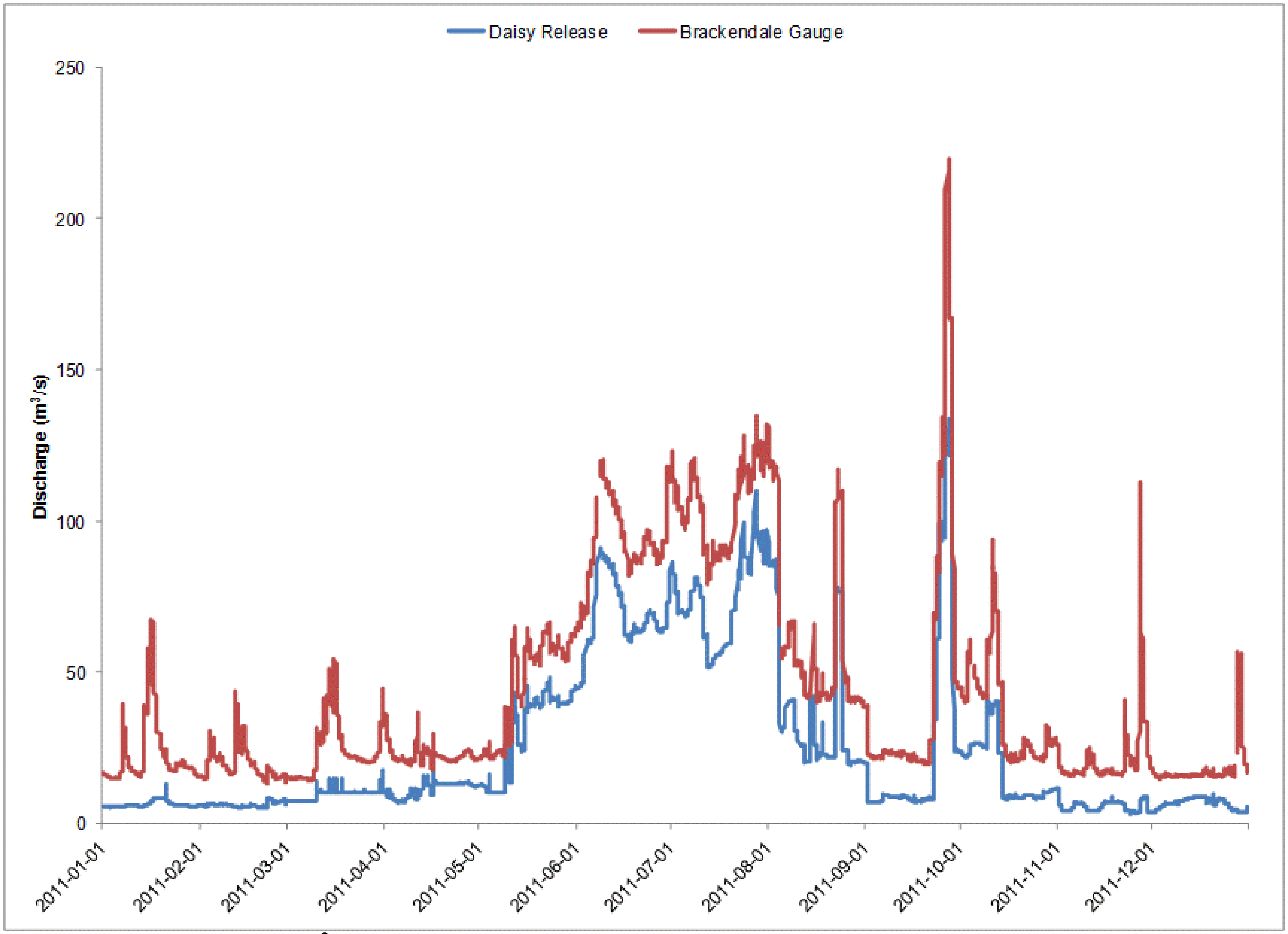

Figure 12B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2011.

