Cheakamus Project Water Use Plan

Cheakamus River Channel Morphology Monitoring

Implementation Year 10

Reference: CMSMON-8

FINAL REPORT (MQ1, MQ2, MQ3)

Study Period: 2008-2018

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Executive Summary

The Fisheries Technical Committee for the Cheakamus Water Use Plan developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the Consultative Committee, and to better inform the next Water Use Plan. CMSMON8 deals with questions related to channel morphology and tributary flows.

BC Hydro's Terms of Reference for CMSMON8 identifies three management questions (MQs), which the Cheakamus River monitoring program is intended to answer. Also outlined in the Terms of Reference are three specific impact hypotheses, which accompany the MQs.

Years 1 through 5 of CMSMON8 were implemented by a previous contractor. BC Hydro awarded CMSMON8 Years 6 through 10 to Kerr Wood Leidal Associates Ltd. (KWL). Work to address MQ1, MQ2, and MQ3 was completed in Year 8, Year 10, and Year 6 of the monitor, respectively.

Table E-1 below summarizes the MQs, their associated Impact Hypotheses, and the conclusions.

Table E-1: MQ Summary

Management Question	Management Impact Hypotheses	Status and Conclusions
MQ1: 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?	**$H_{0,1}$:** Total area of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP.	• **$H_{0,1}$** was not directly addressed due to a lack of pre-WUP information on suitable spawning habitat[1]. • The revised methodology[1] for addressing MQ1 focused on estimating the discharge threshold above which suitable spawning habitat substrate would be mobile and subject to erosion and determining the influence of WUP implementation on the threshold. • Two monitoring sites with suitable spawning habitat were identified and selected in Year 7. • Sediment mobility thresholds were predicted using analytical methods based on driving forces (shear stress from river flow) and resisting forces (river bed sediment mixture resistance to movement). The analytical methods were supported by field collection of surface grain size and by BC Hydro's in-house 2-D hydraulic model. • Sediment mobility at the monitoring sites was monitored in Year 7 and Year 8 by using sediment traps to capture mobile sediments from three various flow events. The main finding of MQ1 analysis is that the discharges required to mobilize the river bed and erode spawning habitat occur as part of BC Hydro flood routing operations. BC Hydro has specified that there is no difference in flood routing between pre-WUP and WUP operations. Therefore, the WUP has not changed the occurrence of bed mobility and erosion of spawning sediments when compared to the pre-WUP condition. **CMSMON8 concludes that the implementation of the WUP has not resulted in additional erosion of spawning sediments compared with the pre-WUP condition.**

<table>
<tr><th>Management Question</th><th>Management Impact Hypotheses</th><th>Status and Conclusions</th></tr>
<tr><td>MQ2: 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?</td><td>H$_{0,2}$: Total length (km) of connected side-channel habitat wetted at typical flows has not changed since implementation of the WUP, and

H$_{0,3}$: The diversity of side-channel habitat as measured by the number and ratio of pool, run and riffle habitats has not changed since implementation of the WUP.</td><td>• Repeat geomorphic and habitat mapping was carried out based on orthophotography collected in 2008, 2012, and 2017.
• Statistical analyses were carried out to compare geomorphic and habitat features and determine whether changes had occurred between years of mapping.
CMSMON8 concludes that following implementation of the WUP:
• The total area of natural side channel habitat wetted at typical flows has increased (measurements of side channel area are considered more appropriate when quantifying habitat, than length).
• The diversity of natural, mainstem side channel habitat as measured by the area of pool, riffle, and rapid habitat units has not significantly changed.
The question of access was not directly addressed due to limitations of the inherited methodology. This future work will be included and reported in CMSMON1b.</td></tr>
<tr><td>MQ3: 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?</td><td>N/A</td><td>• Y1 to Y5 hydrometric data collected by BC Hydro and the Water Survey of Canada were analyzed.
• General hydrology of the lower Cheakamus River was characterized, and tributary inputs to the CMSMON8 reach as a whole were quantified.
• The attenuation effect of the tributary inputs was assessed and quantified.
CMSMON8 concludes that:
• Tributary inflows have a large impact on flow regime downstream of Daisy Lake Dam. Tributary inflow averages approximately 138% of dam outflow.
• The attenuating effect of tributary inflow is strongest during fall and winter, when dam discharge is low.
• Absolute tributary inflow is greatest in the summer but accounts for a lower proportion of total flow due to high discharge at the dam.
• Y1-Y5 data from additional stations between dam and WSC Brackendale gauge do not provide much additional benefit for answering MQ3 due to measurement uncertainty.</td></tr>
<tr><td colspan="3">Notes:
1. Refer to Addendum 2 of Cheakamus Water Use Plan Monitoring Program Terms of Reference for CMSMON8 (BC Hydro, 2015)</td></tr>
</table>

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) has been retained by BC Hydro to conduct monitoring work for CMSMON8: Cheakamus River Channel Morphology Monitoring. This monitoring program arose from the Water Use Plan (WUP) process that initiated in 1996 and resulted in the current WUP, accepted by the Comptroller of Water Rights in 2005. CMSMON8 has a 10-year duration; the first 5 years of the monitoring program were completed by Northwest Hydraulic Consultants (NHC). BC Hydro awarded the CMSMON8 project to KWL in August 2013 for the remaining 5 years of the monitor (2013 through 2018).

CMSMON8 is intended to answer the following management questions (MQs):

1. *Following implementation of the WUP (Water Use Plan), 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?*
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?*

1.1 Chronology

MQ1, MQ2, and MQ3 lend themselves to different hypotheses and scopes of work that have been completed separately in Years 8, 10, and 6 of the monitor, respectively. Each MQ has been summarized in a separate standalone report; these are included as appendices in this compendium. The main body of this compendium is meant to provide background for the work that was carried out and summarize the main conclusions of the analyses. Refer to Attachment A, B, and C for the complete reports.

1.2 Water Use Plan

The Cheakamus River Water Use Plan (WUP) was accepted by the Comptroller of Water Rights and implemented in February 2006. The Cheakamus Consultative Committee (CC) agreed on six fundamental objectives for the Cheakamus Water Use Plan (in no particular order):

1. **Power:** Maximise economic returns from power generated at Cheakamus Generating System;
2. **First Nations:** Protect the integrity of Squamish First Nation’s heritage sites and cultural values;
3. **Recreation:** Maximise physical conditions for recreation;
4. **Flooding:** Minimise adverse effects of flood events through operation of the Cheakamus Generating system;
5. **Fish:** Maximise wild fish populations; and
6. **Aquatic Ecosystem:** Maximise area and integrity of the aquatic and riparian ecosystem.

The Fisheries Technical Committee developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the CC, and to better inform the next WUP. The CC recognized that it is essential to address critical scientific uncertainties that can affect future decision making, and to comprehensively assess the response of the system to changes in the operation of the Cheakamus Generating System. CMSMON8 is one of 10[1] monitors related to the WUP.

1.3 Project Location and Description

The Cheakamus generating system was completed in 1957 (BC Hydro, 2005). Daisy Lake Dam impounds the Cheakamus River creating Daisy Lake Reservoir, located about 30 km north of Squamish, adjacent to Highway 99. From Daisy Lake Reservoir, some of the water is released via the dam to the lower Cheakamus River while some is diverted, via a tunnel, to the Cheakamus Generating Station. The water diverted for power is not returned to the lower Cheakamus River since the Cheakamus Generating Station discharges to the Squamish River. Daisy Lake Reservoir can store about 55 million m^3 of water: about 3.5% of average annual inflow (BC Hydro, 2005). The maximum discharge capacity of the generating station is 65 m^3/s.

Cheakamus River is a ‘mixed-regime’ watershed, exhibiting characteristics of both rain- and snow melt-dominated streamflow regimes. The annual hydrograph contains a summer snowmelt freshet peak, but peak flows also occur in the fall and winter from intense rainstorms combined with snowmelt (BC Hydro, 2005). The fall and winter peak flows are characteristically larger than the freshet peak flows. Continuous hydrometric data is available from a Water Survey of Canada hydrometric station located on lower Cheakamus River about 5 km upstream of the confluence with Squamish River (WSC 08GA043).

The Cheakamus River provides critical habitat for many anadromous and resident fish species. A list of fish species present within the Cheakamus River is shown in Table 1-1.

Table 1-1: Anadromous and Resident Fish Species of the Cheakamus River[1]

Anadromous Species	Resident Species
Coho salmon (*Oncorhynchus kisutch*) Chum salmon (*O. keta*) Chinook salmon (*O. tshawytscha*) Pink salmon (*O. gorbuscha*) Steelhead trout (*O. mykiss*)	Rainbow trout (*O. mykiss*) Cutthroat trout (*O. clarkia*) Bull trout (*Salvelinus confluentus*) Dolly varden (*S. malma*) Brook trout (*S. fontinalis*) Threespine stickleback (*Gasterosteus aculeatus*) Coastrange sculpin (*Cottus aleuticus*)

Notes:
1. Results of a search within BC’s Fisheries Information Summary System (FISS) for the Cheakamus River (2016)

[1] Monitors 1 through 9, with 1a and 1b considered separately.

1.4 Project Design

Management Question 1 (MQ1)

During the course of background information review and consultation with other Cheakamus River monitors it became evident that there is limited pre-WUP data available to support an approach to answer MQ1 as originally stated. In addition, consultants in charge of other Cheakamus River monitors were of the opinion that spawning habitat in the lower Cheakamus River is not limiting.

In response to these issues, BC Hydro proposed a revision to MQ1:

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

The revised MQ1 proposes to evaluate whether there has been degradation in spawning habitat via erosion following implementation of the WUP. In the absence of physical data on spawning habitat conditions during the pre-WUP period, this assessment relies on the available record of flow releases from Daisy Lake Dam to represent pre-WUP vs. WUP conditions.

In order to evaluate the revised MQ1, a relation was developed between discharge and sediment mobility at specific monitoring sites where fish spawning is known to occur. Sediment mobility was assessed by determining the shear stress required to initiate bed sediment movement (i.e. critical threshold), whereupon erosion of spawning habitat may occur. The frequency with which critical threshold shear stresses are experienced under pre-WUP vs. post-WUP conditions was then compared.

The main tasks in the MQ1 analysis include:

- Determining the critical shear stress required to initiate sediment mobility at specific monitoring locations within the Cheakamus River.
- Estimating the shear stress on the river bed at specific monitoring locations within the Cheakamus River for different flows.
- Validating predictions of mobility by monitoring sediment mobility following a variety of flows.
- Providing a comparison between the WUP operational discharges in relation to the pre-WUP operational discharges.

