Cheakamus Water Use Plan

Monitoring Program Synthesis Report

- **CMSMON-1A Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring**
- **CMSMON-1B Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey**
- **CMSMON-2 Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)**
- **CMSMON-3 Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring**
- **CMSMON-4 Monitoring Stranding Downstream of Cheakamus Generating Station**
- **CMSMON-5 Monitoring Stranding Downstream of Daisy Lake Dam**
- **CMSMON-6 Monitoring Groundwater in Side Channels of the Cheakamus River**
- **CMSMON-7 Cheakamus River Benthic Community Monitoring**
- **CMSMON-8 Monitoring Channel Morphology in Cheakamus River**
- **CMSMON-9 Cheakamus River Recreational Angling Access Monitoring**

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Executive Summary

The Cheakamus Water Use Plan (WUP) process was first initiated in 1996. However, in May 1997, DFO issued a Flow Order requiring the discharge of minimum flows from Daisy Lake Dam. The Water Use Plan process was then paused. In July 1998, a working group comprised of BC Hydro, DFO, BC Ministry of Fisheries, BC Ministry of Environment, Lands and Parks, the Steelhead Society of BC and Squamish First Nation began meeting to develop an interim flow regime and achieve consensus with all parties. The Comptroller of Water Rights (CWR) accepted an out of court interim flow settlement (the "Interim Flow Agreement" or IFA), which was implemented in December 1998. The WUP project was again initiated in February 1999 and completed in April 2002, ending in a non-consensus recommendation to implement a set of target flows that differed from the IFA. In 2005 the Cheakamus WUP was finalized and submitted to the CWR.

On February 17, 2006, the CWR issued an Order under the *Water Act*[1] (the "WUP Order") in response to the Cheakamus WUP. The CWR decided in favour of the WUP recommendations including the implementation of 10 monitoring projects conducted between 2007 and 2019. There were no physical works projects required by the WUP Order.

Monitoring studies were initiated under the Cheakamus WUP to assess the uncertainties surrounding potential benefits or impacts of the WUP flow regime on fish, fish habitat, and recreational angling. 10 monitoring projects are as follows:

- CMSMON-1a: Cheakamus River Juvenile Outmigrant Enumeration: A 12-year monitoring program to enumerate juvenile salmonid outmigration from the Cheakamus River mainstem and key side channels.
- CMSMON-1b: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey: A 12-year monitoring program to enumerate Chum spawning escapement and examine groundwater in mainstem spawning areas.
- CMSMON-2: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon): A five-year monitoring program for Rainbow trout in the non-anadromous section of the Cheakamus River.
- CMSMON-3: Cheakamus River Steelhead Adult Abundance, Fry Emergence-Timing, and Juvenile Habitat Use Abundance Monitoring: A 12-year monitoring program to examine the effects of mainstem flows on steelhead production.
- CMSMON-4: Monitoring Stranding Downstream of Cheakamus Generating Station: A three-year monitoring program to examine stranding downstream of the Cheakamus generating station tailrace on the Squamish River.

[1] The *Water Act* was replaced by the *Water Sustainability Act* in February 2016; however Orders and Water Licences continue to be valid and are governed by the new *Water Sustainability Act*.

- CMSMON-5: Monitoring Stranding Downstream of Daisy Lake Dam: A one-year monitoring program to monitor fish stranding downstream of Daisy Lake Dam.
- CMSMON-6: Monitoring Groundwater in Side Channels of the Cheakamus River: A five-year program to monitor the effect of Cheakamus mainstem flows on groundwater-fed side channels.
- CMSMON-7: Cheakamus River Benthic Community Monitoring: A three-year monitoring program and modelling exercise to examine the effects of mainstem flows on the benthic community.
- CMSMON-8: Monitoring Channel Morphology in Cheakamus River: A 10-year monitoring program to examine the effects of flows on channel morphology in the Cheakamus River mainstem.
- CMSMON-9: Cheakamus River Recreational Angling Access Monitoring: A one-year monitoring program to examine the benefits to recreational angling access (available angling locations) of the 1 January to 31 March 5.0 $m^3 \cdot s^{-1}$ minimum flow release from Daisy Lake Dam.

This document was prepared as a part of the WUP Order Review process. It summarizes the outcomes from the monitoring projects and outlines whether the management questions have been addressed (Table E-1).

The WUP Order Review process includes two stages with two core deliverables:

- Stage 1: The Monitoring Program Synthesis Report (MPSR – this report); and
- Stage 2: The WUP Order Review Report.

The purpose of the WUP Order Review is to determine whether the ordered facility operational constraints and the physical works in lieu of operation changes are achieving the specific environmental and social objectives identified in the WUP.

Both the draft MPSR and draft WUP Order Review Report are shared with government agencies, First Nations and key stakeholders for review and comment. The WUP Order Review process will enable BC Hydro to recommend to the Comptroller of Water Rights how the WUP Order and its conditions may be concluded, clarified, modified, or confirmed for future operations.

Effects of the WUP Flow Regime on Fish Production

A primary objective of the Cheakamus WUP monitoring programs was to examine the effects of the WUP flow regime on the production of juvenile salmonids in the mainstem of the Cheakamus River. These monitoring studies found limited evidence of substantial changes to fish abundance associated with the WUP flow regime; however, some of the studies were unable to control for external variables and/or had limited statistical power to detect changes. No significant changes in juvenile production were detected for Chinook, Coho salmon (CMSMON-1a) between WUP and IFA flow regimes; however, statistical power was weak because of low sample size and high natural variability in fish population among years. Pink salmon abundance data were considered too sparse to complete reliable tests. Although there was a negative trend in Rainbow trout fry density in the non-anadromous reach of the Cheakamus River over the study period, the Rainbow trout parr density appeared to remain stable, which indicates the impacts to fry were compensated by a density-dependent effect (CMSMON-2).

Significant increases in resident Rainbow trout in the anadromous reaches of the Cheakamus River were observed under the WUP flow regime; however, it is unclear whether increased Rainbow trout abundance under WUP flow was a flow-related effect or caused by some other factor coincidental to the WUP flow regime (CMSMON-3).

Steelhead adult returns to the Cheakamus River increased significantly under the WUP flow regime; however, Steelhead marine survival rate increased and Pink salmon returns also increased during this same period. Correcting adult return data for changes in Steelhead marine survival and Pink salmon adult returns, it is possible that there was actually a decrease in Steelhead freshwater production under the WUP, which is supported by observed decreases in Steelhead smolt abundance at the rotary screw trap; however, there are large uncertainties associated with the correction factors applied to adult Steelhead returns analysis and limited sample size and precision of the Steelhead smolt data (CMSMON-3).

The characteristics of flow that affect fish

Because some of the Cheakamus WUP monitoring studies lacked the ability to compare between flow regimes, inter-annual variability in discharge characteristics was used to assess flow related effects to fish production and productivity. Key aspects of the flow regime were identified though the monitoring studies to impact fish production and/or productivity, including high discharges during fall/winter, flow ramp down rates and minimum discharges during summer/fall spawning.

Large or highly variable flows in the Cheakamus River while juvenile early-life stages of salmon are present appear to negatively affect juvenile salmon production. Pink fry, Chinook fry, Coho smolt abundance (CMSMON-1a), Chum egg-to-fry survival (CMSMON-1b), and Steelhead fry over-winter survival (CMSMON-3) all appear to be negatively affected by large discharge events during fall and winter. In addition, high flow events during the summer rearing period may impact Rainbow trout spawning success in the non-anadromous reach of the Cheakamus River (CMSMON-2). Causal mechanisms may vary from redd scour, juvenile displacement, and/or fish/redd stranding during flow ramping. Large discharges down the Cheakamus River are typically caused by rainfall events associated with fall/winter storms. The small storage capacity of the Daisy Lake Reservoir limits the ability to manage the magnitude and duration of these discharges from Daisy Lake Dam. However, there may be further opportunities to evaluate options for down ramping of flows to mitigate potential fish stranding related impacts.

Studies found evidence that WUP specified flow ramp down rates likely result in a risk of fish stranding in the Cheakamus River and the Squamish River (CMSMON-3, 4, and 5). WUP ramp rates from Daisy Dam that exceed the DFO guideline of -2.5 cm/hr while fry are present were observed to strand fish in the non-anadromous reach of the Cheakamus River; however, stranding levels were deemed low and within maximum acceptable levels of stranding (CMSMON-5). Studies also identified fish stranding in the tailrace and Squamish River side-channel immediately downstream of the Cheakamus powerhouse; however stranding levels were low and unlikely to have a population level impact

(CMSMON-4). Risk of juvenile fish stranding in the Squamish River was identified as highest during winter low-flow periods while the Cheakamus Generating Station fluctuates discharge (CMSMON-3 and 4); however, this risk has not been quantified.

In the Cheakamus River, rapid changes in discharge during summer months appear to significantly reduce Steelhead egg-to-fry survival, and during fall/winter months, reduce Steelhead fry over-winter survival (CMSMON-3). Monitoring of fish stranding during a flow ramp down with a change of minimum flow of ~38 m^3/s to ~20 m^3/s on the anadromous section of the Cheakamus River in August 2018, following WUP maximum ramp rates, identified substantial juvenile fish stranding. This field study supported the conclusion that WUP ramp rates can result in stranding of early life stages of salmon in the Cheakamus River, which may be having a population-level effect. To further understand causal mechanisms of fish stranding associated with rapid flow ramp downs and test the effectiveness of potential mitigation measures, the Cheakamus Adaptive Stranding Protocol (CASP) has recently been implemented on the Cheakamus River. Information gathered during the CASP is intended to inform WUP Order Review with regards to fish stranding impacts associated with Cheakamus River flow management (e.g., effects of ramp rates, flow thresholds, wetted history, etc.).

Seasonally targeted higher minimum flows for Chinook during late summer or pulse flows during Chum salmon upstream migration and spawning during the fall, appear to be associated with increased juvenile abundance and survival (CMSMON-1a and 1b). Higher flows may allow spawning salmon to access more or higher productivity spawning habitat in the Cheakamus River. In the case of Chinook, it appears that higher discharges during summer are positively associated with juvenile abundance (CMSMON-1a); however, it is unclear whether higher summer discharges provide adult access to higher productivity spawning habitats, or result in cooler water temperatures which influence egg incubation and juvenile emergence timing. In the case of Chum, pulse flows trigger adult Chum to enter groundwater influenced, side-channel or upstream habitats where egg-to-fry survival rates are higher (CMSMON-1b). Consequently, pulse flows during the Chum adult migration period may increase Chum salmon freshwater productivity in the Cheakamus River.

The effects of WUP flow regime on fish habitat

A key uncertainty of the WUP flow regime was impacts to fish habitat. Several aspects of fish habitat were monitored under the Cheakamus River WUP including mainstem and artificial side-channel habitat quantity and quality, groundwater availability, spawning gravel availability, and benthic community. Findings suggest a limited impact of the WUP flow regime on fish habitat in the Cheakamus River.

During the period of the WUP flow regime, the total area of wetted natural side channel habitat has increased at typical WUP flows in the Cheakamus River (CMSMON-8). In addition, the habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time (CMSMON-8). Changes in mainstem discharge associated with WUP operation were unlikely to have any impact of water quality and consequential habitat suitability for aquatic organisms in the side-channels (CMSMON-6). Groundwater quantity and quality in the side-channels was found to be relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s. In addition, the availability of wetted habitat and total suitable habitat in the groundwater-fed, side-channels was considered insensitive to changes in Cheakamus River mainstem flow below 40 m^3/s (CMSMON-6).

Although not attributed to WUP flows, there was evidence of overall channel stabilization, at the same time as potential erosion and downstream transfer of sediment in the Cheakamus River (CMSMON-8). However, implementation of the WUP flow regime has likely not resulted in any changes to erosion of spawning sediment compared to pre-WUP levels. Within the mainstem of the Cheakamus River, discharge during the fall and winter period does appear to affect the upwelling of groundwater in the mainstem spawning areas, as indicated by redd temperature monitoring. However, the magnitude and direction of changes in redd temperatures was highly variable both among and within sites on the Cheakamus River (CMSMON-1b).

Results of Chum spawning physical habitat modelling conducted during the Water Use Plan process predicted increased habitat availability in the upper reaches of the Cheakamus River. Instead, it was found that strong groundwater upwelling, which is more prevalent in the lower river relative to upstream of the Bailey Bridge, is a primary factor in adult Chum salmon spawning site selection, and that those upper reaches are rarely used by Chum salmon except when prompted by pulse flow events and/or density dependent behavior (CMSMON-1b).

Finally, river discharge was found to be the strongest predictor of benthic productivity in the Cheakamus River; therefore, significant changes in the Cheakamus River flow regime would likely indirectly affect juvenile salmon productivity (CMSMON-7). However, summer flow variation between IFA and WUP was too limited to explain any of the observed changes in benthic production between the two flow regimes suggesting non-WUP factors (e.g., climatic factors or sewage treatment effects) were more likely the cause of observed changes in benthic community.

Recreational angler access during the winter months

A WUP monitoring study was designed to assess angler access during winter months to the upper section of the Cheakamus River under the WUP flow regime. The study found little or no angler effort occurs within the upper reaches of the Cheakamus River during winter (January through March). In addition, providing a minimum flow release from Daisy Lake Dam of 5.0 m^3/s as opposed 3.0 m^3/s likely resulted in little to no additional benefits to recreational angler access and opportunities in the upper reaches of the Cheakamus River from January to March (CMSMON-9).

Below is a summary of key findings of these studies as well as their implications (Table E-1).

Table E-1. Summary of objectives, management questions, outcomes, and implications for the Cheakamus WUP monitoring projects.

Project	Objectives	Management Questions	Response	Implications
CMSMON-1a Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring	The objective of this monitor is to estimate the annual outmigration of juvenile salmonids from the Cheakamus River mainstem and key side-channels, and investigate for effects of discharge and flow regime.	1. What is the relation between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River? 2. Does juvenile salmonid production, productivity, or habitat capacity change following implementation of the WUP flow regime?	1. Flow magnitude in the Lower Cheakamus River during fall and winter months appeared to influence juvenile salmon abundance. High and variable discharges (typically storm events) during fall and winter appeared to negatively affect both Coho smolt and Pink salmon fry production. Whereas, consistent and low base flows in the winter incubation and rearing period may be associated with higher Chinook salmon abundance. Large discharge events in the fall and winter could affect incubating eggs and juvenile salmonids by mobilizing small river bed material and scouring redds, or potentially increasing risk of standing or displacement of newly emerged fry during sudden changes in discharge. However, the ability to manage discharge changes downstream during large inflow events is limited due to the small storage capacity of Daily Reservoir. Higher minimum flows in the Cheakamus River during late-winter/early-spring positively affected Pink salmon fry production; however, the reason is not well understood. Flow magnitude during summer months may also influence juvenile salmon abundance. Higher Minimum flow during Chinook adult migration and spawning appeared to increase juvenile abundance. Cooler water temperatures during Chinook spawning and early egg incubation were also positively associated with juvenile abundance. Late summer/fall water temperature during egg incubation may affect juvenile emergence timing, which could influence survival rate and/or outmigration timing of juveniles in the Cheakamus River. Because discharge and water temperature during August are correlated, it is unclear which variable is primarily affecting Chinook production. 2. Juvenile salmon abundances (Coho and Chinook) were not significantly different between IFA and WUP flow regimes; however high annual variability in juvenile salmon abundance and small sample sizes affects the statistical power of the study (e.g., Pink salmon abundance data were considered too sparse to complete reliable tests).	Reducing flow ramp rates during and following fall storm events may reduce juvenile fish displacement and/or stranding, resulting in increased freshwater production. Higher seasonal minimum discharges in the Cheakamus River during late-summer Chinook upstream migration and spawning may improve Chinook fry production.
CMSMON-1b Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey	The objective of this monitoring project is to estimate annual escapement of adult Chum salmon in the Cheakamus River, and examine the relationships between discharge, groundwater upwelling, and the selection of spawning habitat by adult Chum salmon in the mainstem.	1. What is the relationship between discharge and Chum salmon spawning site selection and incubation conditions? 2. Do the models used 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? 3. Are there other alternative metrics that better represent Chum salmon spawning habitat?	1. Increasing the number of days with discharge between 25 and 80 m^3/s (pulse flows) during the adult Chum salmon migration and spawning appeared to have a positive effect on juvenile productivity. Daily side-channel entries by adult Chum was positively correlated with increases in discharge in the Cheakamus River, which likely resulted in higher productivity because side-channel spawning habitats are known to have increased Chum salmon egg-to-fry survival rates relative to mainstem habitat. In addition, Chum were observed accessing groundwater influenced spawning habitat in the upper reaches of the river in days following pulse flow event, potentially leading to reduced density dependent mortality of eggs. Large magnitude discharge events may result in lower egg-to-fry survival, potentially due to redd scour or alevin displacement. Discharge during the Chum salmon spawning and incubation period does appear to affect the upwelling of groundwater in mainstem spawning areas, as indicated by redd temperature monitoring. However, the magnitude and direction of changes in redd temperatures was highly variable both among and within sites on the Cheakamus River 2. & 3. Results of Chum salmon spawning and physical habitat modelling conducted during the Water Use Plan process predicted increased habitat availability in the upper reaches of the Cheakamus River. Instead, it was found that strong groundwater upwelling, which is more prevalent in the lower river relative to upstream of the Bailey Bridge, is a primary factor in adult Chum salmon spawning site selection, and that those upper reaches are rarely used by Chum salmon except when prompted by pulse flow events and/or density dependent behavior.	Providing pulse flows during the Chum adult migration period may increase Chum salmon freshwater productivity in the Cheakamus River. Consideration of spawning habitat enhancements should be focused on areas of naturally occurring groundwater upwelling.
CMSMON-2 Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)	To assess the potential impacts of flow releases from Daisy Lake Dam under the WUP flow regime on resident Rainbow trout population in the non-anadromous reaches of the Cheakamus River below Daisy Lake Dam.	1. Do Daisy Lake Dam water flow releases affect the resident Rainbow trout population located immediately downstream of Daisy Lake Dam? The parameters of interest include fish density or relative abundance, age class distribution, size-at-age, and relative condition.	1. During the spawning and incubation period (Feb. 1-May 30), Rainbow trout fry density did not appear to be affected by Daisy Lake Dam discharge characteristics; although, minimum discharge appeared to be positively related to the growth of age-0 Rainbow trout. During the summer growth period (June 1-Aug. 31) higher discharges appeared to negatively affect age-0 Rainbow trout density; however, higher mean summer flows were positively related to age-1 Rainbow trout density. There was a slight negative trend in age-0 density detected over the study period; however, age-1 rainbow trout parr density appeared to remain stable over the same period. These results suggest that any decreases in fry densities that occurred under the WUP flow regime were compensated by some density dependent effects. The apparent stable Rainbow trout parr populations observed over the monitoring period suggest there was no population level effect from the WUP flow regime; however, limited data was available to inform conclusions of the study.	The apparent stable Rainbow trout parr populations observed over the monitoring period suggest there was no population level effect from the WUP flow regime.
CMSMON-3 Cheakamus River Steelhead Adult Abundance, Fry Emergence-	Examine the effects of the flow regime on the abundance and survival of key Steelhead life-stages, and ultimately the	1. Do increased flows during July and August negatively affect emergent Steelhead young of year (YoY)? 2. How do changes in flow	1. There was limited statistical support that higher discharges during Steelhead fry early emergence influenced Steelhead egg-to-fry survival, suggesting the prescribed WUP minimum flows during fry emergence (i.e., 38 m^3/s) had limited effect on Steelhead egg-to-fry survival rates. 2. There was insufficient contrast in flow regimes during the WUP study period to answer this management question.	There was no strong evidence to suggest that higher WUP flows during late-summer months (i.e., 38 m^3/s) effected Steelhead egg-to-fry survival. Instead, there was strong evidence to suggest that rapid

Project	Objectives	Management Questions	Response	Implications
timing, and Juvenile Habitat Use and Abundance Monitoring	production of Steelhead smolts in freshwater. Addendum: The terms of reference addendum in 2018 included an objective to assess the potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station	effect habitat use of Steelhead YoY and parr? 3. Will an annual index of parr abundance provide a more robust estimate of Steelhead production in the Cheakamus River relative to the downstream migrant trapping program? 4. Do flows affect juvenile Steelhead production? Addendum: What is the potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station?[1]	3. Abundance estimates of age-0+ and 1+, and survival rates from egg-0+ (fall) and between later life stages, provide a more robust indicator of juvenile steelhead production than downstream trapping. 4. Rapid up- and down-ramps in discharge to the Cheakamus River during early-emergence period (mid-July to early-August) was negatively associated with Steelhead egg-to-fry survival rates. In addition, fry overwinter survival rate was negatively influenced by rapid changes in discharge as well as peak discharge during winter months. There was limited evidence to suggest that Steelhead parr annual survival rate was influenced by discharge; although, Pink salmon returns to the Cheakamus River during odd years had a significant positive effect on Steelhead parr annual survival rate. Steelhead adult returns to the Cheakamus River increased significantly under the WUP flow regime; however, the potential effect was confounded by an increased Steelhead marine survival rate and an effect of increased Pink salmon returns during this period. Correcting for changes in marine survival and Pink salmon returns, Steelhead freshwater production may have decreased during WUP; however, there are large uncertainties in the correction factors applied. Addendum: Potential risks to juvenile fish in the Squamish River associated with Cheakamus Generating Station operations were identified in a desktop study. These risks were highest during winter months when natural inflows were low and during hydropeaking operations at the Cheakamus Generating station. However, further studies would be required to verify the effect of flows from Cheakamus Generating Station on fish populations in the Squamish River[4].	changes in discharge (i.e., flow ramp downs) were associated with reduced survival of early-life stages of Steelhead in the Cheakamus River. To further understand causal mechanisms of fish stranding associated with rapid flow ramp downs and to test the effectiveness of potential mitigation measures, the Cheakamus Adaptive Stranding Protocol (CASP) has been implemented on the Cheakamus River outside of the WUP Order projects. Information gathered during the CASP will also be used to inform WUP Order Review with regards to fish stranding impacts associated with flow changes (e.g., effects of ramp rates, minimum flows, wetted history, etc.) on the Cheakamus River. Large uncertainties associated with marine survival rates of Cheakamus Steelhead limit the value of examining escapement trends to evaluate freshwater flow effects on production. Addendum: The Squamish River desktop stranding analysis highlighted key areas for focus in future study to identify potential effects of fluctuating discharges from Cheakamus Generating Station on juveniles.[2]
CMSMON-4 Monitoring Stranding Downstream of Cheakamus Generating Station	To address key uncertainties related to the Cheakamus generating station operation and potential fish stranding impacts in the tailrace channel and Squamish River side-channel downstream. (Stranding potential in the Squamish River downstream of the tailrace is being reviewed under CMSMON-3.)	1. What is the magnitude of stranding risk in the tailrace channel downstream of the Cheakamus Generating Station, and at what time of the year is it at its highest level? 2. What is the aerial extent of the stranding impact should it occur? 3. Does a peaking operation at the powerhouse prevent juvenile salmonids from colonizing habitats that are prone to dewatering? 4. What is the stranding risk to spawning adults and resulting redds when in the tailrace channel? 5. If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?	1. Stranding risk below the Cheakamus Generating Station was relatively low compared to risks identified in Cheakamus River (Hoogendoorn et al. 2009); therefore monitoring results suggest in general that the observed stranding rate would likely not be harmful to local fish populations, although the effect on populations could vary by species abundance. The highest fish stranding risk resulting from ramp downs at the Cheakamus Generating Station occur during time of year when water levels in the Squamish River are typically low (December-April, September). 2. Due to limited channel bathymetric data, the hydraulic model was incapable of evaluating the total aerial extent of stranding or site specific fish stranding patterns. During low water levels/high stranding risk periods, the relative area of potential stranding risk was the highest for the 55-0 m^3/s ramp-down mode, followed by the 25-0 m^3/s, and finally the 55-25 m^3/s ramp-down scenarios. 3. Although juvenile fish abundances appeared lower under higher discharge from the Cheakamus Generating Station, peaking operations do not prevent juvenile fish from colonizing habitats prone to dewatering in the tailrace channel or side-channel downstream. 4. Based on fish stranding survey results and corresponding calculation of relative fish stranding risk index, adult stranding risk was lower than the average stranding risk calculated during monitored ramp downs from the Cheakamus Generating Station, and only occurred during one stranding risk survey. However, redds located in the tailrace and side-channel area have the potential to dewater if Cheakamus Generating Station was ramped down when the Squamish River level was at low flow levels. 5. While the risk of stranding was relatively low, several mitigation measures were discussed.	Fish stranding risk in the Cheakamus Generating Station tailrace channel and Squamish River side-channel immediately downstream was relatively low and unlikely to have fish population level impact[3]. Fish stranding risk was highest during period of low flow in the Squamish River (December-April, or September), during larger ramp downs from the generating station, and when ramped down to zero discharge. Mitigation options were discussed in the study, but none were assessed during the study period. Note: further assessment of potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station was completed as an addendum to CMSMON-3 (see above).
CMSMON-5 Monitoring Stranding Downstream of Daisy Lake Dam	To assess efficacy of WUP ramp rates to minimize fish stranding risk downstream of Daisy Lake Dam, and to assess the attenuating effect of downstream tributary inflow on flow ramping.	1. Is the prescribed ramping rate for flows less than 10 m^3/s adequate to prevent fish stranding when the minimum release out of the Daisy Lake Dam is lowered on 1 Nov to 3 m^3/s from its high of 7 m^3/s during the preceding growing season? 2. To what extent do the inflows of Rubble Creek impact the rate of stage change downstream of Rubble Creek, and do the inflows of other tributaries impact the rate of stage change at the Brackendale Gauge?	1. A total of 35 fish were observed stranded during the Daisy Lake Dam flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018. This was considered to be below the maximum acceptable level of stranding established in consultation with regulatory agencies (DFO and MOE). 2. The magnitude and rate of the stage change downstream of Rubble Creek had clearly been attenuated by tributary inflow. However, the total stage change in several of the sites still exceeded the target rate of $2.5 cm\text{-}hr^{-1}$.	Although prescribed WUP ramp rates from Daisy Lake Dam (1 m^3/s per 60 min) resulted in stage change rate downstream that exceeded -2.5 cm/hr during the flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018, the study concluded that fish stranding rates were below maximum acceptable levels established by DFO and MOE (discussed below). Given that stranding is a low risk in the resident reach, and given the results of CMSMON-3 suggest that flow reductions may have a measurable impact on anadromous populations in the Cheakamus River, the Cheakamus Adaptive Stranding Protocol will focus its efforts on mitigating stranding risks in the lower reaches of the Cheakamus River.

Project	Objectives	Management Questions	Response	Implications
CMSMON-6 Monitoring Groundwater in Side Channels of the Cheakamus River	To investigate linkages between Cheakamus River mainstem flows, floodplain groundwater systems, and corresponding effects on fish habitat and productivity.	1. To what extent does seasonal North Vancouver Outdoor School (NVOS) and Tenderfoot Hatchery floodplain shallow groundwater flow direction, and selected water quality parameters (temperature, dissolved oxygen, and pH) vary in response to Cheakamus River mainstem flows ≤ 40 m^3/s? 2. To what extent does seasonal NVOS and Tenderfoot Hatchery side channel hydrology depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s? 3. To what extent do key fish habitat variables related to flow (average depth, average velocity, discharge) and water quality (temperature, dissolved oxygen, and pH) in NVOS and Tenderfoot Hatchery side channels depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s? 4. To what extent does salmonid production vary in NVOS and Tenderfoot Hatchery side channels in relation to groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s, and to what extent has the implementation of the WUP affected salmonid production in the NVOS and Tenderfoot Hatchery side channel habitats compared to the pre-WUP state?	1. The ground-surface water interface in the Cheakamus River side-channel area was relatively stable at low and moderate flows. Between 15 and 40 m^3/s the magnitude of change in groundwater elevation in the side-channel habitat was very minor. Analysis showed that the groundwater source for each side channel was the Cheakamus River. Therefore, Cheakamus River flow variation within the relevant management range (e.g., 15 to 70 m^3/s) had no practical effect on pH, dissolved oxygen, or temperature in upwelling groundwater or surface water in the side-channels. 2. The magnitude of effect of Cheakamus River flows on side channel seasonal hydrology was very small and diminished with mainstem flows below 40 m^3/s; therefore, side-channel hydrology is considered functionally insensitive to changes in mainstem discharge between 40 and 15 m^3/s. 3. The availability of wetted habitat and total suitable habitats in the side-channel habitats was considered insensitive to changes in Cheakamus River mainstem flow below 40 m^3/s. Changes in mainstem discharge associated with WUP operation were unlikely to have any impact of water quality and consequential habitat suitability for aquatic organisms in the side-channels 4. There was limited evidence of any causal relationship between groundwater parameter and fish production in the side channels. A significant correlation was observed between water level fluctuations in the groundwater channels during incubation and the Chum salmon egg-to-fry survival rate; however, variability in water level was relatively independent of Daisy dam operations. In addition, there was no evidence to support that quantity or quality of habitat available in the groundwater side channels has been meaningfully impacted by the WUP compared to pre-WUP state.	Because the groundwater quantity and quality in the side-channels was relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s, it is unlikely that the WUP flow regime resulted in any biologically significant impact to fish habitat or fish productivity in the Cheakamus side-channel area.
CMSMON-7 Cheakamus River Benthic Community Monitoring	The objective of this study was to continue on work in 1996 and 1999 to develop the Cheakamus Benthos Model for use in evaluating river health as indicated by attributes of benthic invertebrate and periphyton communities.	1. What habitat and flow attributes best determines the composition, abundance, and biomass of benthic invertebrates in the Cheakamus River? 2. Among all habitat and flow attributes, what is the relative importance and magnitude of effect of water release from the Daisy Lake Dam in determining the composition, abundance, and biomass of benthic communities in the Cheakamus River?	1. Metrics of flow, temperature, turbidity, elevation, periphyton biomass, cover from riparian vegetation, and suspended solids were the top predictors of benthic invertebrate biomass, composition, and abundance. 2. River discharge was found to be the strongest predictor of benthos biomass, abundance, and richness in the Cheakamus River. However, these trends did not explain the variability in benthos production between samples in 1996, 1999 and 2009.	Modeling results showed that river discharge was the strongest predictor of benthic productivity; therefore, significant changes in the Cheakamus River flow regime would likely indirectly affect juvenile salmon productivity. Non-flow related factors (e.g. climatic factors or sewage treatment effects) were likely responsible for any observed differences in benthic production between the between IFA and WUP, as variation in summer flow is too limited between the flow regimes to explain the differences in production. This model could provide a basis for evaluating potential future flow regimes in the WUP Order Review if the potential flow regimes have substantial differences in average seasonal discharge.
CMSMON-8	The objective of this	1. Following implementation of	1. At two known salmon spawning sites on the Cheakamus River, discharges that could result in erosion of	Implementation of the WUP flow regime did not change the

Project	Objectives	Management Questions	Response	Implications
Monitoring Channel Morphology in Cheakamus River	study was to assess the response of Cheakamus River morphology and sediment transport to changes in flow patterns from Daisy Lake Dam associated with WUP flow regime.	the WUP, has there been degradation in spawning habitat via erosion?[2] 2. Following implementation of the WUP, has there been a change in the overall length, access and utility for fish of naturally occurring side channels from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factors? 3. To what extent does the hydrology of Rubble Creek, Culliton Creek, and Swift Creek contribute to the general hydrology of lower Cheakamus River and how does it attenuate the effects of Daisy Lake Dam operations?	spawning substrate varied between 160 and 270 m^3/s. Because changes to the flow regime between pre-WUP and WUP are generally below 50 m^3/s, implementation of the WUP flow regime has not resulted in any additional erosion of spawning sediment compared to pre-WUP levels. 2. The total area of wetted natural side channel habitat has increased at typical flows in the Cheakamus River. The habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time. Although not attributed to WUP flows, results of the study show evidence of overall channel stabilization, at the same time as potential erosion and downstream transfer of sediment in the Cheakamus River. The question of access could not be directly addressed by the study methodology. 3. Tributary inflows have a large impact on flow regime downstream of Daisy Lake Dam. Daily average tributary inflow to the Cheakamus River between Daisy Lake Dam and the WSC gauge was 16 m^3/s; under the WUP flow regime, tributary inflow was about 1.4 times that of Daisy Lake Dam discharges. The attenuating effects of tributary inflow are strongest during fall and winter when Daisy Lake Dam discharge is low; even though tributary inflow is highest during summer months, the attenuating effects were relatively weak as Daisy Lake Dam discharge are typically at their highest.	presence of spawning gravel or fish habitat types; therefore it is unlikely that future flow changes within the operating bounds of the WUP and the IFA would affect the availability of spawning gravel or fish habitat types. Tributary inflows are most influential during the fall and winter, when Daisy Lake Dam discharges are low.
CMSMON-9 Cheakamus River Recreational Angling Access Monitoring	To understand potential effects of the WUP winter minimum flow on recreation angler access and utility of the Upper reaches of the Cheakamus River	1. Does angling occur during this time of year in sections of the river that would be affected by this operation? 2. Is access to recreational angling locations during 1 January to 31 March improved under the 5.0 m^3/s minimum flow release from Daisy Lake Dam relative to that which would occur with a 3.0 m^3/s minimum flow release?	1. Little or no angler effort occurs within the upper reaches of the Cheakamus River during winter January through March. 2. Angler opportunity is unlikely to differ between 5.0 m^3/s and 3.0 m^3/s.	Providing a minimum flow release from Daisy Lake Dam of 5.0 m^3/s as opposed 3.0 m^3/s likely resulted in little to no additional benefits to recreational angler access and opportunities in the upper reaches of the Cheakamus River from January to March. It is unlikely that any further change in flow would result in any meaningful improvement to angler access. The current minimum flow has potential fisheries benefits.

[1] This management question was added to address changes made to the study in terms of reference addendum (BC Hydro 2018a).
[2] CMSMON-4 investigated only the impacts of operations in the Cheakamus Generating Station tailrace and Squamish River side-channel directly downstream and concluded there was likely no population level effect associated with the impacts observed in those locations.
[2] CMSMON-3 addendum investigates potential stranding risk in the mainstem of the Squamish River downstream of the Cheakamus Generating Station.

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List of Abbreviations

CC Consultative Committee

CMS Cheakamus facilities

CWR Comptroller of Water Rights

DFO Fisheries and Oceans Canada

IFA Interim Flow Agreement

MALS Maximum Acceptable Level of Stranding

MOE BC Ministry of Environment

PIT Passive Integrated Transponder

TOR Terms of Reference

WLR Water License Requirements

WSC Water Survey of Canada

WUP Water Use Plan

YOY Young of Year

Glossary of Terms

Consultative Committee (CC): Consisted of 20 members who represented Federal, Provincial, Regional, and Municipal governments; the Squamish Nation; BC Hydro; environmental and recreational interests; and local stakeholders.

Escapement: Refers to the number of adult fish allowed to escape the fishery and spawn.

Fry: Refers to a recently hatched fish that has reached the stage where its yolk-sac has almost disappeared and the fish can actively feed for itself up to 1 year of age.

Maximum Acceptable Level of Stranding (MALS): A measurable criteria for assessing fish stranding risk established for CMSMON-5 in consultation with regulatory agencies (DFO and MOE) in 2008.

Operating Strategy: A collection of operating constraints applied to BC Hydro facilities in the Cheakamus system.

Parr: A juvenile salmon (or trout) between the stages of fry and smolt where it grows and develop for up to 3 years.

Significant: Means statistically significant when used in this document.

Smolt: A juvenile salmon (or trout) that is a process of physiological change to allow it to migrate out to the ocean.

Water Use Plan Order (WUP Order): legal document issued by the Comptroller of Water Rights defining how water control facilities will be operated to support WUP objectives and outlines the monitoring programs and/or physical works required to support the those WUP operations.

Water Use Plan (WUP): technical document that, following review by provincial and federal agencies and acceptance by the provincial Comptroller of Water Rights (CWR), supports the development of a WUP Order issued to BC Hydro by the Comptroller of Water Rights

Cheakamus Water Use Plan
Monitoring Program Synthesis Report

1.0 CONTEXT

The Cheakamus Water Use Plan (WUP) process was first initiated in 1996. However, in May 1997, DFO issued a Flow Order requiring the discharge of minimum flows from Daisy Lake Dam. The Water Use Plan process was then paused. In July 1998, a working group comprised of BC Hydro, DFO, BC Ministry of Fisheries, BC Ministry of Environment, Lands and Parks, the Steelhead Society of BC and Squamish First Nation began meeting to develop an interim flow regime and achieve consensus with all parties. The Comptroller of Water Rights (CWR) accepted an out of court interim flow settlement (the “Interim Flow Agreement” or IFA), which was implemented in December 1998. The WUP project was again initiated in February 1999 and completed in April 2002, ending in a non-consensus recommendation to implement a set of target flows that differed from the IFA. In 2005 the Cheakamus WUP was finalized and submitted to the CWR.

On February 17, 2006, the CWR issued an Order under the *Water Act*[2] (the “WUP Order”) in response to the Cheakamus WUP. The CWR decided in favour of the WUP recommendations including the implementation of 10 monitoring projects conducted between 2007 and 2019. There were no physical works projects required by the WUP Order.