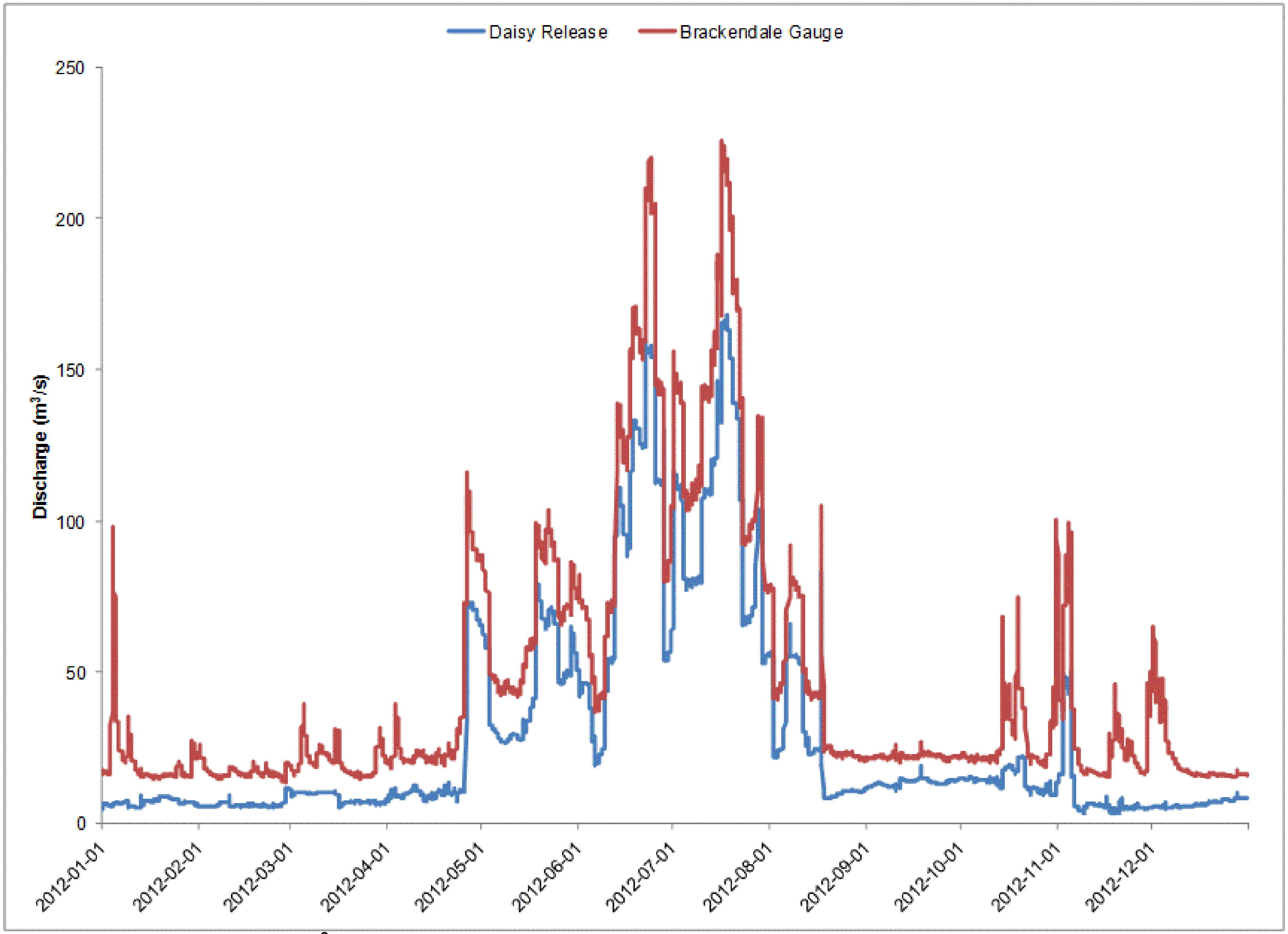

Figure 13B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2012.