A major assumption in the MQ1 analysis is that when critical shear stresses are reached the mobilization and erosion of spawning sized sediment occurs, and that it results in the degradation of spawning habitat. Studies have shown that intense and frequent sediment mobilization events can limit salmonid production (Lisle, 1989). On the other hand, mobilization of spawning substrate by flood flows is necessary for maintaining long-term productivity of spawning habitat (Lapointe et al, 2000).

Defining an optimal degree of physical disturbance to spawning substrate is beyond the scope of this project. However, observations made during this field study, and a related discussion on physical disturbance to spawning substrate is provided.

Management Question 2 (MQ2)

MQ2 asks the following question:

2. *Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?*

To answer this management question, two impact hypotheses were developed by BC Hydro to test whether the morphology, and hence aquatic habitat, has been significantly altered since implementation of the WUP.

> $H_{0,2}$: *Total length (km) of connected side channel habitat wetted at typical flows has not changed since implementation of the WUP, and*
>
> $H_{0,3}$: *The diversity of side channel habitat as measured by the number and ratio of pool, run and riffle habitats has not changed since implementation of the WUP.*

The approach to addressing MQ2 was established in Year 1 through Year 5 of the study, which relies on repeat channel and habitat mapping from orthophotos (NHC, 2014). The main tasks in the analysis include:

- Mapping channel morphology and wetted channel habitats using morphological and habitat categories established in the first CMSMON8 monitor;
- A field visit to ground-truth morphologic channel mapping and wetted habitat classification; and
- Statistical analyses of current morphologic and channel mapping, and comparison with the previous mapping.

The inherited methodology relies on repeat mapping of orthophotography taken at relatively similar flows. The static nature of this approach did not allow the question of access (both spatial and temporal) to be directly addressed. This future work will be included and reported in CMSMON1b.

Management Question 3 (MQ3)

MQ3 asks the following question:

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?*

Based on discussions with BC Hydro, this Management Question is specifically concerned with how tributary flows "attenuate", or reduce the effect of, the operation of Daisy Lake Dam. The approach to addressing MQ3 involves an analysis of hydrometric data collected in Year 1 through Year 5 of the monitor. This generally consists of:

- Reviewing inflows between Daisy Lake Dam and the Cheakamus River near Brackendale hydrometric station (WSC 08GA043);
- Estimating the absolute increase in flow between Daisy Lake Dam and WSC 08GA043;
- Estimating the relative increase in flow between Daisy Lake Dam and WSC 08GA043; and
- Comparing flow duration curves for Daisy Lake Dam outflows and WSC 08GA043.

1.5 Project Team

The KWL project team and roles for this study are as follows:

- Erica Ellis – Project Manager and Professional of Record,
- David Sellars – Senior Water Resources Engineer,
- Chad Davey – Project Fluvial Geomorphologist,
- Amir Taleghani – Project Engineer, and
- Shayna Scott – Junior Engineer and Hydraulic Modeller.

The following BC Hydro staff provided input to the CMSMON8 analysis:

- Mark Sherrington and Darin Nishi – BC Hydro Contract Managers,
- Alexis Hall and Brent Wilson – BC Hydro – Fish and Aquatic Issues (Subject Matter Experts),
- Faizal Yusuf – BC Hydro Hydraulic Modelling Lead and Reviewer,
- Les Giles and Dusanka Urosevic – BC Hydro Photogrammetry Services,
- James McNaughton and Wuben Luo – BC Hydro Operations, and
- Colin Rombough – BC Hydro Environmental Field Services.

We would like to acknowledge the Cheakamus Centre (Jason Fullerton, Steven Chappell) for allowing us to locate a field site within their property.

Finally, both Caroline Melville (InStream Fisheries Research Inc.) and Josh Korman (Ecometric Research) provided background information and useful input during MQ-related discussions.

2. Summary and Conclusions

CMSMON8 set out to answer the following three management questions put forward by the Fisheries Technical Committee for the Cheakamus Water Use Plan:

1. *Following implementation of the WUP, has there been degradation in spawning habitat via erosion?*
2. *Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to 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?*

2.1 Management Question 1 (MQ1)

Attachment A presents the final report summarizing the MQ1 analysis. Below we present the conclusions from that report.

The analysis for MQ1 determined that the critical shear stress (for τ_{*c} = 0.045) for which erosion of spawning substrate may occur is likely exceeded at discharges greater than:

- 270 m^3/s for Eagle Point, and
- 160 m^3/s for Pedestrian Bridge.

These site-specific shear stress discharge relationships are based on reach-average shear stress derived from a hydraulic model, and generally supported by field-based shear stress estimations collected by the sediment traps.

Operational impacts to flow from the WUP vs. pre-WUP (IFA) are limited to the lower end of the range of flows, below about 50 m^3/s. As such, we conclude that the implementation of the WUP has not resulted in additional erosion of spawning sediments compared with the pre-WUP condition.

Other Potential WUP Impacts to Spawning Habitat

It is important to consider other effects that WUP implementation may have had on spawning substrate, apart from erosion. As mentioned earlier, Cheakamus River fisheries monitors are of the opinion that availability of suitable spawning habitat (i.e. of a suitable surface sediment size) is not limiting. However, the quality of the sub-surface sediments has not been directly assessed, and sub-surface quality has been shown to be a limiting factor for spawning success. In particular, siltation of fine sediment into spawning redds during low flow events can lead to increased egg to fry mortality (Chapman, 1988).

A local study on Steelhead in the Cheakamus River (CMSMON-3) involved the collection of physical habitat information, in particular pore depth: an estimation of fine sediment intrusion within the interstitial space of framework particles. Pore depth data were collected at many sites along lower Cheakamus River during fall 2014, and repeated at the same sites in spring 2015 (Korman and Schick 2015). The data shows that tributaries, such as Culliton Creek, are important sources of fine-grained sediment to the lower Cheakamus. In addition, the data showed that fine-grained material accumulated in interstitial space of gravel and cobbles between fall and spring sampling events.

However, this same Steelhead study (CMSMON-3) also found that egg to fry mortality does not appear to be a limiting factor for population growth. Egg to fry survival rates for Steelhead in the Cheakamus River appear to be negatively correlated with egg deposition (Korman and Schick 2015), although the sample size is limited. This is possibly a result of greater predation on Steelhead fry during emergence. There is some indication that high flows during summer and/or rapid reductions in flow during this period limited egg to fry survival rates for Steelhead, but in general the greatest mortality appears to occur after fry emergence (Korman and Schick 2015). This finding suggests that, at least for Steelhead, operational impacts to sub-surface sediment quality do not require further monitoring.

It should be noted that even if sub-surface sediment quality is assessed in future work it would not be possible to contrast current (WUP) conditions with previous conditions as the IFA-era supporting data do not exist.

Another means by which the WUP may affect spawning is in the timing of releases to meet the flow targets. During this study apparent stranding of adult spawners (Pink salmon) was noted at the Pedestrian Bridge monitoring site during the initial field visit (Sep. 16, 2015). A large number of dead adult Pink salmon were observed on gravel bar tops, at elevations of up to 1 m above the water level at the time of the site visit (36 m^3/s at WSC 08GA043). It is not known how WUP operations affect the flow levels at spawning sites, and whether there is a significant impact of operations on stranding that affects spawning success, compared with IFA conditions.

Other Considerations

Other potential impacts that a regulated river may have on spawning habitat include scour and/or entombment of redds and reductions in sediment supply. As mentioned earlier, the main assumption of this study is that the erosion and the resultant degradation of spawning habitat is likely to occur when the critical shear stress has been exceeded. In addition to potential changes in overall quality or quantity of spawning habitat, another pathway of effect resulting from high sediment mobility during flood events is the potential for scour, and/or entombment, of eggs (Lisle 1989).

During this study, discharge event #3 at Eagle Point (267 m^3/s) caused the deposition of ~30 cm of a sandy gravel layer on top of both sediment traps. A local study on Chum salmon (CMSMON-1b) postulated that the egg to fry mortality in the mainstem compared to side channels was higher due to bed scour, which resulted from several large flow events that occurred 2014 (Fell et al 2015).

In contrast, others have found that the mobilization of spawning substrate by flood flows is necessary for maintaining long-term productivity of spawning habitat (Lapointe et al 2000). Flood events causing scour and fill of sediment are a natural characteristic of gravel bed streams to which salmonid species have adapted.

Previous work evaluating the operational impact of 1960 to 1994 Cheakamus River peak flows concluded that regulation resulted in a modest reduction in peak flows:

- the 2-year return period flood was reduced by about 15%,
- the 10-year return period flood was reduced by about 9%, and
- the 100-year return period flood was reduced by about 13% (NHC, 2000).

These findings suggest that regulation has likely not resulted in a higher frequency of scour/fill events than would be experienced under no regulation. However, the construction of the Daisy Lake Dam has reduced the supply of coarse sediment to the lower Cheakamus River by half or more (NHC 2000). A more detailed study would be needed to understand the combined effect of lower peak flows and a reduced sediment supply on spawning habitat quality in the Lower Cheakamus River.

2.2 Management Question 2 (MQ2)

Attachment B presents the final report summarizing the MQ2 analysis. Below we present the conclusions from that report.

The methodology to determine whether there has been a change in the total length, diversity and access of natural side channel habitat following WUP implementation was inherited from the previous consultant during the first five years of the monitor. The methodology involved delineating the areal extent of geomorphic and habitat features in 2008, 2012, and 2017, and comparing the mapping using statistical analyses to determine whether changes since implementation of the WUP could be considered significant. KWL made some adjustments to the original mapping methodology to more directly address MQ2.

Findings of the analysis include the following:

- The total area and number of mainstem side channels has increased over the study period.
- The total area of floodplain side channels (wet) has increased from 2008 to 2017, while the total area of floodplain side channels (dry) has declined; the combined area of wet and dry floodplain side channels has remained relatively constant. Differences in the proportion of wet vs. dry floodplain side channels may be due to differences in flows at the time of orthophotography.
- Riffles are the most dominant habitat unit by area; the overall area of riffles has remained relatively constant over the study period.
- Riffles make up nearly 100% of the habitat found within mainstem side channels; this trend has remained constant over the study period.
- The total area and mean areal extent of rapids has decreased over the study period; however, this is believed to be related to interpretive error due to poor orthophoto image quality in the canyon areas.
- Since 2012, the area of pools has increased in the upper reaches (Reach 10 to 14) and decreased in the lower reaches (Reach 2 to Reach 8), which is indicative of downstream sediment transfer initiated through threshold flow events.
- The decrease in total area and number of bar features, and the increase in total area and number of young and mature islands, and mainstem side channels, suggests that the Cheakamus River continues to stabilize over time.
- The increase in the mean areal extent and decrease in mean areal variance of sparsely vegetated bars were found to be statistically significant over the study period which is indicative of consolidation of features and further evidence of channel stabilization.
- Five flow events between 2012 and 2017 that exceeded the 270 m^3/s threshold for mobilization, in combination with the observed loss in area of unvegetated gravel bars, suggest that erosion of gravel material in the lower reaches of the Cheakamus River may have occurred.