Monitoring studies were initiated under the Cheakamus WUP to assess the uncertainties surrounding potential benefits or impacts of the WUP flow regime on fish, fish habitat, and recreational angling. The 10 monitoring projects are as follows:

1. CMSMON-1a: Cheakamus River Juvenile Outmigrant Enumeration: A 12-year monitoring program to enumerate juvenile salmonid outmigration from the Cheakamus River mainstem and key side channels.
2. CMSMON-1b: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey: A 12-year monitoring program to enumerate Chum spawning escapement and examine groundwater in mainstem spawning areas.
3. CMSMON-2: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon): A five-year monitoring program for Rainbow trout in the non-anadromous section of the Cheakamus River.
4. CMSMON-3: Cheakamus River Steelhead Adult Abundance, Fry Emergence-Timing, and Juvenile Habitat Use Abundance Monitoring: A 12-year monitoring program to examine the effects of mainstem flows on Steelhead production.

[2] The *Water Act* was replaced by the *Water Sustainability Act* in February 2016; however Orders and Water Licences continue to be valid and are governed by the new *Water Sustainability Act*.

5. CMSMON-4: Monitoring Stranding Downstream of Cheakamus Generating Station: A three-year monitoring program to examine stranding downstream of the Cheakamus generating station tailrace on the Squamish River.
6. CMSMON-5: Monitoring Stranding Downstream of Daisy Lake Dam: A one-year monitoring program to monitor fish stranding downstream of Daisy Lake Dam.
7. CMSMON-6: Monitoring Groundwater in Side Channels of the Cheakamus River: A five-year program to monitor the effect of Cheakamus mainstem flows on groundwater-fed side channels.
8. CMSMON-7: Cheakamus River Benthic Community Monitoring: A three-year monitoring program and modelling exercise to examine the effects of mainstem flows on the benthic community.
9. CMSMON-8: Monitoring Channel Morphology in Cheakamus River: A 10-year monitoring program to examine the effects of flows on channel morphology in the Cheakamus River mainstem.
10. CMSMON-9: Cheakamus River Recreational Angling Access Monitoring: A one-year monitoring program to examine the benefits to recreational angling access (available angling locations) of the 1 January to 31 March 5.0 $m^3 \cdot s^{-1}$ minimum flow release from Daisy Lake Dam.

This document was prepared as a part of the WUP Order Review process. It summarizes the outcomes from the monitoring projects and outlines whether the management questions have been addressed (Table E1).

The WUP Order Review process includes two stages with two core deliverables:

- Stage 1: The Monitoring Program Synthesis Report (MPSR – this report); and
- Stage 2: The WUP Order Review Report.

The purpose of the WUP Order Review is to determine whether the ordered facility operational constraints and the physical works in lieu of operation changes are achieving the specific environmental and social objectives identified in the WUP.

Both the draft MPSR and draft WUP Order Review Report are shared with government agencies, First Nations and key stakeholders for review and comment. The WUP Order Review process will enable BC Hydro to recommend to the Comptroller of Water Rights how the WUP Order and its conditions may be concluded, clarified, modified, or confirmed for future operations.

The specific objectives of the MPSR are to:

1. Provide a summary of the objectives, activities, and results for each of the 10 monitoring projects;
2. Relate monitoring project findings to the objectives of the Cheakamus WUP and provide any updates to these project findings from other work conducted after the projects were completed;
3. Where management questions were not addressed, identify the data gaps that persist; and

4. Summarize the implications of study outcomes as they may pertain to future operating decisions in the WUP Order Review.

2.0 PROJECT BACKGROUND

2.1 Hydroelectric Facilities

The Cheakamus facilities are located roughly 30 km north of Squamish BC (Figure 2.1). Daisy Lake Reservoir is located adjacent to the Sea-to-Sky Highway (Highway 99) and impounds water flowing south from the headwaters of the Cheakamus River. A portion of that water is released from the Daisy Lake Dam down the 26 km stretch of Cheakamus River to its confluence with the Squamish River. The remainder of the water in Daisy Lake Reservoir is diverted through a tunnel that runs through Cloudburst Mountain to the Cheakamus Generating Station, located on the left bank of the Squamish River (BC Hydro 2005)

The Cheakamus generating system was completed in 1957 and is comprised of the Daisy Lake Dam and Reservoir, the 180 MW (current nameplate capacity) Cheakamus Powerhouse in the Squamish Valley, and a connecting tunnel through Cloudburst Mountain. The normal operating range of Daisy Lake Reservoir is 368.50 m to 376.50 m above sea level, a fluctuation of 8 m. The reservoir can store approximately 42.5 million cubic meters of water, which is only 2.7 per cent of average annual inflow (Table 2.1).

Water for generating electricity is drawn from Daisy Lake Reservoir via a canal under the Sea-to-Sky Highway into Shadow Lake where it enters a 5.5 m diameter, 11 km long tunnel that runs through Cloudburst Mountain to the Squamish Valley. Twin penstocks carry the water from the tunnel exit to the Cheakamus generating station after which it is discharged into the Squamish River. The maximum flow from the generating station is 65 m^3/s with a 340 m difference in elevation between Shadow Lake and the generating station (BC Hydro 2005)

Cheakamus Power Facility operates under the Conditional Water Licence 110107 and Conditional Water Licence 114268, which authorise the diversion, storage, and use of water for power purpose at the Cheakamus power development. (Comptroller of Water Rights, 2006)

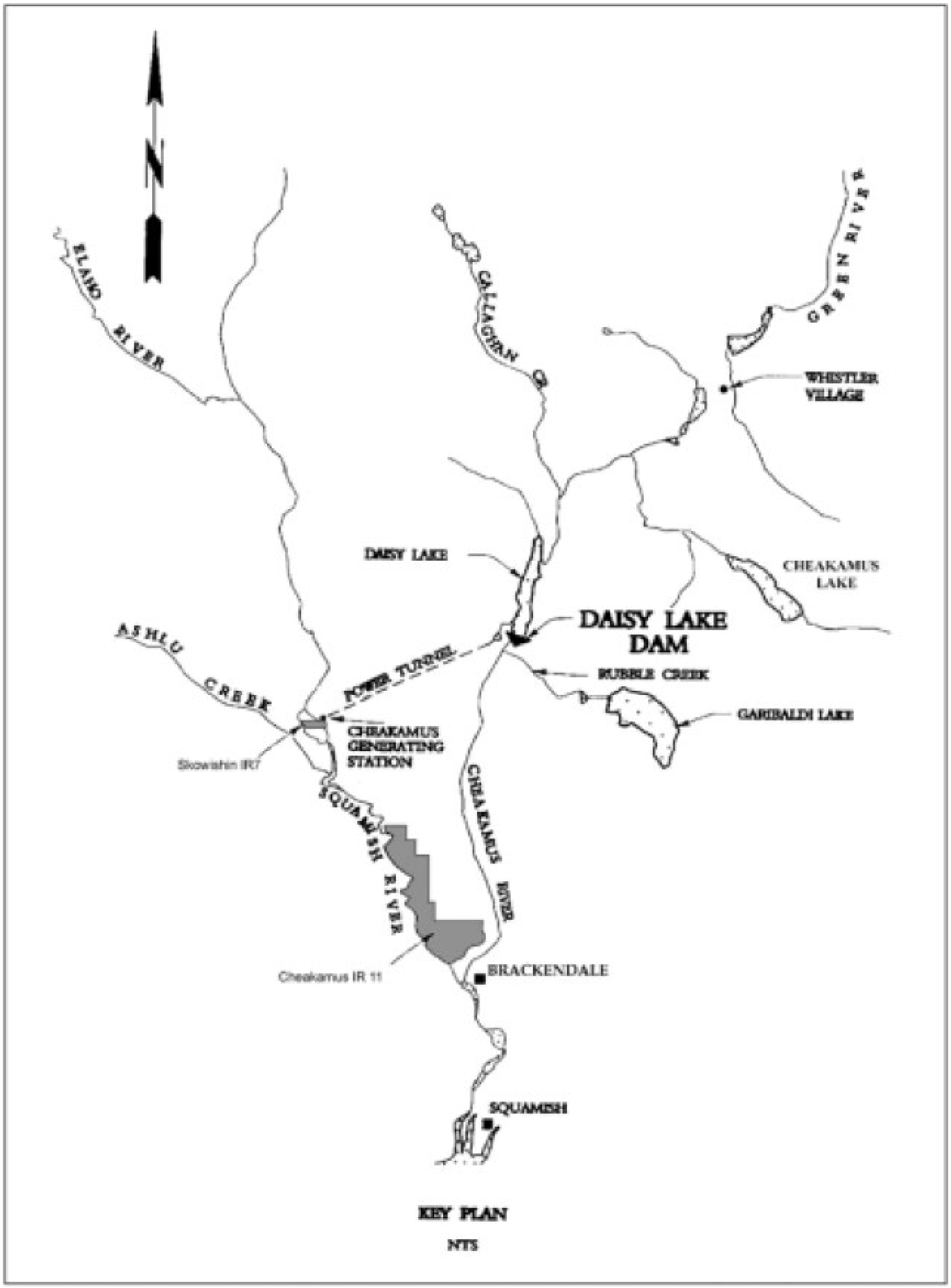

Figure 2.1. Site map of Cheakamus Facility.

Table 2.1. Cheakamus Project general information (BC Hydro 2018b)

Dam Name	Daisy Lake Dam
Year of Completion	1957
Dam Type	Concrete (Main Dam and Wing Dam adjoining the Main Dam) and Earthfill (adjoining the Main Dam).
Dam Use	Diversion and Storage
Dam Height	29 m
Spillway Type	High Radial Outlet Gates (SPOG) (2)
Max. Discharge Capacity of Spillway	1140 m^3/s at 376.5 m
Generating Station	Cheakamus Generating Station
Nameplate Capacity	180 MW
Storage	42.5 Mm^3 (26.5 Mm^3 - normal Operations)
Reservoir Name	Daisy Lake Reservoir
Reservoir Area at Max. Normal Level	4.3 km^2 at 378.0 m
Water Course	Cheakamus River
Drainage Area	721 km^2
Reservoir Operating Range	364.90 m to 377.95 m (Full Water Licence Range) 368.50 m to 376.50 m (Normal Operating Range)
Upstream Project	N/A
Downstream Project	N/A
Nearest City	Squamish, BC

3.0 Cheakamus WUP Process

The Cheakamus WUP process was initiated in 1996. However, in May 1997 the project was put on hold when DFO placed a Flow Order that specified minimum flows to be discharged from Daisy Lake Dam. The Comptroller of Water Rights accepted an out of court interim flow agreement (IFA) in December 1998. The WUP process was again initiated in February 1999 following the Water Use Plan Guidelines developed by the province (Province of British Columbia 1998). The consultative process wrapped up in 2002 but consensus was not achieved. In 2006, the CWR issued the WUP Order that included implementation of the WUP operating regime and recommended monitoring projects. The process created the following outputs (in chronological order):

- Cheakamus WUP: Report of the WUP CC (BC Hydro 2002) – documentation of the structured decision making process which evaluated operating alternatives against objectives represented by the WUP CC, and documented uncertainties that would define the study project for implementation following WUP approval.
- Cheakamus WUP (BC Hydro 2005) – submitted by BC Hydro to the CWR as the summary of operating constraints and implementation commitments (monitoring projects) to be appended to its Water Licences.

- Cheakamus Facility WUP Order (Comptroller of Water Rights 2006) – the *Water Act* Order issued by the CWR to implement the WUP as a condition of Conditional Water Licences 110107 and 114268 associated with the Cheakamus projects.
- Water Licence Requirements (WLR) Terms of Reference (TOR; BC Hydro 2007a-j, 2012 a, b, and 2018 a) – for monitoring projects ordered by the CWR; management questions and methodologies were prepared to address uncertainties defined in the WUP consultative process and submitted to the CWR for Leave to Commence.
- Project progress and annual watershed reports – reports summarizing results for projects were prepared for each study by consultants and watershed activities were summarized each year by BC Hydro in a watershed annual report and submitted to the CWR. Reports are available on BC Hydro's WUP website:

  https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html

The WUP CC identified uncertainty of the benefits associated with the following operating conditions (Marmorek and Parnell 2002).

- Minimum flows for fish production
- Ramping rates for stranding mitigation downstream from Daisy Lake Dam and the Cheakamus Generating Station
- Minimum flows to maintain groundwater levels in side-channels
- Minimum flows for benthic productivity
- Flow effects on channel morphology
- Minimum flows for Steelhead angling access 1 January to 31 March

The Cheakamus IFA, which defined the flow regime from December 1998 to February 2006, prescribed discharge from Daisy Lake Dam into the Cheakamus River to be the greater of 5 m^3/s or 45% (+/- 7%) of the previous seven days average inflows to the reservoir. The current WUP flow regime provides minimum flows requirements at the Daisy Lake Dam and further downstream at Water Survey of Canada's Brackendale stream gauge (WSC Gauge). The WUP operating conditions under the Cheakamus WUP Order are shown in Table 3.1.

Monitoring projects were ordered to address the data gaps and uncertainties in the Cheakamus WUP and to assess whether anticipated benefits from changes made under the WUP were actually achieved. Results from monitoring projects are reviewed upon completion as part of BC Hydro's WUP Order Review process, and the results are used and considered along with other values to support decisions about whether further changes may be considered during the WUP Order Review.

The following projects were implemented under BC Hydro's Water Licence Requirements program according to these terms of references:

- CMSMON-1a: Cheakamus River Juvenile Outmigrant Enumeration: A 12-year monitoring program to enumerate juvenile salmonid outmigration from the Cheakamus River mainstem and key side channels.

- CMSMON-1b: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey: A 12-year monitoring program to enumerate Chum spawning escapement and examine groundwater in mainstem spawning areas.
- CMSMON-2: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon): A five-year monitoring program for Rainbow trout in the non-anadromous section of the Cheakamus River.
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- CMSMON-9: Cheakamus River Recreational Angling Access Monitoring: A one-year monitoring program to examine the benefits to recreational angling access (available angling locations) of the 1 January to 31 March 5.0 $m^3 \cdot s^{-1}$ minimum flow release from Daisy Lake Dam.

All WUP Terms of reference, including any revisions and addenda were reviewed by agencies and circulated to First Nations for review and comment prior to submission to the Comptroller of Water Rights.

The operating conditions under the Cheakamus WUP Order issued by the CWR are shown in Table 3-1.

Table 3.1. Operating conditions of the WUP Order for the Cheakamus Hydroelectric system (Comptroller of Water Rights 2006)

System Component	Constraint	Time of Year	Purpose
Daisy Lake Reservoir (Clause 2. a)	To reduce flood risk downstream of Daisy Lake Dam, the target maximum reservoir level shall be 373.5 m, measured at Daisy Lake Dam using the local datum.	October 1 to December 31	Provide additional storage space in the reservoir to assist in managing high inflow events.
Daisy Lake Dam (Clause 2. b)	For fisheries habitat, the licensee shall release from Daisy Lake Dam a minimum flow of: i) 3 m^3/s ii) 5 m^3/s iii) 7 m^3/s	 November 1 to December 31 January 1 to March 31 April 1 to October 31	Provide minimum environmental flows for fish production in the non-anadromous reach of Cheakamus River.
Daisy Lake Dam (Clause 2. c)	For fisheries habitat and recreational use, the licensee shall release additional flows to those specified in 2b) above in order to maintain a minimum flow at the location of Water Survey of Canada (WSC) gauge 08GA043 near Brackendale of: 1. 15 m^3/s 2. 20 m^3/s 3. 38 m^3/s 4. 20 m^3/s 5. 20 m^3/s	 November 1 to March 31 April 1 to June 30 July 1 to August 15 August 16 to August 31, unless otherwise directed by the Comptroller to increase flows to 38 m^3/s for the benefit of recreation. September 1 to October 31	Provide minimum environmental flows for fish production in the anadromous reach of Cheakamus River and recreation flows for kayaking.
	Ramping rates shall not exceed the maximum rates prescribed in Schedule A [listed below].		
Daisy Lake Dam (Clause 2. D and Schedule A)	1. With respect to the Cheakamus River below Daisy Lake Dam, BC Hydro shall limit changes to flow rates according to the following: • If total discharge from Daisy Lake Dam was less than 10 m^3/s: ○ maximum rate of increase:13 m^3/s per 15 minutes	Year-round	Mitigate fish stranding risk downstream form Cheakamus Dam

System Component	Constraint	Time of Year	Purpose
	○ maximum rate of decrease: 1.0 m^3/s per 60 minutes • If total discharge from Daisy Lake Dam was 10-62 m^3/s: ○ maximum rate of increase: 13 m^3/s per 15 minutes ○ maximum rate of decrease: 13 m^3/s per 60 minutes • If total discharge from Daisy Lake Dam was greater than 62 m^3/s: ○ maximum rate of increase: 13 m^3/s per 10 minutes ○ maximum rate of decrease: 13 m^3/s per 10 minutes 2. The above ramping rates will be reviewed following the results of the monitoring outlined in 4 vi) of the order [CMSMON-5].		
Cheakamus Generating Station (Schedule A, Clause 3.)	During reduction of load a the Cheakamus powerhouse between loads of 40 MW and 10 MW, the rate of reduction shall not exceed: • 10 MW per 5 minutes Turbine ramping rates will be reviewed following results of the monitoring outlined in 4 iv) and v) of the order [CMSMON-4].	Year-round	Mitigate fish stranding risk downstream from the Cheakamus Generating Facility

4.0 ORDERED MONITORING PROJECT SUMMARY

4.1 CMSMON-1a: Cheakamus River Juvenile Outmigrant Enumeration

4.1.1 Project Summary

The primary objective of this monitoring program was to examine the effects of the WUP flow regime on the production of juvenile salmonids from the mainstem of the Cheakamus River and major side channels. This program was a continuation and expansion of a program initiated during the consultative process to monitor juvenile outmigration under the Interim Flow Agreement (IFA) which was accepted by the CWR in December 1998. Juvenile salmon abundance data collected under this program was used in conjunction with spawner data collected under CMSMON-1b to develop stock-recruitment relationships for Chum Salmon. The stock-recruitment relationships were evaluated to separate effects of spawning escapement from flow-related changes in survival during incubation and freshwater rearing (BC Hydro 2007a).

The original TOR specified a five-year monitoring period from implementation. Results following the first five years of the monitoring program were deemed insufficient to answer the management questions[3]. In addition, the caustic soda spill into the Cheakamus River in 2005 occurred during the five-year study period, affecting the results of monitoring. Consequently, the TOR was revised in 2012 (BC Hydro 2012a) to extend the CMSMON-1a monitoring program an additional five years. No changes were made to the management questions, with only minor modification to some tasks and methodologies. The CMSMON-1a program was extended an additional two years until spring 2019 to complement adult escapement data collected under CMSMON1b.

Objectives	Management Questions[1]	Response	Implications
The objective of this monitor is to estimate the annual outmigration of juvenile salmonids from the Cheakamus River mainstem and key side-channels, and investigate for effects of discharge and flow regime.	1. What is the relation between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side channels of the Cheakamus River? 2. Does juvenile salmonid production, productivity, or habitat capacity change following implementation of the WUP flow regime?	1. Flow magnitude in the Lower Cheakamus River during fall and winter months appeared to influence juvenile salmon abundance. High and variable discharges (typically storm events) during fall and winter appeared to negatively affect both Coho smolt and Pink salmon fry production. Whereas, consistent and low base flows in the winter incubation and rearing period may be associated with higher Chinook salmon abundance. Large discharge events in the fall and winter could affect incubating eggs and juvenile salmonids by mobilizing small river bed material and scouring redds, or potentially increasing risk of standing or displacement of newly emerged fry during sudden	Reducing flow ramp rates during and following fall storm events may reduce juvenile fish displacement and/or stranding, resulting in increased freshwater production. Higher seasonal minimum discharges in the Cheakamus River during late-summer Chinook upstream migration and spawning may improve Chinook fry production.

[3] The status of answering the Management Questions after the first five years of study was discussed with the Cheakamus WUP Monitoring Committee at an Interim Review in 2012.

		changes in discharge. However, the ability to manage discharge changes downstream during large inflow events is limited due to the small storage capacity of Daily Reservoir. Higher minimum flows in the Cheakamus River during late-winter/early-spring positively affected Pink salmon fry production; however, the reason is not well understood. Flow magnitude during summer months may also influence juvenile salmon abundance. Higher Minimum flow during Chinook adult migration and spawning appeared to increase juvenile abundance. Cooler water temperatures during Chinook spawning and early egg incubation were also positively associated with juvenile abundance. Late summer/fall water temperature during egg incubation may affect juvenile emergence timing, which could influence survival rate and/or outmigration timing of juveniles in the Cheakamus River. Because discharge and water temperature during August are correlated, it is unclear which variable is primarily affecting Chinook production. 2. Juvenile salmon abundances (Coho and Chinook) were not significantly different between IFA and WUP flow regimes; however high annual variability in juvenile salmon abundance and small sample sizes affects the statistical power of the study (e.g., Pink salmon abundance data were considered too sparse to complete reliable tests).	

[1] TOR reference; BC Hydro 2007a, pp.19

4.1.2 Project Approach

In 2001, a juvenile salmonid migration monitoring program was initiated by the Cheakamus WUP Consultative Committee to evaluate anadromous fish production and productivity in the Cheakamus River under the Interim Flow Agreement (IFA). This monitoring study was continued under the WUP monitoring project CMSMON-1a starting in spring 2007, and extended until spring 2019 to complement CMSMON-1b Chum salmon adult escapement data. The monitoring project was completed by InStream Fisheries Research, Inc. Annual reports were compiled each year following 2007. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach to this monitoring project was to annually estimate out-migrating juvenile salmon (Chum, Pink, Chinook and Coho salmon) abundances in the Cheakamus River across two different flow treatments (IFA: 2001-2006, and WUP: 2007-2019). Prior to implementation of the WUP studies, only mainstem juvenile fish production was monitored; however, in order to answer WUP management questions, side-channel production was monitored separately from mainstem production starting in 2007. From 2001 to 2019, juvenile salmon were trapped on the mainstem Cheakamus River using Rotary Screw Traps (RSTs). Starting in 2007, juvenile salmon were also trapped in side-channels using fyke nets and weir- style fish fences. Locations on trap sites on the mainstem and side-channels of the Cheakamus River are shown in Figure 4.1.a.

Mark-recapture methods were used to estimate weekly abundance for both side-channels and mainstem habitats (Lingard et al. 2019). Spawner abundance data were required to evaluate where differences in annual juvenile production are attributable to changes in freshwater survival. Spawner abundance data were not collected for Coho, Chinook and Pink salmon in the Cheakamus River during the WUP monitoring program; therefore, stock-recruit relationships were only developed for Chum salmon – discussed in the following chapter for CMSMON-1b.

To assess the effect of discharge on juvenile salmon production (Coho, Chinook and Pink salmon) a suite of discharge and temperature variables were calculated for the Cheakamus River (selected based on hypothesised effects from literature). Discharge and temperature variables were summarized for the spawning, incubating/rearing, and migrating periods for each species. Linear regression models were used to test if each variable explained variability in juvenile salmon abundance across years. Variables that significantly predicted abundance in linear regressions were critically assessed using professional judgement as well as clustering of Pearson's correlations coefficient to select final regression models for each species (Lingard et al. 2019). Variables from final regression models were tested to see if there were significant changes between IFA and WUP flow treatments. Finally, T-tests were used to compare differences in juvenile salmon abundances between IFA and WUP flow treatments.

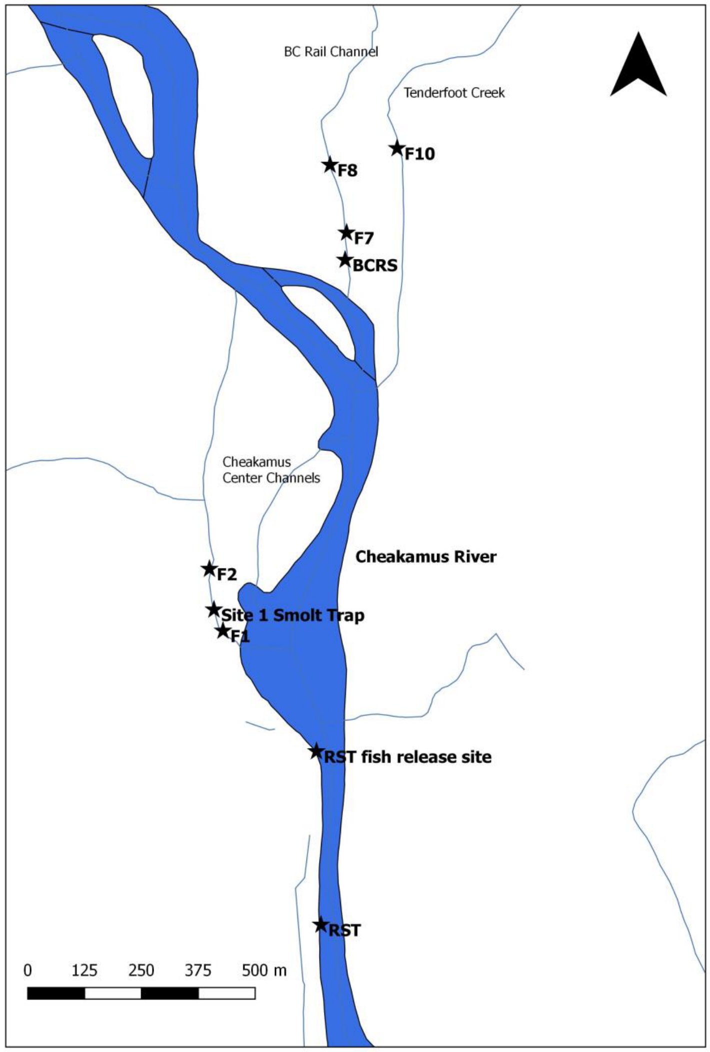


Figure 4.1.a: Site map indicating fyke and RST trap locations utilized for the Cheakamus River Juvenile Migration CMSMON-1a (Lingard et al. 2019).

4.1.3 Interpretation of Data

The main focus of this monitoring study was to assess the effects of the WUP flow regime and discharge in general on juvenile salmon production in the Cheakamus River. Juvenile abundance estimates from 2001 to 2019 were highly variable, and ranged from 17,000 to 870,000 for Chinook salmon, 69,000 to 150,000 for Coho salmon, and 82,000 to 29,000,000 for Pink salmon (in odd years). The majority (>60%) of juvenile salmon originated from the mainstem of the Cheakamus River, as opposed to side channel habitat (Lingard et al. 2019), indicating that the majority of fish would be susceptible to mainstem flow effects.

No significant difference in juvenile salmon abundance was detected between the IFA and WUP flow regimes. Juvenile salmon abundance was highly variable over the monitoring period and sample size under each flow treatment was relatively small, leading to low statistical power to detect differences (Lingard et al. 2019). Significant relationships were discovered between certain discharge and temperature variables in the Cheakamus River and juvenile abundances, and these relationships were variable among species (Lingard et al. 2019). Productivity of Chum salmon and Steelhead in the Cheakamus River are assessed under CMSMON-1b and CMSMON-3, respectively.

Answers to 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?*

   Freshwater productivity of Pink, Coho, and Chinook salmon could not be directly assessed under the CMSMON1a study as there were no reliable estimates for adult escapement within the Cheakamus River (i.e., changes in juvenile abundances could not take into account potential changes in spawner abundance). However, in the absence of adult escapement, juvenile abundance can be a valuable indicator of productivity.

   Lingard et al. (2019) found significant relationships between juvenile salmon production (Coho, Chinook and Pink salmon) and environmental variables in the Cheakamus River; however, these relationships varied among different salmon species indicating a complex array of trade-offs between species.

   Pink Salmon

   Pink salmon young-of-year (YOY) abundance was found to be negatively associated with fall discharge and positively associated with late winter/early spring discharge. Both discharge variance in October and minimum discharge in November were found to have a negative linear relationships with Pink salmon abundance (Figure 4.1.b), suggesting stable base flows during the incubation and rearing period may be associated with higher Pink salmon abundance (Lingard et al 2019). Large discharge events in the fall could affect incubating eggs and juvenile salmonids by mobilizing small river bed material and scouring redds, or potentially increase risk of standing of newly emerged fry during sudden changes in discharge (Lingard et al 2019). Whereas, minimum discharge in February was found to have positive linear relationship with Pink salmon abundance (Figure 4.1.b), suggesting higher discharges during the onset of the outmigration may be associated with higher Pink salmon abundance by affecting migration timing and survival (Lingard et al 2019).

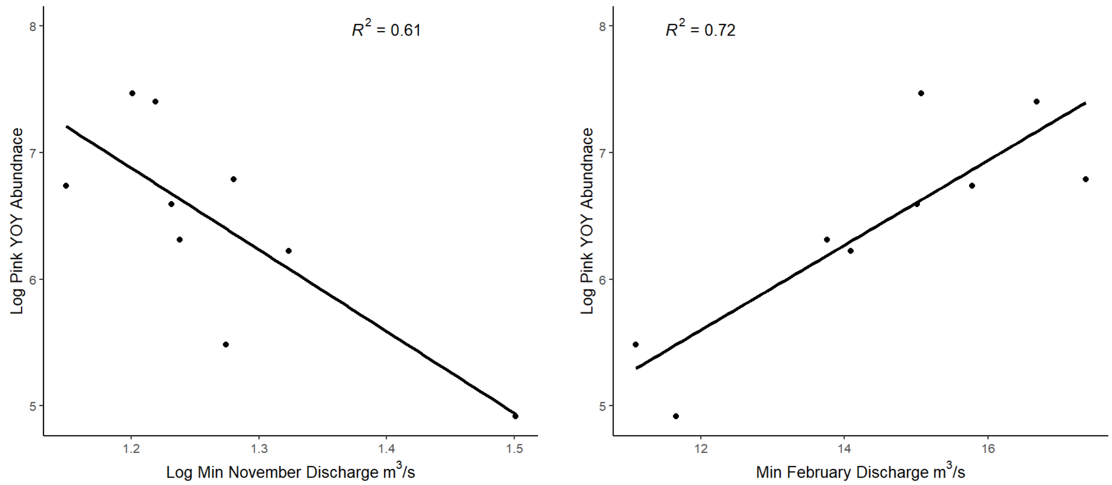


Figure 4.1.b: Plots of a subset of significant linear relationships between YOY Pink salmon abundance and Cheakamus River environmental variables (Lingard et al. 2019).

Coho Salmon

Relationships between Coho Salmon abundance and environmental variables were weaker than for the other species. Lingard et al. (2019) suggested that owing to the length of period Coho juveniles spend in freshwater, it is likely that effects of freshwater variables on juvenile production are confounded and difficult to assess individually. However, based in the linear regression modelling, Lingard et al. (2019) identified three general themes of relationships between discharge and juvenile Coho abundance, including: late summer water temperature, winter discharge, and fall discharge.

Lingard et al. (2019) found that cumulative December discharge, maximum December discharge, discharge variance in December, and discharge variance in February all had negative linear relationships with Coho smolt abundance (Figure 4.1.c). Of these relationships, variance in December discharge was the strongest predictor of abundance. High winter discharge events have been associated with early smolt outmigration to the marine environment in other systems. Consequently, Lingard et al. (2019) suggest that consistent base flows and low discharge variation during the winter portion of the Coho salmon parr rearing period may be associated with higher Coho smolt abundances. Although not noted in the report, a potential causal mechanism for the observed decreases in juvenile abundances is rapid flow ramp rates from Daisy Dam during and following fall storm events, which may result in juvenile fish displacement and/or stranding downstream in the Cheakamus river. Slower ramp rates may mitigate fish stranding and displacement associated with these large fall/winter flow events. There may be limited opportunity to manage winter flow event in the Cheakamus river system given the limited size of Daisy Reservoir.

Similarly, variance in discharge in October was negatively associated with Coho smolt abundance (Figure 4.1.c), suggesting lower consistent flows during the fall parr rearing period may be associated with higher Coho smolt abundance. Although significant, the authors caution the reliability of these relationships may be low due to low R^2 values and correlation coefficient clustering inconsistent with linear regression results.

Minimum September temperature was also found to be weakly negatively associated with Coho smolt abundance (Figure 4.1.c) (Lingard et al. 2019); however, the authors caution that this relationship was highly influenced by the one low abundance point in 2015. The winter of 2014/ 2015 was extremely wet with several discharge events over 300 m^3/s which confound this result.

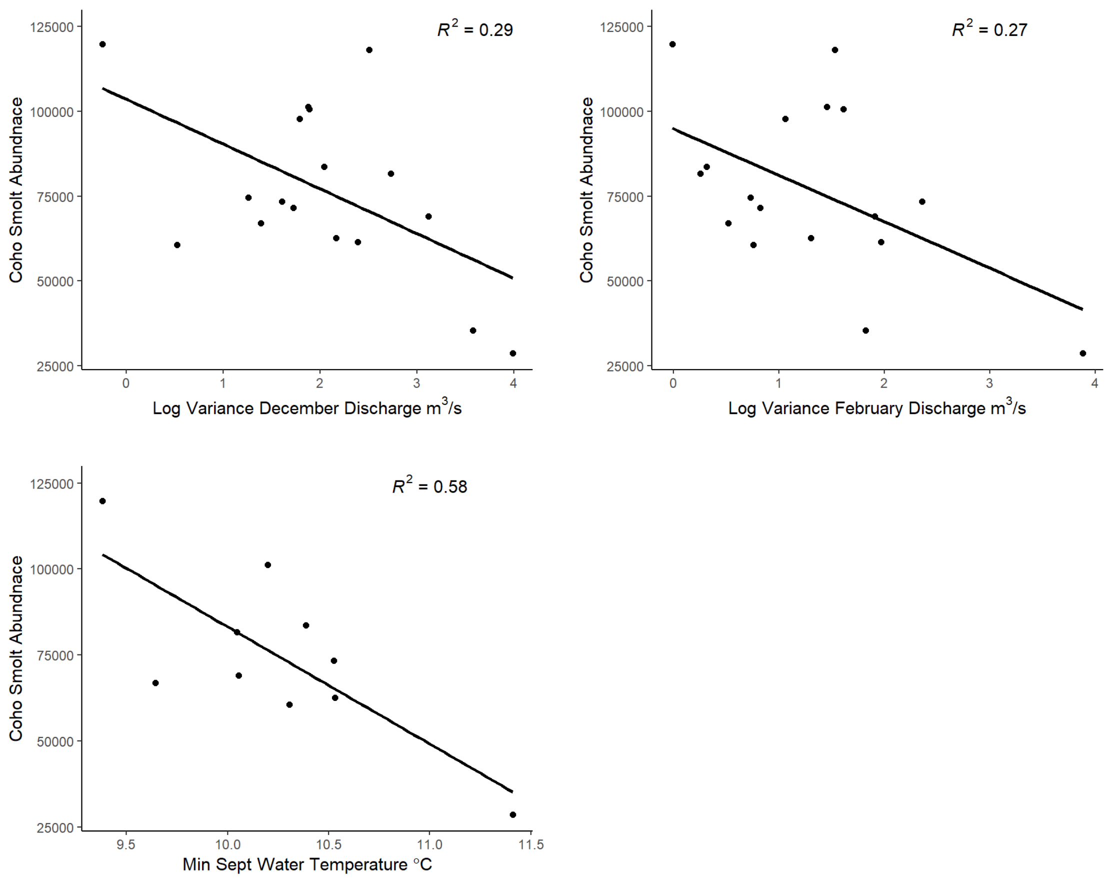


Figure 4.1.c: Plots of a subset of significant linear relationships between Coho salmon smolt abundance and selected variables (Lingard et al. 2019).

Chinook Salmon

Finally, Chinook salmon young-of-year (YOY) abundance were related to summer and winter river discharge, as well as spring and summer water temperature.

Lingard et al. (2019) found that minimum discharge in January, minimum discharge in February, and up-ramping rate over the winter all had a weakly significant negative linear relationship with abundance; however, all variables were also highly correlated with each other. Of all variables within this theme, minimum discharge in January was the strongest predictor of abundance (Figure 4.1.d). Lingard et al. (2019) suggest that results could mean that consistent and low base flows in the winter incubation and rearing period may be associated with higher Chinook salmon abundance (Figure 4.1.d).

Whereas, Lingard et al. (2019) found that maximum discharge in July, discharge variance in July, and minimum discharge in August all showed significant positive linear relationships with Chinook salmon abundance. The strongest linear relationship of this variable grouping was minimum August discharge (Figure 4.1.d). Lingard et al. (2019) postulate that higher and more variable discharge in the summer during adult spawning may be associated with higher Chinook salmon abundance: August is the peak spawning period for summer Chinook salmon in the Squamish watershed, and more water during the spawning period may provide better migration conditions and opportunities for spawning in habitat shallower habitats.

In addition to discharge, Lingard et al. (2019) found that water temperature also influenced juvenile Chinook abundance. Minimum temperature in July and cumulative temperatures in July, August, and September all had significant negative linear relationships with Chinook salmon abundance, although these variables were also all correlated with each other. The strongest of the negative linear relationship was for cumulative August temperature (Figure 4.1.d). Lingard et al. (2019) suggests this result may be showing that higher water temperatures in the summer during adult spawning is associated with lower Chinook salmon abundance: Late summer/fall water temperature during egg incubation will effect juvenile emergence timing, which could influence survival rate and/or outmigration timing of juveniles in the Cheakamus River (Lingard et al. 2019).