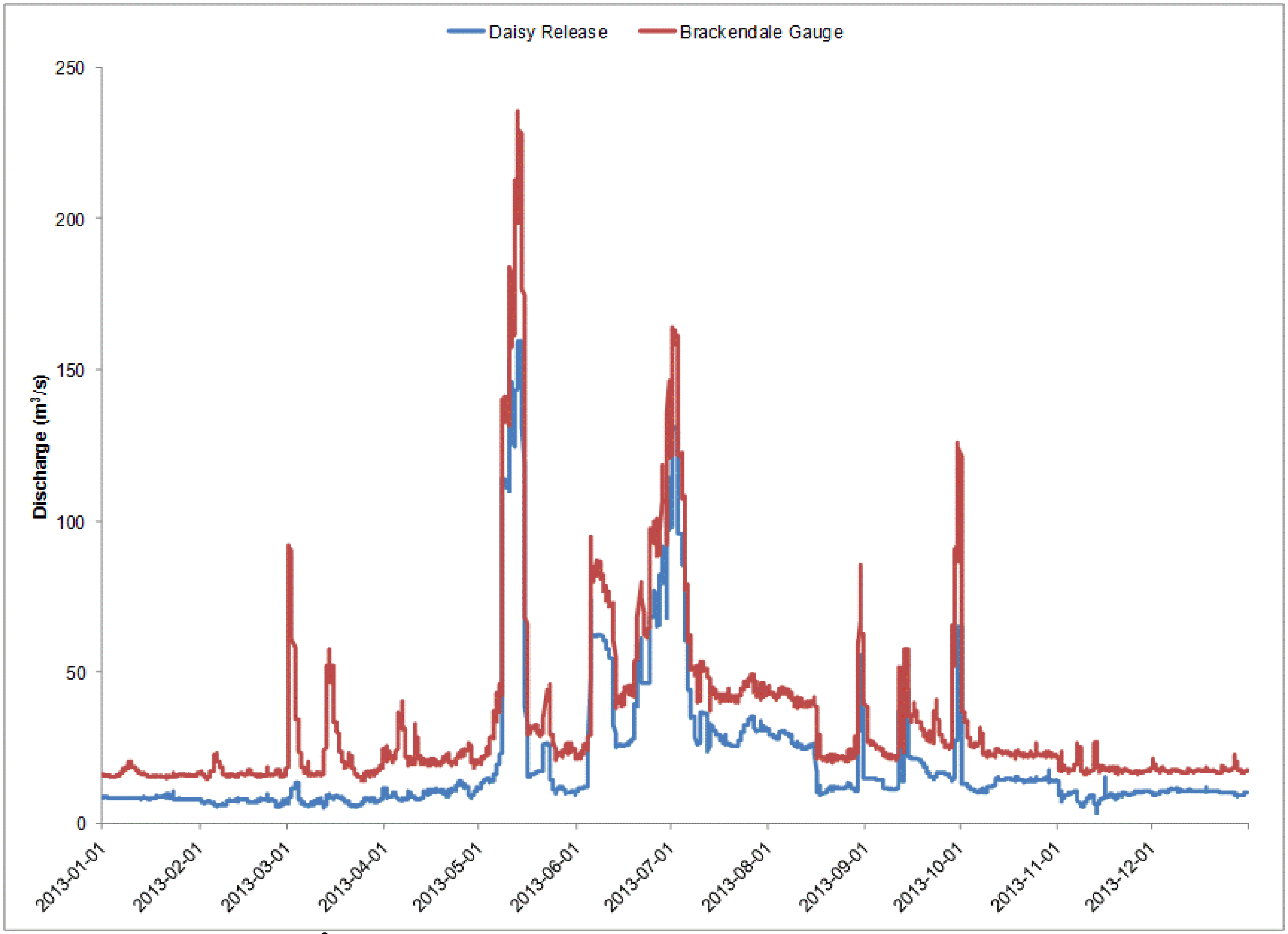

Figure 14B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2013.