Based on the statistical analyses of the geomorphic and habitat mapping, and supported by the findings listed above, CMSMON8 concludes that following implementation of the WUP:

- The total area of natural side channels has increased; and
- The diversity of natural, mainstem side channels as measured by the area of pool, riffle, and rapid habitat units has not significantly changed.

The question of whether access to natural side channel habitat may have changed as a result of the WUP could not be answered by the current study. It is our understanding that this question will be further investigated in CMSMON1b.

2.3 Management Question 3 (MQ3)

Attachment C presents the final report summarizing the MQ3 analysis. Below we present the conclusions from that report.

Based on discussions with BC Hydro, the Management Question can be interpreted as a question related to general tributary inputs downstream of Daisy Lake Dam. “Attenuation” speaks to the degree to which the tributary inputs downstream of the Dam increases the Cheakamus River flow beyond what is released from Daisy Lake.

Using the CMSMON8 Y1 to Y5 data, the following statements can be made which speak to both the general hydrology of lower Cheakamus River, and also the degree to which the tributary inflows attenuate the effects of Daisy Lake dam:

- Average daily tributary inflow over this 5-year period is 16 m^3/s, with a range from 3 m^3/s to 119 m^3/s.
- On average, the tributary inflow results in about a 138% increase in flow between Daisy Lake Dam and WSC 08GA043 (i.e. tributary inflow is about 1.4 times the dam outflows).
- Monthly average tributary inflow ranges from a minimum of 11 m^3/s in February, to a maximum of 22 m^3/s, which occurs in both July and November.
- Tributary inflow is consistently larger during the summer months, as an absolute value.
- However, the largest *relative* increases (i.e., as a percentage of the dam outflow) occur during in fall and winter months, when dam outflows are lowest. During fall and winter the relative inflow downstream of the dam ranges from 95% to 294% as a monthly average (i.e. the tributary inflow varies from equal to almost triple the dam outflow).
- For the more regularly-occurring flows (i.e., those that are equalled or exceeded for more than 50% of the Y1 to Y5 record), the difference between the WSC 08GA043 and Daisy Lake dam outflow is in the range of 10 m^3/s to 13 m^3/s.
- Uncertainties associated with the additional CMSMON8 hydrometric station data mean that it is difficult to accurately assess how much flow is being contributed by specific tributaries (or sub-reaches).

The general hydrology of the lower Cheakamus has been characterized and tributary inputs to the CMSMON8 reach as a whole have been quantified. In addition, the attenuation effect of the tributary inputs has also been assessed and quantified. All of the foregoing has been accomplished *solely based* on BC Hydro and WSC discharge data.

Tributary inflows downstream of the dam have a large impact on the Cheakamus River flow downstream of the dam. Over the CMSMON8 study reach, the average tributary inflow from 2008 to 2012 was about 138% of dam outflow. As represented by the *relative* increase in flow (i.e., %), the attenuating effect of tributary inflow is felt most strongly during fall and winter months. However, absolute tributary inflow is highest during summer months but this is when dam outflow is also higher, so the relative impact of the tributary inflows is less.

The CMSMON8 hydrometric stations located between Daisy Lake Dam and WSC 08GA043 do not appear to provide a great deal of additional value when attempting to answer the Management Question. Attempts to resolve the flow contributions from specific tributaries or tributary sub-reaches using data from these stations results in unrealistic flows (e.g. negative flows) or unrealistic downstream trends in flows (e.g., loss of flow downstream, or reaches with no runoff).

Using the existing WSC 08GA043 station and Daisy Lake Dam outflows, it is possible to quantify tributary inflow to the reach downstream of the Dam as a whole, as this analysis has demonstrated. It is assumed that the additional CMSMON8 hydrometric stations were intended to provide a greater degree of spatial resolution and increase understanding of how the tributary inflows might vary through the reach downstream of the dam. However, there are two main challenges associated with this premise:

1. During much of the year, the total tributary inflow downstream of the dam is 20 m^3/s or less. In rough terms, this would imply that the flow difference to be resolved between the three CMSMON8 stations would be in the order of about 7 m^3/s or less. This is a very high level of precision relative to the expected average uncertainty associated with the rating curves for the stations. In other words, <u>the difference in flow that would need to be measured is on the same order as the associated uncertainty of the measurement</u>. Therefore, this measurement of flow difference appears impractical to attempt to achieve.
2. During peak flow events, water levels rise above the range of existing measurements and therefore in order to calculate a discharge the rating curve was extrapolated. Extrapolation of the rating curve can lead to a large increase in associated uncertainty.

In the case of (1) above, there is little that can be done to address this challenge. In the case of (2), the degree of associated uncertainty can be reduced by obtaining additional high flow measurements to reduce the extrapolation in the event of peak flows, but it is unlikely that extrapolation could be eliminated completely for large events.

Report Submission

This document is a copy of the sealed and signed hard copy original retained on file. The content of the electronically transmitted document can be confirmed by referring to the filed original.

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Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of BC HYDRO for the CMSMON8: Cheakamus River Channel Morphology Monitoring. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

Revision History

Revision #	Date	Status	Revision	Author
0	October 25, 2018	Final	Issued as final.	SMS/CD

OQM CERTIFIED

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Attachment A

CMSMON-8 MQ1 Final Report

Cheakamus Project Water Use Plan

Cheakamus River Channel Morphology Monitoring

Implementation Year 8

Reference: CMSMON-8

Annual Progress Report

Study Period: 2015-2016

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Executive Summary

The Fisheries Technical Committee for the Cheakamus Water Use Plan developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the Consultative Committee, and to better inform the next Water Use Plan. CMSMON8 deals with questions related to channel morphology and tributary flows.

BC Hydro's Terms of Reference for CMSMON8 identify three management questions (MQs), which the Cheakamus River monitoring program is intended to answer. CMSMON8 is a 10-year program, and 2016 is Year 8 of the program. MQ3 was addressed in Year 6, and MQ2 will be addressed in future work (Year 10). This report summarizes the work done in addressing MQ1.

Table E-1, below, summarizes MQ1, its associated Management Hypothesis, and the Year 8 status on addressing it.

Table E-1: MQ1 Summary after Year 8

Management Question	Management Hypotheses	Year 8 (2016) Status
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?	**H_0**: Total area of accessible substrate suitable for salmonid spawning has not changed since implementation of the WUP	• **H_0** was not directly addressed due to a lack of pre-WUP information on suitable spawning habitat[1]. • The revised methodology[1] for addressing MQ1 focused on estimating the discharge threshold above which suitable spawning habitat substrate would be mobile and subject to erosion, and determining the influence of WUP implementation on the threshold. • Two monitoring sites with suitable spawning habitat were identified and selected in Year 7. • Sediment mobility thresholds were predicted using analytical methods based on driving forces (shear stress from river flow) and resisting forces (river bed sediment mixture resistance to movement). The analytical methods were supported by field collection of surface grain size and by BC Hydro's in-house 2-D hydraulic model. • Sediment mobility at the monitoring sites was monitored in Year 7 and Year 8 by using sediment traps to capture mobile sediments from three various flow events. **CMSMON8 concludes that the implementation of the WUP has not resulted in additional erosion of spawning sediments compared with the pre-WUP condition.**
1. Refer to Addendum 2 of Cheakamus Water Use Plan Monitoring Program Terms of Reference for CMSMON8 (BC Hydro, 2015)		

The main finding of MQ1 analysis is that the discharges required to mobilize the river bed and erode spawning habitat occur as part of BC Hydro flood routing operations. BC Hydro has specified that there is no difference in flood routing between pre-WUP and WUP operations. Therefore, the WUP has not changed the occurrence of bed mobility and erosion of spawning sediments when compared to the pre-WUP condition.

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) has been retained by BC Hydro to conduct monitoring work for CMSMON8: Cheakamus River Channel Morphology Monitoring. This monitor arose from the Water Use Plan (WUP) process that initiated in 1996 and resulted in the current WUP, accepted by the Comptroller of Water Rights in 2005. BC Hydro awarded the CMSMON8 project to KWL in August 2013. The project has a 5-year duration (2013 through 2018).

CMSMON8 is intended to answer the following management questions (MQs):

1. *Following implementation of the WUP (Water Use Plan), 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?*
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.*

KWL has addressed MQ3 in a previous report (KWL, 2014). MQ2 will be addressed in the final year of the project. The current report addresses MQ1.

1.1 Water Use Plan

The Cheakamus River Water Use Plan (WUP) was accepted by the Comptroller of Water Rights, and implemented in February 2006. The Cheakamus Consultative Committee (CC) agreed on six fundamental objectives for the Cheakamus Water Use Plan (in no particular order):

1. **Power:** Maximise economic returns from power generated at Cheakamus Generating System;
2. **First Nations:** Protect integrity of Squamish First Nation's heritage sites and cultural values;
3. **Recreation:** Maximise physical conditions for recreation;
4. **Flooding:** Minimise adverse effects of flood events through operation of the Cheakamus Generating system;
5. **Fish:** Maximise wild fish populations; and
6. **Aquatic Ecosystem:** Maximise area and integrity of the aquatic and riparian ecosystem.

The Fisheries Technical Committee developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the CC, and to better inform the next WUP. The CC recognised that it is essential to address critical scientific uncertainties that can affect future decision making, and to comprehensively assess the response of the system to changes in the operation of the Cheakamus Generating System. CMSMON8 is one of 10[1] monitors related to the WUP.

[1] Monitors 1 through 9, with 1a and 1b considered separately.

1.2 Project Location and Description

The Cheakamus generating system was completed in 1957 (BC Hydro, 2005). Daisy Lake Dam impounds the Cheakamus River creating Daisy Lake Reservoir, located about 30 km north of Squamish, adjacent to Highway 99. From Daisy Lake Reservoir, some of the water is released via the dam to the lower Cheakamus River while some is diverted, via a tunnel, to the Cheakamus Generating Station. The water diverted for power is not returned to the lower Cheakamus River since the Cheakamus Generating Station discharges to the Squamish River. Daisy Lake Reservoir can store about 55 million m^3 of water: about 3.5% of average annual inflow (BC Hydro, 2005). The maximum capacity of the generating system is 65 m^3/s.

Cheakamus River is a 'mixed-regime' watershed, exhibiting characteristics of both rain- and snow melt-dominated streamflow regimes. The annual hydrograph contains a summer snowmelt freshet peak, but also peak flows in fall and winter from intense rainstorms combined with snowmelt (BC Hydro, 2005). The fall and winter peak flows are characteristically larger than the freshet peak flows. Water Survey of Canada operates a hydrometric station on lower Cheakamus River about 5 km upstream of the confluence with Squamish River (WSC 08GA043).