Spring water temperatures, including minimum and cumulative temperatures in April, had significant negative linear relationships with Chinook salmon abundance. Cumulative April temperature was the strongest predictor of abundance (Figure 4.1.d). This suggests higher water temperatures in the spring during the juvenile outmigration may be associated with lower Chinook salmon abundance (Lingard at al. 2019). Although there is little biological evidence to support an effect of April water temperature on juvenile Chinook abundance, Lingard et al (2019) suggested that higher water temperature in April may affect migration timing of juveniles from the fall run of adult Chinook that spawn in October.

It is currently unclear how water temperature in the anadromous reach of the lower Cheakamus River are effected by discharge from Daisy Dam during summer and fall months. Lingard et al. (2019) suggested that a lower, late summer hydrograph may result in an increase in water temperatures, supported by the negative correlation between the two variables, although this relationship has not been studied in detail. In terms of whether of impoundment of water in Daisy Lake affects water temperature in the anadromous reach, Lingard et al (2019) note that a previous study indicated the effects of Daisy Dam on water temperature are mitigated in the anadromous reach by inflows from upstream tributaries (Rubble and Culliton Creeks)(McAdam 2001).

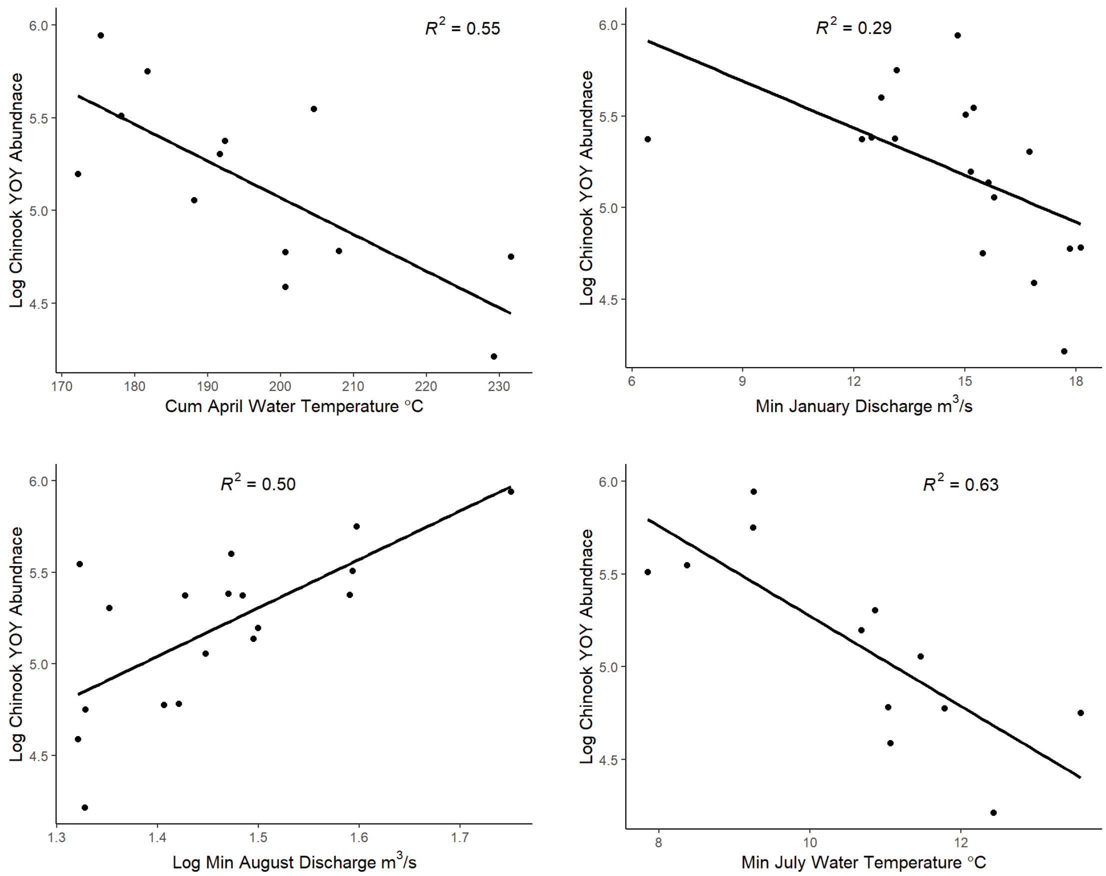


Figure 4.1.d: Plots of a subset of significant linear and log-linear relationships between YOY Chinook salmon abundance and Cheakamus River environmental variables (Lingard et al. 2019).

2. *Did juvenile salmonid production, productivity, or habitat capacity change following implementation of the WUP flow regime?*

No significant differences were detected between Chinook and Coho salmon production under the WUP and IFA flow regimes. Pink salmon data were not tested due to the sparsity of the data resulting from their bi-annual presence in the watershed. Lingard et al. (2019) asserted that the low sample size of pre-WUP data and high variability in annual abundance of the Cheakamus River salmon populations resulted in a low power to detect a difference between datasets:

- Pink salmon: although alternating Pink runs resulted in a much smaller sample size compared to other species, mean Pink salmon YOY abundance under the WUP flow treatment was 20-fold greater than the mean abundance under the IFA flow treatment (Figure 4.1.e., frame A). Lingard et al. (2019) suggest that it is unlikely that this increase was in response to WUP flows as the trend has been observed in many odd-year Pink salmon populations in the Pacific Ocean, and resulted from favourable marine conditions.

- Coho salmon: smolt abundance data was most robust of species in the study (Lingard et al. 2019); however, no significant difference in mean abundance of Coho smolts was detected between flow treatments (Figure 4.1.e., frame B).

- Chinook salmon: fry abundances did not differ significantly between IFA and WUP flow treatments (Figure 4.1.e., frame C). However, the estimates were highly variable among years with high uncertainty of estimates in early years which limited the ability to detect changes. The authors also highlight that Chinook in the Cheakamus River display a range of juvenile rearing and emigration strategies which are not necessarily fully characterized by the RST trapping program. The authors assert these two factors limit the ability to detect changes in juvenile Chinook salmon abundance in relation to the flow treatment (Lingard et al. 2019).

Lingard et al. (2019) analyzed whether any of the significant flow variables associated with juvenile abundance were statistically different between the WUP and IFR periods. None of the flow variables found to be significantly correlated with Coho smolt or Chinook YOY abundance were significantly different between IFA and WUP flow regimes. Of the flow variables found to have significant correlations to juvenile Pink salmon fry abundance, only February minimum discharge was found to be significantly different between WUP and IFA flow treatments. Late winter/early spring minimum flows were higher on average during WUP years, which may have been associated with the increase in Pink fry production. However, Pink salmon adult returns were coincidentally higher during WUP years, (i.e., believed to be associated with ocean survival conditions rather than WUP flow); therefore, confounding these results.

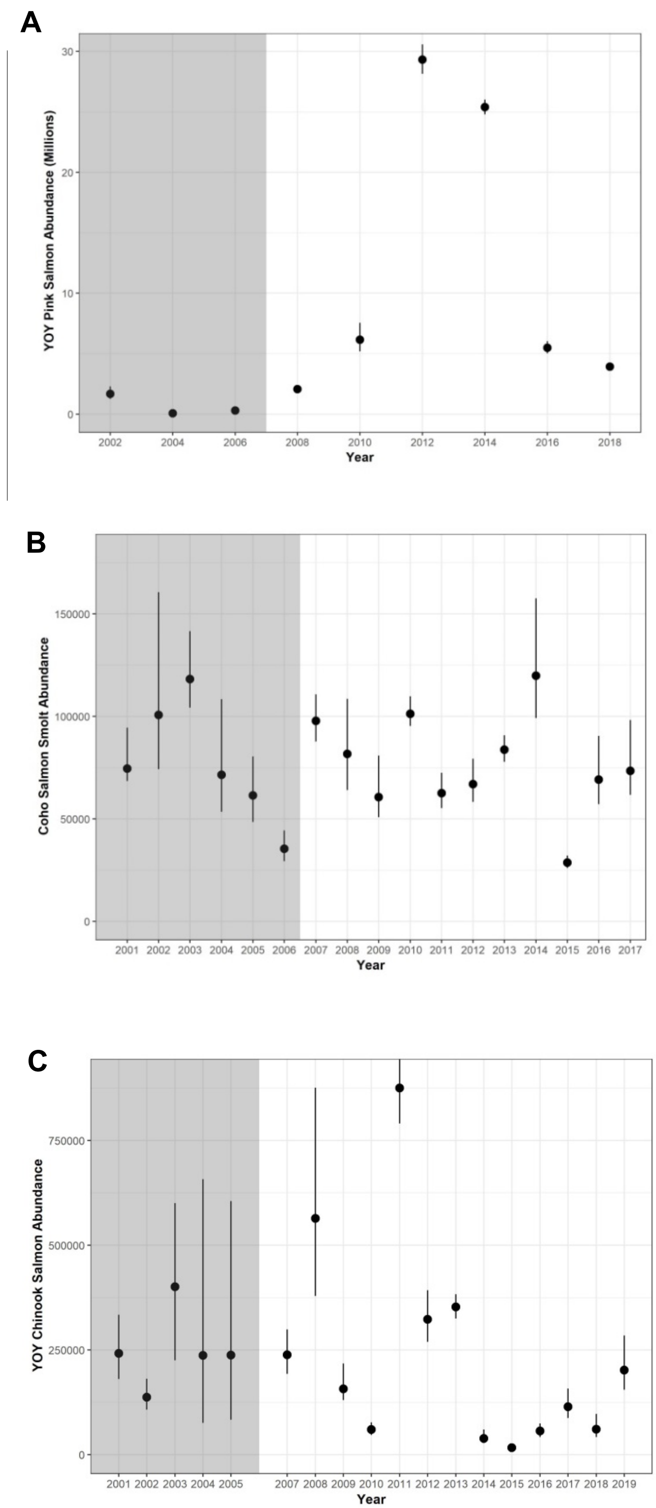


Figure 4.1.e: Annual abundance estimates of (A) YOY Pink salmon, (B) Coho salmon yearling smolts, and (C) YOY Chinook salmon in the Cheakamus River. Error bars represent 97.5% confidence intervals. Grey shaded area represents abundance estimates (Lingard et al. 2019).

Other Results

Lingard et al. (2019) note that there may be conflicting effects of discharge between salmon species within the Cheakamus River. For example, increased discharge in August may benefit Chinook salmon migration and spawning; however, this timing overlaps with the emergence and early rearing of Steelhead trout, which may result in displacement of juveniles (Korman et al., 2017). These tradeoffs will have to be explicitly assessed in relation to conservation priorities prior to decisions being made regarding any changes in the flow regime at Daisy Lake Dam.

4.1.4 Conclusions and Implications

There was no significant difference in fish production between IFA and WUP flow regimes; however, the study had limited statistical power to detect a difference.

Significant relationships between discharge variables and juvenile salmon abundances were observed in the Cheakamus River over the study period:

1) High and variable discharges (typically storm events) during fall and winter months appeared to negatively affect both Coho smolt and Pink salmon fry production. Whereas, consistent and low base flows in the winter incubation and rearing period may be associated with higher Chinook salmon abundance. Large discharge events in the fall and winter could affect incubating eggs and juvenile salmonids by mobilizing small river bed material and scouring redds, or potentially increasing risk of standing or displacement of newly emerged fry during sudden changes in discharge. Slower ramp rates may mitigate fish stranding and displacement associated with these large fall/winter flow events. However, the authors recognize there may be limited opportunity to manage winter flow event in the Cheakamus river system given the limited size of Daisy Reservoir.

2) Higher minimum flows during in the Cheakamus River during late-winter/early-spring were positively associated with Pink salmon fry production. The causal mechanism of effect is not well understood. It is possible that higher discharges during the onset of the outmigration may be associated with higher Pink salmon abundance by affecting migration timing and survival. In which case, the WUP flow regime offered higher minimum flows during late-winter/early-spring months relative to the IFA flow regime, which would indicate that the WUP flow regime may have had a positive effect of Pink salmon production in the Cheakamus River. Increases in Pink escapement occurred coincidentally with increased minimum discharges, which may have been responsible for the observed increase in pink production.

3) Both higher discharge during Chinook migration and spawning and cooler water temperatures during Chinook spawning and early egg incubation appeared to have a positive effect on Chinook salmon fry the following spring. Because discharge and water temperature during August are correlated, it is unclear which variable is primarily affecting Chinook abundance, though causal mechanisms were proposed for both. Higher flows could increase spawning success of adult Chinook by increasing migration success, or increasing spawning habitat availability and suitability.

Higher water temperature during incubation likely influences when juvenile Chinook salmon emerge and their subsequent downstream migration timing, which could affect the abundance of juvenile chinook present in the watershed during the spring trapping program and may also have implication for juvenile survival rate.

4.2 CMSMON-1b: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

4.2.1 Project Summary

The primary objective of this monitoring program was to examine the effects of the WUP flow regime on Chum salmon productivity in the mainstem and major side channels of the Cheakamus River.

The monitoring program included two primary components:

i) Estimating annual escapement of adult Chum salmon in the Cheakamus River.
ii) Examining the relationship between discharge, groundwater upwelling, and the selection of spawning habitat by Chum salmon in the mainstem.

For this monitoring project, Chum salmon escapement data was used in combination with Chum fry abundance estimates from CMSMON-1a to examine the linkages between adult returns and juvenile outmigration (i.e., freshwater productivity) with the WUP flow regime. This monitoring program also aimed to investigate the relationship between river discharge and groundwater upwelling in mainstem spawning areas, and the potential effects of the WUP flow regime on Chum salmon spawning site selection and corresponding effects on egg-to-fry survival (BC Hydro 2007b).

The original TOR specified a five-year monitoring period from implementation which was deemed insufficient to answer the management questions[4]. In addition, the caustic soda spill into the Cheakamus River in 2005 occurred during the five-year study period, affecting the results of monitoring. Consequently, the TOR was revised in 2013 (BC Hydro 2013) to extend the CMSMON-1b monitoring program an additional five years. No changes were made to the management questions, and methodologies were largely unchanged.

In 2017 BC Hydro and the Cheakamus Monitoring Committee conducted a review of study results to assess whether any remaining uncertainties should be addressed before the WUP Order Review. The outcome of the review was a recommendation to continue CMSMON-1b in order to investigate the behavioural response of Chum salmon to increased flows (pulse flows) during the fall spawning migration period. The study was extended until May 2019 (BC Hydro 2017).

Objectives	Management Questions[1]	Response	Implications

[4] The status of answering the Management Questions after the first five years of study was discussed with the Cheakamus WUP Monitoring Committee at an Interim Review in 2012.

The objective of this monitoring project is to estimate annual escapement of adult Chum salmon in the Cheakamus River, and examine the relationships between discharge, groundwater upwelling, and the selection of spawning habitat by adult Chum salmon in the mainstem.	1. What is the relationship between discharge and Chum salmon spawning site selection and incubation conditions? 2. Do the models used 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? 3. Are there other alternative metrics that better represent Chum salmon spawning habitat?	1. Increasing the number of days with discharge between 25 and 80 m^3/s (pulse flows) during the adult Chum salmon migration and spawning appeared to have a positive effect on juvenile productivity. Daily side-channel entries by adult Chum was positively correlated with increases in discharge in the Cheakamus River, which likely resulted in higher productivity because side-channel spawning habitats are known to have increased Chum salmon egg-to-fry survival rates relative to mainstem habitat. In addition, Chum were observed accessing groundwater influenced spawning habitat in the upper reaches of the river in days following pulse flow event, potentially leading to reduced density dependent mortality of eggs. Large magnitude discharge events may result in lower egg-to-fry survival, potentially due to redd scour or alevin displacement. Discharge during the Chum salmon spawning and incubation period does appear to affect the upwelling of groundwater in mainstem spawning areas, as indicated by redd temperature monitoring. However, the magnitude and direction of changes in redd temperatures was highly variable both among and within sites on the Cheakamus River 2. & 3. Results of Chum salmon spawning and physical habitat modelling conducted during the Water Use Plan process predicted increased habitat availability in the upper reaches of the Cheakamus River. Instead, it was found that strong groundwater upwelling, which is more prevalent in the lower river relative to upstream of the Bailey	Providing pulse flows during the Chum adult migration period may increase Chum salmon freshwater productivity in the Cheakamus River. Consideration of spawning habitat enhancements should be focused on areas of naturally occurring groundwater upwelling.

		Bridge, is a primary factor in adult Chum salmon spawning site selection, and that those upper reaches are rarely used by Chum salmon except when prompted by pulse flow events and/or density dependent behavior.	

[1]TOR reference; BC Hydro 2007b, pp.15

4.2.2 Project Approach

The CMSMON-1b monitoring program was conducted from 2007 to 2019. The monitoring project was completed by InStream Fisheries Research Inc. Reports were compiled each year following 2007. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach to this monitoring project was to produce annual estimates of adult Chum salmon escapement in the Cheakamus River and in combination with fry enumeration estimates from CMSMON-1a, develop stock-recruitment relationships to evaluate effects of spawning escapement from flow-related changes in survival during incubation.

Mark-recapture methods were used to generate adult Chum salmon escapement estimates with individuals captured and tagged at two locations along the Cheakamus River (Figure 4.2.a) from mid-October through late November. Recaptures were estimated using a passive tag recovery approach, which involved the use of fixed location resistivity fish counters to enumerate fish entering selected side channels, paired with Passive Integrated Transponder (PIT) readers to scan for tagged fish at these locations. Escapement estimates were calculated using stream walk counts and stream walk efficiencies during years when electronic counters were non-operational (e.g. years of consecutive high-water events). Egg deposition rates were calculated using estimates of sex ratio, female fecundity, and pre-spawn mortality rates. Finally, Chum salmon fry abundance estimates were provided from the CMSMON-1a program (see 4.1.2 for general approach).

Yearly subsets of adult Chum salmon were also implanted with radio telemetry tags to assess distribution and identify spawning locations. Finally, sub-surface temperature loggers were deployed at approximate redd depths in the gravel at known and suspected spawning locations during the migration and egg incubation period to assess the role and presence of groundwater in Chum salmon spawning site selection and incubation conditions in upstream and downstream locations in the Cheakamus River.

Modified Ricker (1954) stock-recruitment analyses were used to examine relationships between the WUP discharge regime and adult-to-fry and egg-to-fry survival as indices of overall juvenile Chum salmon productivity in the Cheakamus River. Modeled results of the effects of different WUP discharge metrics on juvenile productivity were ranked using Deviance Information Criteria (DIC).

In addition to developing a stock-recruit relationship, the study also investigated Chum Salmon spawning distribution within the Cheakamus River and side-channel habitat, as well as microhabitat conditions (including the influence of groundwater) associated with spawning site selection.

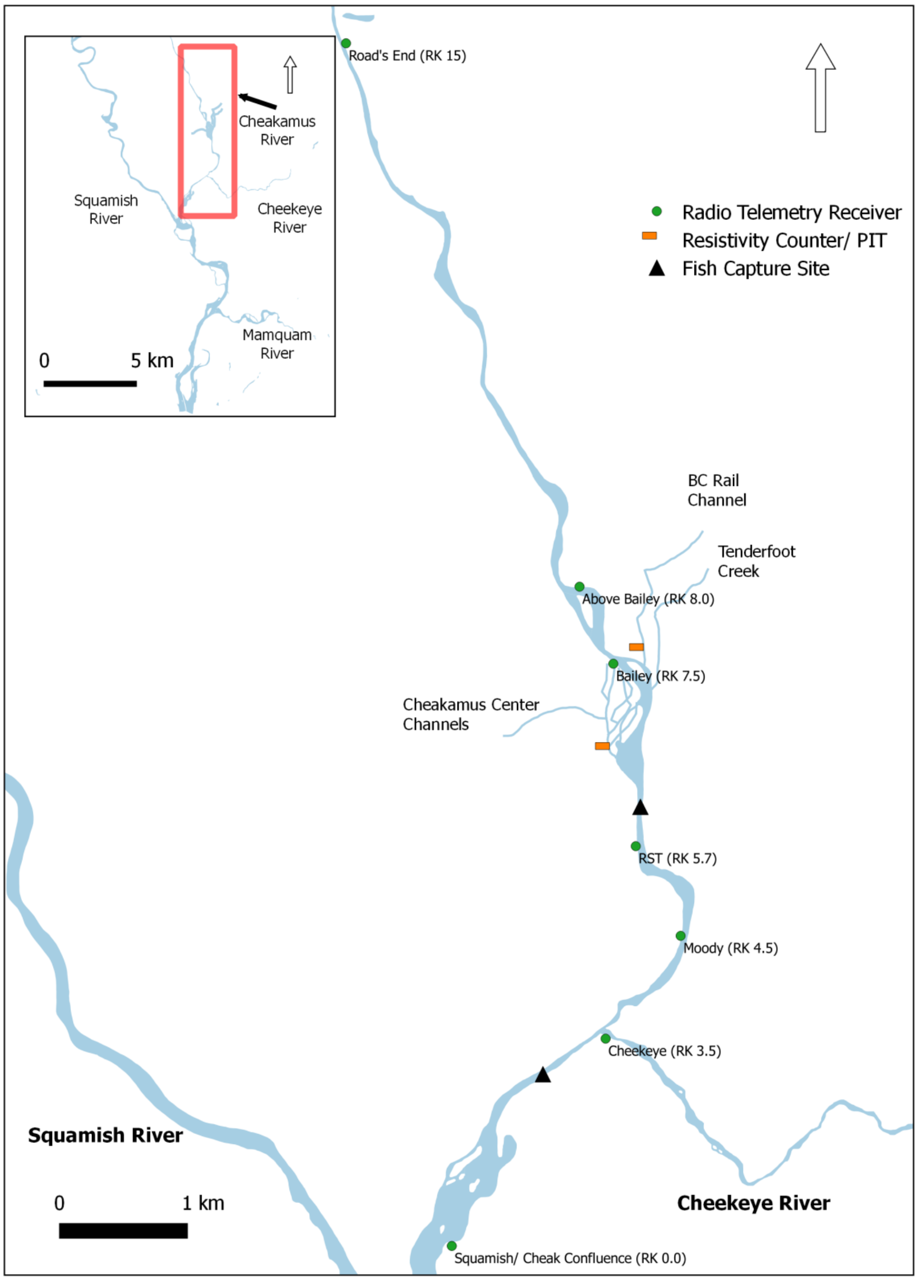


Figure 4.2.a: Cheakamus River study site showing locations of fish collection sites, radio-telemetry receivers, artificial spawning channels, and rotary screw trap. Inset shows location relative to the greater Squamish River watershed (Middleton et al. 2019).

4.2.3 Interpretation of Data

The main focus of this monitoring project is to assess the effects of the WUP discharge regime on Chum salmon spawning site selection and more generally, overall juvenile Chum salmon productivity in the Cheakamus River. Over the course of the study period, adult Chum escapement has varied between 34,333 and 602,619, and estimated Chum salmon fry production has varied between 1,442,931 and 10,795,444. These data were used to develop stock-recruitment relationships; which were examined to for effects of flow on Chum productivity.

Answers to Management Questions

1. *What is the relationship between discharge and Chum salmon spawning site selection and incubation conditions?*

   Middleton et al. (2019) did not observe any empirical relationship between Cheakamus River discharge during the fall migration period and the distance Chum salmon travelled upstream to spawn (i.e., neither variations in base flow nor discharge pulses triggered adult fish to move to available spawning habitat in upstream reaches (above Bailey Bridge) in the Lower Cheakamus River based on radio telemetry data. However, visual observations confirmed adult Chum spawning in groundwater influenced habitat in the upper reaches of the anadromous section of the River (near Roads End) in days following pulse flow events (Middleton et al. 2019). The authors hypothesize that utilization of these upper reaches by Chum salmon is more likely a function of spawner density rather than river discharge (Middleton et al. 2018). Although, there was some evidence to suggest that discharge above WUP base flows during the adult migration and spawning period may influence ground water availability and provide access to additional preferred spawning habitat in the upper reaches of the river (Middleton et al. 2019).

   During the monitoring period, Chum salmon were generally observed spawning in side-channel habitats characterized by lower velocity (0.1 – 0.3 ms^{-1}) and strong groundwater upwelling. These habitats are abundant in the lower reaches of the Cheakamus River, and as such, adult Chum salmon are not likely inclined to utilize the modeled ‘effective’ habitat above the Bailey Bridge unless driven by density dependent behavior or triggered by pulse flow events.

   A positive effect was observed between the number of days during the adult migration with discharge between 25 and 80 m^3/s (pulse flows) and the corresponding adult-to-fry and egg-to-fry survival (i.e. overall productivity) (Figure 4.2.b). Concurrently, daily side-channel entries by adult Chum salmon was positively correlated with increases in discharge (i.e., during mainstem river discharge pulses, more Chum salmon adults enter and presumably utilize spawning habitat within side-channels) (Figure 4.2.c). Because side-channel spawning habitats are known to have increased egg-to-fry survival rates relative to mainstem habitat for Chum salmon (15% and 4.6%, respectively; Middleton et al. 2018), the increased side channel spawning that results from higher discharges in the Cheakamus River mainstem likely explains the observed increased egg-to-fry survival rates. In addition, pulse flows may provide increased access to additional spawning habitat upstream, reducing spawner densities and associated density-dependent mortality. Potential positive interactions between a pulse flow effect and total escapement support this conclusion (i.e., pulse flows have a stronger effect during years of larger escapement).

Middleton et al. (2010) identify that in both adult-to-fry and egg-to-fry stock-recruitment models there was a high degree of uncertainty associated with each of the predicted relationships, and any management decisions based on their findings should be approached with caution and supported by additional data collection.

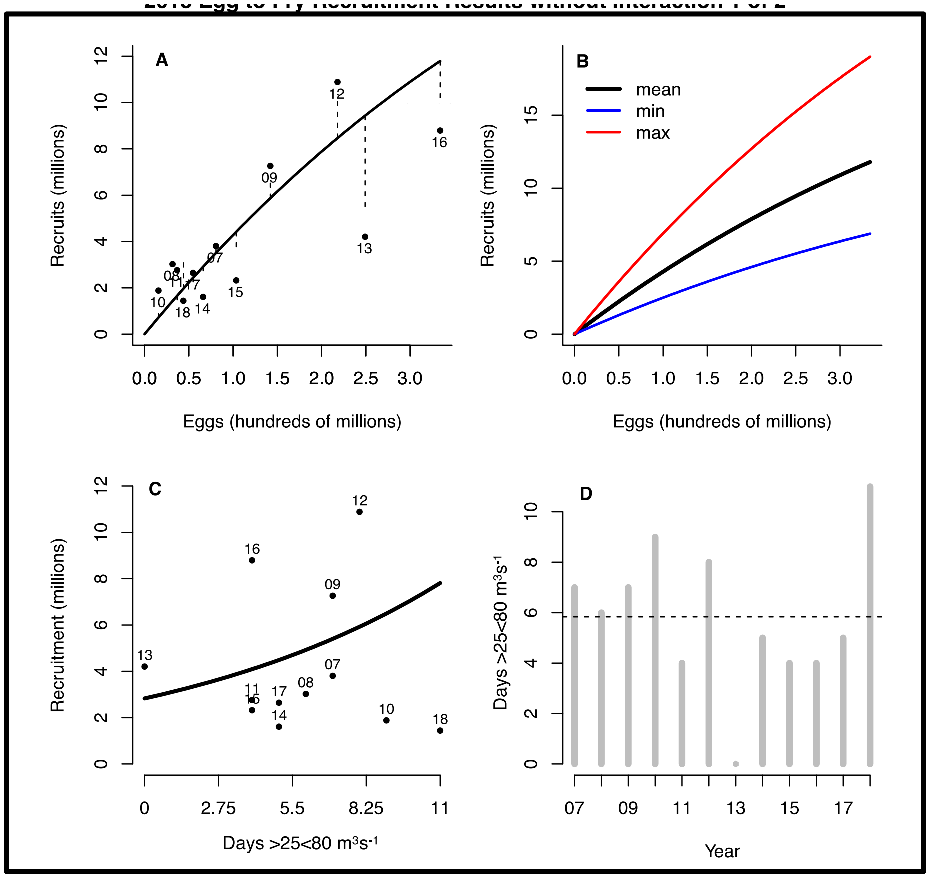


Figure 4.2.b: Stock-recruitment curve for the number of Chum salmon fry produced per hundreds of millions of eggs; individual points are data from each of the 12 years of monitoring (panel A). Estimated numbers of recruits per hundred million eggs at the mean, minimum, and maximum values of pulse flow days >25<80 m^3/s during the adult migration period (panel B). Estimated juvenile recruitment by pulse flow days >25<80 m^3/s over the 12 years of monitoring (panel C). Average number of days per year from 2007 – 2018 when discharge was >25<80 m^3/s (panel D). (Middleton et al. 2019).

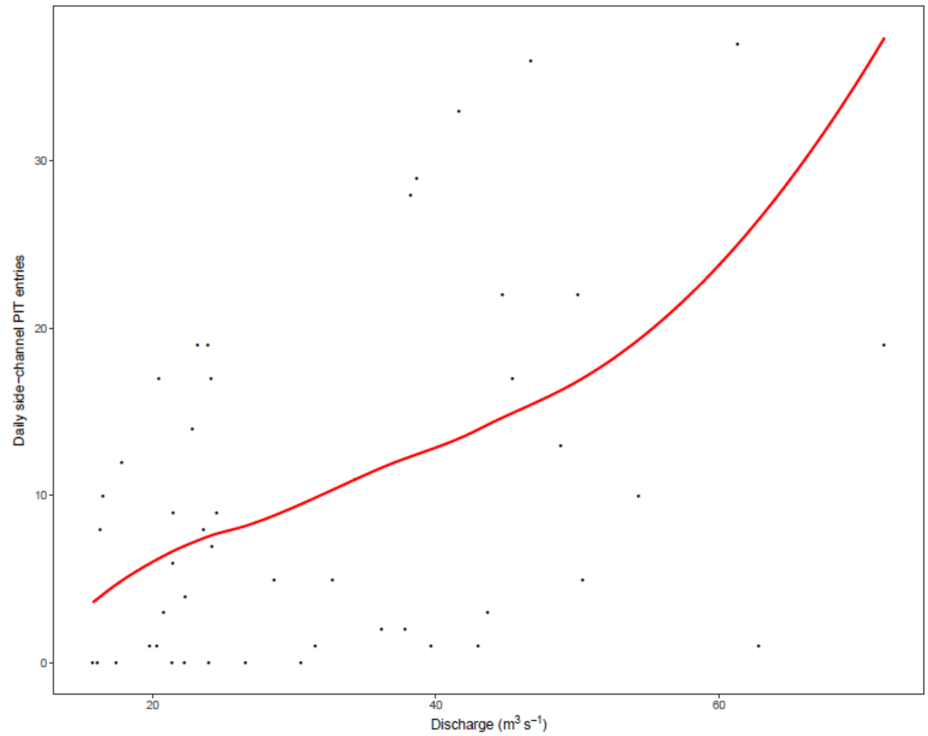


Figure 4.2.c: Predicted relationship (red line) between daily average discharge (m^3/s) and the daily number of entries from PIT tagged Chum salmon into monitored side channels in the Cheakamus River between October 15 – December 15, 2017(Middleton et al. 2018).

In addition, there was a negative effect observed between the maximum discharge during the egg incubation period and Chum salmon egg-to-fry survival. Large magnitude discharge events may result in excessive scour or burial of redds, and/or potentially injure or displace newly hatched aevlins; all of which could decrease egg-to-fry survival. Although not within the scope this study, it is unlikely that the absolute magnitude of winter spill events has changed as a result of flow regime.

Groundwater upwelling is known to be an important factor in Chum salmon spawning site selection (Salo 1991). The majority of areas with evidence of strong groundwater upwelling were located in the lower reaches of the river (within six kilometers of the Bailey Bridge) which generally corresponded to areas where the majority of adult Chum salmon are observed spawning. However, Middleton et al. (2019) also suggest that there was evidence of groundwater influenced spawning habitat upstream of the Bailey Bridge near Roads End where adult Chum have been observed spawning. Discharge during the Chum salmon spawning and incubation periods appeared to affect the upwelling of groundwater in mainstem spawning areas, as indicated by redd temperature monitoring. However, the magnitude and direction of changes in redd temperatures was highly variable both among and within sites on the Cheakamus River.

2. *Do the models used 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?*

See response below.

3. *Are there other alternative metrics that better represent Chum salmon spawning habitat?*

   The majority of adult Chum spawned in the lower reaches of Cheakamus River, with 18% on average utilizing side-channel habitat, and 16% utilizing upper portions of the anadromous reaches on the Cheakamus River (Middleton et al. 2019). Contrary to predictions during the WUP process, it was uncommon to observe adult Chum salmon spawning in high densities in the upstream reaches of the Cheakamus River (upstream of Bailey Bridge) over the 12-year monitoring period. The exception was in 2012, which was a year of relatively high Chum escapement, which suggests that spawning above the Bailey Bridge is likely related to density dependent movement rather than spawning habitat suitability (Middleton et al. 2018). The study suggested that strong groundwater upwelling, not depth and velocity characteristics, is a primary factor in adult Chum salmon spawning site selection. Additional results of ground water monitoring collected during fall 2018 in combination with visual observations of Chum spawning activity support this conclusion.

4.2.4 Conclusions and Implications

Flow pulses (natural and artificial) above base WUP flows in the Cheakamus River mainstem during peak adult Chum salmon migration periods have an effect on Chum salmon freshwater productivity. There is also evidence to suggest that pulse flows trigger adults to enter side-channel habitats and provide access to additional groundwater influenced spawning habitats in the upstream reaches of the mainstem of the river where egg-to-fry survival rates are higher. Consequently, pulse flow operation during the fall salmon migration period could be considered as a mechanism to increase Chum salmon freshwater productivity in the Cheakamus River, although these relationships are still uncertain.

Study results indicate that artificial side-channels and spawning sites with dominant groundwater inflows in the lower reaches of the Cheakamus River (downstream from Bailey Bridge) are critical to Chum salmon productivity. Consideration of spawning habitat enhancements should be focused on areas of naturally occurring groundwater upwelling.

4.3 CMSMON-2: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)

4.3.1 Project Summary

A key uncertainty identified during the Cheakamus WUP process was the relationship between discharge from Daisy Lake Dam and the quantity of resident trout habitat available to produce a sustainable Rainbow trout population. The impact of the Water Use Plan flow regime on the Rainbow trout population was uncertain because of uncertainties in discharges and their effects for both WUP and Interim Flow Agreement (IFA) flow regimes. Consequently, the CMSMON-2 monitoring program was designed to assess the effects of the WUP flow regime on resident Rainbow trout population located immediately downstream of Daisy Lake Dam (BC Hydro 2007c).

Objectives	Management Question[1]	Response	Implications
To assess the potential impacts of flow releases from Daisy Lake Dam under the WUP flow regime on resident Rainbow trout population in the non-anadromous reaches of the Cheakamus River below Daisy Lake Dam.	Do Daisy Lake Dam water flow releases affect the resident Rainbow trout population located immediately downstream of Daisy Lake Dam? The parameters of interest include fish density or relative abundance, age class distribution, size-at-age, and relative condition.	During the spawning and incubation period (Feb. 1-May 30), Rainbow trout fry density did not appear to be affected by Daisy Lake Dam discharge characteristics; although, minimum discharge appeared to be positively related to the growth of age-0 Rainbow trout. During the summer growth period (June 1-Aug. 31) higher discharges appeared to negatively affect age-0 Rainbow trout density; however, higher mean summer flows were positively related to age-1 Rainbow trout density. There was a slight negative trend in age-0 density detected over the study period; however, age-1 rainbow trout parr density appeared to remain stable over the same period. These results suggest that any decreases in fry densities that occurred under the WUP flow regime were compensated by some density dependent effects. The apparent stable Rainbow trout parr populations observed over the monitoring period suggest there was no population level effect from the WUP flow regime; however, limited data was available to inform conclusions of the study.	The apparent stable Rainbow trout parr populations observed over the monitoring period suggest there was no population level effect from the WUP flow regime.

[1] TOR reference; BC Hydro 2007c, pp.13

4.3.2 Project Approach

CMSMON-2 was conducted annually from 2007 to 2011. The monitoring project was completed by Squamish Nation in association with Golder Associates Ltd. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach to this monitoring project was to annually collect field data on the Rainbow trout population in the non-anadromous reach of the Cheakamus River and track population variables through time to determine if any changes could be attributed to changes in Daisy Lake Dam discharge. Variables collected included juvenile abundance, adult abundance, size at age, and relative condition. These variables collectively allow for the management question to be addressed.

Two fish capture programs were used to collect data to inform estimates of fish density, size-at-age, relative condition and relative spawning success. First, a closed-site, multi-pass electrofishing program was used to catch juvenile Rainbow trout at ten select sites located between the Daisy Lake Dam and the Cheakamus Canyon. Second, an angling program targeted adult Rainbow trout in the Cheakamus River from the confluence of Rubble Creek to the Cheakamus Canyon (Figure 4.3.a).

Statistical analysis included the following:

- Fry densities were compared across year and site using an ANOVA.
- Condition factor was compared between years using General Linear Models using factors such as year, sample site, and age class.
- Summer growth and condition factor was evaluated using linear regression to assess the relationship to discharge during the summer growth season at each site and year.