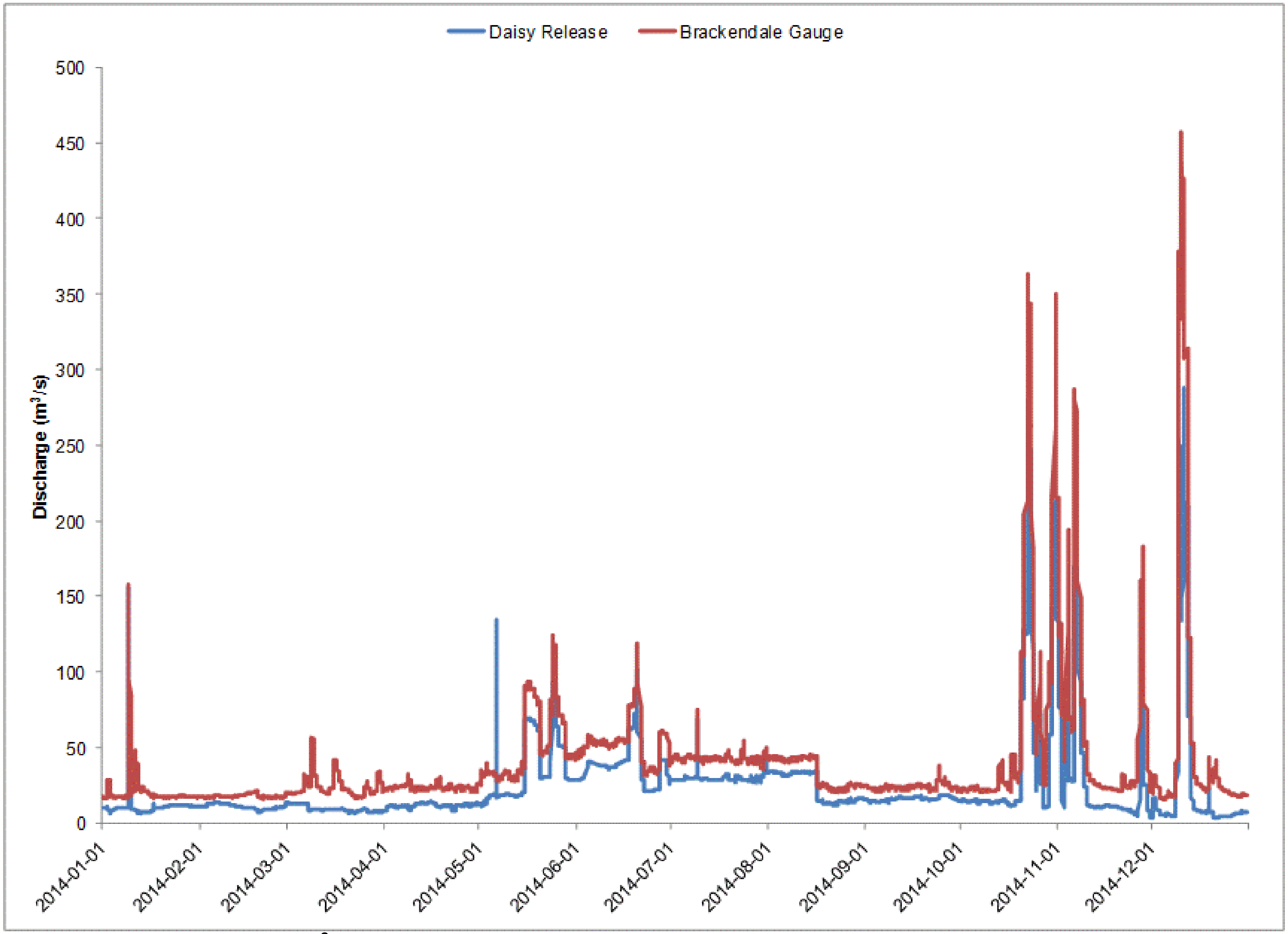

Figure 15B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2014.