The Cheakamus River provides critical habitat for many anadromous and resident fish species. A list of fish species present within the Cheakamus River is shown in Table 1. Results of a search through BC's Fisheries Information Summary System for the Cheakamus River are presented in Table 1.

Table 1: Anadromous and Resident Fish Species of the Cheakamus River*.

Anadromous Species	Resident Species
Coho salmon (*Oncorhynchus kisutch*)	Rainbow trout (*O.mykiss*)
Chum salmon (*O. keta*)	Cutthroat trout (*O.clarkia*)
Chinook salmon (*O.tshawytscha*)	Bull trout (*Salvelinus confluentus*)
Pink salmon (*O.gorbuscha*)	Dolly varden (*S. malma*)
Steelhead trout (*O.mykiss*)	Brook trout (*S. fontinalis*)
	Threespine stickleback (*Gasterosteus aculeatus*)
	Coastrange sculpin (*Cottus aleuticus*)

* Results of a search within BC's Fisheries Information Summary System (FISS) for the Cheakamus River (2016)

1.3 Project Design

During the course of background information review and consultation with other Cheakamus River monitors it became evident that there is limited pre-WUP data available to support an approach to answer MQ1 as originally stated. In addition, consultants in charge of other Cheakamus River monitors were of the opinion that spawning habitat in the lower Cheakamus River is not limiting.

In response to these issues, BC Hydro proposed a revision to MQ1:

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

The revised MQ-1 proposes to evaluate whether there has been degradation in spawning habitat via erosion following implementation of the WUP. In the absence of physical data on spawning habitat conditions during the pre-WUP period, this assessment relies on the available record of flow releases from Daisy Lake dam to represent pre-WUP vs. WUP conditions.

In order to evaluate the revised MQ1, we have developed a relation between discharge and sediment mobility at specific monitoring sites where fish spawning is known to occur. Sediment mobility is assessed by determining the shear stress required to initiate bed sediment movement (i.e. critical threshold), whereupon erosion of spawning habitat may occur. The frequency with which critical threshold shear stresses are experienced under pre-WUP vs. post-WUP conditions is then compared.

The main tasks in the MQ1 analysis include:

- Determining the critical shear stress required to initiate sediment mobility at specific monitoring locations within the Cheakamus River.
- Estimating the shear stress on the river bed at specific monitoring locations within the Cheakamus River for different flows.
- Validating predictions of mobility by monitoring sediment mobility following a variety of flows.
- Providing a comparison between the WUP operational discharges in relation to the pre-WUP operational discharges.

A major assumption in the MQ1 analysis is that when critical shear stresses are reached the mobilization and erosion of spawning sized sediment occurs, and that it results in the degradation of spawning habitat. Studies have shown that intense and frequent sediment mobilization events can limit salmonid production (Lisle, 1989). On the other hand, mobilization of spawning substrate by flood flows is necessary for maintaining long-term productivity of spawning habitat (Lapointe et al, 2000).

Defining an optimal degree of physical disturbance to spawning substrate is beyond the scope of this project. However, observations made during this field study, and a related discussion on physical disturbance to spawning substrate is provided in Section 4.

1.4 Project Team

The KWL project team and roles for this study are as follows:

- Erica Ellis, M.Sc, P.Geo – Project Manager,
- David Sellars, M.Sc., P.Eng. – Technical Reviewer,
- Chad Davey, M.Sc., R.P.Bio – Project Fluvial Geomorphologist,
- Amir Taleghani, M.Eng., EIT – Project Engineer, and
- Shayna Scott, EIT – Hydraulic Modeller.

The following BC Hydro staff provided input to the CMSMON8 MQ1 analysis:

- Mark Sherrington and Darin Nishi – BC Hydro Contract Managers,
- Alexis Hall and Brent Wilson – BC Hydro - Fish and Aquatic Issues (Subject Matter Experts),
- Faizul Yusuf – BC Hydro Hydraulic Modelling Lead and Reviewer,
- Colin Rombough – BC Hydro Environmental Field Services,
- Wuben Luo – BC Hydro Operations, and
- James McNaughten – BC Hydro Operations.

We would like to acknowledge the Cheakamus Centre (Jason Fullerton, Steven Chappell) for allowing us to locate a field site within their property.

Finally, both Caroline Melville (InStream Fisheries Research Inc.) and Josh Korman (Ecometric Research) provided background information and useful input during MQ1-related discussions.

2. Methodology

This section describes the monitoring sites and the methods (desktop and field) used in addressing the revised MQ1.

2.1 Monitoring Sites

KWL conducted a desktop review to identify potential sites suitable for evaluating degradation to spawning habitat in the Cheakamus River. The desktop review was based on data provided by BC Hydro, including:

- 2012 orthophotos; and
- location of 2007 and 2011 channel bathymetry data used in the development of the existing BC Hydro Cheakamus River 2-D hydraulic model.

Site selection criteria included:

- Suitability for spawning;
- Proximity to surveyed channel bathymetry; and
- Logistical considerations such as site access.

A field visit was conducted on September 15, 2015 by Erica Ellis, Chad Davey and Amir Taleghani (all KWL staff) to review potential monitoring sites and finalize site selection. The discharge at the time of the field visit was about 36 m^3/s based on real-time provisional data from WSC 08GA043.

To the authors knowledge, preferred fish spawning substrate sizes have not been developed for the Cheakamus River. Based on data from Kondolf and Wolman (1993) a range of sediment size between 5 mm to 80 mm was considered to be suitable for spawning sediment to cover all anadromous and resident salmons and char that are present in the Cheakamus River.

During the course of the field visit many spawning salmon (pink salmon) were observed both in the wetted channel along the gravel bar edges, as well as carcasses. The presence of active spawners was used as confirmation of the suitability of potential monitoring sites, in addition to the observed grain sizes at the sites in comparison with documented ranges of spawning gravel sizes (5 to 80 mm).

Following review of a number of potential locations, two sites were selected for monitoring:

1. Pedestrian Bridge; and
2. Eagle Point (Cheakamus Centre).

The location of the sites is shown in Figure 2-1. Site layout is shown in Figure 2-2, including proximity to the 2011 surveyed channel bathymetry.

2.2 Determination of Critical Shear Stress

The Shields Criterion (Equation 1) was used to determine the critical shear stress, or force exerted by flowing water, which would be required to initiate sediment mobility. By specifying a dimensionless critical shear stress (τ_{*c}), Equation 1 can be used to determine the shear stress threshold (τ_c, Pa) for particles of a specific size:

$$\tau_c = \tau_{*_c}\, g\, (\rho_s - \rho) D$$

Equation 1

where *g* is acceleration due to gravity (9.8 m/s^2), ρ_s is the density of the sediment particles (2650 kg/m^3), ρ is the density of water (1000 kg/m^3) and *D* is the particle nominal diameter (m) (Buffington, 1999).

Application of the Shields Criterion to a natural river requires that one single grain size, *D*, be used to represent the river bed material which is a mixture of grain sizes in typical gravel bed rivers such as the Cheakamus River. Selecting a single grain size to represent natural river bed mixtures can be problematic given the relatively wide range of sediment sizes that are present on a stream bed. A common approach to assessing sediment mobility of the entire river bed mixture involves substituting the median size of the river bed surface grain size distribution (D_{50}) in place of the individual particle nominal diameter (*D*) in Equation 1. With this modification, Equation 1 can be used to estimate the threshold shear stress required for mobility of the river bed mixture. The use of D_{50} reflects the hiding and protrusion of individual particles within a river bed mixture.

The threshold for mobility of natural river beds is a continuum rather than an exact threshold. Sediment transport theory identifies different stages of transport ranging from partial transport, where typically finer sediments are mobile before the rest of the bed, to mobility of the entire river bed mixture.

The focus of this study is the initiation of the mobility of the entire river bed. As mentioned in Section 1.3, a major assumption of this study is that when critical shear stresses are reached the mobilization and erosion of spawning sized sediment occurs. It is assumed that above this threshold, it is reasonable to assume that mobility may result in degradation of spawning habitat.

Church (2006) cites a τ_{*c} value of 0.045 for the entrainment of the "usual mixtures of sediments on stream beds" when D_{50} is used to represent the bed mixture. Knighton (1998) indicates a τ_{*c} value range of 0.03 to 0.06. Petit et al (2015) reviewed 26 studies of critical shear stress in gravel-bed rivers and generally validates a τ_{*c} range of 0.03 to 0.06, and identifies 0.045 as the most frequently used value.

At the two monitoring sites, we estimated the critical shear stress threshold (τ_c) based on surface grain size information and the τ_{*c} values presented above.

2.3 Estimation of Shear Stress at Different Discharges

As the information available to characterize the pre-WUP vs. UP environments for CMSMON8 is discharge, we require a method to estimate shear stress from discharge. The primary approach was analytical, using a BC Hydro hydraulic model. The analytical approach was validated against field-based methods. Both approaches are presented below.

Analytical Derivation of Shear Stress

BC Hydro's existing Telemac2D hydraulic model of the Cheakamus River was used to estimate the shear stress exerted on the river bed at varying discharges. The model covers a reach extending from approximately 3 km upstream of the Culliton Creek confluence downstream to beyond the confluence of Cheakamus and Squamish Rivers. Details of the model development, calibration, and appropriate usage are described in an internal BC Hydro report (BC Hydro, 2012).

The model was run with a series of discharges to represent flows up to a nominal 'bankfull' discharge. Reach-average shear stress (τ, Pa), the average shear stress applied to the wetted channel at a cross-section, was calculated from the model results using :

$$Reach\ Average\ Shear\ Stress = \tau = \gamma \times R \times S$$

Equation 2

where γ is the unit weight of water (9,810 N/m^3), R is the hydraulic radius (m), and S is the slope of the hydraulic energy grade line (m/m). By running the model for a number of different discharges, the variation of shear stress with discharge was estimated.

The hydraulic radius describes the hydraulics of a reach at specific channel cross-section, and is calculated as the cross-sectional wetted area (m^2) divided by the cross-sectional wetted perimeter (m). Hydraulic radius is not a direct output of the Telemac2D model. For purposes of this analysis, it was assumed that the Cheakamus River can be approximated as a wide channel, with the channel top width being much greater than the depth. This assumption allows hydraulic radius to be approximated by mean water depth, which is readily available from the model results.

Model simulations, results processing, and assumptions were conducted under the supervision and technical review of Specialist Engineer Mr. Faizul Yusuf, P.Eng. of BC Hydro's Hydrotechnical Department.