Conclusions from the original analysis identified substantial uncertainties in resolving the management question (Harrison et al. 2013). To address the uncertainties, BC Hydro retained Poisson Consulting Ltd. to complete a review and additional analysis of the CMSMON-2 Rainbow trout abundance monitoring program (Irvine et al. 2015).

Irvine et al. (2015) re-analysed trends in Rainbow trout biological metric data from Harrison et al. (2013) and fish abundance monitoring study completed in the same reach of Cheakamus River to assess the impacts of a Caustic soda spill on resident fish populations (2006-2008; Triton 2009). The Authors used three metrics of to evaluate whether discharge from Daisy Lake Dam had an effect on Rainbow trout during two periods of the year (Feb. 01-May 30 and June 1-Aug. 31).

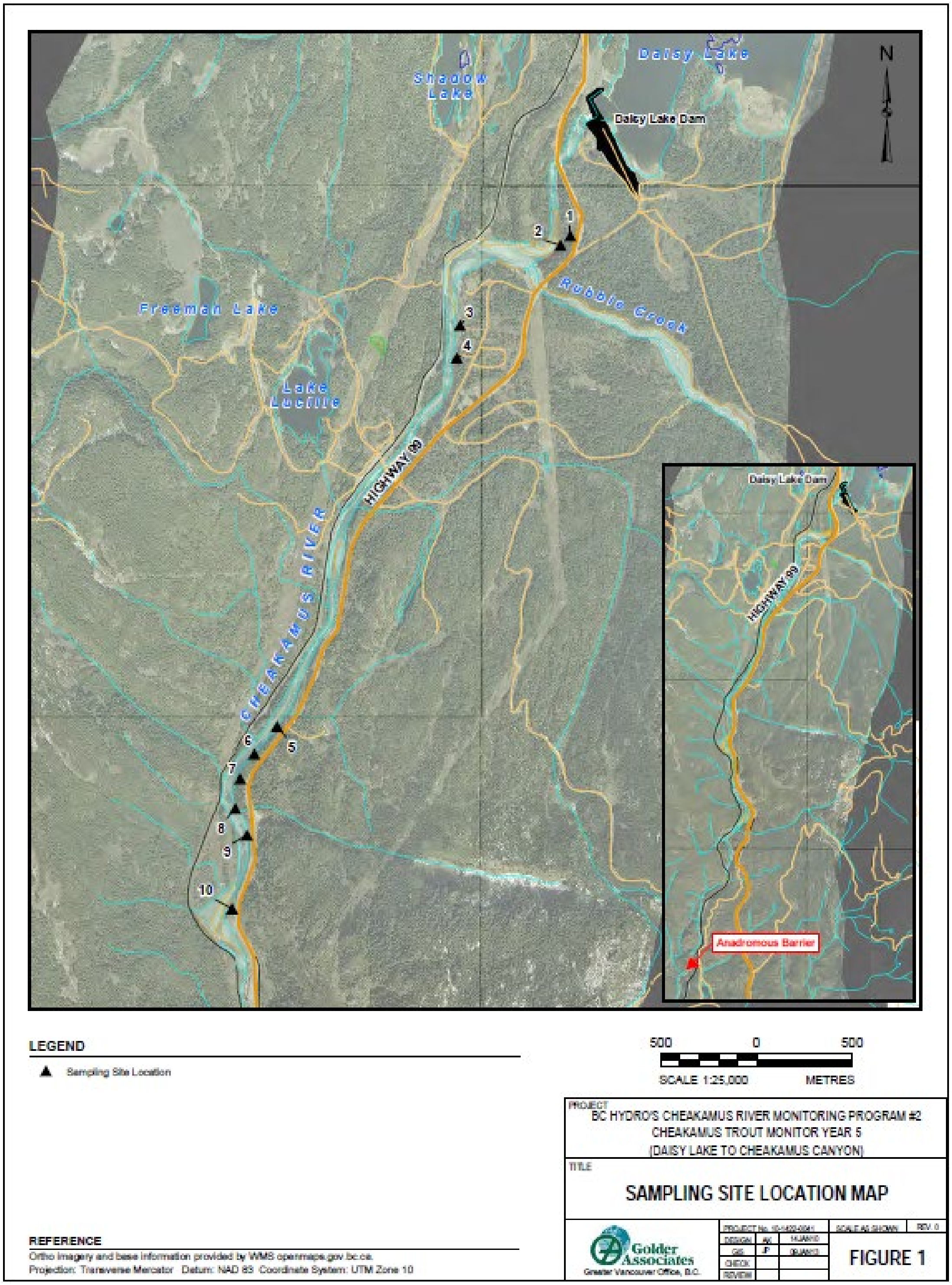


Figure 4.3.a: Map of the upper canyon reaches of the Cheakamus River and Daisy Lake Reservoir, showing fish Sampling site locations (Harrison et al. 2013)

4.3.3 Interpretation of Data

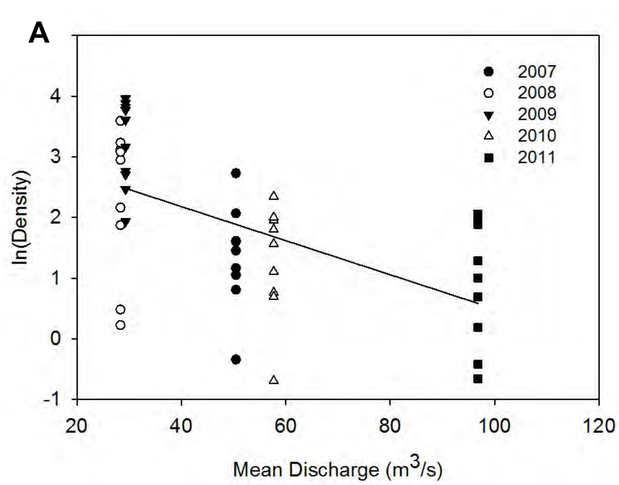
The primary objectives of the CMSMON-3 are to determine whether the WUP flow regime from Daisy Lake Dam affect resident Rainbow trout population downstream of the Dam and above the anadromous barrier.

Answers to Management Questions

1. *Do Daisy Lake Dam water flow releases affect the resident Rainbow trout population located immediately downstream of Daisy Lake Dam? The parameters of interest include fish density or relative abundance, age class distribution, size-at-age, and relative condition.*

   Initial analyses by Harrison et al. 2013 found:

   - Densities of age-0 Rainbow trout were significantly different among study years, with fish densities increasing from 2007 to 2009, before generally decreasing through 2011;
   - Significant negative relationships between age-0 Rainbow trout density and increasing discharge during the summer growth period in the Cheakamus River (Figure 4.3.b);
   - High flows (90th percentile) during the summer growth period explained the most variance in fry density, suggesting that higher discharge events may negatively affect juvenile Rainbow trout production, presumably by reduced habitat availability or increased downstream displacement;
   - Length-at-age and condition factors during the study period were similar in value to other studies in the same river system, with no clear trend over time. Harrison et al (2013) concluded there was little evidence to suggest that fish condition factor was correlated to river discharge during the summer growth period;
   - Adult catch and spawning success (fry per adult) statistics were deemed to be too uncertain given the limited collection period (~2 days of adult angling per year) and the lack of information to support the use of angling data as a proxy for spawner abundance. Angling catch varied substantially over the review period.



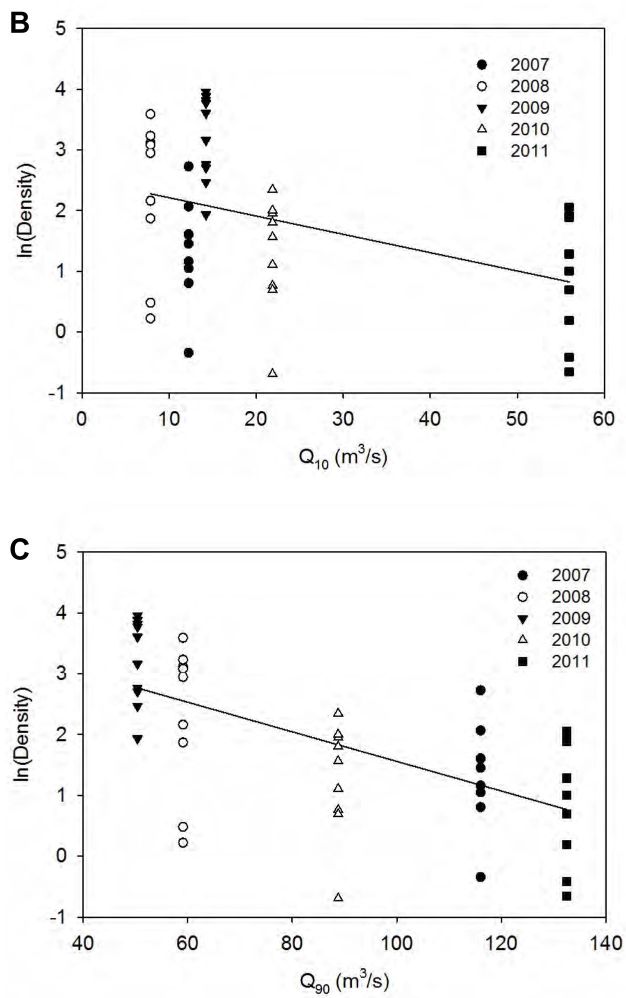


Figure 4.3.b: Relationship between natural logarithm of age-0 Rainbow trout density and (A) mean discharge, (B) 10th percentile discharge (Q_{10}), and (C) 90th percentile discharge (Q_{90}) during the summer growth season in the Cheakamus River (Harrison et al. 2013).

Due to the substantial uncertainty in the data, the management question was not effectively answered by the first five years of field study. BC Hydro had the information re-analysed in consideration of other studies that were completed over the same sample period. Upon re-analysis of the data, Irvine et al. (2015) were able to answer the management question by concluding the following (Figure 4.3.c):

- Rainbow trout fry density did not appear to be affected by discharge characteristics from Daisy Lake Dam during the spawning and incubation period (Feb. 01-May 30);
- Over the course of the study period, a slight negative trend in fry density was observed, which indicates a reduction in relative spawning success over time;
- Growth of age-0 Rainbow trout was positively related minimum discharge during the spawning and incubation period;

- During the summer growth period (June 1-Aug. 31), higher mean flows were positively related to age-1 Rainbow trout density; which indicates an increase in relative rearing success;
- However, there was no indication of a positive or negative trend in the age-1 Rainbow trout density over the study period, which indicates that the population was stable.

Irvine et al. (2015) identified that there was limited data was available to inform conclusions of the study.

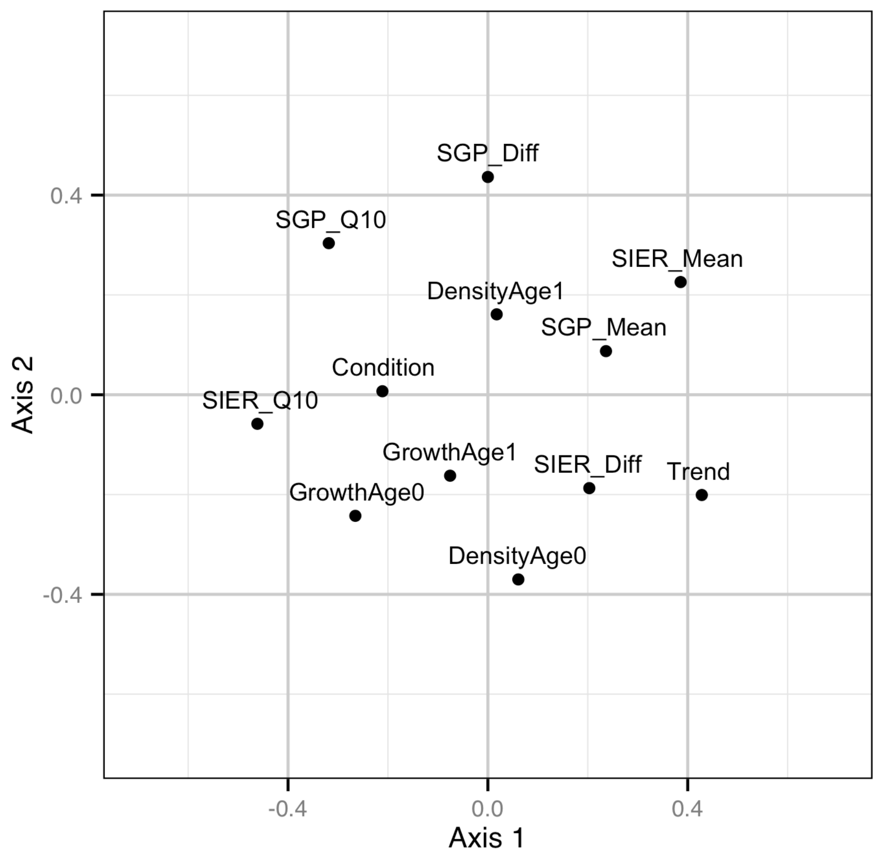


Figure 4.3.c: Non---metric multidimensional scaling (NMDS) plot showing clustering of variables by absolute correlations. (Irvine et al. 2015).

4.3.4 Conclusions and Implications

The apparent stable Rainbow trout parr populations observed over the monitoring period suggested there is no population effect from the WUP flow regime. While rearing success appeared to increase with increase mean and minimum discharge levels, there was a slight reduction in fry densities over the study period. These results suggest that any decreases in fry densities that occurred under the WUP flow regime were compensated by some density dependent effects.

The primary objective of this study was met with the re-analysis by Irvine (2015).

4.4 CMSMON-3: Cheakamus River Steelhead Adult Abundance, Fry Emergence Timing, and Juvenile Habitat Use and Abundance Monitoring

4.4.1 Project Summary

A key objective of the Cheakamus WUP was to establish a flow regime that maximized productivity of wild fish populations in the river. During the Cheakamus WUP, there was debate regarding the preferred flow regime on the Cheakamus River, in particular surrounding the importance of aspects of a natural hydrograph and minimum flows to Steelhead and salmon production.

The CMSMON-3 monitoring program (BC Hydro 2007d), was designed to assess the effects of the WUP flow regime on the abundance and survival of key Steelhead trout life-stages, and more broadly the production of Steelhead in the freshwater system to determine the effects of the WUP operation on Steelhead production. Because of their freshwater life-history, Steelhead growth and survival rates are a good indicator of overall fresh water productivity for fish.

The original terms of reference (TOR) specified a five-year monitoring period. Results following the first five years of the monitoring program were deemed insufficient to answer the management questions[5]. In addition, the caustic soda spill into the Cheakamus River in 2005 occurred during the five-year study period, affecting the results of monitoring. Consequently, the TOR was revised in 2012 (BC Hydro 2012b) to extend the CMSMON-3 monitoring program and additional five years with no changes to the management questions, and only minor modifications to some tasks and methodologies.

During the final year of the Cheakamus WUP monitoring studies in 2017, a final review of study results was completed by BC Hydro and the monitoring committee in order to determine whether any remaining uncertainties should be addressed in advance of the WUP Order Review. Recommendations from the review were that of the four management questions posed in the original TOR, two questions remain unanswered and required further investigation to better support future WUP Order Review decisions:

> Management Question 2: *How do changes in flows affect habitat use of Steelhead young-of-year and parr?*
>
> Management Question 4: *Do flows affect Steelhead production?*

Because of the limited amount of variation in flows observed during the monitoring period, these questions could not be answered using the current approach without extending and modifying the existing TOR.

The recommendations from the review also included the need to complete:

- an assessment of stranding effects on Steelhead productivity in the Cheakamus River; and

[5] The status of answering the Management Questions after the first five years of study was discussed with the Cheakamus WUP Monitoring Committee at an Interim Review in 2012.

- an assessment of the stranding potential for juveniles in the Squamish River downstream of the Cheakamus Generating Station.

These recommendations were incorporated into a TOR revision in 2018 (BC Hydro 2018a); however, stakeholder concern related to increased risk of fish stranding associated with the proposed approach to assess of stranding effects on Steelhead productivity on the Cheakamus River combined with the limited ability to created contrast in flow treatment and low likelihood of increasing statistical power led to the cancellation of that study component funded under the WUP program. Portions of the Steelhead monitoring program were continued through 2019 under BC Hydro funding. The assessment of juvenile stranding in the Squamish River is also summarized in this chapter.

Objectives	Management Questions[1]	Response	Implications
Examine the effects of the flow regime on the abundance and survival of key Steelhead life-stages, and ultimately the production of Steelhead smolts in freshwater. Addendum: The terms of reference addendum in 2018 included an objective to assess the potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station	1. Do increased flows during July and August negatively affect emergent Steelhead young of year (YoY)? 2. How do changes in flow effect habitat use of Steelhead YoY and parr? 3. Will an annual index of parr abundance provide a more robust estimate of Steelhead production in the Cheakamus River relative to the downstream migrant trapping program? 4. Do flows affect juvenile Steelhead production? Addendum: What is the potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station?[2]	1. There was limited statistical support that higher discharges during Steelhead fry early emergence influenced Steelhead egg-to-fry survival, suggesting the prescribed WUP minimum flows during fry emergence (i.e., 38 m^3/s) had limited effect on Steelhead egg-to-fry survival rates. 2. There was insufficient contrast in flow regimes during the WUP study period to answer this management question. 3. Abundance estimates of age-0+ and 1+, and survival rates from egg-0+ (fall) and between later life stages, provide a more robust indicator of juvenile steelhead production than downstream trapping. 4. Rapid up- and down-ramps in discharge to the Cheakamus River during early-emergence period (mid-July to early-August) was negatively associated with Steelhead egg-to-fry survival rates. In addition, fry overwinter survival rate was negatively influenced by rapid changes in discharge as well as peak discharge during winter months. There was limited evidence to suggest that Steelhead parr annual survival rate was influenced by discharge; although, Pink salmon returns to the Cheakamus River during odd years had a significant positive effect on Steelhead parr annual survival rate. Steelhead adult returns to the Cheakamus River increased significantly under the WUP flow regime; however, the potential	There was no strong evidence to suggest that higher WUP flows during late-summer months (i.e., 38 m^3/s) effected Steelhead egg-to-fry survival. Instead, there was strong evidence to suggest that rapid changes in discharge (i.e., flow ramp downs) were associated with reduced survival of early-life stages of Steelhead in the Cheakamus River. To further understand causal mechanisms of fish stranding associated with rapid flow ramp downs and to test the effectiveness of potential mitigation measures, the Cheakamus Adaptive Stranding Protocol (CASP) has been implemented on the Cheakamus River outside of the WUP Order projects. Information gathered during the CASP will also be used to inform WUP Order Review with regards to fish stranding impacts associated with flow changes (e.g., effects of ramp rates, minimum flows, wetted history, etc.) on the Cheakamus River. Large uncertainties

Objectives	Management Questions[1]	Response	Implications
		effect was confounded by an increased Steelhead marine survival rate and an effect of increased Pink salmon returns during this period. Correcting for changes in marine survival and Pink salmon returns, Steelhead freshwater production may have decreased during WUP; however, there are large uncertainties in the correction factors applied. Addendum: Potential risks to juvenile fish in the Squamish River associated with Cheakamus Generating Station operations were identified in a desktop study. These risks were highest during winter months when natural inflows were low and during hydropeaking operations at the Cheakamus Generating station. However, further studies would be required to verify the effect of flows from Cheakamus Generating Station on fish populations in the Squamish River[4].	associated with marine survival rates of Cheakamus Steelhead limit the value of examining escapement trends to evaluate freshwater flow effects on production. Addendum: The Squamish River desktop stranding analysis highlighted key areas for focus in future study to identify potential effects of fluctuating discharges from Cheakamus Generating Station on juveniles.[2]

[1]BC Hydro 2007d, pp.3-4
[2] This management question was added to address changes made to the study in terms of reference addendum (BC Hydro 2018a).
[3] CMSMON-4 investigated only the impacts of operations in the Cheakamus Generating Station tailrace and Squamish River side-channel directly downstream and concluded there was likely no population level effect associated with the impacts observed in those locations.

4.4.2 Project Approach

CMSMON-3 was conducted from fall 2007 to fall 2018. The monitoring project was completed by Ecometric Research. The final report summarized results from the study period. As per the 2018 TOR addendum, an additional report was prepared to evaluate potential impacts of Cheakamus Generating Station operations on fish populations in the Squamish River during low flow periods. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The overall approach of the monitoring program to address the management questions was to:

1. quantify adult escapement and juvenile abundance in the fall and spring, and smolt production in the spring;
2. use these metrics to determine the survival rate between life stages and define life stage-specific stock-recruitment relationships; and
3. compare abundance, survival rates and stock-recruitment relationships under different flows, and relate changes in these metrics to IFA and WUP flow regimes or unique flow events (Korman and Schick 2018).

Adult Steelhead escapement to the Cheakamus River was estimated from 1996 to 2019 using a model which integrated data on raw counts from swim surveys, run-timing determined from radio telemetry, and mark-recapture (Korman and Schick 2018). The area surveyed for returning Steelhead begins approximately 500 m below a natural barrier, extending to the confluence with the Cheekye River (around 14.5 km in length; Figure 4.4.a). Resident Rainbow trout swim counts combined with radio telemetry data were also collected in 2016 and 2017 to estimate their abundance in the Cheakamus River.

Historical escapement was analysed across flow regimes using Beverton-Holt stock-recruitment relationships between Steelhead spawning stock (escapement and egg deposition) and the resulting adult recruit from that stock. Estimates were also corrected for non-flow related variable effects, including marine survival rate (using estimates from Puget Sound and Keogh River Steelhead stocks) and Pink salmon, and then reanalysed for flow related effects.

Juvenile Steelhead abundance was estimated using a combination of snorkel index surveys and electrofishing for various life stages (fall fry, age 0+, 1+, and 2+ parr in spring) in the lower Cheakamus River and Brohm River from fall 2007 to fall 2017. Brohm River abundance provided a control for any environmental variables that would have masked flow regime effects in the lower Cheakamus River (Korman et al. 2012). Fall estimates of abundance were based exclusively on electrofishing as water clarity is too turbid at that time of year for snorkeling, while spring abundance estimates are based on data from both electrofishing and snorkel surveys. Total abundance was estimated for each life stage by combining index survey data with detection probability data and then expanded to the river scale using usable shoreline habitat data.

Juvenile abundance monitoring in CMSMON1a (Lingard et al 2017) includes Steelhead smolt outmigration monitoring, but low trapping efficiencies and low overall abundance reduced the effectiveness of this monitoring to support the management questions in this study.

Ricker stock-recruitment curves were fit between different juvenile life-stages to investigate potential density dependent and flow related effect to survival. A variety of flow covariates were evaluated to explain the variability around the relationships, including rapid change in discharge (up and down), average discharge, variation in discharge, and the proportion of time discharge different flow thresholds. Flow covariates were calculated for the period of time that was most relevant for the life stages being compared.

Finally, emergence timing of Cheakamus River juvenile Steelhead was calculated using a combination of estimated spawn timing from radio telemetry data, water temperature data, and incubation-thermal unit models.

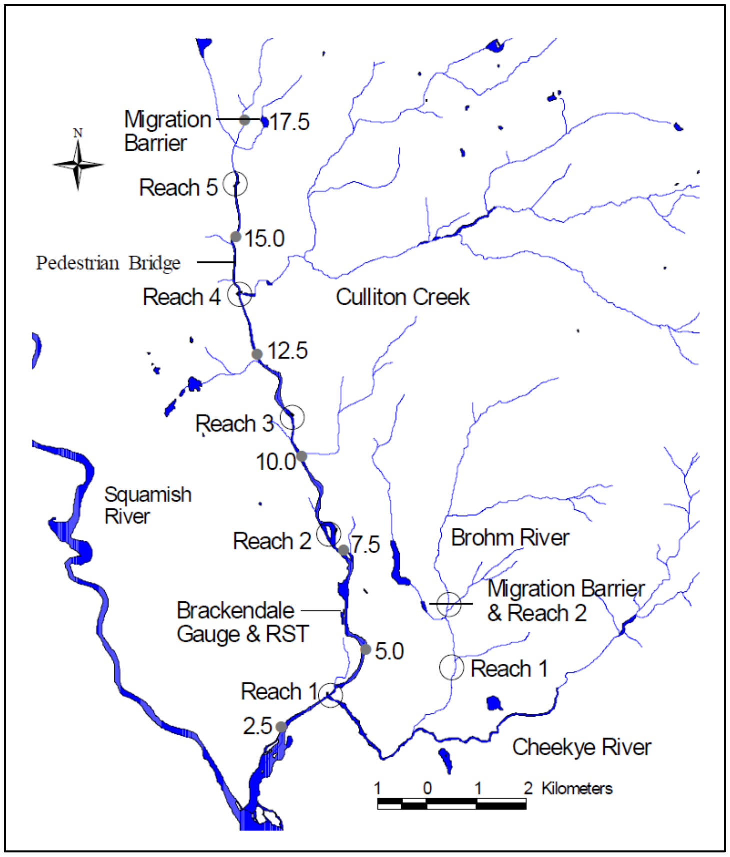


Figure 4.4.a: Map of the Cheakamus River study area showing (Korman and Schick 2018).

To address the 2018 TOR addendum (BC Hydro 2018a) requirements to assess potential risk of fish stranding in the Squamish River associated with powerhouse operations, a hydrologic analysis was performed and contrasted against key fish use periods in the Squamish River (Korman 2019).

4.4.3 Interpretation of Data

As very limited juvenile Steelhead abundance monitoring was completed prior to the implementation of the WUP flow regimes, inferences regarding the effect of flow on Steelhead production were made using the long-term escapement record for the river and from observed effects of inter-annual flow variation on juvenile Steelhead life stages.

Answers to Management Questions

1. *Do increased flows during July and August negatively affect emergent Steelhead young of year (YoY)?*

   Steelhead fry in the Cheakamus River typically emerge mid-July to early-August; which indicates the most flow-sensitive time period for recently emerged fry. Korman and Schick (2019) found limited statistical support that summer discharge magnitude, in particular those prescribed WUP minimum flows during fry emergence (i.e., 38 m^3/s), had an effect on egg-to-fry survival. Models that included the level of flow during summer explained far less variability in egg-to-fry stock recruit relationship than models that included rapid up- and down- ramps in discharge; rapid up- and down-ramps in discharge in the Cheakamus River during this early Steelhead emergence period was negatively associated egg-to-fry survival rates (Figure 4.4.b; describe in more detail in management question 4).

2. *How do changes in flow effect habitat use of Steelhead YoY and parr?*

   There was insufficient contrast in flow regimes during the WUP study period to answer this management question.

3. *Will an annual index of parr abundance provide a more robust estimate of Steelhead production in the Cheakamus River relative to the downstream migrant trapping program?*

   Results from the monitoring study show that electrofishing provides the most unbiased and precise estimates of age-0+ abundance in habitat types where the gear can be effectively applied (riffle and shallow water habitat), while snorkeling provides the most unbiased and precise estimates of abundance for age-1+ and older juvenile Steelhead in shallow and deep water habitats (Korman and Schick 2018). Both methodologies provided improved abundance monitoring estimates over the downstream migrant trapping program which was limited by low trap efficiencies and low catch.

4. *Does flow affect juvenile Steelhead production?*

   Korman and Schick (2019) collected and analysed juvenile Steelhead abundance data from in the Cheakamus River during the WUP period to analyse whether any characteristics of the flow regime (discharge covariates) could explain variation Steelhead freshwater survival rate. Rapid up- and down-ramps in discharge in the Cheakamus River during early-emergence period (mid-July to early-August) were found to be negatively associated Steelhead egg-to-fry survival rates (Figure 4.4.a). In addition, fry overwinter survival rate was negatively influenced by rapid changes in discharge as well as peak discharge during winter months (Figure 4.4.b). There was limited evidence to suggest that any of the discharge covariates analysed explained variation in Steelhead parr annual survival rate.

   Korman and Schick (2019) explain that early life stages of Steelhead are dependent on shallow and slow-water habitat at the river's edge. In the Cheakamus River, these habitats are typically limited to river margins and are very sensitive to flow changes. Rapid reductions in river discharge can result in stranding and mortality of sensitive fry stages utilizing habitat along the river margins, while high flows can result in velocities that exceed the limited swimming capacity for fry and can cause displacement downstream. Larger parr have a greater swimming capacity and utilize deeper habitat with higher velocities, therefore are less susceptible to high discharge and rapid changes in discharge. Findings of fish stranding studies conducted on the Cheakamus River during flow ramp downs during 2018 add support to the conclusion that rapid flow ramping on the Cheakamus river can results in substantial fish stranding on bar and side-channel habitats.

   Although no flow effects were found to impact parr survival rates, Korman and Schick (2019) found that Pink salmon returns to the Cheakamus River during odd year had a significant positive effect Steelhead parr over-winter survival rate. During years with Pink salmon runs, Steelhead parr annual survival rates were significantly higher than years with no Pink salmon (49% and 15%, respectively)(Figure 4.4.c). Korman and Schick (2019) explain that these parr are large enough by fall to consume Pink salmon eggs. In odd years with high Pink salmon returns, parr were observed with distended bellies likely from the consumption of large numbers of Pink salmon eggs; this availability and consumption of this lipid-rich food source likely results in increased in survival over the winter.

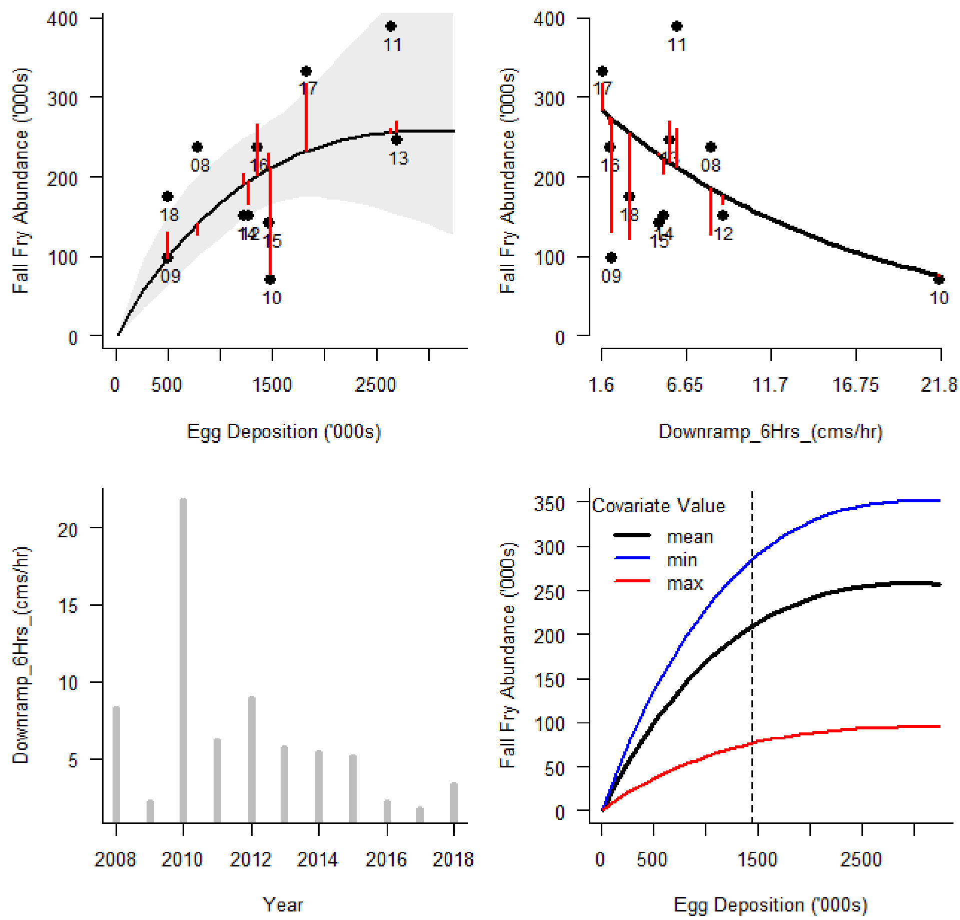


Figure 4.4.b: Fit of a Ricker flow covariate model to Steelhead egg deposition – fall fry abundance in the Cheakamus River. This model shifts the stock-recruitment curve each year based on the maximum decrease in discharge over 6 hours (down ramp rate). Also shown are the annual covariate values (bottom left) and the effect of the covariate on the recruitment curve based on the minimum, mean, and maximum covariate values across years (bottom right) (Korman and Schick 2019).

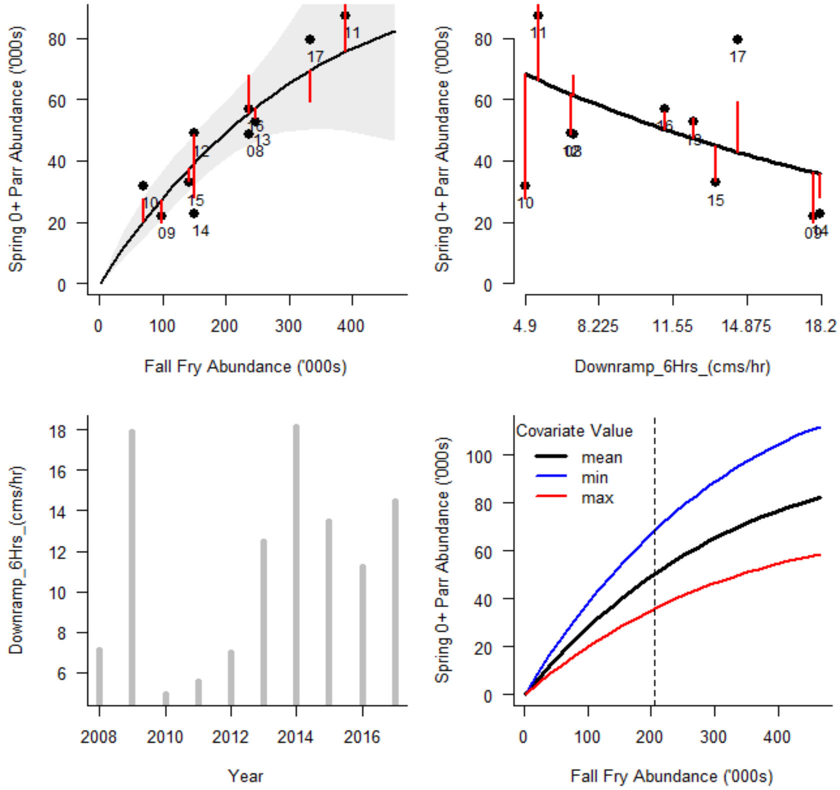


Figure 4.4.c: Fit of a Ricker flow covariate model to Steelhead fall fry – spring age 0 parr abundance in the Cheakamus River. See caption for Figure 4.4.b for additional details (Korman and Schick 2019).

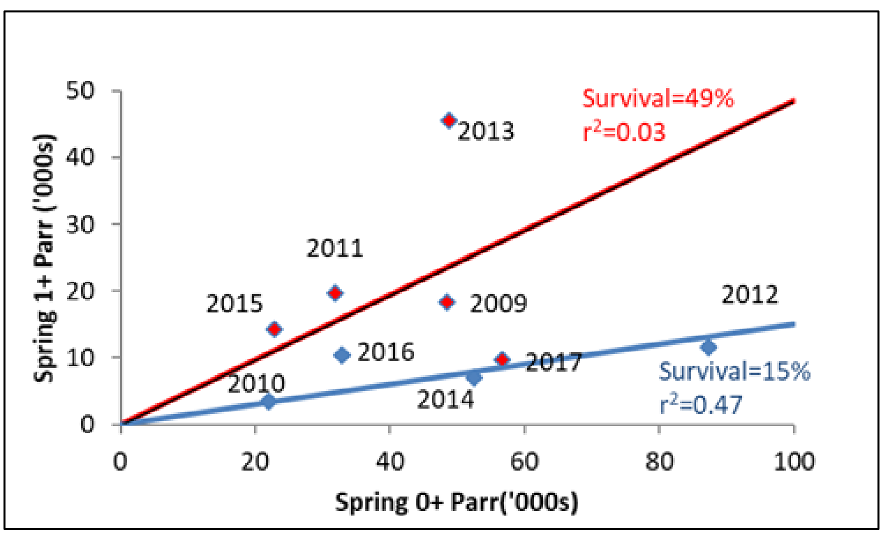


Figure 4.4.d: Relationship between 0+ parr abundance in the spring and 1+ abundance the following spring. Separate relationships in even and odd years are used to highlight differences in survival in odd and even years (Korman and Schick 2019).

Evidence for density dependence was limited during the egg-to-fry and parr life stage and very weak during fry over-winter period, suggesting habitat and resources were not substantively limiting to juvenile Steelhead under the WUP flow regime and that flow related effects on early-life stages of Steelhead may translate into overall freshwater productivity impacts to the population.