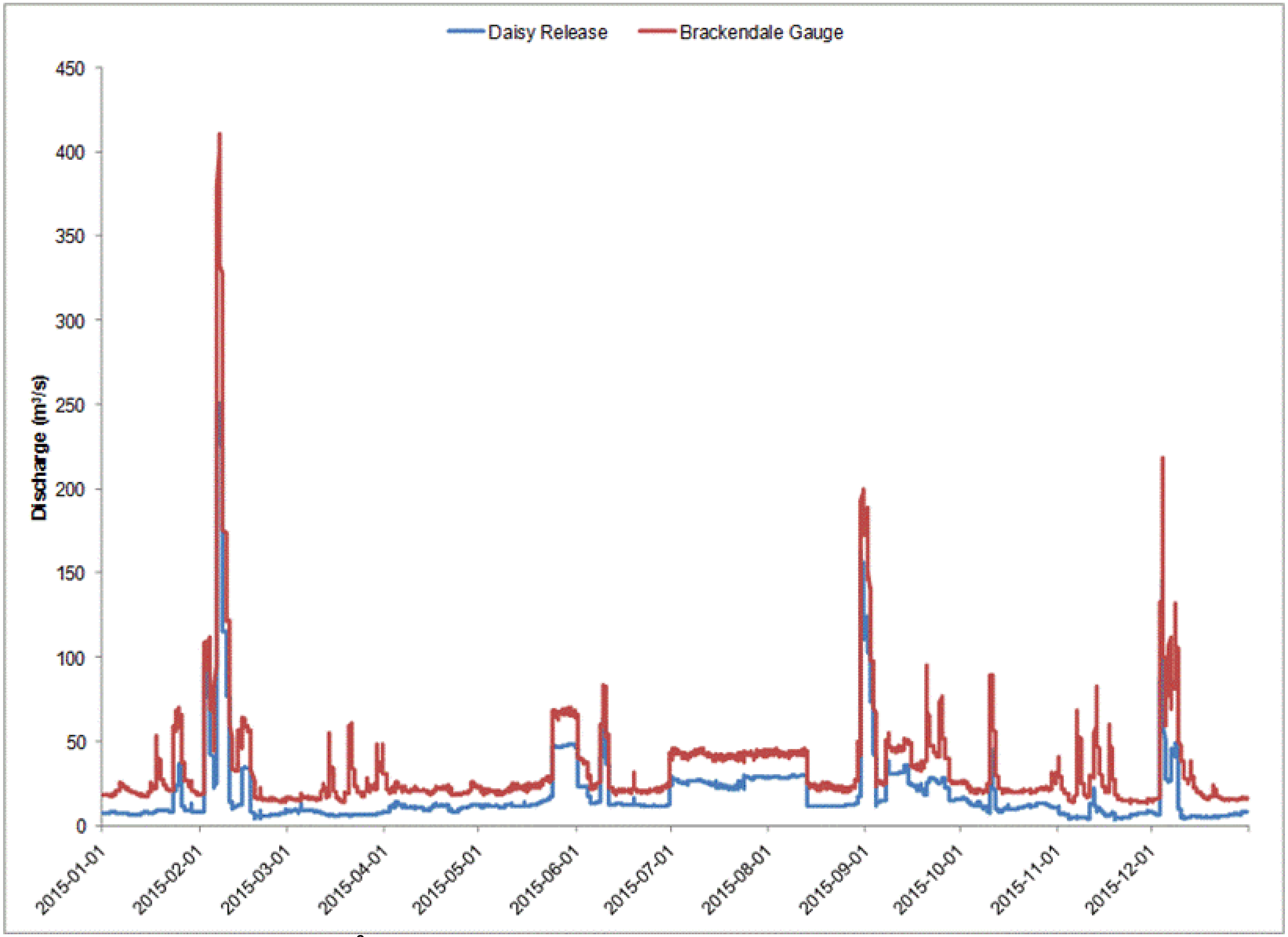

Figure 16B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2015.