Field-based Derivation of Shear Stress

A field-based method for estimating shear stress for a given flow event was implemented using bedload (sediment) traps and surface sediment sampling. Komar (1996) presents the following equation to estimate the shear stress (τ_o, Pa) required to mobilize the larger material captured in a sediment trap (defined here as the D90):

$$\tau_o = 0.045 g(\rho_s - \rho) D_{50}^{0.6} D_{90}^{0.4}$$

Equation 3

where ρ_s is the density of sediment (2,650 kg/m^3), ρ is the density of water (1,000 kg/m^3), D_{50} is the diameter of the median sediment particles of the bed immediately surrounding the trap (m), and D_{90} is the 90th percentile sized particles found within the trap (m). The constant, 0.045, is the value of the dimensionless critical shear stress (τ_{*c}).

2.4 Field Data Collection

This section describes the field methods employed to collect the necessary data for computing critical shear stress and observed shear stress at each monitoring site.

Surface Grain Size Characterization

The surface sediments of suitable spawning habitat and the substrate on the emergent bar top were sampled during multiple field visits (i.e. prior to and following flood events captured in sediment traps).

The Wolman (1954) pebble count technique was conducted at each sediment trap for both monitoring sites. This technique involves laying out a tape measure along the area to be characterized and measuring individual sediment particles at a specified interval along the tape, using a gravelometer. The sample interval of the pebble count technique was at least twice the diameter of the largest visible particle in the sampling area to avoid double counting of large particles (Bunte and Abt, 2001).

The generally coarser material on the bar top was used to represent the assumed substrate distribution in the wetted channel at each monitoring site, and is the basis for determining the critical threshold for erosion of substrate (including spawning areas) for the entire cross section.

Sediment Traps

Sediment traps were installed on September 16, 2015 at each of the monitoring sites to capture sediments mobilized during flood events. During the fall/winter storm season, three separate flood events of different magnitude were experienced, and the traps were emptied following each of these events. After being emptied, a new trap was installed to capture the next flood event.

Nested, orange 2.5-gallon plastic buckets with drainage holes were used as sediment traps. Installation involved excavating a hole (Photo 1), placing one bucket within the hole such that a second bucket, nested inside the first, would be positioned with the lip flush with the river bed. Afterwards the excavated sediment was backfilled around the outside of the installed buckets (Photo 2). Using nested buckets allowed quick retrieval and reinstallation of a new trap without having to re-excavate a new hole. The contents of each sediment trap were sent to a laboratory for sieve analysis. Approximate sediment trap locations are illustrated on Figure 2-2.

Photo 1: Excavating sediment for sediment trap installation.

Photo 2: Trap is installed with lip of bucket flush with river bed.

The sediment trap installation and site visit dates are presented in Table 2 for the Eagle Point site and in Table 3 for the Pedestrian Bridge site. The tables also present the peak discharge which occurred between site visits. Note that discharges at the Eagle Point site are assumed to be equivalent to discharges recorded at WSC 08GA043 due to the proximity of the site to the hydrometric station (see Figure 2-2). The Pedestrian Bridge site discharges are approximated using the releases from Daisy Lake dam: it is acknowledged that this approach neglects the inputs from tributary areas downstream of the dam (such as Rubble Creek) and therefore the flows should be considered to be lower-bound estimates.

Table 2: Eagle Point Monitoring Site Sediment Trap Visits

Site Visit Date	Peak Discharge[1] Preceding Site Visit (Magnitude and Date)	Activity
September 16, 2015	N/A[2]	Initial sediment trap installation
September 24, 2015	72 m^3/s (September 20, 2015)	Collected captured sediment and replaced sediment traps
December 15, 2015	166 m^3/s (December 4, 2015)	Collected captured sediment and replaced sediment traps
February 2, 2016	267 m^3/s (January 28, 2016)	Collected captured sediment and removed sediment traps.

Notes:
1. Discharge at the Eagle Point monitoring site is represented by real-time data from the nearby WSC station 08GA043 (Cheakamus River near Brackendale). Real-time data are provisional and subject to change.
2. Traps are empty at installation; therefore a peak preceding discharge is not relevant.

Table 3: Pedestrian Bridge Monitoring Site Sediment Trap Visits

Site Visit Date	Peak Discharge[1] Preceding Site Visit (Magnitude and Date)	Activity
September 15, 2015	N/A[2]	Initial sediment trap installation
September 24, 2015	28 m^3/s (September 22, 2015)	Collected captured sediment and replaced sediment traps
December 15, 2015	107 m^3/s (December 4, 2015)	Collected captured sediment and replaced sediment traps
June 17, 2016	148 m^3/s (January 29, 2016)	Collected captured sediment and removed sediment traps.

Notes:
1. Discharge at the Pedestrian Bridge monitoring site is represented by releases from Daisy Lake Dam into the Cheakamus River. Recorded discharges for tributaries between Daisy Lake Dam and the Pedestrian Bridge monitoring site are not available.
2. A peak preceding discharge is not applicable to the initial sediment trap installation visit.

2.5 WUP vs. Pre-WUP Discharge Comparison

As outlined in Section 1.3, to address the revised MQ1 it is necessary to compare the WUP and pre-WUP flow regimes. However, records of pre-WUP and WUP discharges cannot be directly compared because of varying climatic conditions impacting inflow into the Daisy Lake Dam reservoir. Instead, pre-WUP discharges were simulated for the period of recorded WUP discharges based on the known pre-WUP operational rules and inflow records (data provided by BC Hydro). This allows for the comparison of recorded WUP discharges and simulated pre-WUP discharges for the same inflow period.

Pre-WUP Discharges: Interim Flow Agreement

Pre-WUP discharges from Daisy Lake Dam into the Cheakamus River were defined by an Interim Flow Agreement (IFA), which was in place from 1996 to 2006 when the WUP operations started.

The IFA required that average daily discharges into the Cheakamus River to be the maximum of:

- 5 m^3/s, or
- 45% of the average of the average of the previous 7 days of daily average inflows into the reservoir (acceptable range of 37% to 52%), or
- a discharge deemed necessary for flood routing operations.

It is understood that the IFA did not affect flood routing operations and does not specify a maximum discharge into the Cheakamus River.

WUP Discharges

The WUP requires average daily discharges into the Cheakamus River as follows:

- Between November 1 and December 31: a minimum release of 3 m^3/s, or more as required to achieve a discharge of 15 m^3/s at the downstream WSC Cheakamus River near Brackendale hydrometric station 08GA043;
- Between January 1 and March 31: a minimum release of 5 m^3/s, or more as required to achieve a discharge of 15 m^3/s at WSC 08GA043;
- Between April 1 and June 30: a minimum release of 7 m^3/s, or more as required to achieve a minimum discharge of 20 m^3/s at WSC 08GA043;
- Between July 1 and August 15: a minimum release of 7 m^3/s, or more as required to achieve a minimum discharge of 38 m^3/s at WSC 08GA043;
- Between August 16 and August 31: a minimum release of 7 m^3/s, or more as required to achieve a minimum discharge of 20 m^3/s at WSC 08GA043, unless otherwise directed by the Comptroller of Water Rights to increase flows to 38 m^3/s for the benefit of recreation; and
- Between September 1 and October 31: a minimum release of 7 m^3/s, or more as required to achieve a minimum discharge of 20 m^3/s at WSC 08GA043.

With regards to maximum discharges for flood routing, the WUP specifies that the reservoir level will be limited to elevation 373.5 m or less from October 1 to December 31 to provide storage to assist with managing high inflow events. The WUP does not specify a maximum discharge and specifies that emergency / dam safety management activities take precedence over the WUP.

Flood Routing

The WUP states that no changes are expected to the level of flood management provided, and discussions with BC Hydro staff indicate that flood routing approaches did not change significantly between the IFA and WUP.

BC Hydro advises that published rules for flood routing discharges into the Cheakamus River do not exist, and that it is not possible to accurately simulate flood routing due to the real-time nature of the decisions being made by facility operations staff based on information available at the time (e.g. forecasts).

We assume that flood routing discharges would be generally the same between IFA and WUP operations under the same inflow conditions. To estimate a threshold inflow above which flood routing may commence we used the WUP flow release rules presented above to estimate the minimum discharges that would be required under the WUP from 2006 to 2015. This was compared to the actual recorded WUP discharges in the same period. It is estimated that flood routing may commence when reservoir inflows exceed 50 m^3/s.

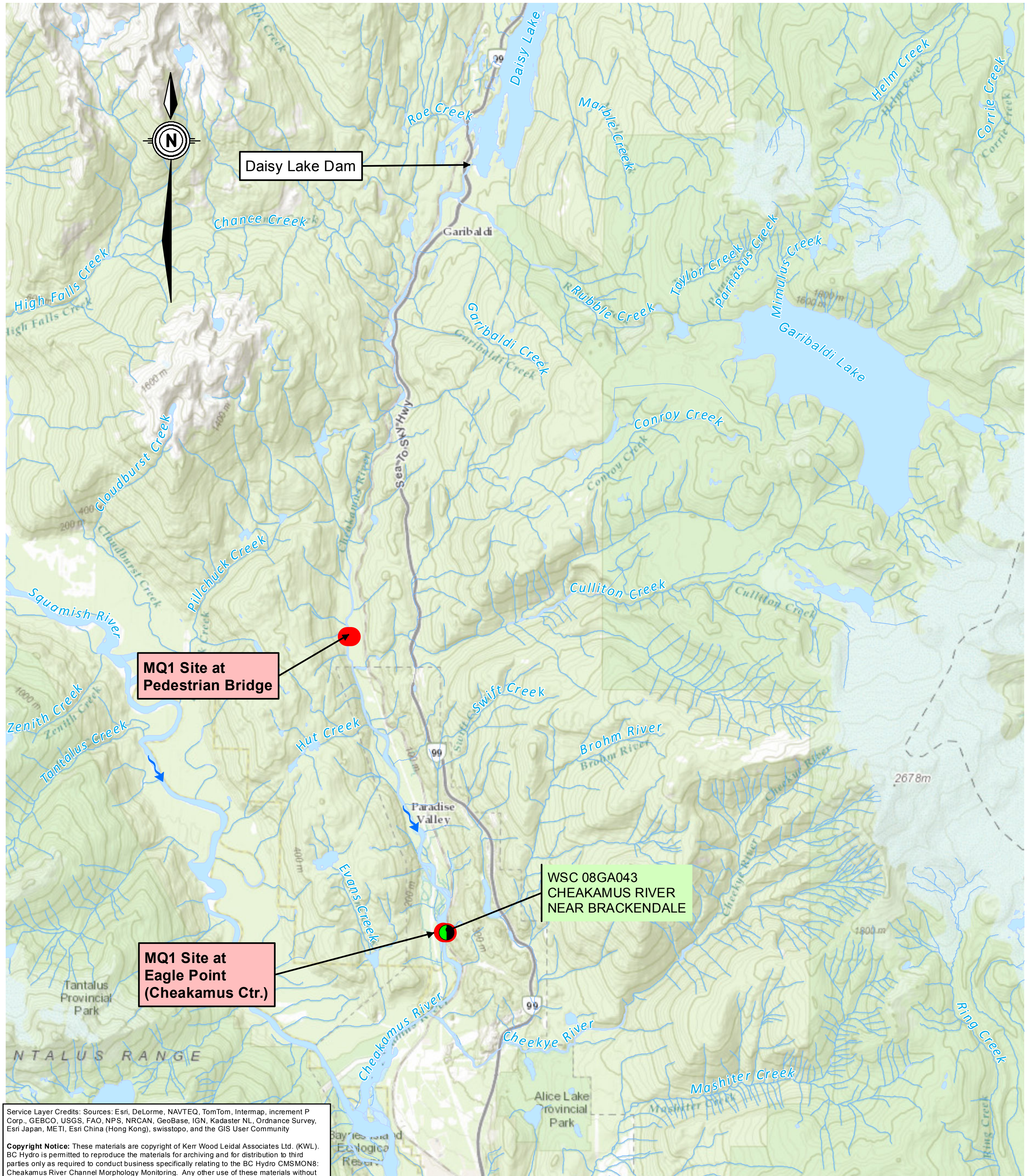
Although not necessarily accurate, this estimation creates an upper bound for comparing IFA and WUP operations above which it is assumed that discharges into the Cheakamus River are governed by flood routing and have not changed significantly from IFA to WUP periods.