Average Steelhead escapement to the Cheakamus River increased significantly during the IFA period (385) relative to the pre-IFA period (170), and increased significantly again during the WUP period (575) (Figure 4.4.e). However, Korman and Schick (2019) explain that the effects of flow regime on Steelhead escapement are likely confounded by changes in marine and freshwater survival rates during the study period. Based on information from other Steelhead rivers in southern BC and Washington, Korman and Schick (2019) estimated that marine survival was on average ~1.3-fold higher in years effecting adult returns during the WUP regime relative to IFA years. In addition, high Pink salmon escapement during WUP years, which were not attributed to the WUP flow regime, likely resulted in on average ~1.5 fold higher parr survival rates during the WUP regime relative to IFA. After correcting for changes in marine survival rate and the effect of Pink salmon on parr survival, freshwater production of Steelhead was estimated to have decreased by 20% under the WUP flow treatment relative years as relative to IFA. Steelhead smolt production was estimated to have declined by 55% during the WUP regime relative to the average under the IFA regime. This independently-derived production decline is consistent with the conclusions from the escapement analysis. However, the estimated decline from the RST should be considered uncertain owing to the very limited sample size during the IFA period (n=3) coupled with considerable uncertainty in annual estimates due to low catch.

Significant increases in resident Rainbow trout in the Cheakamus River were also observed under the WUP flow regime. There are several competing hypotheses regarding the mechanism behind the observed increase in Rainbow trout: (1) the WUP flow regime increased freshwater production for Rainbow trout in the Cheakamus River; (2) other, non-flow related variables (e.g., effluent releases), resulted in increased freshwater production or increased residency rate for Rainbow trout coincidental to the WUP flow change; or (3) increase Steelhead escapement to the Cheakamus River during the WUP period resulted in increased resident Rainbow trout abundance. Unfortunately, controls in this monitoring program focused on Steelhead and could not be used to interpret changes in Rainbow trout abundance.

Based results from their discharge covariate – juvenile survival correlation analysis, Korman and Schick (2019) suggest that reducing flow ramping rates from Daisy Dam during July and August could result in increased Steelhead egg-to-fry survival rates in the Cheakamus River. Findings from the fish stranding survey conducted during August 2018 add support to the hypothesis that rapid ramp down rates associated with the WUP flow regime result in reduced juvenile Steelhead survival rates in the Cheakamus River; however, field observations also suggest that there may be a number of factors that contribute to juvenile stranding in the Cheakamus River, including ramp rates, wetted history, and minimum flows.

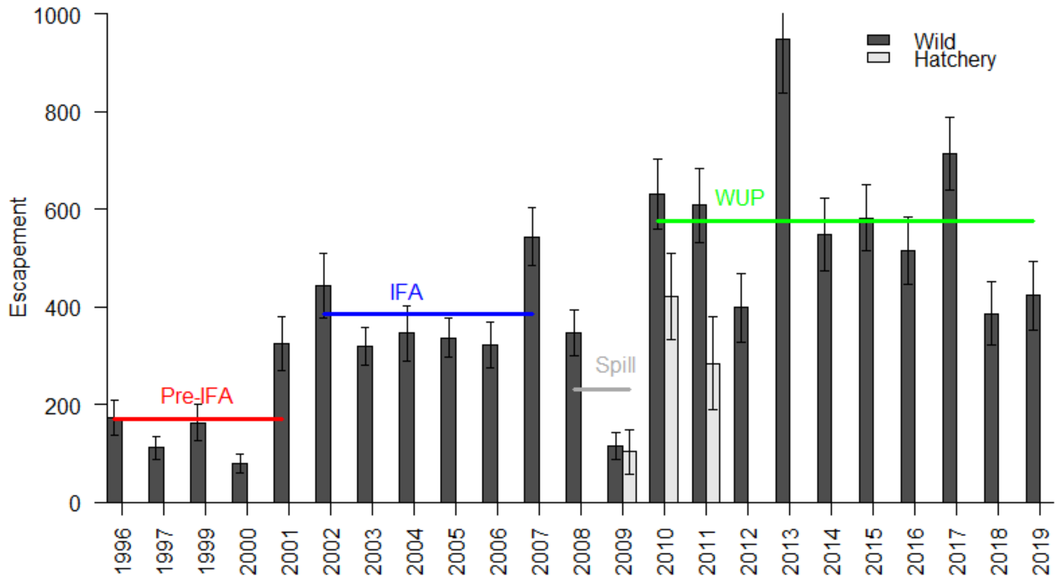


Figure 4.4.e: The Steelhead escapement trend in the Cheakamus River, 1996-2018. The colored horizontal lines show the average escapement for years where the returns had reared as juveniles before and after the Interim Flow Agreement (pre-IFA and IFA, respectively) and under the Water Use Plan flows (WUP), respectively. Also shown are years where returns were reduced due to the CN caustic soda spill (Korman and Schick 2019).

Addendum: What is the potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station?

Korman (2019) found the effects of Cheakamus Generating Station were greatest during winter months when natural inflows were low. During periods of very low inflow, while Cheakamus Generating Station was hydropeaking, peak flows in the Squamish River downstream could be twice that of base flows within a 24 hr period and maximum rates of stage change could reach 12-15 cm/hr (Brackendale gauge on the Squamish River - WSC gauge 08GA022).

Korman (2019) identified potential risks to juvenile fish during fluctuation in discharge in the Squamish River associated with the Cheakamus Generating Station operations, when juvenile fish are using of downstream habitats potentially affected by those fluctuation in river discharge.

During this period of highest potential of daily fluctuations in flow (specifically February through March), Chinook, Pink, and Chum salmon fry out-migrate from the Squamish River; these juvenile fish utilize habitat in the shallow margins of the river and therefore could be vulnerable to fluctuations in Squamish River levels associated with the Cheakamus Generating Station operations. In addition, Chinook, Coho, and Steelhead parr overwinter in the mainstem of the Squamish River, and may experience reduced habitat quality associated with discharge fluctuations.

Although risks to juvenile fish were identified in this desktop study, no field sampling was conducted. Further studies would be required to verify the effect of flows from Cheakamus Generating Station on fish populations in the Squamish River.

4.4.4 Conclusions and Implications

Steelhead escapement to the Cheakamus River increased significantly under the WUP flow regime; however, the effects of flow were confounded by a coincidental increase in regional Steelhead marine survival rates, and increased Pink salmon returns to the Cheakamus River that lead to higher parr survival rates during the WUP period. After correcting for increases in marine survival and Pink salmon escapement during WUP years, Korman and Schick (2019) estimated that freshwater production may have decreased by approximately 20% under the WUP flow treatment relative to IFA; this finding is supported by observed decreases in Steelhead smolt abundance at the rotary screw trap. However, these results should be considered uncertain due to large uncertainties associated with the correction factors applied and limited sample size and precision of the Steelhead smolt data. Given the large uncertainties associated with marine survival rates of Cheakamus Steelhead, there is limited value in examining escapement trends to evaluate freshwater flow effects on production. Direct estimates of juvenile survival rates in conjunction with purposeful manipulation in flow would provide a more accurate estimate of flow effects of productivity.

Although limited contrast in hydrograph characteristics across the WUP study period restricted the power of the study to distinguish flow effects on juvenile Steelhead, the correlation analysis showed that rapid changes in discharge during July and August could result in reduced Steelhead egg-to-fall fry and fry over-winter survival in the Cheakamus River. These results were supported by field observations of juvenile fish stranding during flow ramping in August 2018. Because there was limited evidence of density dependence, reduction in survival of early life stages may result in overall reduced Steelhead freshwater productivity. To further understand and potentially mitigate the effects of rapid flow reductions, the Cheakamus Adaptive Stranding Protocol has been implemented on the Cheakamus River.

Potential risks to juvenile fish in the Squamish River associated with Cheakamus Generating Station operations were identified in a desktop study. These risks were highest during winter months when natural inflows were low and during hydropeaking operations at the Cheakamus Generating Station. However, further studies would be required to verify the effect of flows from Cheakamus Generating Station on fish populations in the Squamish River.

4.5 CMSMON-4: Monitoring Stranding Downstream of Cheakamus Generating Station

4.5.1 Project Summary

During the Cheakamus WUP process, the Fish Technical Committee identified an uncertainty regarding the potential impacts of the Cheakamus Generating Station on fish stranding in the tailrace channel and Squamish River side channel downstream of the station. Fluctuating discharge from Cheakamus

Generating Station, which is located on the eastern bank of the Squamish River, results in tailrace water level fluctuations that could strand redds or juvenile fish. Consequently, the Fisheries Technical Committee recommended the development of a monitoring program to address the key uncertainties related to the generating station operation and consequential fish stranding impacts (BC Hydro 2007e).

Objectives	Management Questions[1]	Response	Implications
To address key uncertainties related to the Cheakamus generating station operation and potential fish stranding impacts in the tailrace channel and Squamish River side-channel downstream. (Stranding potential in the Squamish River downstream of the tailrace is being reviewed under CMSMON-3.)	1. What is the magnitude of stranding risk in the tailrace channel downstream of the Cheakamus Generating Station, and at what time of the year is it at its highest level? 2. What is the aerial extent of the stranding impact should it occur? 3. Does a peaking operation at the powerhouse prevent juvenile salmonids from colonizing habitats that are prone to dewatering? 4. What is the stranding risk to spawning adults and resulting redds when in the tailrace channel? 5. If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?	1. Stranding risk below the Cheakamus Generating Station was relatively low compared to risks identified in Cheakamus River (Hoogendoorn et al. 2009); therefore monitoring results suggest in general that the observed stranding rate would likely not be harmful to local fish populations, although the effect on populations could vary by species abundance. The highest fish stranding risk resulting from ramp downs at the Cheakamus Generating Station occur during time of year when water levels in the Squamish River are typically low (December-April, September). 2. Due to limited channel bathymetric data, the hydraulic model was incapable of evaluating the total aerial extent of stranding or site specific fish stranding patterns. During low water levels/high stranding risk periods, the relative area of potential stranding risk was the highest for the 55-0 m^3/s ramp-down mode, followed by the 25-0 m^3/s, and finally the 55-25 m^3/s ramp-down scenarios. 3. Although juvenile fish abundances appeared lower under higher discharge from the Cheakamus Generating Station, peaking operations do not prevent juvenile fish from colonizing habitats prone to dewatering in the tailrace channel or side-channel downstream. 4. Based on fish stranding survey results and corresponding calculation of relative fish stranding risk index, adult stranding risk was lower than the average stranding risk calculated during monitored ramp downs from the Cheakamus Generating Station, and only occurred during one stranding risk survey. However, redds located in the tailrace and side-channel area have the potential to dewater if Cheakamus Generating Station was ramped down when the Squamish River level was at low flow levels. 5. While the risk of stranding was relatively low, several mitigation measures were discussed.	Fish stranding risk in the Cheakamus Generating Station tailrace channel and Squamish River side-channel immediately downstream was relatively low and unlikely to have fish population level impact[3]. Fish stranding risk was highest during period of low flow in the Squamish River (December-April, or September), during larger ramp downs from the generating station, and when ramped down to zero discharge. Mitigation options were discussed in the study, but none were assessed during the study period. Note: further assessment of potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station was completed as an addendum to CMSMON-3 (see above).

[1] TOR reference; BC Hydro 2007e, pp.15
[2] CMSMON-3 addendum investigate potential stranding risk in the mainstem of the Squamish River downstream of the Cheakamus Generating Station.

4.5.2 Project Approach

CMSMON-4 was conducted from September 2008 to October 2011 by Squamish Nation in association with Golder Associates Ltd. Reports were compiled starting in 2009. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach of this monitoring project was to use a combination of hydraulic modeling, fish use assessments and stranding surveys to assess fish stranding risk in the Cheakamus Generating Station tailrace channel and the Squamish River side channel ("the study area"; Figure 4.5.a).

A 2-D hydraulic model was developed to determine the aerial extent of fish stranding and potential stranding risk at under a variety of flow scenarios.

Fish use assessments were completed at sites selected in a range of different fish habitat types to quantify an index of abundance of vulnerable fish in the study area. Methods included visual observations, minnow trapping, snorkel surveys, beach seine, and dip-net sampling techniques.

Fish stranding surveys were completed following ramp downs to the Cheakamus Generating Station on eight occasions. Stranding surveys investigated dewatered areas throughout the sample sites for evidence of stranded fish by turning over rocks, checking underneath woody debris, and substrate surveys in and around shallow pools. Stranded fish were identified to species, counted, their fork lengths measured and their stranding location documented. A relative index of stranding risk was estimated by comparing the number of fish found stranded to the number of fish observed within the study area.

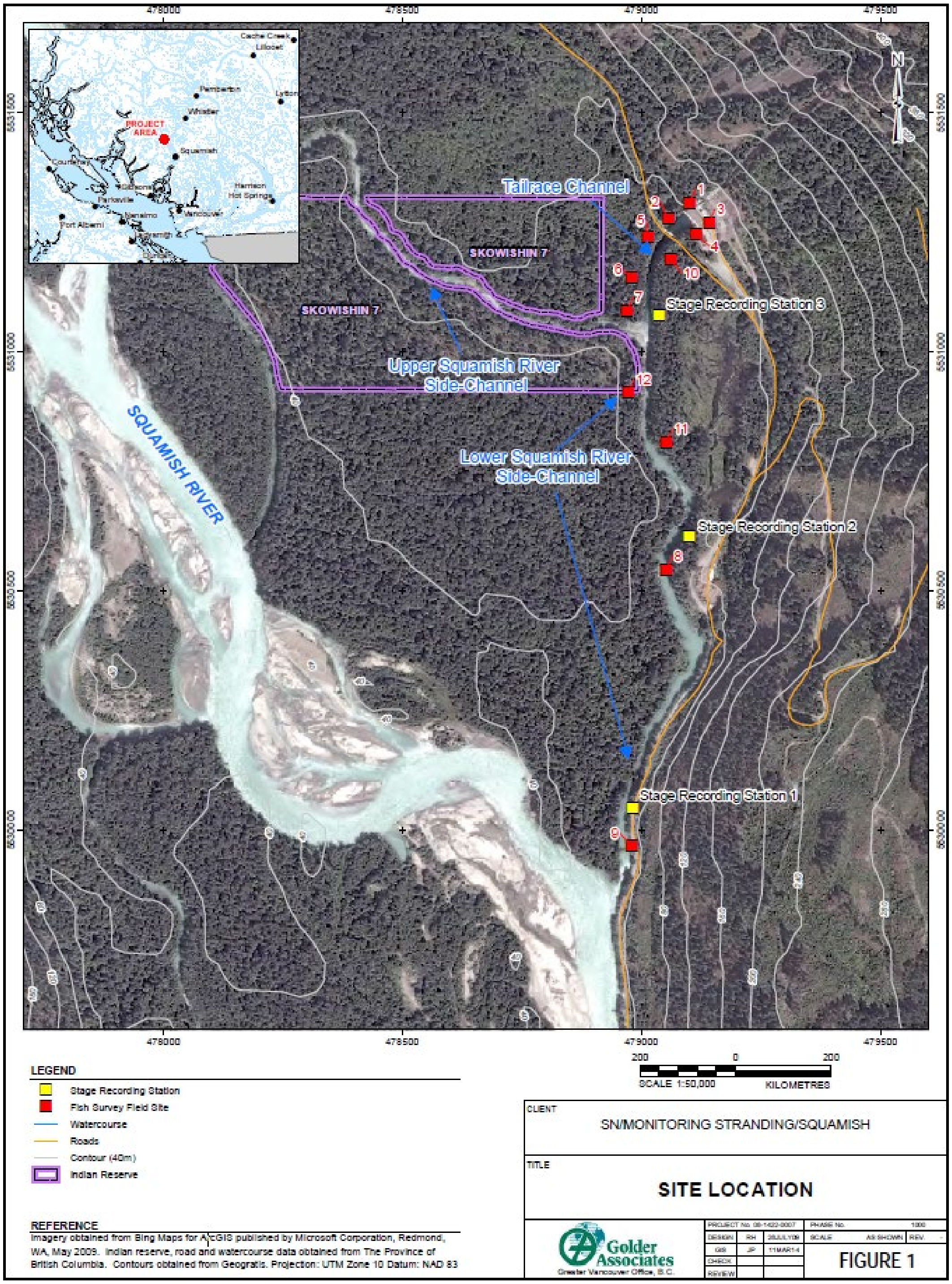


Figure 4.5.a: : Map of the Cheakamus Generating Station, tailrace channel, and Squamish River side-channel relative to the Squamish River, showing fish sampling sites and stage recording locations (Harrison et al. 2014)

4.5.3 Interpretation of Data

The purpose on CMSMON-4 was to address key uncertainties related to the Cheakamus Generating Station operation (changing from higher to lower flow) and potential fish stranding impacts in the tailrace channel and Squamish River side-channel downstream. Fish use sampling combined with fish stranding survey results were used to estimate an index of relative fish stranding risk over a range ramp down types. Hydraulic modelling was used to describe the area of potential fish stranding as a function of Squamish River water levels and Cheakamus Generating Station flows.

Answers to Management Questions

1. *What is the magnitude of stranding risk in the tailrace channel downstream of the Cheakamus Generating Station, and at what time of the year is it at its highest level?*

   Stranding risk below the Cheakamus Generating Station was relatively low compared to risks identified in Cheakamus River (Hoogendoorn et al. 2009); therefore Harrison et al. (2014) assert that the observed stranding rate would not be harmful to local fish populations, although the effect on populations could vary by species abundance. The highest fish stranding risk resulting from ramp downs at the Cheakamus Generating Station occur during time of year when water levels in the Squamish River are typically low (December-April, September).

   Harrison et al. (2014) completed eight stranding surveys in the Cheakamus Generating Station tailrace channel and the Squamish River side-channel downstream of the tailrace ("the study area"). Stranding surveys were completed following ramp downs from the Cheakamus Generating Station during times of year when flows in the Squamish River are typically low. During the eight stranding surveys a total of 10 stranded fish were observed; based on these stranding survey results, Harrison et al. (2014) categorized the overall magnitude of fish stranding as low.

   Stranding index for each ramp down (Table 4.5.b - calculated as the fraction of fish found stranded to the number of fish observed within the study area) was variable among ramp downs, with an average of 0.05 (i.e., 5 fish stranded per 100 fish observed inhabiting the channel).

   Overall, the authors suggest that stranding risk below the Cheakamus Generating Station was relatively low compared Cheakamus River below Daisy Lake Dam (Hoogendoorn et al. 2009); and therefore asserts that the observed stranding rate would not be harmful to local fish populations.

Table 4.5.a: Stranding risk index by sample date (Harrison et al. 2014)

Field Visit	Date	# Fish Observed[1]	# Fish Stranded	Stranding Index
1	Sept 22/08	67	2	0.03
2	Nov 17/08	5	0	0.00
5	Mar 14-15/09	83	1	0.01
7	Apr 17-18/09	41	4	0.10
14	Sept 16/09	5	0	0.00
15	Sept 22/09	65	2	0.03
18	Oct 30/09	10	2	0.20
20	Dec 18/09	2	0	0.00
			Mean Stranding Index	0.05

The authors also concluded that the highest fish stranding risk resulting from ramp downs at the Cheakamus Generating Station occur during times of year when water levels in the Squamish River are typically low. Squamish River typically is at its lowest levels between December and April, or September (Figure 5.4.b).

2. *What is the aerial extent of the stranding impact should it occur?*

   Due to limited channel bathymetric data, the hydraulic model was incapable of evaluating the total aerial extent of stranding or site specific fish stranding patterns. The area of potential fish stranding, which provides a relative indication of fish stranding risk, was modelled as a function of Squamish River water levels under three ramp-down scenarios at Cheakamus Generating Station (Figure 4.5.b). Harrison et al. (2014) observed the following trends: (1) for ramp-down scenarios, the area of potential stranding risk increases with lower flows/water levels in the Squamish River; and (2) for low flows/water levels in the Squamish River where fish stranding is more likely, the relative area of potential stranding risk was the highest for the 55-0 m^3/s ramp-downs, followed by the 25-0 m^3/s ramp-downs, and finally the 55-25 m^3/s ramp-downs from Cheakamus Generating Station.

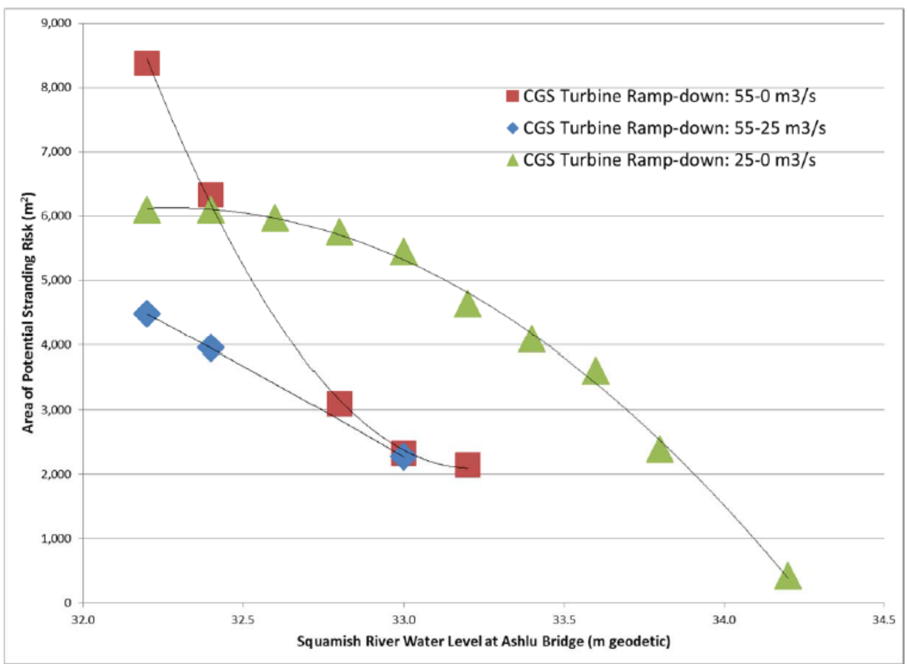


Figure 4.5.**b: Area of potential stranding risk versus Squamish River water level at Ashlu Bridge (Harrison et al. 2014).**

3. *Does a peaking operation at the powerhouse prevent juvenile salmonids form colonizing habitats that are prone to dewatering?*

   Based on fish use assessment data, juvenile fish abundance appears lower in the tailrace and Squamish River side-channel while discharge from the Cheakamus Generating Station is high (Figure 4.5.c). However, the authors admitted that the effect of discharge on capture efficiency may bias results and therefore concluded that generating station discharges do not prevent juvenile fish from colonizing habitats prone to dewatering in the tailrace channel or side-channel downstream.

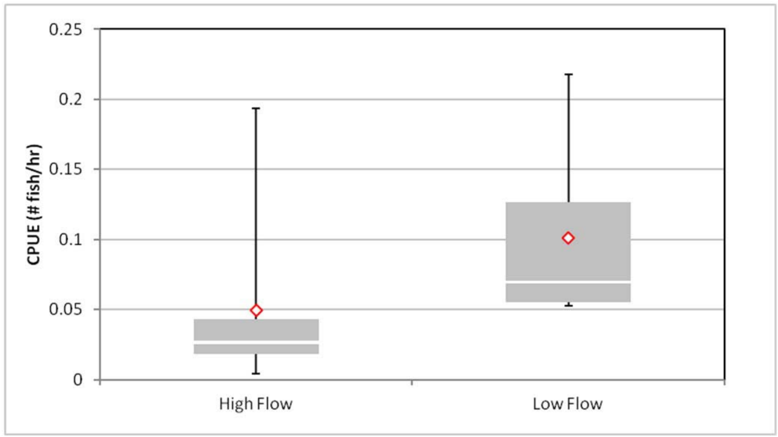


Figure 4.5.c: Box-Whisker Plot comparison of catch per unit effort during low and high flows in the Tailrace Channel and Squamish River Side-channel.

4. *What is the stranding risk to spawning adults and resulting redds when in the tailrace channel?*

   Based on fish stranding survey results and corresponding calculation of relative fish stranding risk index, adult stranding risk was lower than the average stranding risk calculated during monitored ramp downs from the Cheakamus Generating Station, and only occurred during one stranding risk survey. However, redds located in the tailrace and side-channel area have the potential to dewater if Cheakamus Generating Station was ramped down when the Squamish River level was at low flow levels.

5. *If the rate of stranding is found to be significant, what kind of actions can be taken to mitigate the impact?*

   Although the stranding risk at the Cheakamus Generating Station tailrace channel and Squamish River downstream was found to be relatively low, Harrison et al. (2014) suggest the following mitigation measures that could reduce stranding rates:

   - Seasonally altering ramping rates based on Squamish River water levels and powerhouse discharge conditions;
   - Fish barriers for adults to prevent spawning in specified high-risk stranding areas;
   - Reshaping the channel to limit access to high-risk areas where dewatering occurs; and
   - Redd salvage.

4.5.4 Conclusions and Implications

Fish stranding risk in the Cheakamus Generating Station tailrace channel and Squamish River side-channel immediately downstream was relatively low and unlikely to have a fish population level impact. Fish stranding risk was highest during period of low flow in the Squamish River (December to April and September), during larger ramp downs from the generating station, and when the station was ramped down to zero discharge. Mitigation options were discussed in the study, but none were assessed during the study period. Korman (2019; summarized in section 4.3) hypothesized in a desktop study that stranding risk due to flows from Cheakamus Generating Station is likely highest during fry out migration in late winter/early spring when Squamish River discharges are typically the lowest.

4.6 CMSMON-5: Monitoring Stranding Downstream of Daisy Lake Dam

4.6.1 Project Summary

Implementation of the Cheakamus WUP Order resulted in changes to the flow regime downstream of Daisy Lake Dam from the previous Interim Flow Agreement (IFA). While the IFA minimum flow discharges from Daisy Lake Dam were the greater of 5 m^3/s, or 45% of the previous day's average reservoir inflows[6], the WUP flow minimum flows were linked to minimum flows downstream at the Water Survey Canada Brackendale gauge. Under the WUP, different minimum flows are discharged from Daisy Lake Dam depending on time of year (i.e., 1 Jan. – 31 Mar.: 5 m^3/s; 1 Apr – 31 Oct.: 7 m^3/s; and 1 Nov. to 31 Dec.: 3 m^3/s). The primary concern raised by the Fisheries Technical Committee was associated with the proposed WUP flow ramp down at Daisy Lake Dam from 7 m^3/s to 3 m^3/s during November, and the potential stranding of fish that had been habituated to areas near the margins of the river under the stable 7 m^3/s flow conditions. The primary area of concern was the mainstem of the Cheakamus River directly below Daisy Lake Dam to the confluence of the Rubble Creek tributary, which was believed to attenuate the effects of flow ramping on fish stranding.

The WUP prescribed ramp rates from Daisy Lake Dam change depending on discharge releases from the Dam (Table 4.6.a). BC Hydro developed terms of reference to assess the effectiveness of WUP ramp rates at Daisy Lake Dam to better understand and potentially mitigate fish stranding risk, and also to assess the attenuating effect of downstream tributary inflow on flow ramping (BC Hydro 2007f).

Table 4.6.a: Water Use Plan ramp down rates from Daisy Lake Dam (BC Hydro 2005).

Discharge from Daisy Dam	Ramp Down Rate
<10 m^3s^{-1}	1.0 m^3s^{-1} per 60 min
10-62 m^3s^{-1}	13 m^3s^{-1} per 15 min
>62 m^3s^{-1}	13 m^3s^{-1} per 10 min

[6] The Interim Flow Agreement was negotiated between BC Hydro, DFO and the Comptroller of Water Rights to ensure Daisy Lake Dam discharge were set to the greater of 5 m^3/sec or 45% of the previous day's average inflows to the reservoir (within a daily range of 37% to 52% and within 45% of the previous 7 days' average inflows).

Objectives	Management Questions[1]	Response	Implications
To assess efficacy of WUP ramp rates to minimize fish stranding risk downstream of Daisy Lake Dam, and to assess the attenuating effect of downstream tributary inflow on flow ramping.	1. Is the prescribed ramping rate for flows less than 10 m^3/s adequate to prevent fish stranding when the minimum release out of the Daisy Lake Dam is lowered on 1 Nov to 3 m^3/s from its high of 7 m^3/s during the preceding growing season? 2. To what extent do the inflows of Rubble Creek impact the rate of stage change downstream of Rubble Creek, and do the inflows of other tributaries impact the rate of stage change at the Brackendale Gauge?	1. A total of 35 fish were observed stranded during the Daisy Lake Dam flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018. This was considered to be below the maximum acceptable level of stranding established in consultation with regulatory agencies (DFO and MOE). 2. The magnitude and rate of the stage change downstream of Rubble Creek had clearly been attenuated by tributary inflow. However, the total stage change in several of the sites still exceeded the target rate of 2.5cm-hr^{-1}.	Although prescribed WUP ramp rates from Daisy Lake Dam (1 m^3/s per 60 min) resulted in stage change rate downstream that exceeded -2.5 cm/hr during the flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018, the study concluded that fish stranding rates were below maximum acceptable levels established by DFO and MOE (discussed below). Given that stranding is a low risk in the resident reach, and given the results of CMSMON-3 suggest that flow reductions may have a measurable impact on anadromous populations in the Cheakamus River, the Cheakamus Adaptive Stranding Protocol will focus its efforts on mitigating stranding risks in the lower reaches of the Cheakamus River.

[1] TOR reference; BC Hydro 2007f, pp.8

4.6.2 Project Approach

The CMSMON-5 monitoring project was conducted in October and November of 2008 by Squamish Nation in association with Golder Associates Ltd. A final report was compiled that summarized results. Reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach of this monitoring project was to first establish maximum acceptable level of stranding (MALS) which would be used as a measurable criteria for assessing fish stranding risk. (Hoogendoorn et al. 2009)

A field reconnaissance of the study area was completed by Squamish Nation in association with Golder Associates and BC Hydro on October 30, 2008, prior to the November 1, 2008 ramp down event in order to assess and classify high and moderate risk stranding habitat locations (e.g., include potholes, side-channels and low gradient bars) in the study area. The location of the study area is provided in Figure 4.6.a. (Hoogendoorn et al. 2009).

River stage was monitored using pressure transducers at two locations within the study reach between Daisy Lake Dam and the confluence of Rubble Creek. Standard fish stranding surveys and salvage were carried out during the flow rampdown from Daisy Lake Dam on November 1, 2008. Fish stranding surveys consisted of examining dewatered habitat for stranded fry and parr within four identified high and moderate risk sites and as the ramp down proceeded by flipping rocks and excavating areas in shallow depressions by hand. Salvaged fish were enumerated, identified to species, and measured for fork length. Live fish were immediately returned to the adjacent mainstem river (Hoogendoorn et al. 2009).

4.6.3 Interpretation of Data

Squamish Nation staff in association with Golder Associates Ltd. in consultation with regulatory agencies (DFO and MOE) in 2008, (Hoogendoorn et al. 2009) defined a maximum acceptable level of stranding (MALS) as “dozens” of fish rather than “hundreds” of fish, which would present more of a concern in regards of the potential impact of stranding of the resident fish populations.

Answers to Management Questions

1. *Is the prescribed ramping rate for flows less than 10 m^3/s adequate to prevent fish stranding when the minimum release out of the Daisy Lake Dam is lowered on 1 November to 3 m^3/s from its high of 7 m^3/s during the preceding growing season?*

   During the ramp down, fish stranding was observed at three of the four sites monitored. A total of 35 fish were observed stranded; of the total, 12 were Rainbow trout, including four fry, seven 1+ parr, and one larger sized Rainbow trout (2+ or older; Table 4.6.b).

   Hoogendoorn et al. (2009) compared the total number of stranded fish observed during the flow ramp down from Daisy Lake Dam (i.e., 35 fish total) to the MALS guideline established by DFO and MOE. Because the observed rate of resident fish stranding downstream of the Dam does not exceed the MALS, the study concludes that the ramp rates were adequate to prevent significant fish stranding.

   The authors note that a large side-channel was isolated during the ramp down that was not part of the study area, and could pose a potential risk isolated fish survival that was not accounted for in this study.

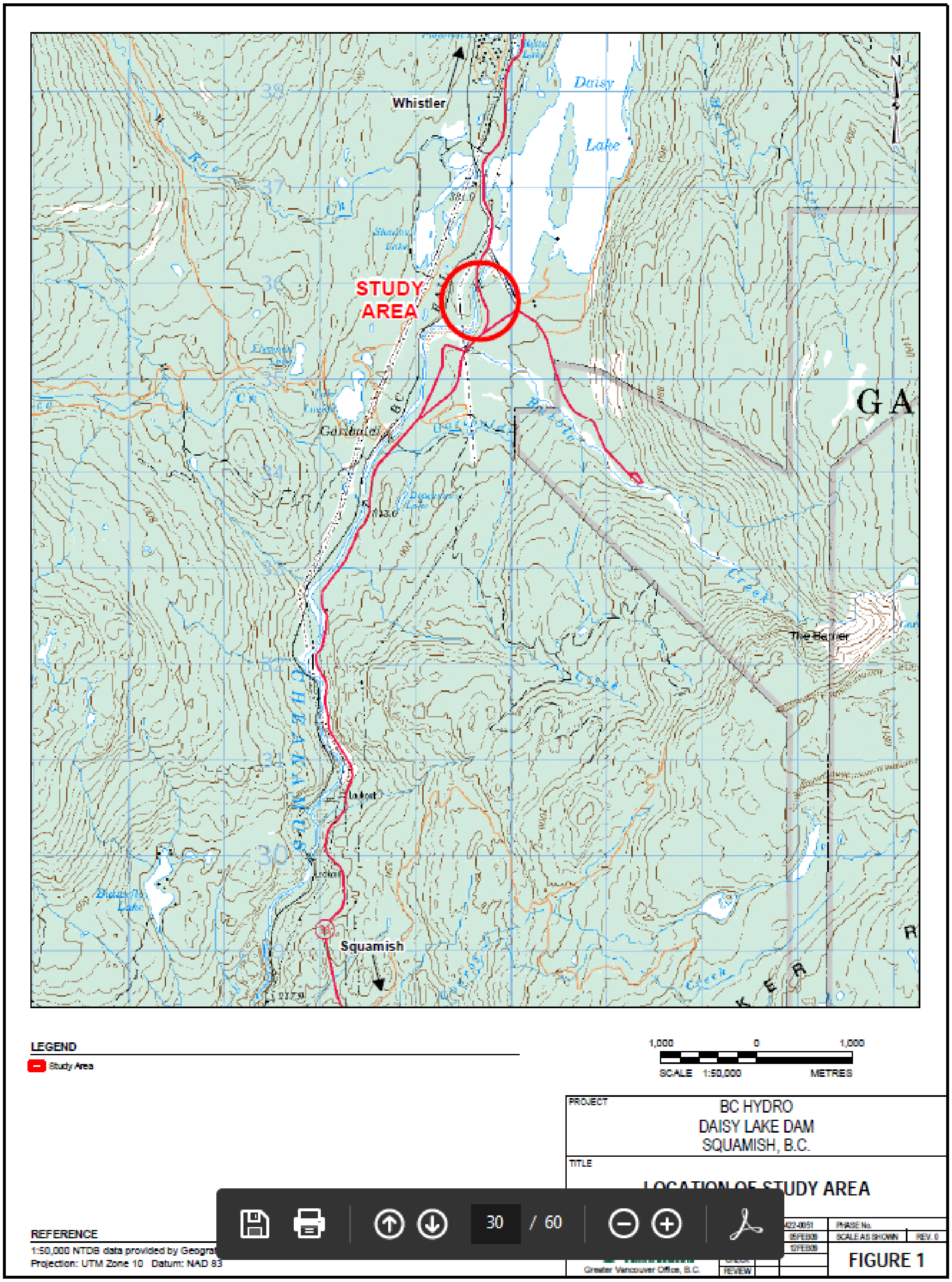


Figure 4.66.a: Fish standing study area on the Cheakamus River, downstream from Daisy Lake Dam (Hoogendoorn et al. 2009).

Table 4.6.b: Stranding Survey Results for Daisy Lake Dam Rampdown Event, November 1, 2008 (Hoogendoorn et al. 2009).

SITE #	1	2	3	4	
Risk	Mod	High	Mod	High	
Staff Guage Stage Change (cm)	11.5	24	7.5	n/a	
Salvaged					TOTAL
Rainbow Trout (*Oncorhynchus mykiss*)					
Fry	0	0	0	0	0
Parr (1+)	2	2	0	1	5
Juvenile (>=2+)	0	0	0	0	0
Sculpin	0	4	0	4	8
Three Spine Stickleback (*Gasterosteus aculeatus*)	2	10	0	2	14
Subtotal	4	16	0	7	27
Mortalities					
Rainbow trout					
Fry	2	2	0	0	4
Parr (1+)	0	1	0	1	2
Juvenile (>=2+)	0	1	0	0	1
Sculpin (*Cottus sp.*)	0	0	0	0	0
Three Spine Stickleback	0	1	0	0	1
Subtotal	2	5	0	1	8
TOTAL FISH (Salvaged + Mortalities)	**6**	**21**	**0**	**8**	**35**
TOTAL Rainbow Trout	**4**	**6**	**0**	**2**	**12**

2. *To what extent do the inflows of Rubble Creek impact the rate of stage change downstream of Rubble Creek, and do the inflows of other tributaries?*

The magnitude and rate of the stage change downstream of Rubble Creek had clearly been attenuated by tributary inflow. However, the total stage change in several of the sites still exceeded the target rate of 2.5cm-hr^{-1}.

The study compared rates of stage change observed during the rampdown from Daisy Lake Dam on Nov. 1, 2008 with DFO guidelines for British Columbia (-2.5 cm-hr^{-1}; summarized in Cathcart 2005) which have been shown to mitigate stranding on other systems.