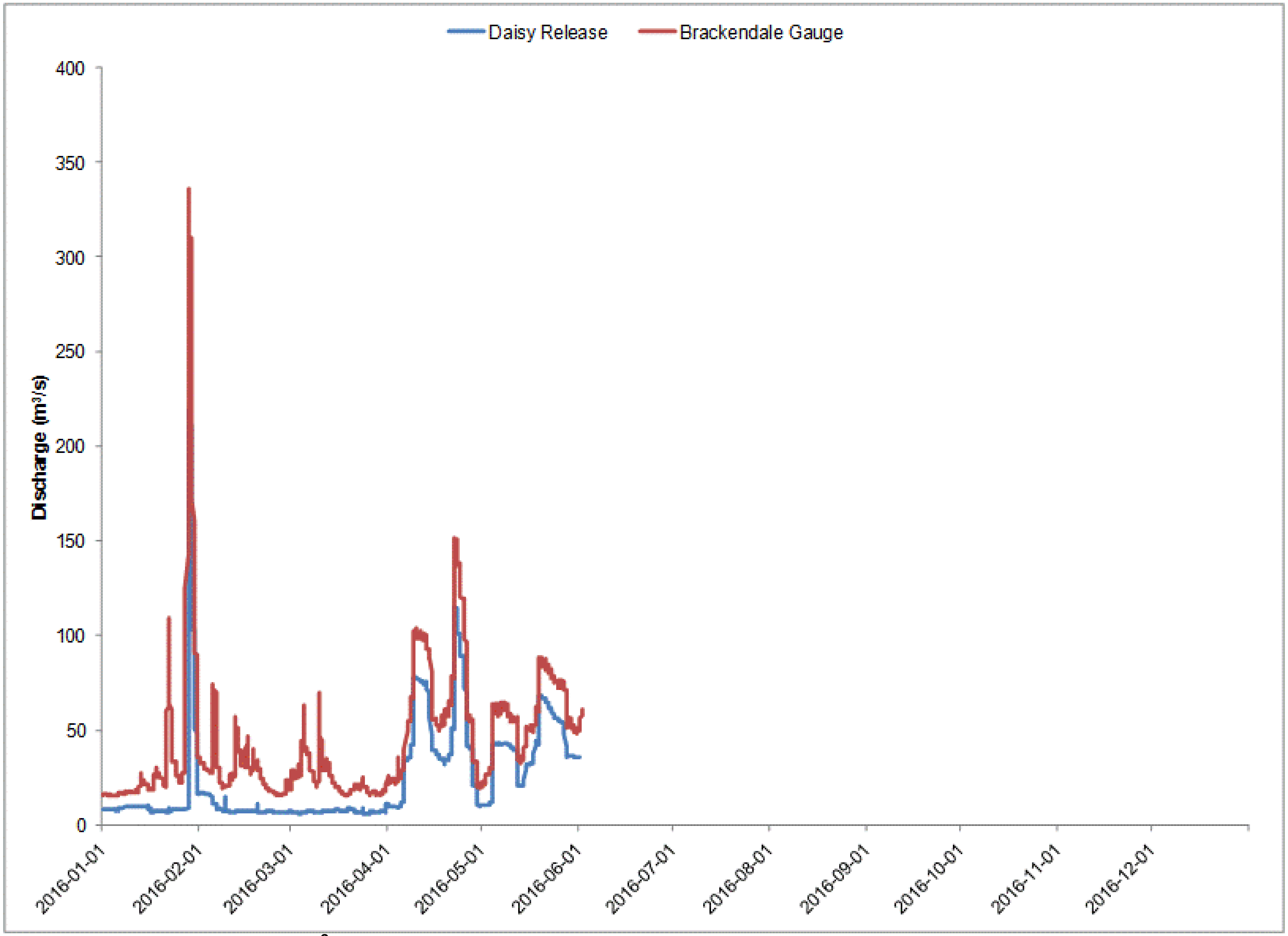

Figure 17B. Hourly discharge (m^3/s) on the Cheakamus River at Brackendale gauge and below Daisy Lake Dam in 2016.