Simulating IFA Operation and Comparing to WUP

Based on the above discussed IFA rules and flood routing estimation, the reservoir inflow record for the WUP period of 2006 to 2015 was used to simulate discharges into the Cheakamus River under IFA operation. The simulated IFA discharges were compared against recorded discharges representing WUP operation. The IFA rules were applied when inflows were below 50 m^3/s; actual recorded discharges were substituted when the inflows were above 50 m^3/s. This assumes that there is not a difference in discharge into the Cheakamus River when reservoir inflows exceed 50 m^3/s.

This comparison of the simulated IFA discharges and the actual recorded WUP discharges was used in reviewing the occurrence of sediment mobility and commenting on whether WUP operations have impacted sediment mobility in comparison to IFA operations.

Appendix A presents figures comparing the WUP discharges and the simulated IFA discharges for the WUP discharge period of 2006 to 2015.



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BC Hydro
CMSMON8: Cheakamus River Channel Morphology Monitoring

Project No.	Date
478-164	November 2015

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MQ1 Field Site Locations

Figure 2-1

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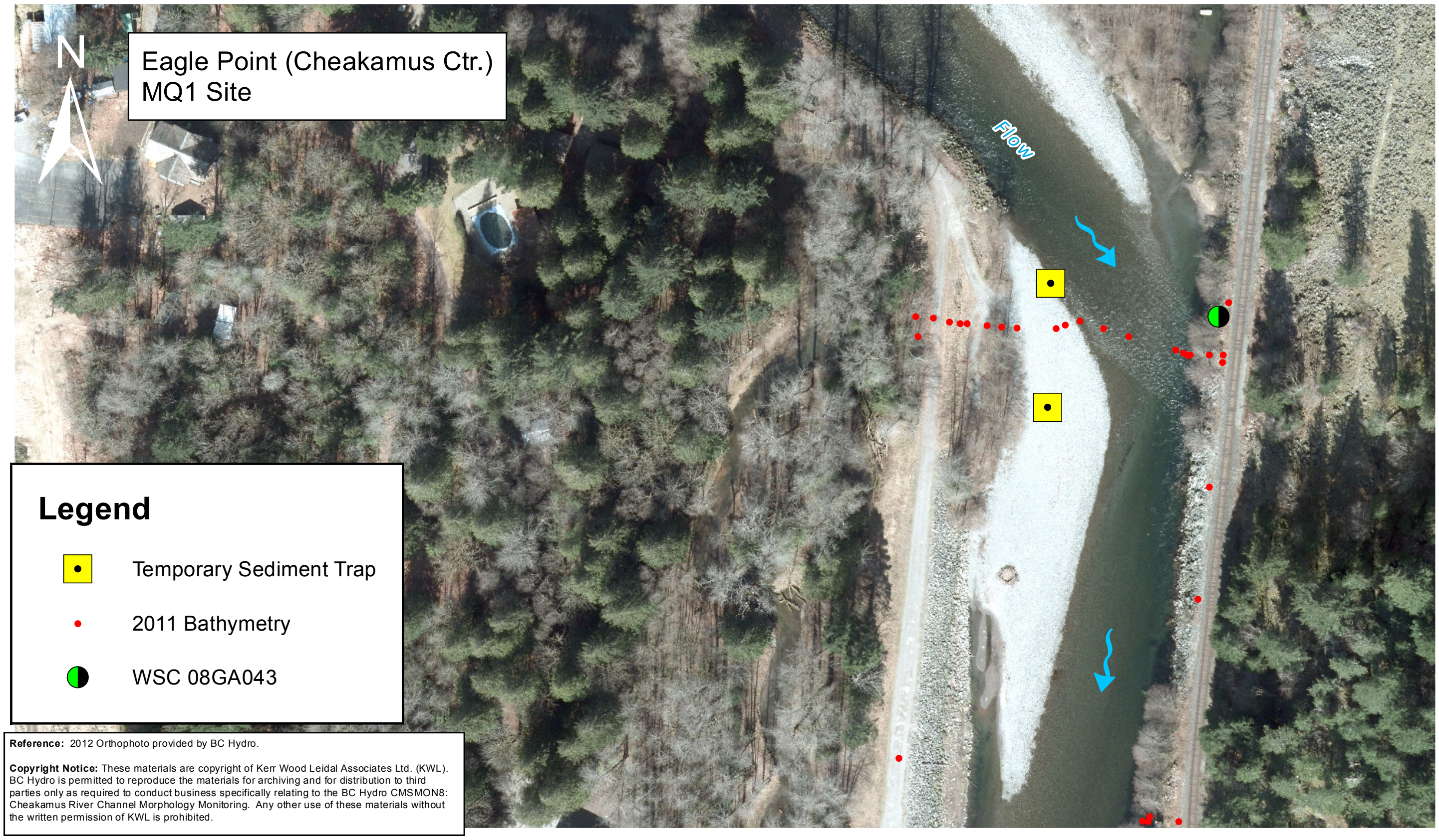

Reference: 2012 Orthophoto provided by BC Hydro.

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CMSMON8: Cheakamus River Channel Morphology Monitoring

Project No. 478-164

Date November 2015

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MQ1 Field Site Layout

Figure 2-2

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3. Results

This section presents results of applying methods from Section 2 to address the revised MQ1.

3.1 Surface Grain Size

Table 4 presents the median grain sizes (D_{50}) of the spawning habitat sediments and the gravel bar top sampled at the two monitoring sites over the study period. For sites and features where multiple samples were collected over the field period, the average D_{50} was used in the evaluation of critical shear stress.

Table 4: Median Grain Size (D_{50}) of Surface Grain Size at Monitoring Sites

Sample Date	Eagle Point		Pedestrian Bridge	
	Spawning Gravels Only (mm)	Gravel Bar Top (mm)	Spawning Gravels Only (mm)	Gravel Bar Top (mm)
Sep. 15, 2015	45	60	36	103
Dec. 15, 2015	26	N/A[1]	N/A[1]	N/A[1]
Feb. 2, 2016	45	51	N/A[1]	N/A[1]
Jun. 17, 2016	N/A[1]	N/A[1]	43	N/A[1]
Average	**39**	**56**	**40**	**103**

Notes:
1. Grain size distribution of this feature not sampled at this location on this date.

As previously mentioned, the spawning habitats were identified by professional judgement and by observing spawning during initial site visits in September 2015. The grain size distributions of the spawning habitat identified at each site fit well into the suitable spawning habitat sediment size range of 5 mm to 80 mm identified in Kondolf and Wolman (1993), validating the size range and the site selections.

The top of the gravel bars at each site is coarser than the spawning habitat, but is still partially in the range for suitable spawning habitat. The use of the grain size distributions from the top of the gravel bars is discussed in the following section.

3.2 Evaluation of Critical Shear Stress Thresholds

Table 5 presents the critical shear stresses required for mobilization of sediment that would represent a potential erosion of spawning sediment. The critical shear stress required to mobilize the sediment mixture at each site is calculated based on Equation 1, and using the gravel bar top D_{50} (Table 4). The gravel bar top D_{50} is used because it is assumed to be more representative of the entire sediment mixture median grain size than the spawning habitat D_{50} which is typically finer. This is a typical approach in mobility analysis as it is often not feasible to determine the median grain size of the entire sediment mixture of the channel. As discussed in Section 2.2, critical shear stresses have been developed using a τ_{*c} range of 0.03 (lower bound) to 0.06 (upper bound), with a general recommended value of 0.045. The recommended value for critical shear stresses required for erosion of spawning substrate are bolded in Table 5.

Table 5: Critical Shear Stress Required for Potential Erosion of Spawning Sediment

Site	Average D_{50} (mm)	Critical Shear Stress Threshold (Pa)		
		$\tau_{*c} = 0.03$	$\tau_{*c} = 0.045$	$\tau_{*c} = 0.06$
Eagle Point	56	28	**42**	56
Pedestrian Bridge	103	52	**77**	103

3.3 Shear Stress and Discharge Thresholds

Reach Average Shear Stress

The BC Hydro Telemac2D hydraulic model results were used to relate discharge and shear stress. The estimated reach-average shear stress, τ, was computed for various discharges using Equation 2, for each monitoring site. The results are provided in Table 6 below.

Table 6: Estimated Shear Stresses at Various Discharges For Each Monitoring Site.

Discharge at Monitoring Site (m^3/s)	Reach-Average Shear Stress (Pa)	
	Eagle Point	Pedestrian Bridge
50	9	44
100	18	61
150	28	75
200	36	85
250	40	87
300	45	88
350	50	91
400	54	91
450	60	90

Site-specific discharge thresholds for sediment mobility were developed by comparing the critical shear stress needed to mobilize and potentially erode spawning substrate (Table 5). The expected reach-average shear stress calculated at the two monitoring sites for varying discharges is shown in Table 6. Table 7 shows the discharge at which erosion of spawning sediment potentially occurs.

Table 7: Site Specific Discharge Thresholds For Potential Erosion of Spawning Sediments

Monitoring Site	Discharge Threshold (m^3/s)		
	Lower Bound ($\tau_{*c} = 0.03$)	Recommended Value ($\tau_{*c} = 0.045$)	Upper Bound ($\tau_{*c} = 0.06$)
Eagle Point	150	**270**	417
Pedestrian Bridge	74	**160**	>450[1]

Notes:
1. Upper bound of mobility discharge threshold not available at Pedestrian Bridge site because the associated shear stress value (103 Pa) exceeds the maximum applied shear stress calculated at the Pedestrian Bridge using the hydraulic modelling data.