The average rate of stage change observed exceeded the target rate of -2.5 cm-hr^{-1} at the WSC Brackendale station 19.3 km downstream, and at 3 of the 4 study area sites.

The study design did not allow for the evaluation of the precise influence of Rubble Creek on rate of stage change in the Cheakamus River Downstream of the confluence. Data from the Brackendale WSC hydrometric station indicated that the effect of the ramp down was noticeable at this station approximately 19.3 km downstream of Daisy Lake Dam. However, the magnitude of the stage change had clearly been attenuated by tributaries inflow downstream of the Dam (Figure 4.6.b).

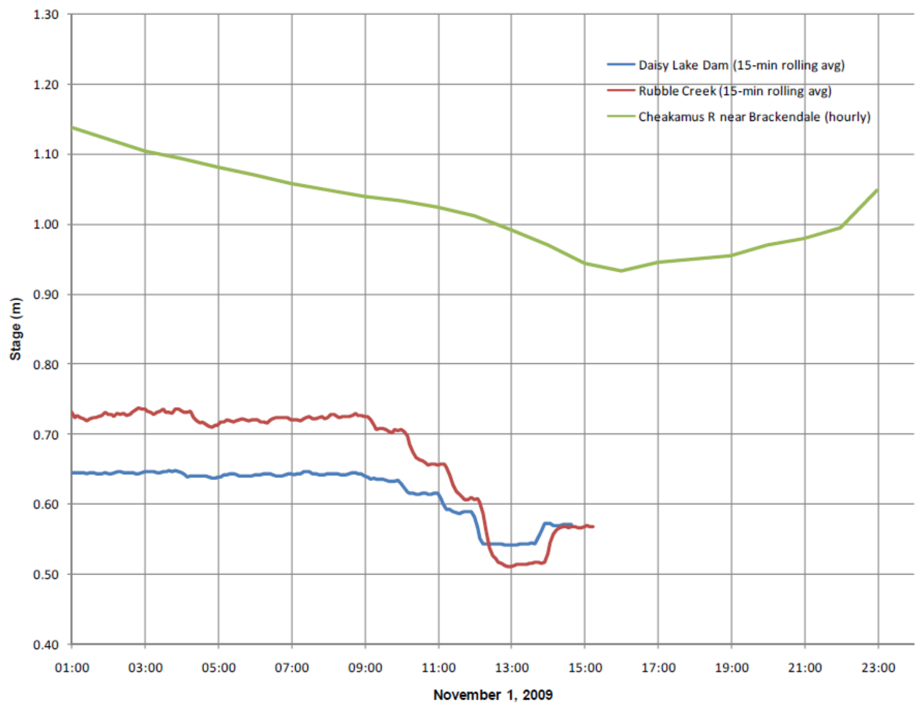


Figure 4.66.b: Observed stage on the Cheakamus River during ramp down on November 1, 2008 (Hoogendoorn et al. 2009).

Although observed ramp rates exceeded the target rate of stage change (-2.5 cm-hr^{-1}), Hoogendoorn et al. (2009) conclude that fish stranding was not significant under the prescribed ramping rate of 1 m^3/s per hour. Consequently, Hoogendoorn et al. (2009) suggested that the WUP ramp rate for Daisy Dam is deemed adequate to prevent a high level of fish stranding during November ramp downs.

4.6.4 Conclusions and Implications

Prescribed WUP ramp rates from Daisy Lake Dam (1 m^3/s per hour) resulted in stage change rate downstream that exceeded -2.5 cm per hour during the flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018. However, this study concluded that WUP ramp down rates were adequate to achieve fish stranding rates downstream that were below maximum acceptable levels in the resident reach, and that there is a low risk of stranding in the resident reach.

Based on data collected from the Brackendale WSC hydrometric station, the magnitude of the stage change is attenuated by tributary inflow downstream of Daisy Lake Dam.

In the anadromous reach of the Cheakamus River, CMSMON-3 results suggest that flow reductions may have a measurable impact on anadromous populations. The Cheakamus Adaptive Stranding Protocol implemented in 2018 focuses its efforts on mitigating stranding risks in the lower reaches of the Cheakamus River.

4.7 CMSMON-6: Monitoring Groundwater in Side Channels of the Cheakamus River

4.7.1 Project Summary

The Cheakamus WUP Consultative Committee and the Fisheries Technical Committee wanted to understand whether the WUP flow regime would impact groundwater input to side channels utilized primarily by Chum salmon in the lower anadromous reaches of the Cheakamus River. The concern was that WUP mainstem flows would negatively affect salmonid side channel production near the Cheakamus Centre (formerly the North Vancouver Outdoor School or NVOS) and the Department of Fisheries and Oceans' Tenderfoot Hatchery. To reduce this uncertainty, BC Hydro initiated a monitoring study aimed at characterising the linkages between Cheakamus River mainstem flows, floodplain groundwater systems, and side channel upwelling (BC Hydro 2007g).

Objectives	Management Questions[1]	Response	Implications
To investigate linkages between Cheakamus River mainstem flows, floodplain groundwater systems, and corresponding effects on fish habitat and productivity.	1. To what extent does seasonal NVOS and Tenderfoot Hatchery floodplain shallow groundwater flow direction, and selected water quality parameters (temperature, dissolved oxygen, and pH) vary in response to Cheakamus River mainstem flows ≤ 40 m^3/s? 2. To what extent does seasonal NVOS and Tenderfoot Hatchery side channel hydrology depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s? 3. To what extent do key fish habitat variables related to flow (average depth, average velocity, discharge) and water quality (temperature, dissolved oxygen, and pH) in NVOS and Tenderfoot Hatchery side channels depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s? 4. To what extent does salmonid production vary in NVOS and Tenderfoot Hatchery side channels in relation to groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s, and to what extent has the implementation of the WUP affected salmonid production in the NVOS and Tenderfoot	1. The ground-surface water interface in the Cheakamus River side-channel area was relatively stable at low and moderate flows. Between 15 and 40 m^3/s the magnitude of change in groundwater elevation in the side-channel habitat was very minor. Analysis showed that the groundwater source for each side channel was the Cheakamus River. Therefore, Cheakamus River flow variation within the relevant management range (e.g., 15 to 70 m^3/s) had no practical effect on pH, dissolved oxygen, or temperature in upwelling groundwater or surface water in the side-channels. 2. The magnitude of effect of Cheakamus River flows on side channel seasonal hydrology was very small and diminished with mainstem flows below 40 m^3/s; therefore, side-channel hydrology is considered functionally insensitive to changes in mainstem discharge between 40 and 15 m^3/s. 3. The availability of wetted habitat and total suitable habitats in the side-channel habitats was considered insensitive to changes in Cheakamus River mainstem flow below 40 m^3/s. Changes in mainstem discharge associated with WUP operation were unlikely to have any impact of water quality and consequential habitat suitability for aquatic organisms in the side-channels 4. There was limited evidence of any causal relationship between groundwater parameter and fish production in the side channels. A significant correlation was observed between water level fluctuations in the groundwater channels during incubation and the Chum salmon egg-to-fry survival rate; however, variability in water level was relatively independent of Daisy dam operations. In addition, there was no evidence to support that quantity or quality of habitat available in the groundwater side channels has been meaningfully impacted by the WUP compared to pre-WUP state.	Because the groundwater quantity and quality in the side-channels was relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s, it is unlikely that the WUP flow regime resulted in any biologically significant impact to fish habitat or fish productivity in the Cheakamus side-channel area.

	Hatchery side channel habitats compared to the pre-WUP state?		

[1] TOR reference; BC Hydro 2007g, pp.12

4.7.2 Project Approach

The CMSMON-6 monitoring project was conducted from January 2008 to February 2011 by Pottinger Gaherty Environmental Consultants Ltd., SRK Consulting (Canada) Inc., and Simon Fraser University, Department of Earth Sciences. Reports were compiled each year. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The monitoring approach was to evaluate the correlation(s) between flow in the Cheakamus River and hydraulic parameters in adjacent floodplain and groundwater-fed spawning channels, in and around the NVOS and Tenderfoot Hatchery sites in Brackendale (Figure 4.7.a). The program also explored how these hydraulic parameters may relate to salmonid productivity in the same area. (Gray et al. 2012).

A complex array of monitoring stations were established within the side-channel habitat area and the Cheakamus River mainstem (Figure 4.7.a) to collect a number of water quality and physical habitat parameters among the study sites. Groundwater parameters collected included: flow direction, temperature, dissolved oxygen (DO), pH, dissolved metals and anions. Side-channel surface water parameters collected included: discharge, depth, velocity and width, temperature, DO, pH, dissolved metals and anions. Groundwater and side-channel surface water parameters were compared to concurrent parameter measurement collected in the Cheakamus River mainstem using time series cross-correlation and regression. To answer the management questions, the project team assessed if there were any relationships between mainstem and side channel flow attributes, and between salmonid production and groundwater variables.

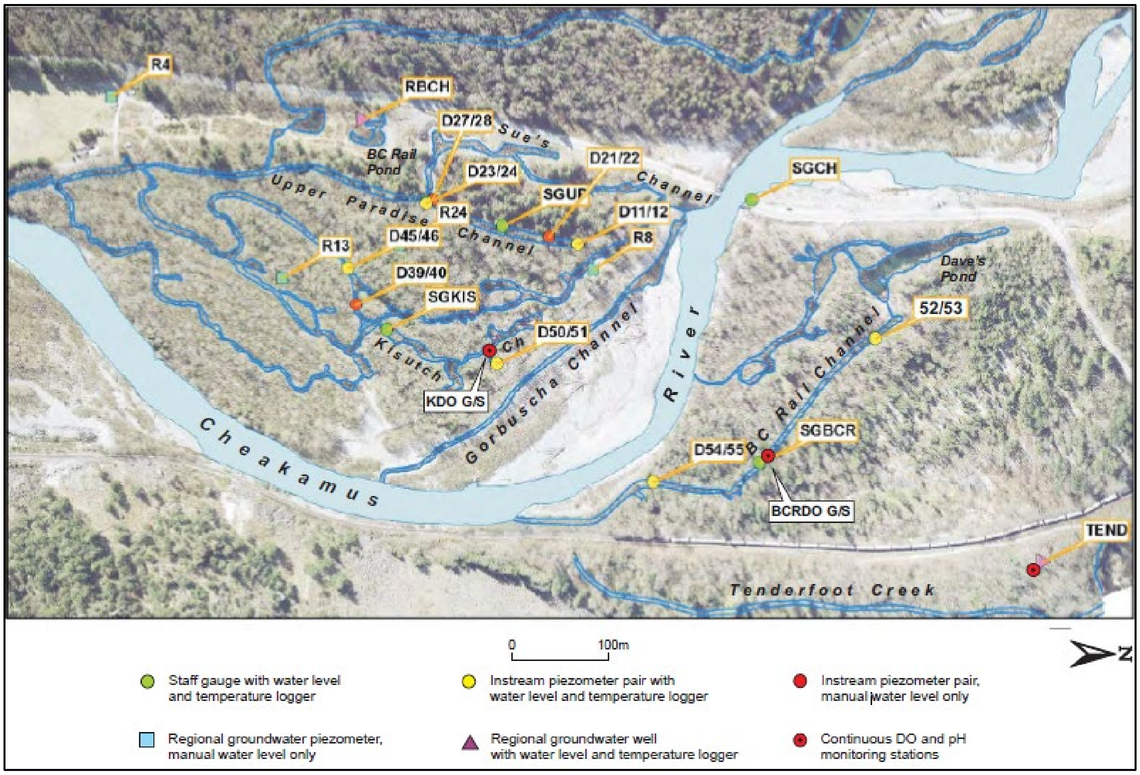


Figure 4.7.a: Site map and sampling location on Cheakamus River (Gray et al. 2012)

4.7.3 Interpretation of Data

Although minimum flow releases are at times higher under the WUP flow regime than the IFA, the WUP has likely resulted in less overall discharge from Daisy Lake Dam. High flow events (e.g. those discharges > 40 m^3/s) are likely linked to natural inflow events, and would be equally as common between the WUP and IFA. The objective of this study was to determine if lower flow releases (those flow releases ≤ 40 m^3/s) would result in a change in side channel production on the lower Cheakamus River, by investigating the interactions between mainstem flow, side channel flows, and side channel productivity.

Answers to Management Questions

1. *To what extent does seasonal NVOS and Tenderfoot Hatchery floodplain shallow groundwater flow direction, and selected water quality parameters (temperature, dissolved oxygen, and pH) vary in response to Cheakamus River mainstem flows ≤ 40 m^3/s?*

Gray et al. (2012) demonstrated that the ground-surface water interface in the Cheakamus River side-channel area was relatively stable at low and moderate flows (Figure 4.7.b). The magnitude of change in groundwater elevation in side-channel habitats across low to moderate mainstem flows was very minor and the practical significance of the observed changes was limited.

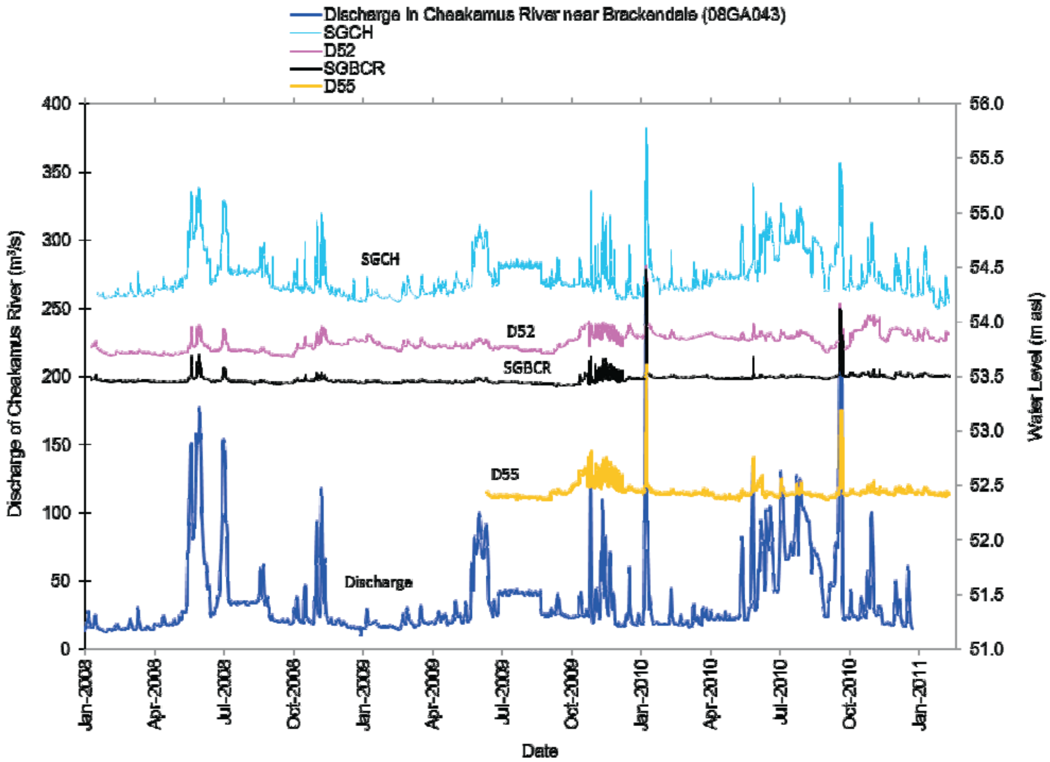


Figure 4.7.b: Water elevation summary data at monitoring drive points (2008-2010) (Gray et al 2012).

Temperature, DO, and pH values in the side-channels were correlated to the values in the Cheakamus River, confirming that the Cheakamus River is the source water for groundwater recharge. The travel time of groundwater from the mainstem of the Cheakamus River to the side-channel habitat is from days to weeks (Figure 4.7.c), delaying the side-channel response to mainstem temperature, DO, and pH changes. Travel time of groundwater was relatively insensitive to Cheakamus River discharge. Therefore, Gray et al. (2012) concluded that Cheakamus River flow within the relevant management range (e.g., 15 to 70 m^3/s) had no practical effect on pH (Figure 4.7.d), DO (Figure 4.7.e) or temperature (Figure 4.7.f) in upwelling groundwater or surface water in the side-channels.

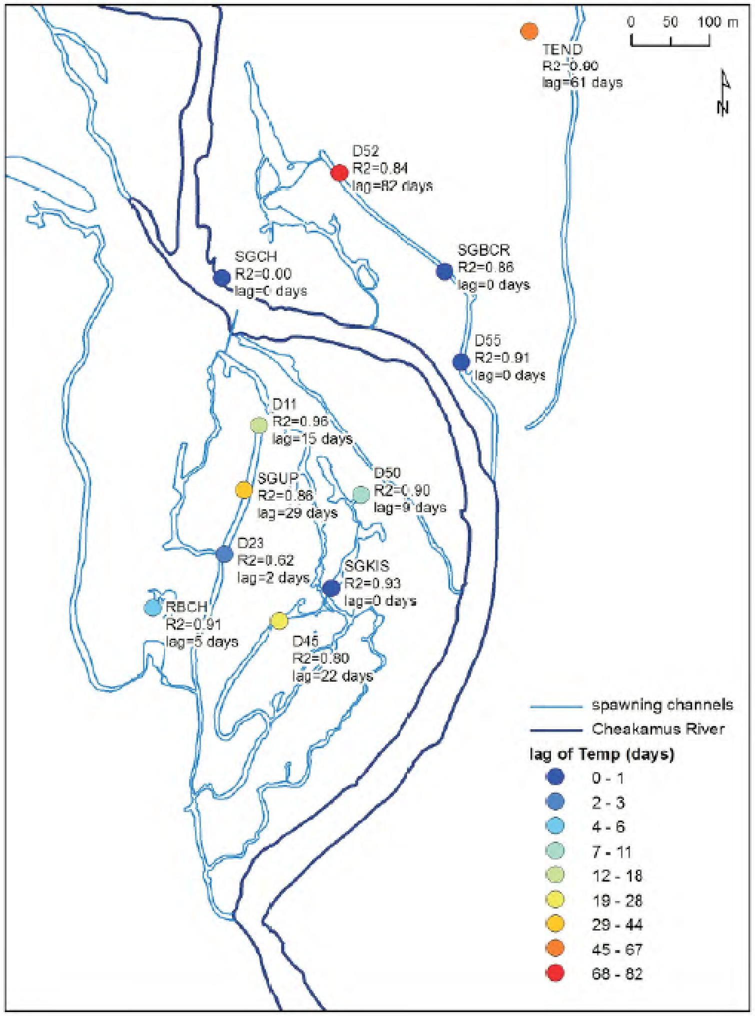


Figure 4.7.c: Ground water travel time across monitoring locations as indicated by temperature time lags (Gray et al. 2012).

Gray et al. (2012) noted that very high Cheakamus River discharges were followed by short-lived decreases of hyporheic DO, which were hypothesized to result from increased concentrations of low-DO, deep groundwater being forced out into the side-channel by the increased hydraulic head. Following the high discharge event in the mainstem of the river, a short-lived increase in DO was observed which likely resulted from reduced ground water travel times associated with higher hydraulic head (Figure 4.7.e). However, as discussed at the opening of this section, these observed effects of high river discharge are unlikely to be an effect of the WUP flow regime.

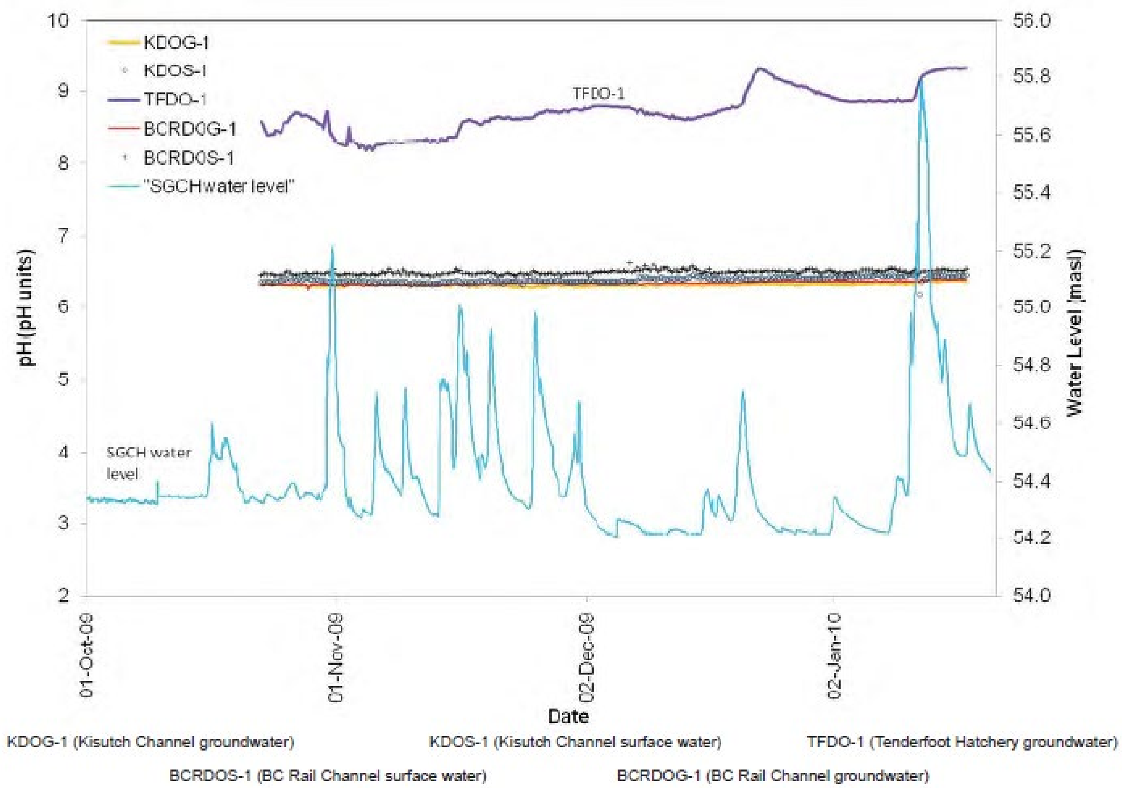


Figure 4.7.d: Continuous Dissolved Oxygen Monitoring: January 8 – 18 2010 (Gray et al. 2012).

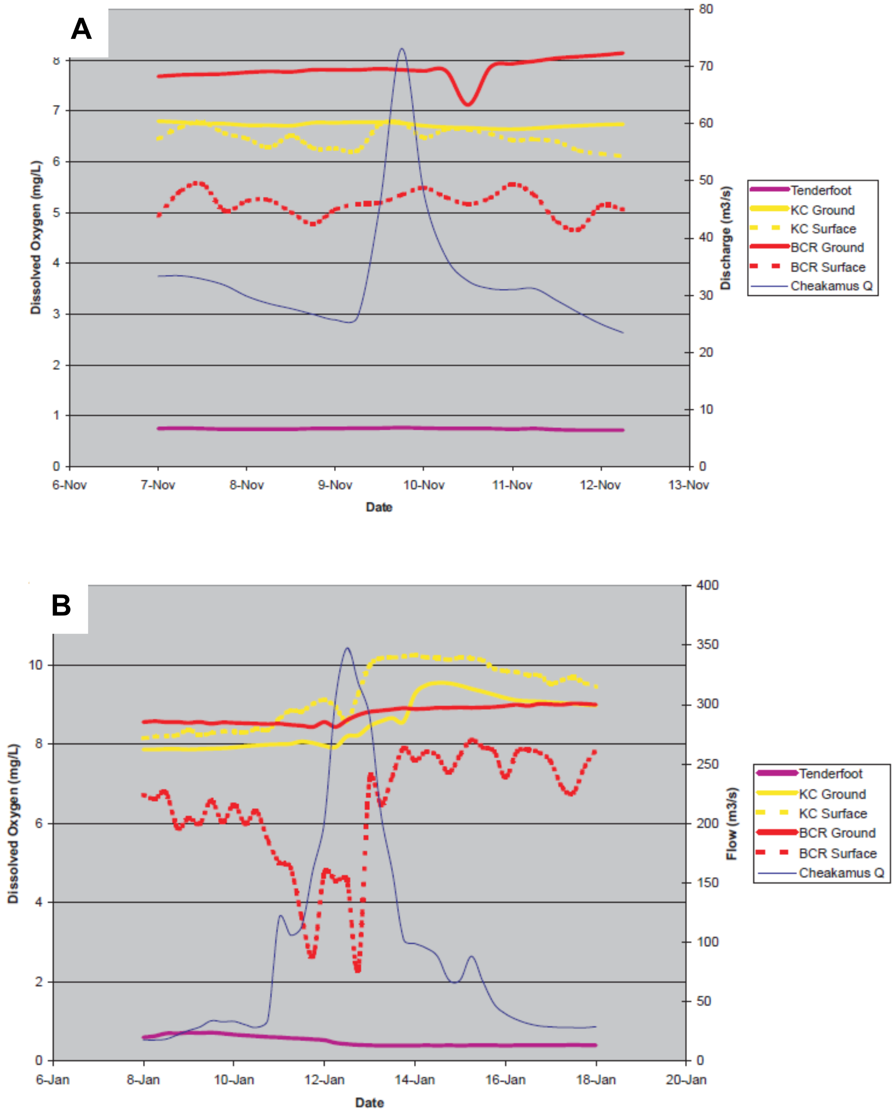


Figure 4.7.e: Continuous Dissolved Oxygen Monitoring: (A) November 7 – 12, 2009; (B) January 8 – 18, 2010 (Gray et al. 2012).

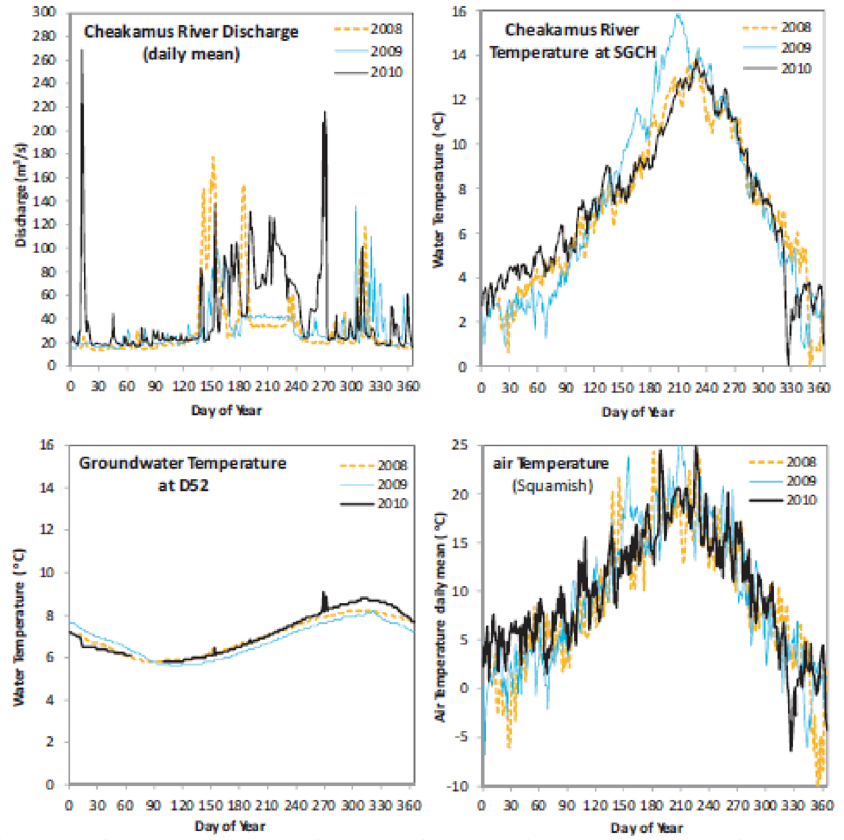


Figure 4.7.f: Continuous Dissolved groundwater, river, and air temperature, and Cheakamus river Discharge: 2008- 2010 (Gray et al. 2012).

2. *To what extent does seasonal NVOS and Tenderfoot Hatchery side channel hydrology depend on groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s?*

Gray et al. (2012) found that while side-channel hydrology was correlated to river discharge for mainstem flows below 40 m^3/s (in the Upper Kisutch and BC Rail Channel), the magnitude of effect was very small and diminished with mainstem flows below 40 m^3/s (Figure 4.7.c). It was therefore concluded that side-channel hydrology is considered functionally insensitive to changes in mainstem discharge between 40 and 15 m^3/s.

3. *To what extent do key fish habitat variables related to flow (average depth, average velocity, discharge) and water quality (temperature, dissolved oxygen, and pH) in NVOS and Tenderfoot Hatchery side channels depend on groundwater flow interactions with Cheakamus River mainstem flows ≤40 m^3/s?*

Gray et al. (2012) found that:

- availability of wetted habitat in side-channel habitats was insensitive to changes in Cheakamus River mainstem flow below 40 m^3/s;
- wetted width of the side-channels were not affected by changes in Cheakamus River discharge; and

- water levels only changed inconsequentially.

Consequently, from a physical habitat perspective, the suitability of habitat in side-channels was not affected by reductions of Cheakamus River mainstem flows ≤40 m^3/s.

Gray et al. (2012) found that surface water quality (temperature, DO, and pH) in the side channels was driven by source water quality (deep and shallow groundwater), which in turn was insensitive to variation in Cheakamus River discharges within the 15 to 40 m^3/s range. Therefore, changes in mainstem discharge associated with WUP operation were unlikely to have any impact of water quality and consequential habitat suitability's for aquatic organisms in the side-channels.

4. *To what extent does salmonid production vary in NVOS and Tenderfoot Hatchery side channels in relation to groundwater flow interactions with Cheakamus River mainstem flows ≤ 40 m^3/s, and to what extent has the implementation of the WUP affected salmonid production in the NVOS and Tenderfoot Hatchery side channel habitats compared to the pre-WUP state?*

Results from this study were inconclusive with respect to the effects of WUP flows on fish productivity in the side-channel habitats. There was no evidence to support that quantity or quality of habitat available in side channels has been meaningfully impacted by the WUP compared to pre-WUP state. Gray et al. (2012) concluded that there was no direct evidence of a causal relationship between groundwater parameters and fish production metrics through this study and parallel monitoring projects.

4.7.4 Conclusions and Implications

Groundwater quantity and quality in the side-channels was found to be relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s. It is therefore unlikely that the WUP flow regime resulted in any biologically significant impact to fish habitat or fish productivity in the Cheakamus side-channel area. Changes to the WUP flow regime between 15 and 40 m^3/s would not address concerns with the target groundwater side-channels of the lower Cheakamus River.

4.8 CMSMON-7: Cheakamus River Benthic Community Monitoring

4.8.1 Project Summary

The effect of flow regulation on benthic production was an important uncertainty identified during the Cheakamus WUP Consultative process. This monitoring project builds on previous studies completed on the Cheakamus River, including a predictive Cheakamus Benthos Model (CBM), used to examine the effect of change in nutrient loading (from the Whistler Wastewater Treatment Plant) and changes in hydraulic attributes on benthic invertebrate and periphyton composition and abundance. Consequently, BC Hydro developed study terms of reference for a monitoring program to collect information required to update the CBM to evaluate potential effects of flow regimes on benthic indicators of ecosystem health and food availability. The model was intended to be a decision support tool for future planning initiatives (BC Hydro 2007h).

Objectives	Management Questions[1]	Response	Implications
The objective of this study was to continue on work in 1996 and 1999 to develop the Cheakamus Benthos Model for use in evaluating river health as indicated by attributes of benthic invertebrate and periphyton communities.	1. What habitat and flow attributes best determines the composition, abundance, and biomass of benthic invertebrates in the Cheakamus River? 2. Among all habitat and flow attributes, what is the relative importance and magnitude of effect of water release from the Daisy Lake Dam in determining the composition, abundance, and biomass of benthic communities in the Cheakamus River?	1. Metrics of flow, temperature, turbidity, elevation, periphyton biomass, cover from riparian vegetation, and suspended solids were the top predictors of benthic invertebrate biomass, composition, and abundance. 2. River discharge was found to be the strongest predictor of benthos biomass, abundance, and richness in the Cheakamus River. However, these trends did not explain the variability in benthos production between samples in 1996, 1999 and 2009.	Modeling results showed that river discharge was the strongest predictor of benthic productivity; therefore, significant changes in the Cheakamus River flow regime would likely indirectly affect juvenile salmon productivity. Non-flow related factors (e.g. climatic factors or sewage treatment effects) were likely responsible for any observed differences in benthic production between the between IFA and WUP, as variation in summer flow is too limited between the flow regimes to explain the differences in production. This model could provide a basis for evaluating potential future flow regimes in the WUP Order Review if the potential flow regimes have substantial differences in average seasonal discharge.

[1] TOR reference; BC Hydro 2007h, pp.15

4.8.2 Project Approach

The CMSMON-7 monitoring project was conducted from January to December 2009 by Limnotek Research and Development Inc. The final report summarized results from the study period. Reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The approach to this study was to collect benthic invertebrates and periphyton count and biomass data over a range of flows, environmental, and seasonal conditions in the Cheakamus River. Benthic invertebrate and periphyton data along with a suite of habitat related variables were collected from five sites downstream from the Daisy Lake Dam (Figure 4.8.a) during the spring, summer, fall, and winter of 2009; this data collection complemented similar data collected in 1996 and 1999. Following data collection, multiple regression analyses were used to identify and rank the most important habitat/environmental variables to explain a number of dependent variables (biological metrics) related to benthic invertebrate and periphyton production, including: benthic invertebrate biomass, an index of benthic invertebrate abundance (referred to as "the Cheakamus benthos index"), benthic invertebrate diversity, periphyton biomass, periphyton diversity, and bio volume of *Didymosphenia geminate* (Didymo). To assess the extent of linkage between benthic invertebrate production in the Cheakamus River to food that is ingested by fish, juvenile salmonids and resident Rainbow trout stomach contents were examined. Finally, best-fit multiple regression models were used to explain changes in biological metrics associated with changes in habitat and environmental variables (Perrin 2010).

In addition to the modelling development completed by Perrin (2010), McArthur (2011) evaluated the quality of the benthos food resource over the study period using the invertebrate abundance dataset and published information on varying availability of invertebrate taxa for fish forage. McArthur (2011) used the Rader scoring system for classifying invertebrates in the Cheakamus River and their availability to salmonids as a food source. Finally, McArthur (2011) compared availability of benthic invertebrates to fish across season and also between flow regimes.

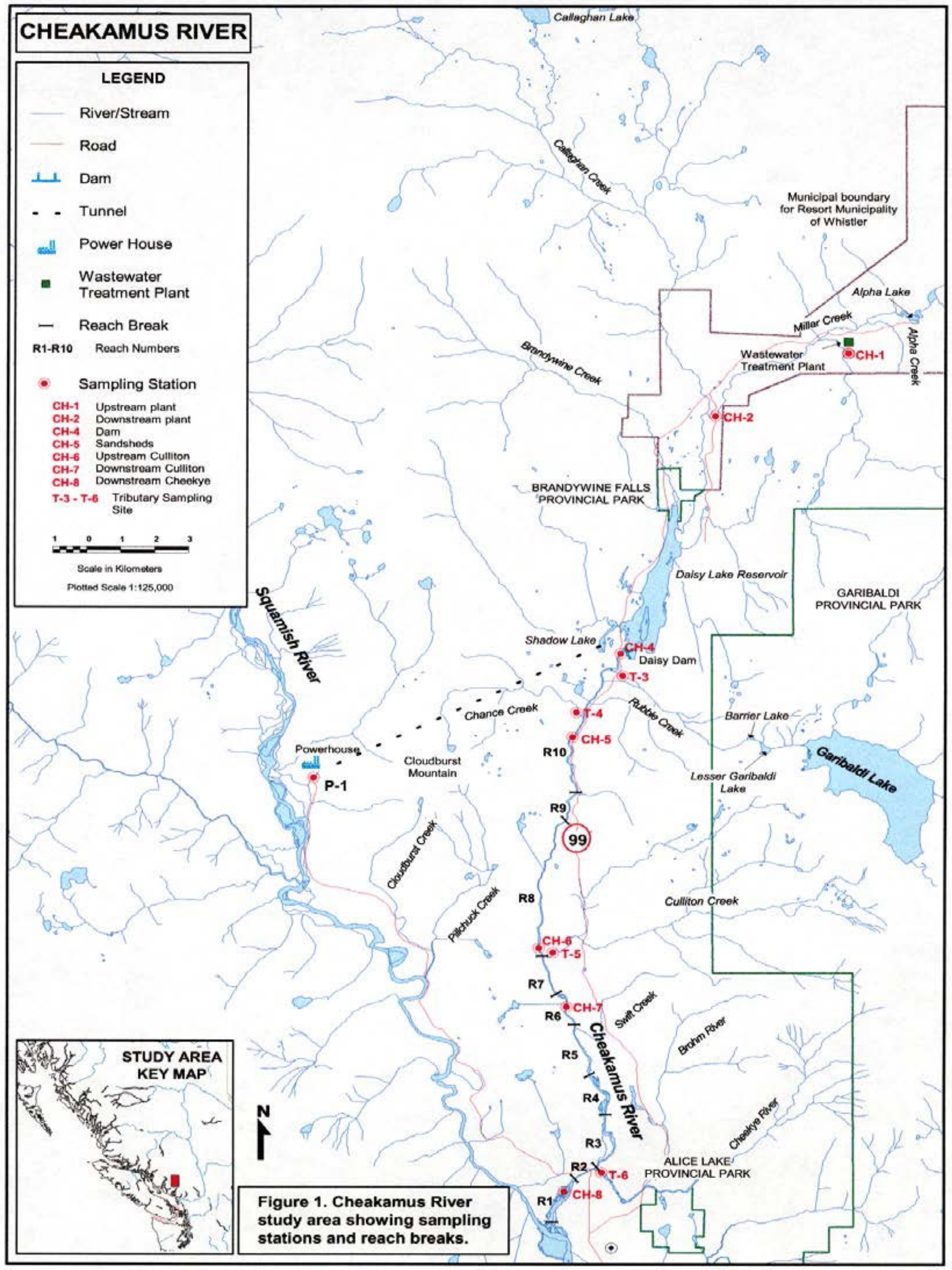


Figure 4.8.a: The Cheakamus River showing geographic location and placement of sampling stations from the earlier and present benthos modeling studies (Perrin 2010)

4.8.3 Interpretation of Data

The objective of CMSMON-7 was to continue work conducted in 1996 and 1999 to develop statistical models to evaluate river health among flow alternatives;

river health was indicated by metrics of the benthic invertebrate and periphyton communities. Models were used to evaluate the effects of habitat/environmental variables on benthic invertebrate and periphyton communities. Overall, the models developed provided support that the river flow was important in determining biomass and composition of the benthic communities in the Cheakamus River; however, they also show that other factors, both those included within the models and those unaccounted for, can modify responses of benthos to change in flow (Perrin 2010).