Field-Based Shear Stress Estimates

As described in Section 3, sediment traps were installed to observe sediment mobility and validate the predicted discharge thresholds established above (Table 7). Sediment traps at each monitoring site were visited and emptied after three discharge events occurring in September 2015, December 2015, and January 2016 (Table 2 and Table 3).

Equation 3 was used compute shear stress estimates based on the sediment trap contents for each discharge event that was captured at the Eagle Point and Pedestrian Bridge sites. The results are presented in Table 8 (Eagle Point) and Table 9 (Pedestrian Bridge).

Table 8: Estimated Shear Stress from Eagle Point Sediment Traps

Discharge Event	Peak Discharge (m^3/s)	Trap At Spawning Site			Trap At Bar Top		
		Trap D_{50} (mm)	Trap D_{90} (mm)	Shear Stress[1], τ_o (Pa)	Trap D_{50} (mm)	Trap D_{90} (mm)	Shear Stress[1], τ_o (Pa)
Sep. 2015	71.6	4.2	31	26	N/A[2]	N/A[2]	N/A[2]
Dec. 2015	166	1.4	63	34	2.2	160	62
Jan. 2016	267	3.8	160	49	1.3	21	28

Notes:
1. Shear stress estimated using Equation 3.
2. Trap contained only a trace of sand following Sep. 2015 flood event.

The following points may be made with respect to the Eagle Point trap data:

- The smallest discharge event (Sep. 2016) filled the trap at the spawning site but left only a trace amount of sand in the bar top sediment trap. This suggests that the discharge barely overtopped the bar.
- The largest discharge event (Jan. 2016) filled and buried both sediment traps at Eagle Point under a ~30 cm depth of gravel-sized material (Photos 3 and 4).
- The grain size distribution of the bar top trap contents is finer for the larger discharge event (i.e. contrast the D_{50} and D_{90} values for the two events). This is somewhat counterintuitive, but it is assumed that the sediment trap was filled on the rising limb of the event and thus the trap contents may not represent the bedload distribution during the peak itself.

Photo 3: Sediment trap in bar top at Eagle Point also buried under ~30 cm of sediment following Jan. 2016 discharge event.

Table 9: Estimated Shear Stress from Pedestrian Bridge Sediment Trap

Discharge Event	Peak Discharge (m^3/s)	Trap at Spawning Site			Trap at Bar Top		
		Trap D_{50} (mm)	Trap D_{90} (mm)	Shear Stress[1], τ_o (Pa)	Trap D_{50} (mm)	Trap D_{90} (mm)	Shear Stress[1], τ_o (Pa)
Sep. 2015	28	0	0	0.0	N/A[2]	N/A[2]	N/A[2]
Dec. 2015	107	21.12	54.52	32.7	130	170	91.7
Jan. 2016	148	0.86	72.96	36.8	N/A[2]	N/A[2]	N/A[2]

Notes:
1. Shear stress estimated using Equation 3.
2. Trap was lost or removed.

Sediment trap results are similar for the Pedestrian Bridge site, although the bar top sediment trap was lost or removed intentionally twice no trap data could be collected for the Sep. 2015 and Jan. 2016 discharge events.

Estimated shear stress thresholds for mobility are presented with the estimated shear stresses from the sediment traps in Figure 3-1 (Eagle Point) and Figure 3-2 (Pedestrian Bridge). It is important to note that shear stresses inferred from sediment trap data is strongly influenced by its relative position in the channel cross-section, whereas is the shear stress derived from the hydraulic model is an average across the entire cross-section or reach. Thus, when comparing shear stress inferred from sediment traps to a reach-averaged shear stress it is the general trend across several discharge events that is of most interest rather than a comparison of any single event.

The following summary points may be made with respect to the Eagle Point shear stress results:

- The reach-averaged shear stresses derived from the hydraulic model data show a general increase in shear stress with discharge, and the trap data from the spawning location show the same general trend.
- The spawning sediment trap shear stresses are similar to, but higher, than the reach-averaged shear stress estimates for similar discharges event magnitudes. The two larger discharge events show closer agreement between the spawning trap shear stresses and the hydraulic model reach-averaged shear stress.
- The bar top sediment trap shear stresses are highly variable with discharge. As mentioned before, the peak of the Jan. 2016 event was likely not captured by the bar top trap as it appears to have filled with finer grained material before the peak in discharge was reached.
- The thresholds for mobility predicted using Equation 1 appear to be validated by the trap data, although some sediment is mobile even at shear stresses below the lower bound.

The following summary points may be made with respect to the Pedestrian Bridge shear stress results:

- The reach-averaged shear stresses derived from the hydraulic model data show a general increase in shear stress with discharges up to approximately 200 m^3/s. At discharges exceeding 200 m^3/s reach-averaged shear stresses appears to reach a maximum of 90 Pa. This appears to be a result of a reduction in energy slope at discharges above 200 m^3/s.
- The inferred shear stress from the sediment trap from the spawning location plots below the critical shear stress lower bound, but seems to follow the same general trend as the reach-averaged shear stress.
- Only one event was captured for the bar top sediment trap and its shear stress plots significantly higher that the reach averaged shears stress of the same event magnitude.

3.4 WUP vs. Pre-WUP Discharge Comparison Results

As discussed in Section 2.5, flood routing is assumed to commence when inflows to the reservoir exceed 50 m^3/s. Flood routing operations take precedence over the WUP, and it is understood that flood routing methods have not changed from pre-WUP to WUP conditions based on discussion with BC Hydro staff. As such, the range of discharges that would be affected by WUP vs. Pre-WUP operations is 50 m^3/s and below. The results presented in Figure 3-3 and Figure 3-4 suggest that flows associated with mobility of spawning material would be well in excess of 50 m3/s.

Figure 3-3 and Figure 3-4 present the simulated Pre-WUP and WUP flows with the estimated discharge thresholds for mobility, for the Eagle Point and Pedestrian Bridge sites, respectively. As indicated, in these figures mobility is predicted to have occurred roughly:

- 8 times in 10 years at Eagle Point, and
- 9 times in 10 years at the Pedestrian Bridge site.

These events tend to be the largest flow of the year in a given year

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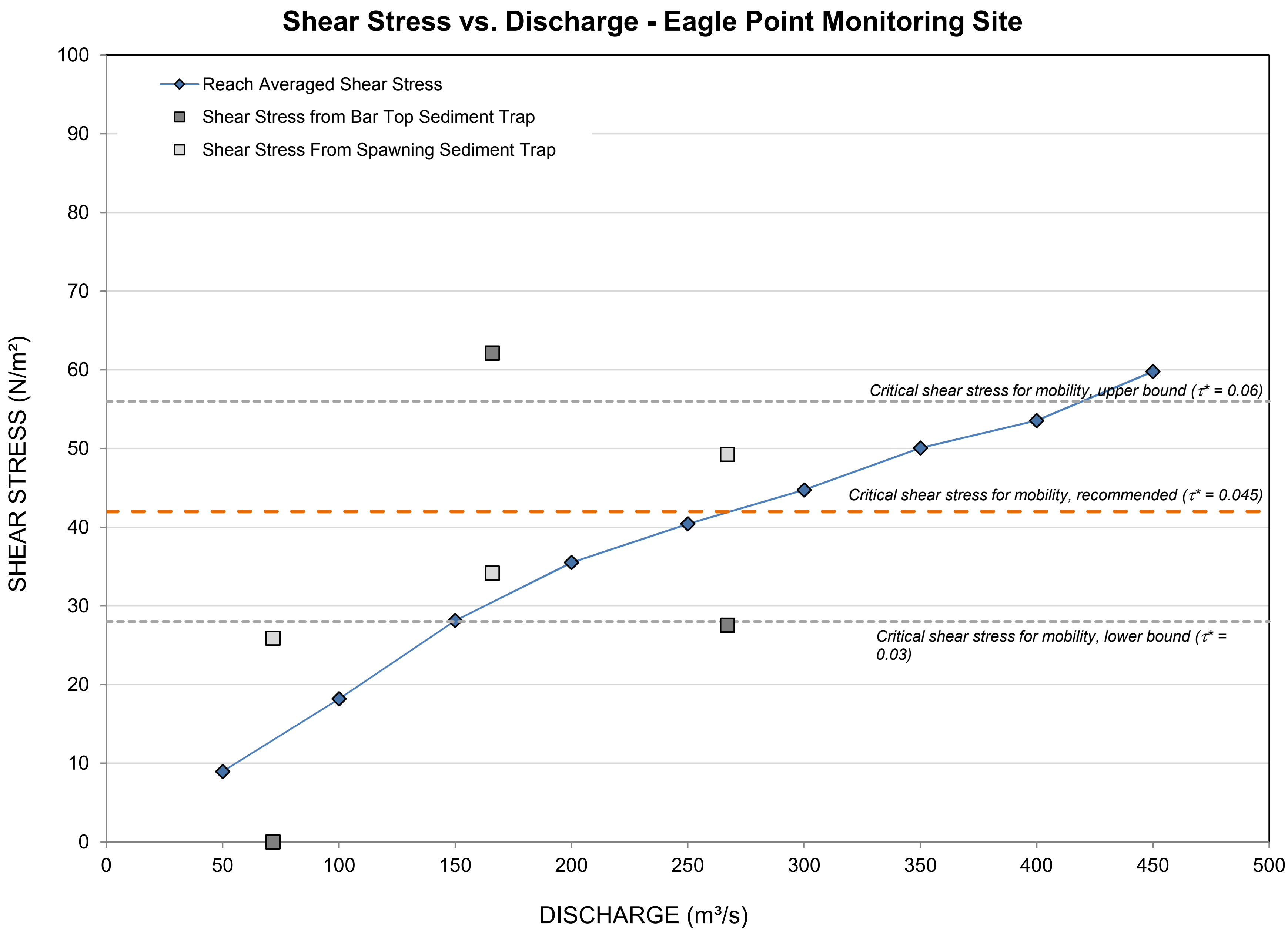