Answers to Management Questions

1. *What habitat and flow attributes best determines the composition, abundance, and biomass of benthic invertebrates in the Cheakamus River?*

Perrin (2010) found that various flow metrics, temperature, turbidity, elevation, periphyton biomass, cover from riparian vegetation, and suspended solids were predictors of benthic invertebrate biomass, composition, and abundance (Table 4.8.b)

2. *Among all habitat and flow attributes, what is the relative importance and magnitude of effect of water release from the Daisy Lake Dam in determining the composition, abundance, and biomass of benthic communities in the Cheakamus River?*

River discharge was found to be the strongest predictor benthos biomass, abundance, and richness in the Cheakamus River. However, there were no consistent trends describing effect of the WUP flow treatment on benthic production (Table 4.8.c). River discharge was found to be a strong indicator for four of the six biological metrics assessed in this study, including: benthos biomass, abundance, and richness, as well as periphyton biomass (Table 4.8.b and c). Benthos abundance was weakly related to variability in discharge. Benthos richness appeared to decline marginally with increasing velocity, increased with water depth, and declined with increased variability in flow (Table 4.8.b). Perrin (2010) explains that higher flows likely provide increased habitat complexity, optimize food availability in drift, and/or optimize availability of refugia, leading the observed increases in benthic invertebrate biomass and abundance. Periphyton biomass was negatively related to increasing flow, increasing water velocity, and variability in flow (Table 4.8.b). Perrin (2010) explained these inverse relationships were likely a result of algal biomass accumulating under lower, less variable discharge, but sloughing from substrate at higher, more variable flows. Perrin (2010) also noted that overall these findings were consistent with other studies investigating the effects of flow on biological assemblages in river ecosystems.

River flow was not found to be an important predictor of periphyton richness or Didymo biomass (Table 4.8.b). Periphyton richness was positively associated with Didymo biomass, which likely acted as increased habitat structure for the periphyton (Perrin 2010). Didymo biomass was influence most strongly by Didymo introduction factor, which simulated an inoculation of Didymo sometime between the 2000 and 2009 sampling periods, and not nutrient levels in the water.

In addition to flow related variables, Perrin (2010) found the following:

- Benthos **abundance** was related to elevation (i.e., distance from Daisy Lake Dam), periphyton biomass, temperature, and turbidity.
- Benthos **biomass** was affected by periphyton biomass, temperature, and turbidity, and vegetation cover, but not elevation.
- Benthos **richness** was related to elevation, temperature and suspended solids concentration (Table 4.8.b)

In addition to the above, the following relationships were found in the analysis:

- Benthos biomass and abundance were positively related to increasing periphyton biomass, as periphyton is an important food source for many benthic invertebrate species.
- As turbidity covaries with flow, positive relationships between benthic production and turbidity were discounted.
- Temperature relationships with benthic productivity were likely driven by seasonal changes in benthos assemblages rather than by within-season temperature changes.
- Overhanging vegetation was found to be a positive but weak predictor of benthos biomass. Riparian vegetation can supply leaf litter to shredder and collector invertebrates as a source of food.
- Elevation, which is inversely related to distance from Daisy Lake Dam, was weakly and negatively related to both benthos richness and benthos abundance, consistent with the hypothesis that tributaries provide important recruitment of benthos to the Cheakamus River downstream from Daisy Lake Dam.

  Perrin (2010) found that primary productivity was nitrogen limited in the Cheakamus River as opposed to being phosphorus limited, which was the outcome under previous iteration of the model, indicating a time course change in nutrient limitation in the Cheakamus River. Benthic invertebrates are indirectly affected by nutrient concentrations through effects on primary production.
- The models explain 55-68% of the observed variance in biological metrics over the three sampling years, but demonstrate the importance of flow's influence on biomass and composition of the benthic invertebrates in the Cheakamus River.

Table 4.8.a: Table of abbreviations on dependent and independent variable used in the multiple regression analysis (Perrin 2010)

Abbreviation	Dependant Variable
CBB	Cheakamus benthos biomass
CBI	Cheakamus benthos index
CBR	Cheakamus benthos richness
CPB	Cheakamus periphyton biomass
CPR	Cheakamus periphyton richness
DIDYMO	biovolume of *Didymosphenia geminata*
	Independent Variable
VEGCOV	overhanging vegetation cover
PB	geometric mean periphyton peak biomass
VEL	geometric mean water velocity
T	geometric average daily mean temperature
Q	geometric mean flow
TURB	geometric mean turbidity
ELEV	elevation above sea level
DUR	number of days the samplers were incubated
D	geometric mean water depth over the samplers
QCV	coefficient of variation of site specific flow
DCV	coefficient of variation of water depth,
VELCV	coefficient of variation of water velocity
SS	geometric mean suspended solids concentration
DIDYMO	biovolume of *Didymosphenia geminata*
BB	total benthos biomass
DIN	geometric mean concentration of dissolved inorganic N
DI	Didymo introduction factor

Table 4.8.b: Fit of multiple regression model to the data for each dependent variable (Perrin 2010).

Model	Significant model parameter	Coefficient	Tolerance	Fit statistics
CBB	Constant	0.53	n/a	R^2=0.56
	Overhanging vegetation cover	0.11	0.8	Standard error of estimate = 0.303
	Periphyton PB	0.77	0.8	
	Mean water velocity at substrate	2.76	0.8	
	Mean temperature	-0.65	0.4	
	Mean site specific flow	0.58	0.6	
	Mean turbidity	0.36	0.7	
CBI	Constant	5.28	n/a	R^2=0.57
	Elevation	-0.38	0.7	Standard error of the estimate = 0.31
	Periphyton PB	0.6	0.8	
	Duration of sampler incubation	-1.52	0.8	
	Mean water depth over samplers	2.93	0.6	
	Mean water velocity at substrate	1.81	0.7	
	Mean temperature	-0.22	0.5	
	Coefficient of variation of flow	0.43	0.7	
	Mean turbidity	0.22	0.7	
CBR	Constant	1.38	n/a	R2 = 0.55
	Elevation	-0.08	0.7	Standard error of the estimate = 0.07
	Coefficient of variation of depth	0.23	0.4	
	Coefficient of variation of velocity	-0.33	0.4	
	Mean temperature	0.18	0.9	
	Coefficient of variation of flow	-0.14	0.7	
	Suspended solids	0.12	0.7	
CPB	Constant	0.29	n/a	R^2 = 0.64
	Mean water velocity at substrate	-1.09	0.7	Standard error of the estimate = 0.22
	Didymo introduction factor	0.3	0.5	
	Mean benthos biomass	0.36	0.6	
	Mean temperature	0.7	0.4	
	Coefficient of variation of flow	-0.43	0.6	
	Mean site specific flow	-0.56	0.6	
	Mean turbidity	-0.26	0.6	
	Mean DIN	0.1	0.5	
CPR	Constant	0.94	n/a	R^2 = 0.55
	Didymo introduction factor	0.15	1	Standard error of the estimate = 0.07
Didymo	Constant	-1.72	n/a	R^2 = 0.68
	Mean benthos biomass	0.94	0.8	Standard error of the estimate = 0.91
	Mean turbidity	-0.72	0.8	
	Didymo introduction factor	2.31	0.7	

Table 4.8.c: Ranking of importance of predictor variables in each model where importance is defined by the absolute value of the regression coefficients (Perrin 2010).

Model	Ranked importance of predictor variables
CBB	VEL > PB > T > Q > TURB > VEGCOV
CBI	D > VEL > DUR > PB > QCV > ELEV > T > TURB
CBR	VELCV > DCV > T > QCV > SS > ELEV
CPB	VEL > T > Q > QCV > BB > DIDYMO > TURB > DIN
CPR	DIDYMO
DIDYMO	DI > BB > TURB

Other Results

Perrin (2010) found that juvenile salmonid stomach content was composed of almost entirely aquatic benthic invertebrate prey (Table 4.8.d). This finding supports the notion that benthos production in the Cheakamus River will likely directly affect juvenile salmon growth and survival, and therefore productivity. Because benthos are sensitive to variation in flow, periphyton biomass, temperature, turbidity, and distance along the river continuum, these factors likely also affect juvenile salmon.

McArthur's (2011) assessment of quality of benthos as fish food concluded that there was no evidence of change in quality of food resource for fish as a result WUP implementation, because there was no consistent change in minimum flow treatment (i.e., annual or winter minimum flows) between pre- WUP (1996, 2000, and 2005) versus post WUP sampling periods (2009) that would create contrast in benthos quality. The observed spatial and temporal variation in benthos quality between the 1996, 1999 and 2009 sampling periods highlights a potential non-WUP factor that may have influenced food for fish (McArthur (2011).

Table 4.8.d: Table of abbreviations on dependent and independent variable used in the multiple regression analysis (Perrin 2010)

Fish species, stage and sample size	Mean count of all invertebrates per stomach	Mean count of CBI invertebrates per stomach	Ratio of CBI to total count	Mean count per stomach of aquatic organisms	Mean count per stomach of invertebrates from terrestrial origin	Percent of total count from aquatic origin
Chinook fry (n=7)	36	33	0.93	35	0.3	99
Coho fry (n=14)	35	30	0.82	35	0.4	99
Resident rainbow (n=28)	37	32	0.75	37	0.1	99
Steelhead fry (n=12)	22	20	0.86	22	0	100
Steelhead parr (n=4)	12	11	0.91	12	0	100

4.8.4 Conclusions and Implications

River discharge metrics were found to be the strongest predictor of benthos biomass, abundance, and richness in the Cheakamus River. In addition, juvenile salmonid stomach content was composed of almost entirely aquatic benthic invertebrate prey. Consequently, significant changes in the Cheakamus River flow regime, through the production of benthic invertebrates, would likely indirectly affect juvenile salmon growth and survival, and therefore productivity.

The contrast between IFA and WUP summer flows was limited; therefore non-flow related factors (e.g. climatic factors or sewage treatment effects) were likely responsible for any observed differences in benthic production between the between IFA and WUP, as variation in summer flow is too limited between the flow regimes to explain the differences in production.

This model could provide a basis for evaluating potential future flow regimes in the WUP Order Review if the potential flow regimes have substantial differences in average seasonal discharge.

4.9 CMSMON-8: Monitoring Channel Morphology in Cheakamus River

4.9.1 Project Summary

During the Cheakamus WUP, initial channel morphology and sediment transport studies showed that the construction and operation of Daisy Lake Dam had contributed to the reduction in channel width, simplification of channel structure, and the vegetation of gravel bars. However, the Fisheries Technical Committee identified additional uncertainties that were not resolved during initial studies regarding potential effects of Daisy Lake Dam discharge on sediment transport channel shaping processes that would have the potential to affect fish habitat quality and quantity. Of particular interest was the uncertainty surrounding potential alteration of channel diversity, development and access to side channels, and the distribution and quality of substrates utilized by rearing and spawning salmonids associated with the WUP flow regime. Consequently, BC Hydro developed terms of reference for a monitoring program to assess these potential effects of WUP operation at Daisy Lake Dam specifically on channel morphology and sediment transport (BC Hydro 2007i). Results from this study may be useful to extrapolate potential effects of alternative flow regimes from Daisy Lake Dam.

Objectives	Management Questions[1]	Response	Implications
The objective of this study was to assess the response of Cheakamus River morphology and sediment transport to Changes in flow patterns from Daisy Lake Dam associated with WUP flow regime.	1. Following implementation of the WUP, has there been degradation in spawning habitat via erosion?[2] 2. Following implementation of the WUP, has there been a change in the overall length, access and utility for fish of naturally occurring side channels from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factors? 3. To what extent does the hydrology of Rubble Creek, Culliton Creek, and Swift Creek contribute to the general hydrology of lower Cheakamus River and how does it attenuate the effects of Daisy Lake Dam operations?	1. At two known salmon spawning sites on the Cheakamus River, discharges that could result in erosion of spawning substrate varied between 160 and 270 m^3/s. Because changes to the flow regime between pre-WUP and WUP are generally below 50 m^3/s, implementation of the WUP flow regime has not resulted in any additional erosion of spawning sediment compared to pre-WUP levels. 2. The total area of wetted natural side channel habitat has increased at typical flows in the Cheakamus River. The habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time. Although not attributed to WUP flows, results of the study show evidence of overall channel stabilization, at the same time as potential erosion and downstream transfer of sediment in the Cheakamus River. The question of access could not be directly addressed by the study methodology. 3. Tributary inflows have a large impact on flow regime downstream of Daisy Lake Dam. Daily average tributary inflow to the Cheakamus River between Daisy Lake Dam and the WSC gauge was 16 m^3/s; under the WUP flow regime, tributary inflow was about 1.4 times that of Daisy Lake Dam discharges. The attenuating effects of tributary inflow are strongest during fall and winter when Daisy Lake Dam discharge is low; even though tributary inflow is highest during summer months, the attenuating effects were relatively weak as Daisy Lake Dam discharge are typically at their highest.	Implementation of the WUP flow regime did not change the presence of spawning gravel or fish habitat types; therefore it is unlikely that future flow changes within the operating bounds of the WUP and the IFA would affect the availability of spawning gravel or fish habitat types. Tributary inflows are most influential during the fall and winter, when Daisy Lake Dam discharges are low.

[1] TOR reference; BC Hydro 2007i, pp.10
[2] Revised MQ1 proposed by BC Hydro. The original MQ1 was: Following implementation of the WUP, has there been a change in the overall availability of suitable fish spawning substrates from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factors? This question could not be directly addressed due to a lack of pre-WUP information on suitable spawning habitat.

4.9.2 Project Approach

The CMSMON-8 monitoring project was conducted from 2008 to 2017 by Northwest Hydraulic Consultants Ltd. during the first five years of the study (2008 to 2012) and Kerr Wood Leidal and Associates Ltd. during the final five years of the study (2013-2017). Reports were compiled each year following 2008. The final report summarized results for the study period. All reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The monitoring approach varied depending on the management question.

To assess whether WUP flows affected salmon spawning habitat in the Cheakamus River, erosion at known spawning sites was evaluated by determining the shear stress required for sediment mobility at two known salmon spawning locations; then relationships between river discharge and sediment mobility were developed at those spawning locations. Field monitoring was completed to verify sediment mobility rates at spawning sites during high flow events. Finally, sediment mobility at spawning locations was compared between pre-WUP and WUP conditions to assess whether there had been any changes in spawning substrate erosion (Taleghani et al. 2017)

Repeated orthophotography was used to assess whether the implementation of WUP flows have resulted in a change in total length and diversity of natural side side-channel habitat in the lower Cheakamus River. Channel morphology and habitat type was mapped using orthophotos taken in 2008, 2012, and 2017 combined with ground-truthing. Changes in channel morphology and habitat were statistically compared between mapping periods (Scott et al. 2018a).

Hydrometric time series were analysed to determine the influence of tributary flows to attenuate the hydraulic effect of the operation of Daisy Lake Dam in the lower Cheakamus River. Both absolute and relative inflows from tributary sources between Daisy Lake Dam and the Water Survey Canada's Brackendale hydrometric station (WSC 08GA043) in the Lower Cheakamus River were calculated. Finally, flow duration curves were compared between Daisy Lake

Dam discharge and Lower Cheakamus River flows at the WSC station (Ellis and Sellars 2014).

4.9.3 Interpretation of Data

The results from this monitoring program were intended to assess the potential effects of WUP operation at Daisy Lake Dam specifically on channel morphology and sediment transport. Scott et al. (2018a) summarizes results from three separate reports that address each management question separately. General findings suggest: (1) that the WUP flow regime had no effects on salmon spawning habitat quality in the Lower Cheakamus River; (2) the total area of natural side channels has increased while the habitat diversity of natural, mainstem side channels has not significantly changed under the WUP flow regime; and (3) tributary inflows have a large impact on flow regime downstream of Daisy Lake Dam. The attenuating effects of tributary inflow are strongest during fall and winter when Daisy Lake Dam discharge is low and weakest during summer months when Daisy Lake Dam discharge is highest.

Answers to Management Questions

1. *Following implementation of the WUP, has there been a change in the overall availability of suitable fish spawning substrates from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factor?*

Because there was limited information available regarding pre-WUP conditions of spawning habitat in the lower Cheakamus River, the management question was modified to:

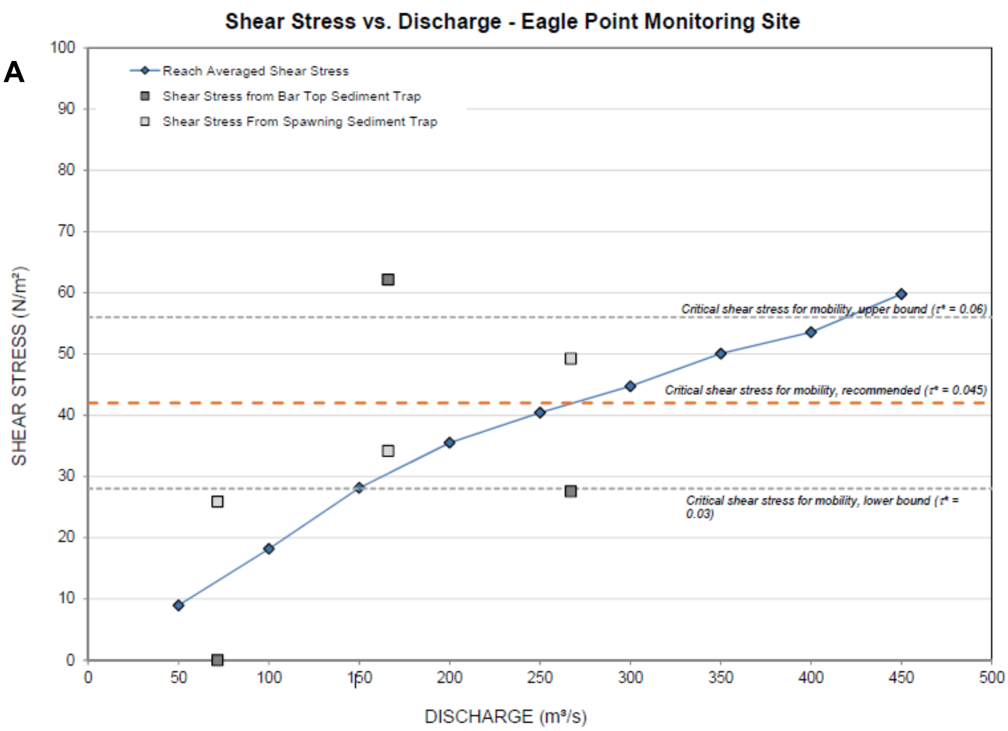
Following implementation of the WUP, has there been degradation in spawning habitat via erosion?

At two known salmon spawning sites on the Cheakamus River, discharges that could result in erosion of spawning substrate varied between 160 and 270 m^3/s. Because changes to the flow regime between pre-WUP and WUP are generally below 50 m^3/s, implementation of the WUP flow regime has not resulted in any changes to erosion of spawning sediment compared to pre-WUP levels.

Taleghani et al. (2017) found that river discharges required to mobilize spawning gravel varied between the spawning locations. At the two known salmon spawning sites on the Cheakamus River investigated in this project, discharges levels that could result in erosion of spawning substrate varied between 160 and 270 m^3/s (Figure 4.9.a). The discharge levels typically only occur during large storm routing events (Figure 4.9.b). Field sampling using sediment traps generally supported this finding. Because changes to the flow regime between pre-WUP and WUP are limited to the lower end of discharge levels (generally below 50 m^3/s), Taleghani et al. (2017) concluded that implementation of the WUP flow regime has not resulted in any changes to erosion of spawning sediment compared to pre-WUP levels.

Taleghani et al. (2017) discussed other potential impacts of the Daisy Lake Dam flow regime on spawning habitat in the Cheakamus River. Sub-surface sediment quality, which was not assessed in this study, can have an implication for salmon spawning success. However, based on results of CMSMON-3 study, Taleghani et al. (2017) concluded that sub-surface sediment quality was likely not linked to change in egg-to-fry survival rates in Steelhead, and does not require future monitoring. Scour and entombment of salmon redds during spill events is another potential implication of flows from Daisy Lake Dam. However, previous work evaluating the impact of Cheakamus River peak flows concluded that regulation resulted in a modest reduction in peak flows; suggesting that regulation has likely not resulted in a higher frequency of scour/fill events than would be experienced under no regulation. Finally, river impoundment is known to effect sediment supply. Daisy Lake Dam has reduced the supply of coarse sediment to the lower Cheakamus River by half or more (NHC 2000).

A



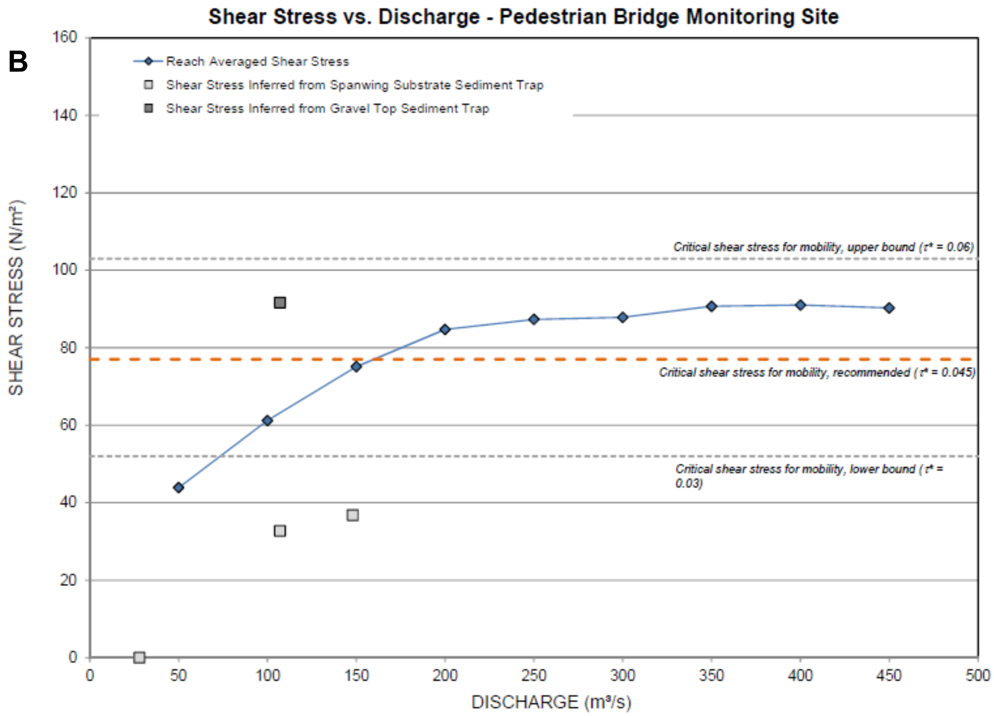
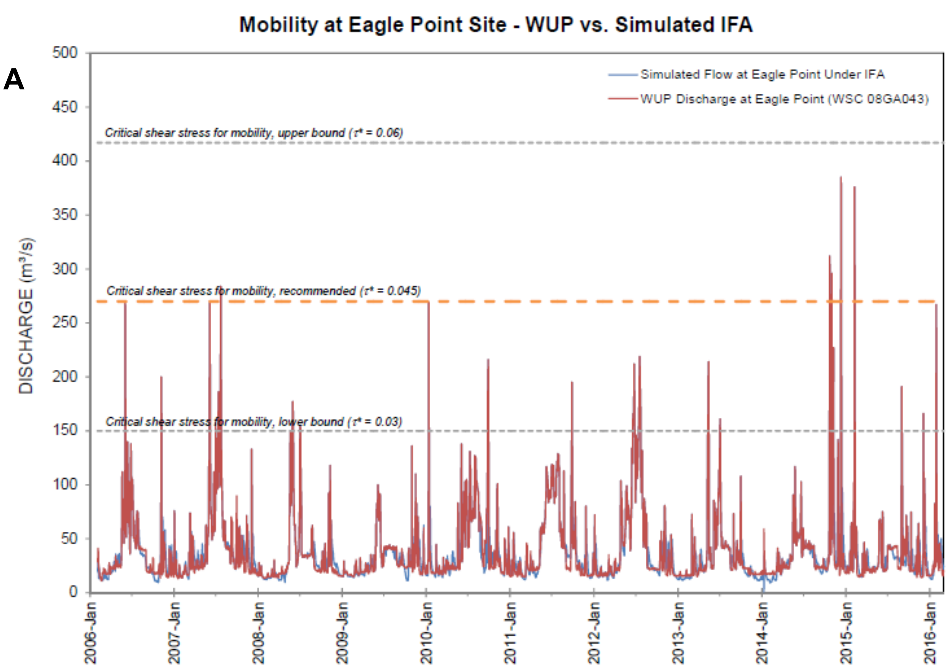


Figure 4.9.a: Shear stress as a function of discharge in the Cheakamus River at two known spawning site (A) Eagle Point and (B) Pedestrian Bridge (Taleghani et al. 2017).



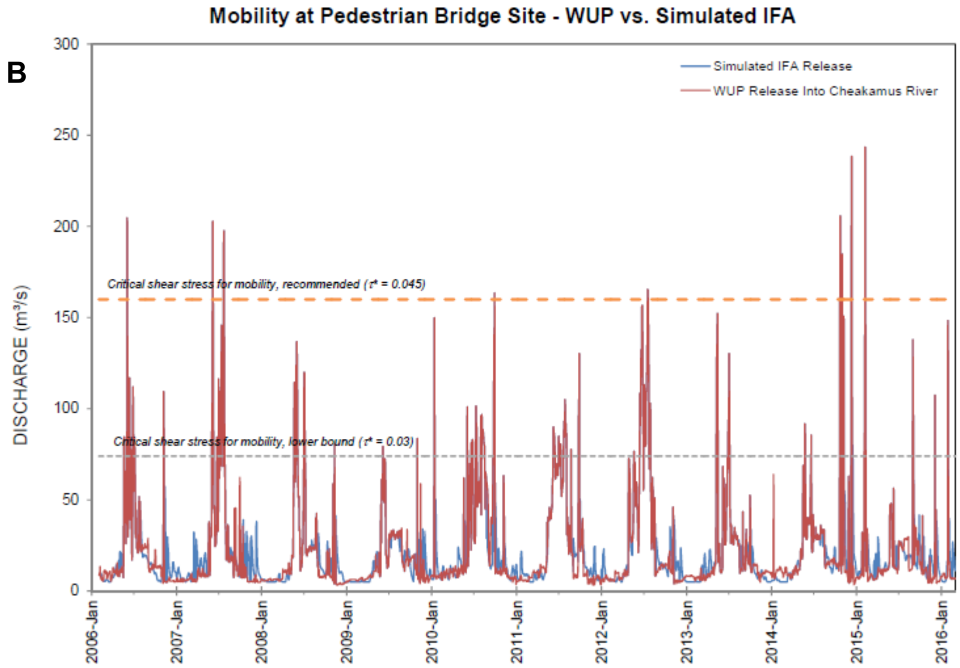


Figure 4.9.b: Cheakamus River hydrograph (WUP and simulated IFA) from 2006 to 2016 under the WUP flow regime with critical shear stress thresholds at (A) Eagle Point and (B) Pedestrian Bridge (Taleghani et al. 2017).

2. *Following implementation of the WUP, has there been a change in the overall length, access and utility for fish of naturally occurring side channels from the present state? If so, can this change be clearly attributed to Daisy Lake Dam operations vs. other environmental or anthropogenic factors?*

The total area of wetted natural side channel habitat has increased at typical flows in the Cheakamus River. The habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time.

Although not attributed to WUP flows, results of the study show evidence of overall channel stabilization, at the same time as potential erosion and downstream transfer of sediment in the Cheakamus River.

Based on comparisons of repeated geomorphic and habitat mapping from 2008, 2012, and 2017, the total number and area of mainstem wetted natural side-channels has increased since the implementation of the WUP (Scott et al. 2018a). Floodplain side-channels total area remained constant over the study; however, the proportion of wet side-channels vs. dry floodplain side channels appeared to decline (Figure 4.9.c). Scott et al. (2018) suggest that this apparent decline in wetted floodplain side-channel habitat may be a result of differences in Cheakamus River discharge levels at the time of orthophotography, and may not represent real changes to wetted floodplain side-channel habitat area.

The habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time (Scott et al. 2018a). Riffle habitat was the most dominant habitat type by area and made up nearly 100% of habitat found within mainstem side-channels; the overall area of riffle habitat did not change in area over the course of the study (Figure 4.9.d). Areas of rapid-type habitat appear to have decreased over the study period; however, Scott et al. (2018a) suggested that this was likely a due to interpretive error related to poor orthophoto image quality in the canyon areas.

Results of the study show evidence of overall channel stabilization: the combination of decreased area of bar features and increased number of young and mature islands and mainstem side-channels (Figure 4.9.c), suggest stabilization of the mainstem channel. In addition, the increase in areal extent and decrease in areal variance of sparsely vegetated bars are indicative of consolidation of features and further evidence of channel stabilization (Scott et al 2018).

Finally, results show evidence of downstream transfer of sediment in the Cheakamus River. The total area of pool habitat has increased in the upper reaches (Reach 10 to 14) and decreased in the lower reaches (Reach 2 to Reach 8) of the Cheakamus River between 2012 and 2017 (Figure 4.9.d), which is indicative of downstream sediment transfer initiated through threshold flow events. Several large flow events that have exceeded thresholds for mobilization (> 270 m^3/s) occurred between 2012 and 2017, during this same time frame there was a loss of un-vegetated bar area. These findings suggest that gravel erosion in the lower reaches of the Cheakamus River may have occurred.

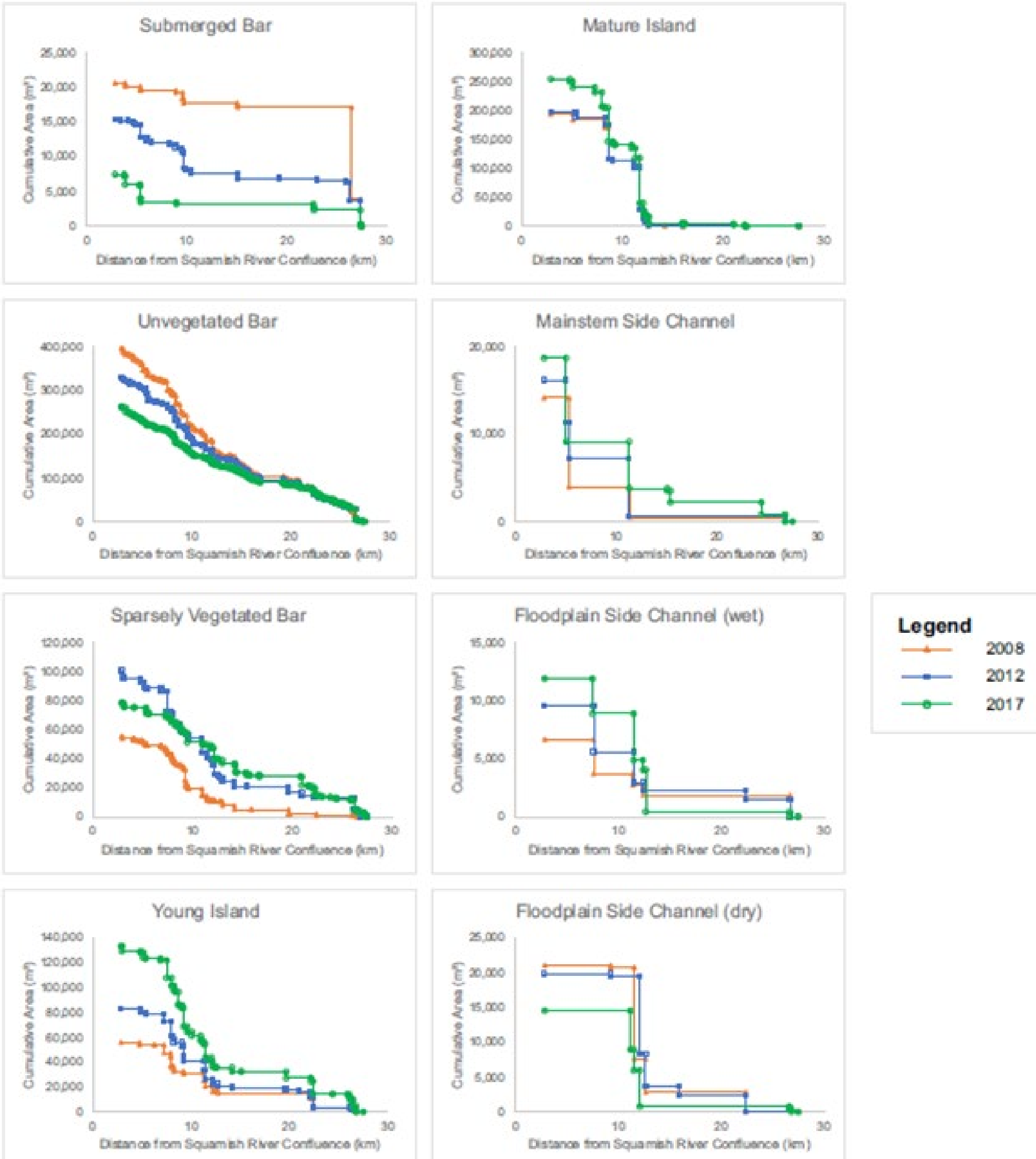


Figure 4.9.c: Cumulative area associated with geomorphic features starting at Daisy Lake and proceeding downstream as a function of chainage (Scott et al. 2017a).

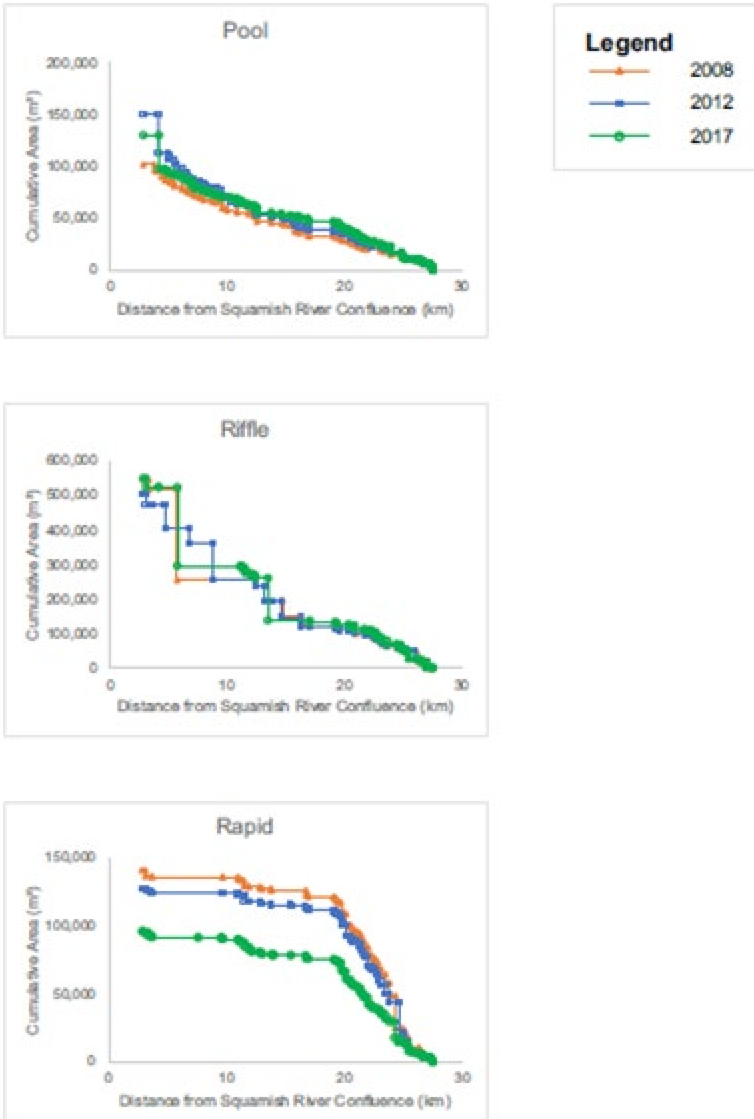


Figure 4.9.d: Cumulative area associated with habitat units starting at Daisy Lake and proceeding downstream as a function of chainage (Scott et al. 2017a).

Whether or not access to side-channel habitat had been affected as a result of the WUP flow regime could not be assessed by the methodologies of this study. The study assumed that side-channel access related issues would be informally investigated under CMSMON-1b.

3. *To what extent does the hydrology of Rubble Creek, Culliton Creek, and Swift Creek contribute to the general hydrology of lower Cheakamus River and how does it attenuate the effects of Daisy Lake Dam operations?*

Tributary inflows have a large impact on flow regime downstream of Daisy Lake Dam. Daily average tributary inflow to the Cheakamus River between Daisy Lake Dam and the WSC gauge was 16 m^3/s; under the WUP flow regime, tributary inflow was about 1.4 times that of Daisy Lake Dam discharges.

The attenuating effects of tributary inflow are strongest during fall and winter when Daisy Lake Dam discharge is low; even though tributary inflow is highest during summer months, the attenuating effects were relatively weak as Daisy Lake Dam discharge are typically at their highest.

Ellis and Sellars (2014) compared Daisy Lake Dam discharge data with the WSC Gauge at Brackendale with calculated tributary inflow downstream of Daisy Lake Dam. Tributary inflows were shown to have a large impact on flow regime downstream of Daisy Lake Dam. Daily average tributary inflow to the Cheakamus River between Daisy Lake Dam and the WSC gauge was 16 m^3/s, with a range from 3 to 119 m^3/s. More than 50% of the time, inflows were in the range of 10-13 m^3/s. Tributary inflow tended to be lowest during late-winter and early-spring, and highest during freshet (June/July) and during fall storms (November) (Table 4.9.a).

Under the WUP flow regime, tributary inflow was about 1.4 times that of Daisy Lake Dam discharge. The highest proportion of tributary inflow relative to Daisy Lake Dam discharge occurred during fall and winter months when Dam discharge was lowest. However, during this period tributary inflow varied from equal to almost triple the Daisy Lake Dam discharge. From May through September, Daisy Lake Dam discharges on average were higher than tributary inflows, and were roughly double tributary inflows from June through August (Table 4.9.a). These results suggest that the attenuating effects of tributary inflow are strongest during fall and winter when Daisy Lake Dam discharge is low; even though tributary inflow is highest during summer months, the attenuating effects were relatively weak as Daisy Lake Dam discharge are typically at their highest.

Ellis and Sellars (2014) noted that they were unable to accurately assess how much flow is being contributed by specific tributaries due to uncertainties associated with data from the CMSMON-8 hydrometric station installed along the Cheakamus River.

Table 4.9.a: Monthly average Daisy Lake Dam discharge and tributary inflow to the Cheakamus River, as well as proportion of tributary inflow relative to Daisy outflow (Ellis and Sellars 2014).

Month	Average Outflow Daisy Lake Dam (m^3/s)	Avg. Tributary Inflow Downstream of Daisy Lake Dam (m^3/s)	Average Tributary Inflow Downstream of Daisy Lake Dam Relative to Dam Outflow (1) (%)
Jan	8.7	16	220
Feb	6.7	11	175
Mar	8.1	12	158
Apr	12	12	119
May	32	16	72
Jun	58	21	47
Jul	61	22	40
Aug	37	16	59
Sep	23	13	95
Oct	14	15	121
Nov	11	22	294
Dec	6.1	15	262
TOTAL (2)	**23**	**16**	**138**

Notes:
1. Percentages calculated as (Daily Average Tributary Inflow / Daily Average Daisy Lake Outflow) * 100.
2. Totals are independently calculated for the entire period of record (2008-2012) from analysis of the daily values.

4.9.4 Conclusions and Implications

Implementation of the WUP flow regime has not resulted in any changes to erosion of spawning sediment compared to pre-WUP levels.

The total area of natural side-channels has increased during the WUP time period; but the diversity of natural, mainstem side-channels as measured by the area of pool, riffle, and rapid habitat units has not significantly changed. Implementation of the WUP flow regime did not change the presence of spawning gravel or fish habitat types; therefore it is unlikely that future flow changes within the operating bounds of the WUP and the IFA would affect the availability of spawning gravel or fish habitat types.

Tributary inflows are most influential during the fall and winter, when Daisy Lake Dam discharges are low.

4.10 CMSMON-9 Cheakamus River Recreational Angling Access Monitoring

4.10.1 Project Summary

A winter minimum flow of 5 m^3/s below Daisy Lake Dam was prescribed as part of the Cheakamus WUP as opposed to 3 m^3/s as there was a presumed benefit to recreational angling access to upper reaches of the Cheakamus. However, the WUP Consultative Committee was uncertain whether (1) whether recreational anglers utilized this section of river during winter low-flow months, and (2) how changes in minimum flow from Daisy Lake Dam between 5 m^3/s and 3 m^3/s would affect recreational angling opportunities if they existed. Consequently, BC Hydro designed a monitoring program to investigate the potential effects of the WUP minimum flow on recreation angler access and utility of the upper reaches of the Cheakamus River (BC Hydro 2007j).

Objectives	Management Questions[1]	Response	Implications
To understand potential effects of the WUP winter minimum flow on recreation angler access and utility of the upper reaches of the Cheakamus River	1. Does angling occur during this time of year in sections of the river that would be affected by this operation? 2. Is access to recreational angling locations during 1 January to 31 March improved under the 5.0 m^3/s minimum flow release from Daisy Lake Dam relative to that which would occur with a 3.0 m^3/s minimum flow release?	1. Little or no angler effort occurs within the upper reaches of the Cheakamus River during winter January through March. 2. Angler opportunity is unlikely to differ between 5.0 m^3/s and 3.0 m^3/s.	Providing a minimum flow release from Daisy Lake Dam of 5.0 m^3/s as opposed 3.0 m^3/s likely resulted in little to no additional benefits to recreational angler access and opportunities in the upper reaches of the Cheakamus River from January to March. It is unlikely that any further change in flow would result in any meaningful improvement to angler access. The current minimum flow has potential fisheries benefits.

[1] TOR reference; BC Hydro 2007j, pp.6

4.10.2 Project Approach

CMSMON-9 was conducted from January 2009 to March 2009 by J.O. Thomas and Associates Ltd. A final report was compiled summarizing the results from the study period. Reports are available on BC Hydro's WUP website:

(https://www.bchydro.com/toolbar/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html).

The general approach of this monitoring project was to review and draw information from five sources, including: 1) current effectiveness monitoring programs on the upper Cheakamus River, 2) previous investigations 3) an onsite roving angler effort survey, 4) an onsite angler habitat survey, and 5) expert angler interviews (Tallman 2009).

The study area was focused on the area of the river immediately below Daisy Lake Dam that are buffered to a lesser extent by tributary inflow, hence, where it was believed that the most pronounced effects of different flows in this winter period would occur.

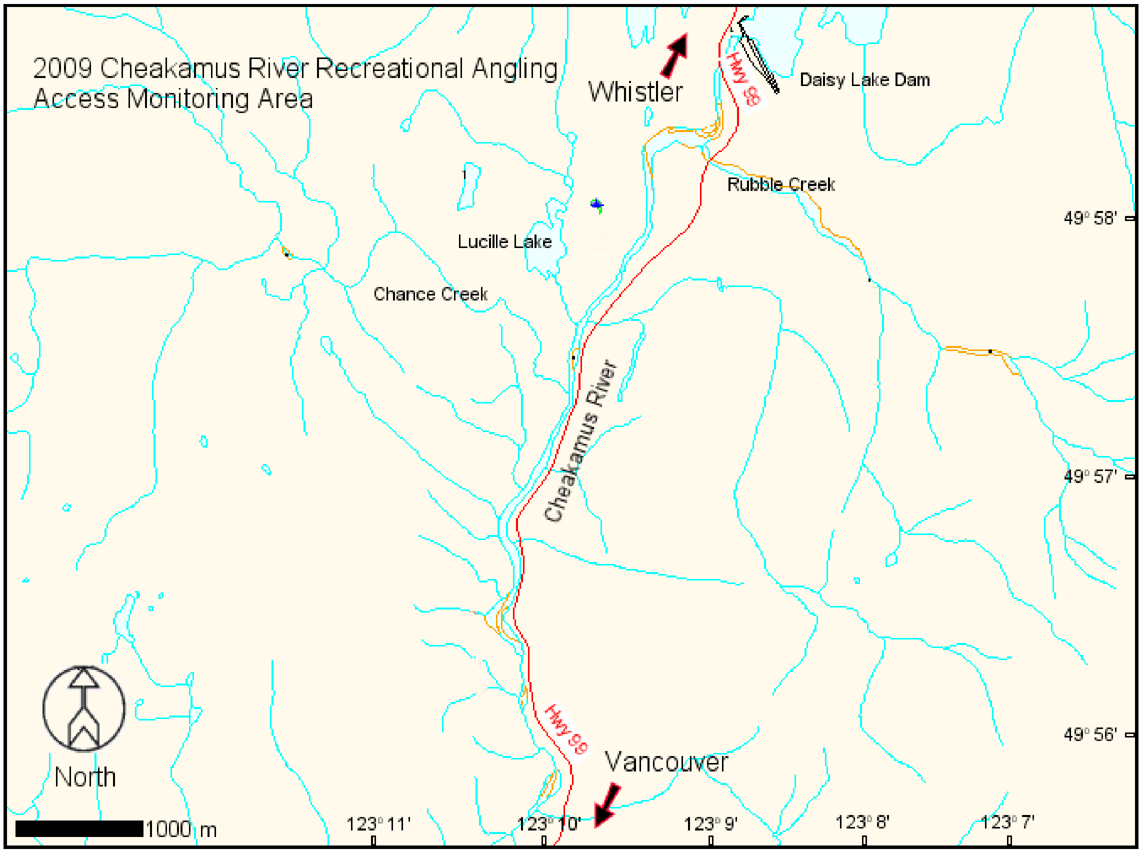


Figure4.10.a: Map of the 2009 Cheakamus River Recreational Angling Access Monitoring Area (Tallman 2009).

To investigate the level and distribution of angling effort in the upper reaches of the Cheakamus River during the winter low-flow period, a roving survey was completed. This roving survey was based on a random-stratified sampling regime, which consisted of visiting ten survey sites over three time periods between January 17 and March 29, 2009. Rod counts and angler interviews were collected during the site surveys.

To investigate difference in angling opportunities at minimum flow of 3.0 m^3/s versus 5.0 m^3/s an onsite angler habitat survey was completed. The onsite angler habitat survey was used to determine access and angling suitability; angler suitability was based on adult Rainbow trout (*Oncorhynchus mykiss*) over-winter habitat potential which was inferred from expert opinion and general literature concerning fish in cold water streams. Finally, potential effects of minimum flows on suitable Rainbow trout over-wintering habitat were inferred by the author (Tallman 2009).

4.10.3 Interpretation of Data

The management questions associated with this study were addressed using results from an angler effort and angler habitat survey, as well as inferences regarding adult Rainbow trout over-wintering habitat preferences. Angler effort surveys suggest very limited or no angling occurs within the upper reaches of the Cheakamus River between January and March. Results from the angler habitat survey suggest angling opportunities were unlikely to be affected by changes in winter minimum flow from 5.0 m^3/s to 3.0 m^3/s (Tallman 2009).

Answers to Management Questions

1. *Does angling occur during this time of year in sections of the river that would be affected by this operation?*

Little or no angler effort occurs within the upper reaches of the Cheakamus River during winter January through March.

During the course of the roving survey, no anglers or evidence of fishing activity was encountered through any of the potential access points or angling locations for the study area. Consequently, Tallman's (2009) estimate of zero angler effort was consistent with expert angler opinion, which indicated a very low level of angling effort in the study reach from January to March (~10 angler trips annually). Expert angler opinion suggested that the trips that did occur were likely opportunistic, as the majority of targeted fishing within the study reach occurs in July and August near the confluence of Rubble Creek and the Cheakamus River.

2. *Is access to recreational angling locations during 1 January to 31 March improved under the 5.0 m^3/s minimum flow release from Daisy Lake Dam relative to that which would occur with a 3.0 m^3/s minimum flow release?*

Angler opportunity is unlikely to differ between 5.0 m^3/s and 3.0 m^3/s.

Based on literature and expert opinion, Tallman (2009) inferred that adult Rainbow trout would most likely be found in slower moving, deeper water during the winter months, as the primary need for these fish during this period is to minimize the expenditure of energy which they do by residing in slow moving water. Tallman (2009) identified areas with deeper pool habitat within the study reach of the upper Cheakamus River that would be suitable for adult Rainbow trout over-wintering (comprising approximately 12% of the study Reach). Approximately one-quarter of those suitable over-wintering habitats area were also accessible to anglers (approximately 3% of the study area).

Tallman's (2009) assessment suggested that changes to the over-wintering pool habitat available to angler would likely not change in function under lower discharge conditions. Although the angler setback from the overwintering pool habitats may increase with lower discharges, it was unlikely that this would affect angling potential in the study area as a whole. Consequently, Tallman (2009) concluded that because angler access, angler potential, and over-wintering habitat suitability would likely remain unchanged in the study reach at lower discharge levels, it was unlikely that angling opportunities in the study area at would differ between 5.0 m^3/s and 3.0 m^3/s.

4.10.4 Conclusions and Implications

The study concluded that little or no angler effort occurs within the upper reaches of the Cheakamus River during winter (January through March). In addition, angling opportunities were unlikely to be affected by changes in winter minimum flow from 3.0 m^3/s to 5.0 m^3/s. It is unlikely that any further change in flow would result in any meaningful improvement to angler access. The current minimum flow has potential fisheries benefits.

5.0 SUMMARY OF CONCLUSIONS AND IMPLICATIONS

Monitoring studies were initiated under the Cheakamus WUP to assess the uncertainties surrounding potential benefits or impacts of the WUP flow regime on fish, fish habitat, and recreational angling. Below is a summary of key findings of these studies as well as implications for BC Hydro operation on the Cheakamus River.

Effects of the WUP Flow Regime on Fish Production

A primary objective of the Cheakamus WUP monitoring programs was to examine the effects of the WUP flow regime on the production of juvenile salmonids in the mainstem of the Cheakamus River. These monitoring studies found limited evidence of substantial changes to fish abundance associated with the WUP flow regime; however, some of the studies were unable to control for external variables and/or had limited statistical power to detect changes. No significant changes in juvenile production were detected for Chinook, Coho salmon (CMSMON-1a) between WUP and IFA flow regimes; however, statistical power was weak because of low sample size and high natural variability in fish population among years. Pink salmon abundance data were considered too sparse to complete reliable tests. Although there was a negative trend in Rainbow trout fry density in the non-anadromous reach of the Cheakamus River over the study period, the Rainbow trout parr density appeared to remain stable, which indicates the impacts to fry were compensated by a density-dependent effect (CMSMON-2).

Significant increases in resident Rainbow trout in the anadromous reaches of the Cheakamus River were observed under the WUP flow regime; however, it is unclear whether increased Rainbow trout abundance under WUP flow was a flow-related effect or caused by some other factor coincidental to the WUP flow regime (CMSMON-3).

Steelhead adult returns to the Cheakamus River increased significantly under the WUP flow regime; however, Steelhead marine survival rate increased and Pink salmon returns also increased during this same period. Correcting adult return data for changes in Steelhead marine survival and Pink salmon adult returns, it is possible that there was actually a decrease in Steelhead freshwater production under the WUP, which is supported by observed decreases in Steelhead smolt abundance at the rotary screw trap; however, there are large uncertainties associated with the correction factors applied to adult Steelhead returns analysis and limited sample size and precision of the Steelhead smolt data (CMSMON-3).

The characteristics of flow that affect fish

Because some of the Cheakamus WUP monitoring studies lacked the ability to compare between flow regimes, inter-annual variability in discharge characteristics was used to assess flow related effects to fish production and productivity. Key aspects of the flow regime were identified though the monitoring studies to impact fish production and/or productivity, including high discharges during fall/winter, flow ramp down rates and minimum discharges during summer/fall spawning.

Large or highly variable flows in the Cheakamus River while juvenile early-life stages of salmon are present appear to negatively affect juvenile salmon production. Pink fry, Chinook fry, Coho smolt abundance (CMSMON-1a), Chum egg-to-fry survival (CMSMON-1b), and Steelhead fry over-winter survival (CMSMON-3) all appear to be negatively affected by large discharge events during fall and winter. In addition, high flow events during the summer rearing period may impact Rainbow trout spawning success in the non-anadromous reach of the Cheakamus River (CMSMON-2). Causal mechanisms may vary from redd scour, juvenile displacement, and/or fish/redd stranding during flow ramping. Large discharges down the Cheakamus River are typically caused by rainfall events associated with fall/winter storms. The small storage capacity of the Daisy Lake Reservoir limits the ability to manage the magnitude and duration of these discharges from Daisy Lake Dam. However, there may be further opportunities to evaluate options for down ramping of flows to mitigate potential fish stranding related impacts.

Studies found evidence that WUP specified flow ramp down rates likely result in a risk of fish stranding in the Cheakamus River and the Squamish River (CMSMON-3, 4, and 5). WUP ramp rates from Daisy Dam that exceed the DFO guideline of -2.5 cm/hr while fry are present were observed to strand fish in the non-anadromous reach of the Cheakamus River; however, stranding levels were deemed low and within maximum acceptable levels of stranding (CMSMON-5). Studies also identified fish stranding in the tailrace and Squamish River side-channel immediately downstream of the Cheakamus powerhouse; however stranding levels were low and unlikely to have a population level impact (CMSMON-4). Risk of juvenile fish stranding in the Squamish River was identified as highest during winter low-flow periods while the Cheakamus Generating Station fluctuates discharge (CMSMON-3 and 4); however, this risk has not been quantified.

In the Cheakamus River, rapid changes in discharge during summer months appear to significantly reduce Steelhead egg-to-fry survival, and during fall/winter months, reduce Steelhead fry over-winter survival (CMSMON-3). Monitoring of fish stranding during a flow ramp down with a change of minimum flow of ~38 m^3/s to ~20 m^3/s on the anadromous section of the Cheakamus River in August 2018, following WUP maximum ramp rates, identified substantial juvenile fish stranding. This field study supported the conclusion that WUP ramp rates can result in stranding of early life stages of salmon in the Cheakamus River, which may be having a population-level effect. To further understand causal mechanisms of fish stranding associated with rapid flow ramp downs and test the effectiveness of potential mitigation measures, the Cheakamus Adaptive Stranding Protocol (CASP) has recently been implemented on the Cheakamus River. Information gathered during the CASP is intended to inform WUP Order Review with regards to fish stranding impacts associated with Cheakamus River flow management (e.g., effects of ramp rates, flow thresholds, wetted history, etc.).

Seasonally targeted higher minimum flows for Chinook during late summer or pulse flows during Chum salmon upstream migration and spawning during the fall, appear to be associated with increased juvenile abundance and survival (CMSMON-1a and 1b). Higher flows may allow spawning salmon to access more or higher productivity spawning habitat in the Cheakamus River. In the case of Chinook, it appears that higher discharges during summer are positively associated with juvenile abundance (CMSMON-1a); however, it is unclear whether higher summer discharges provide adult access to higher productivity spawning habitats, or result in cooler water temperatures which influence egg incubation and juvenile emergence timing. In the case of Chum, pulse flows trigger adult Chum to enter groundwater influenced, side-channel or upstream habitats where egg-to-fry survival rates are higher (CMSMON-1b). Consequently, pulse flows during the Chum adult migration period may increase Chum salmon freshwater productivity in the Cheakamus River.

The effects of WUP flow regime on fish habitat

A key uncertainty of the WUP flow regime was impacts to fish habitat. Several aspects of fish habitat were monitored under the Cheakamus River WUP including mainstem and artificial side-channel habitat quantity and quality, groundwater availability, spawning gravel availability, and benthic community. Findings suggest a limited impact of the WUP flow regime on fish habitat in the Cheakamus River.

During the period of the WUP flow regime, the total area of wetted natural side channel habitat has increased at typical WUP flows in the Cheakamus River (CMSMON-8). In addition, the habitat diversity of natural, mainstem side-channel habitat has not changed significantly over time (CMSMON-8). Changes in mainstem discharge associated with WUP operation were unlikely to have any impact of water quality and consequential habitat suitability for aquatic organisms in the side-channels (CMSMON-6). Groundwater quantity and quality in the side-channels was found to be relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s. In addition, the availability of wetted habitat and total suitable habitat in the groundwater-fed, side-channels was considered insensitive to changes in Cheakamus River mainstem flow below 40 m^3/s (CMSMON-6).

Although not attributed to WUP flows, there was evidence of overall channel stabilization, at the same time as potential erosion and downstream transfer of sediment in the Cheakamus River (CMSMON-8). However, implementation of the WUP flow regime has likely not resulted in any changes to erosion of spawning sediment compared to pre-WUP levels. Within the mainstem of the Cheakamus River, discharge during the fall and winter period does appear to affect the upwelling of groundwater in the mainstem spawning areas, as indicated by redd temperature monitoring. However, the magnitude and direction of changes in redd temperatures was highly variable both among and within sites on the Cheakamus River (CMSMON-1b).

Results of Chum spawning physical habitat modelling conducted during the Water Use Plan process predicted increased habitat availability in the upper reaches of the Cheakamus River. Instead, it was found that strong groundwater upwelling, which is more prevalent in the lower river relative to upstream of the Bailey Bridge, is a primary factor in adult Chum salmon spawning site selection, and that those upper reaches are rarely used by Chum salmon except when prompted by pulse flow events and/or density dependent behavior (CMSMON-1b).

Finally, river discharge was found to be the strongest predictor of benthic productivity in the Cheakamus River; therefore, significant changes in the Cheakamus River flow regime would likely indirectly affect juvenile salmon productivity (CMSMON-7). However, summer flow variation between IFA and WUP was too limited to explain any of the observed changes in benthic production between the two flow regimes suggesting non-WUP factors (e.g., climatic factors or sewage treatment effects) were more likely the cause of observed changes in benthic community.

Recreational angler access during the winter months

A WUP monitoring study was designed to assess angler access during winter months to the upper section of the Cheakamus River under the WUP flow regime. The study found little or no angler effort occurs within the upper reaches of the Cheakamus River during winter (January through March). In addition, providing a minimum flow release from Daisy Lake Dam of 5.0 m^3/s as opposed 3.0 m^3/s likely resulted in little to no additional benefits to recreational angler access and opportunities in the upper reaches of the Cheakamus River from January to March (CMSMON-9).

Table 6.1 below is a summary of key findings of these studies as well as their implications.

Table 6.1: Summary of implications for the Cheakamus WUP monitoring projects.

Project	Implication
CMSMON-1a Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring	Reducing flow ramp rates during and following fall storm events may reduce juvenile fish displacement and/or stranding, resulting in increased freshwater production. Higher seasonal minimum discharges in the Cheakamus River during late-summer Chinook upstream migration and spawning may improve Chinook fry production.
CMSMON-1b Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey	Providing pulse flows during the Chum adult migration period may increase Chum salmon freshwater productivity in the Cheakamus River. Consideration of spawning habitat enhancements should be focused on areas of naturally occurring groundwater upwelling.
CMSMON-2 Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon)	The apparent stable Rainbow trout parr populations observed over the monitoring period suggest there was no population level effect from the WUP flow regime.
CMSMON-3 Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring	There was no strong evidence to suggest that higher WUP flows during late-summer months (i.e., 38 m^3/s) effected Steelhead egg-to-fry survival. Instead, there was strong evidence to suggest that rapid changes in discharge (i.e., flow ramp downs) were associated with reduced survival of early-life stages of Steelhead in the Cheakamus River. To further understand causal mechanisms of fish stranding associated with rapid flow ramp downs and to test the effectiveness of potential mitigation measures, the Cheakamus Adaptive Stranding Protocol (CASP) has been implemented on the Cheakamus River outside of the WUP Order projects. Information gathered during the CASP will also be used to inform WUP Order Review with regards to fish stranding impacts associated with flow changes (e.g., effects of ramp rates, minimum flows, wetted history, etc.) on the Cheakamus River. Large uncertainties associated with marine survival rates of Cheakamus Steelhead limit

Project	Implication
	the value of examining escapement trends to evaluate freshwater flow effects on production. Addendum: The Squamish River desktop stranding analysis highlighted key areas for focus in future study to identify potential effects of fluctuating discharges from Cheakamus Generating Station on juveniles.[2]
CMSMON-4 Monitoring Stranding Downstream of Cheakamus Generating Station	Fish stranding risk in the Cheakamus Generating Station tailrace channel and Squamish River side-channel immediately downstream was relatively low and unlikely to have fish population level impact[3]. Fish stranding risk was highest during period of low flow in the Squamish River (December-April, or September), during larger ramp downs from the generating station, and when ramped down to zero discharge. Mitigation options were discussed in the study, but none were assessed during the study period. Note: further assessment of potential for juvenile stranding in the Squamish River downstream of the Cheakamus Generating Station was completed as an addendum to CMSMON-3 (see above).
CMSMON-5 Monitoring Stranding Downstream of Daisy Lake Dam	Although prescribed WUP ramp rates from Daisy Lake Dam (1 m^3/s per 60 min) resulted in stage change rate downstream that exceeded -2.5 cm/hr during the flow ramp down from 7 m^3/s to 3 m^3/s on November 1, 2018, the study concluded that fish stranding rates were below maximum acceptable levels established by DFO and MOE (discussed below). Given that stranding is a low risk in the resident reach, and given the results of CMSMON-3 suggest that flow reductions may have a measurable impact on anadromous populations in the Cheakamus River, the Cheakamus Adaptive Stranding Protocol will focus its efforts on mitigating stranding risks in the lower reaches of the Cheakamus River.
CMSMON-6 Monitoring Groundwater in Side Channels of the Cheakamus River	Because the groundwater quantity and quality in the side-channels was relatively independent of Cheakamus River mainstem discharge between 15 and 40 m^3/s, it is unlikely that the WUP flow regime resulted in any biologically significant impact to fish habitat or fish productivity in the Cheakamus side-channel area.
CMSMON-7 Cheakamus River Benthic Community Monitoring	Modeling results showed that river discharge was the strongest predictor of benthic productivity; therefore, significant changes in the Cheakamus River flow regime would likely indirectly affect juvenile salmon productivity. Non-flow related factors (e.g. climatic factors or sewage treatment effects) were likely responsible for any observed differences in benthic production between the between IFA and WUP, as variation in summer flow is too limited between the flow regimes to explain the differences in production. This model could provide a basis for evaluating potential future flow regimes in the WUP Order Review given the potential flow regimes have substantial differences in average seasonal discharge.
CMSMON-8 Monitoring Channel Morphology in Cheakamus River	Implementation of the WUP flow regime did not change the presence of spawning gravel or fish habitat types; therefore it is unlikely that future flow changes within the operating bounds of the WUP and the IFA would affect the availability of spawning gravel or fish habitat types. Tributary inflows are most influential during the fall and winter, when Daisy Lake Dam discharges are low.
CMSMON-9 Cheakamus River Recreational Angling Access Monitoring	Providing a minimum flow release from Daisy Lake Dam of 5.0 m^3/s as opposed 3.0 m^3/s likely resulted in little to no additional benefits to recreational angler access and opportunities in the upper reaches of the Cheakamus River from January to March. It is unlikely that any further change in flow would result in any meaningful improvement to angler access. The current flow has potential fisheries benefits.

6.0 REFERENCES

Marmorek, D.R. and I. Parnell. 2002. Cheakamus River Water Use Plan: Report of Consultative Committee. Consultant's report produced by ESSA Technologies Ltd. for Cheakamus River Water Use Plan Consultative Committee. May 2002, pp. 94 + App.

BC Hydro. 2005. Cheakamus Project Water Use Plan: Revised for Acceptance by the Comptroller of Water Rights. October 2005, 12 p. + App.

BC Hydro. 2007a. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Cheakamus River Juvenile Salmonid Outmigrant Enumeration Monitoring. February 2007, pp.19.

BC Hydro. 2007b. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey. February 2007, pp.15.

BC Hydro. 2007c. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Trout Abundance Monitor in Cheakamus River (Daisy Lake Dam to Cheakamus Canyon). February 2007, pp.13.

BC Hydro. 2007d. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring. February 2007, pp.15.

BC Hydro. 2007e. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Monitoring Stranding Downstream of Cheakamus Generating Station. February 2007. pp. 15.

BC Hydro. 2007f. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Monitoring Stranding Downstream of Daisy Lake Dam. February 2007.pp. 8.

BC Hydro. 2007g. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Monitoring Groundwater in Side Channels of the Cheakamus River. February 2007.pp. 12.

BC Hydro. 2007h. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Cheakamus River Benthic Community Monitoring. February 2007.pp. 15.

BC Hydro. 2007i. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Monitoring Channel Morphology in Cheakamus River. February 2007.pp. 10.

BC Hydro. 2007j. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: Cheakamus River Recreational Angling Access Monitoring. February 2007.pp. 6.

BC Hydro. 2012a. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference:CMSMON-1a - Cheakamus River. Juvenile Salmonid Outmigrant Enumeration Monitoring. Addendum 1. December 2012, pp.2.

BC Hydro. 2012b. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: CMSMON-3 – Cheakamus River Steelhead Adult Abundance, Fry Emergence Timing, and Juvenile Habitat Use and Abundance Monitoring. Addendum 1. November 2012, pp.3.

BC Hydro. 2013. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: CMSMON-1b – Cheakamus River Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey. Addendum 1. January 2013, pp.2.

BC Hydro. 2017. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference for CMSMON-1B. Letter from Alsion Briggs, BC Hydro, Manager, Water Program, to B. O'Neill, Deputy Comptroller of Water Rights. Ministry of Forests, Lands, Naturual Resource Operations and Rural Development. November 30, 2017. pp.2.

BC Hydro. 2018a. Cheakamus Project Water Use Plan: Monitoring Program Terms of Reference: CMSMON-3: Cheakamus River Steelhead Adult Abundance, Fry-Emergence Timing and Juvenile Habitat Use and Abundance Monitoring Survey. Addendum 2. January 2018, pp.6.

BC Hydro. 2018b. Generation Operating Order: Cheakamus Project (CMS 4G-25 v3.0). February 2018. pp. 31 + Apps.

Cathcart, J. 2005. Fisheries and Oceans Canada flow ramping study: study of flow ramping rates for hydropower developments. Consultants report prepared by Knight Piesold Ltd. for Fisheries and Oceans Canada. (ref. No. Va103-79/2-1). 50 pp.

Comptroller of Water Rights. 2006. Section 87 and 88 *Water Act* Order for the Cheakamus Power Development. Issued to BC Hydro and prepared by the Ministry of Environment, Victoria, BC.

Ellis, E and D. Sellars. 2014. Cheakamus River Channel Morphology Monitoring – Year 1 to Year 5 Flow Synthesis Report (MQ3). Cheakamus Project Water Use Plan: CMSMON-8. Consultant's report produced by Kerr Wood Leidal Associates Ltd. for BC Hydro. December 2014. pp. 28

Gray T., J. Scibek, D. Mackie, W. Gaherty, and D.M. Allen. 2012. Monitoring Groundwater in Side Channels of the Cheakamus River. Cheakamus Project Water Use Plan: CMSMON-6. Consultant's report produced by Pottinger Gaherty Environmental Consultants Ltd., SRK Consulting (Canada) Inc., and Simon Fraser University, Department of Earth Sciences, for BC Hydro. January 2012. pp. 73 + App.

Harrison, R., D Roscoe, and D. Schmidt. 2013. Rainbow Trout Abundance Monitor of the Cheakamus River (Daisy Lake to Cheakamus Canyon) 2007; Cheakamus Project Water Use Plan: CMSMON-2. Consultant's report produced by Golder Associates Ltd. for BC Hydro and Squamish Nation. January 2013. pp. 33 + App.

Harrison, R., R. Sung, G. Burrell, and C. Coles. 2014. Monitoring Stranding Downstream of Cheakamus Generating Station; Fish and Hydrological Assessments Summary Report; Cheakamus Project Water Use Plan: CMSMON-4. Consultant's report produced by Golder Associates Ltd. for BC Hydro and Squamish Nation. April 2014. pp. 52 + App.

Hoogendoorn, R., C. Coles, and B. Sander. 2009. Monitoring Stranding Downstream of Daisy Lake Dam; Cheakamus Project Water Use Plan: CMSMON-5. Consultant's report produced by Golder Associates Ltd. for BC Hydro and Squamish Nation. April 2014. pp. 21 + App.

Irvine, R.L., P.M. Hogan, and J. Thorley. 2015. Analysis and Review of Rainbow Trout Abundance Monitoring Program CMSMON#2 for the Non-Anadromous Section of the Cheakamus River. Consultant's report produced by Poisson Consulting Ltd. for BC Hydro. March 2015. pp. 29 + App.

Korman, J. 2019. Effects of Cheakamus Generating Station on Discharge in Squamish River and Potential Impacts on Fish Populations (report prepared under Terms of Reference for CMSMON-03). Prepared for BC Hydro Water License Requirements, Burnaby, BC.

Korman J. and J. Schick. 2019. (*DRAFT*) Synthesis of Adult and Juvenile Steelhead Data to Evaluate Effects of the WUP Flow Regime in the Cheakamus River; Cheakamus Project Water Use Plan: CMSMON-3. Consultant's report produced by Ecometric Research for BC Hydro. October 2019. pp. 51 + App.

Korman J. and J. Schick. 2018. Final Report of Adult and Juvenile Data to Evaluate Effects of the WUP Flow Regime on Steelhead in the Cheakamus River; Cheakamus Project Water Use Plan: CMSMON-3. Consultant's report produced by Ecometric Research for BC Hydro. May 2018. pp. 44 + App.

Lingard, S, A. Putt, K. Cook and C. Melville. 2019. Cheakamus River Juvenile Salmon Outmigration Enumeration. Final Data Report 2001-2019; Cheakamus Project Water Use Plan: CMSMON-1a. Consultant's report produced by Instream Fisheries Research, Inc. for BC Hydro. July 2019. pp.59 + App.

McAdam, S. 2001. Water Temperature Measurements on the Cheakamus River—Data Report: June 1999 to December 2000. Consultant's report prepared for B.C. Hydro.

McArthur, M.D. 2011. Cheakamus River benthic community monitoring and model development (CMSMON-7): Appendix to final report. Study period: 2009-2010. BC Hydro, Burnaby, BC

Middleton, C., A. Putt., S. Lingard and K. Cook. 2019. Cheakamus Project Water Use Plan: Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey from 2007-2018, and Chum Fry Production from 2001-2019; Cheakamus Project Water Use Plan: CMSMON-1b. Consultant's report produced by Instream Fisheries Research, Inc. for BC Hydro. October 2019. pp. 49 + App.

NHC, 2000. Analysis of Channel Morphology and Sediment Transport Characteristics of the Cheakamus River. BC Hydro Ref. No. CMS-MRPHLGY. Report prepared for BC Hydro. Pp. 37 + figures, tables & appendices.

Perrin, C. 2010. Cheakamus River Benthic Monitoring; Cheakamus Project Water Use Plan: CMSMON#7. Consultant's report produced by Limnotek Research and Development Inc. for BC Hydro. December 2012. pp. 60.

Ricker, W. E. (1954) Stock and Recruitment Journal of the Fisheries Research Board of Canada, 11(5): 559–623. doi: 10.1139/f54-039

Salo, E.O. 1991. Life history of Chum salmon. Pages 232-309 in C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, Vancouver, Canada.

Scott, S., C. Davey, E. Ellis, and D. Sellars. 2018a. Cheakamus River Channel Morphology Monitoring – Annual Progress Report (MQ2). Cheakamus Project Water Use Plan: CMSMON-8. Consultant's report produced by Kerr Wood Leidal Associates Ltd. for BC Hydro. May 2018. pp. 31 + App.

Scott, S., C. Davey, E. Ellis, and D. Sellars. 2018b. Cheakamus River Channel Morphology Monitoring - Final Report (MQ1, MQ2, MQ3). Cheakamus Project Water Use Plan: CMSMON-8. Consultant's report produced by Kerr Wood Leidal Associates Ltd. for BC Hydro. October 2018. pp. 28 + App.

Taleghani, A., C. Davey, and E. Ellis. 2017. Cheakamus River Channel Morphology Monitoring – Annual Progress Report (MQ1). Cheakamus Project Water Use Plan: CMSMON-8. Consultant's report produced by Kerr Wood Leidal Associates Ltd. for BC Hydro. May 2018. pp. 27 + App.

Triton Environmental Ltd. 2009. Non-Anadromous Reach Fish Abundance Monitoring Program 2008. Consultant's report produced by Triton Environmental Consultants Ltd. for Canadian National Railway Company, Surrey, B.C.

Tallman, D. 2009. Cheakamus River Recreational Angling Access Monitoring. Cheakamus Project Water Use Plan: CMSMON#9. Consultant's report produced by J.O. Thomas and Associates Ltd. for BC Hydro. October 2009. pp. 7 + App.