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Figure 3-1

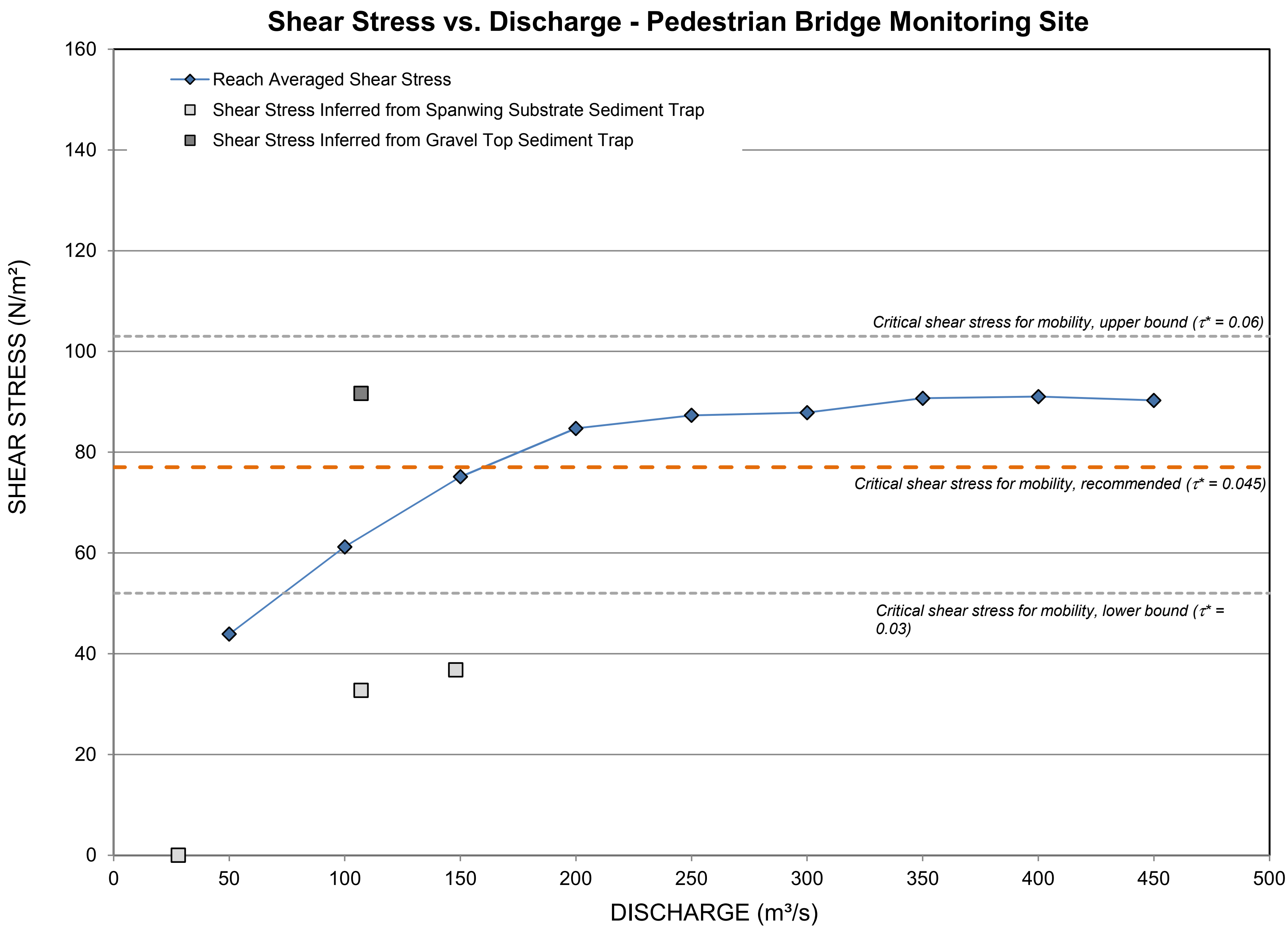

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Figure 3-2

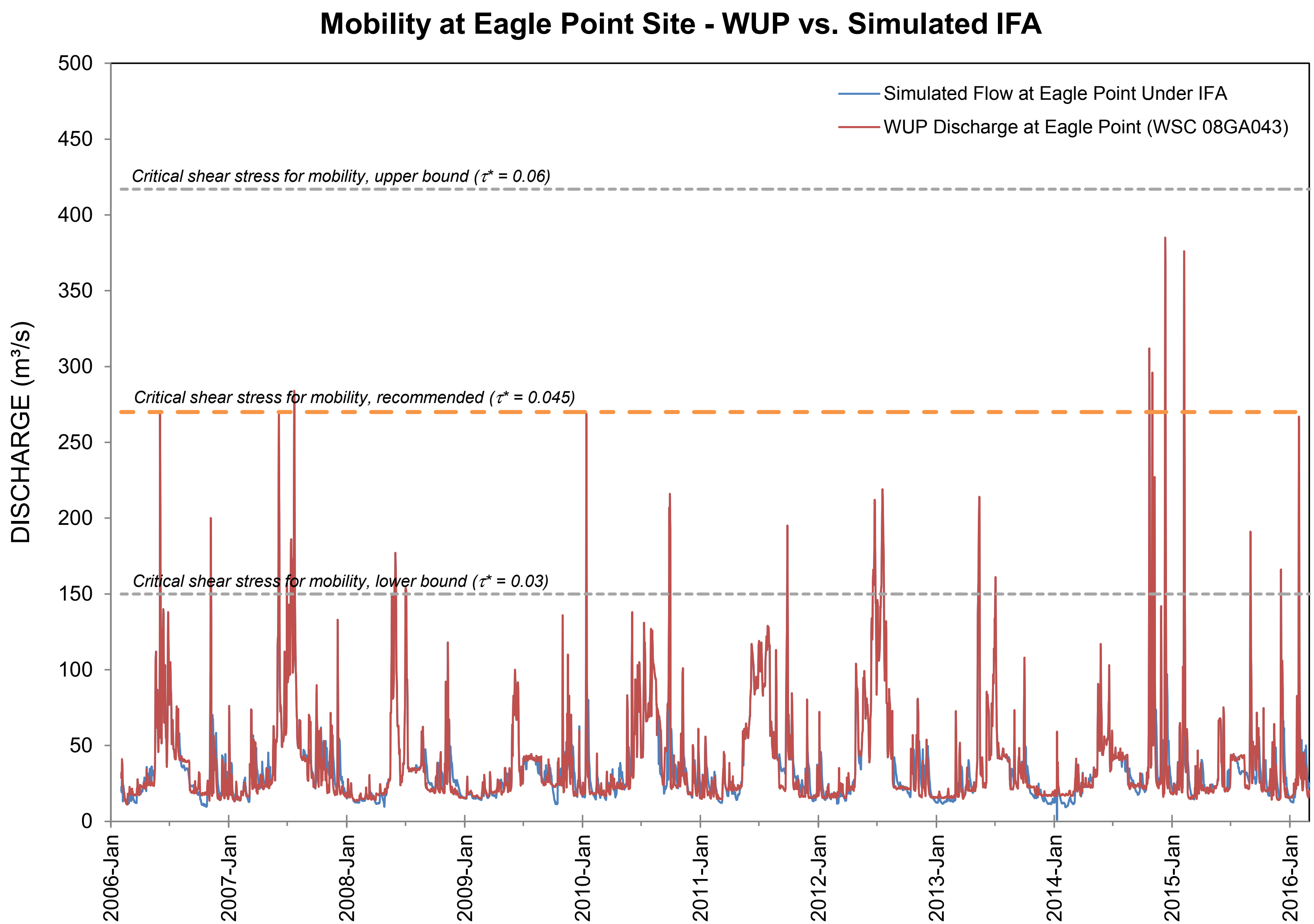

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Figure 3-3

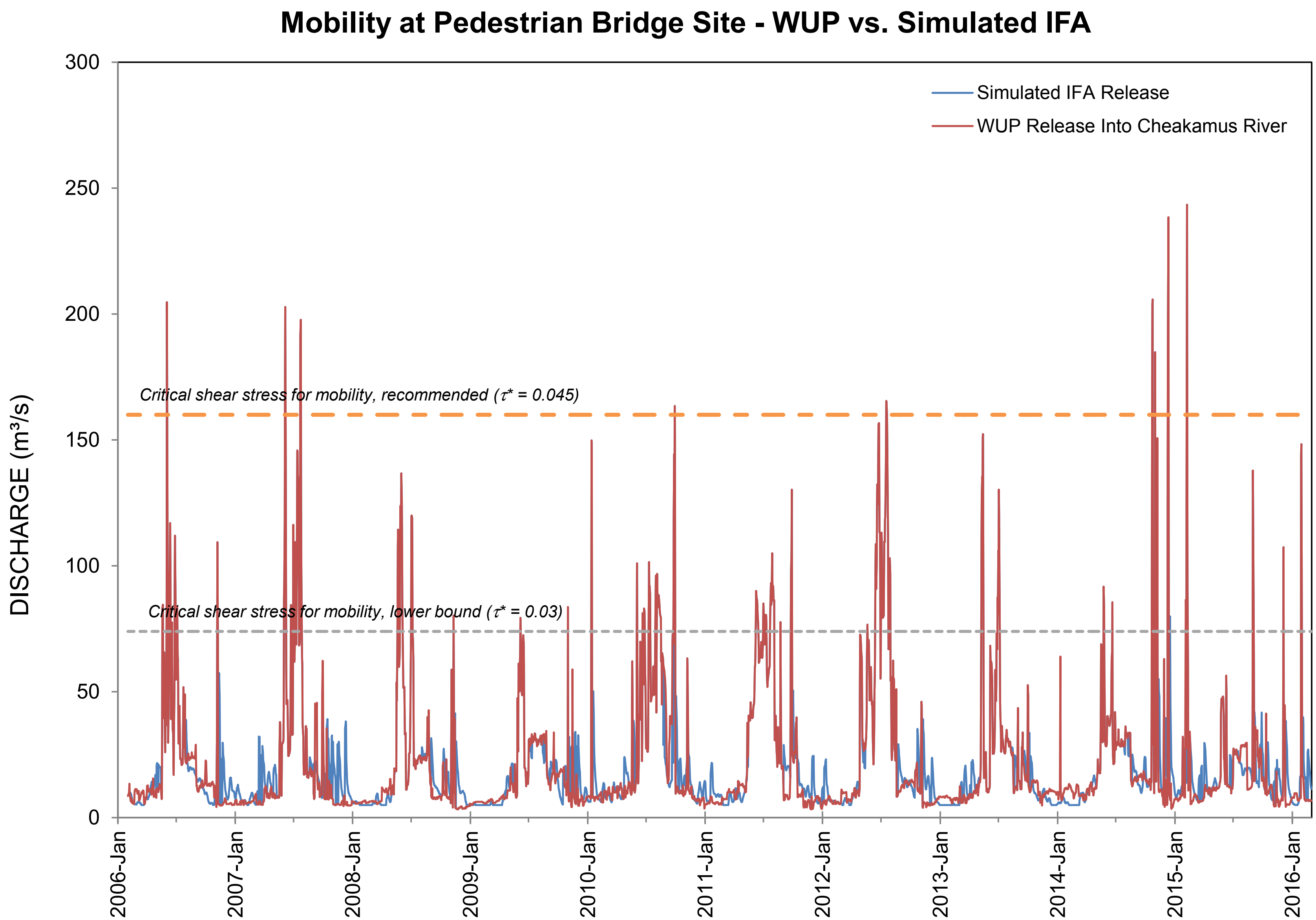

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Figure 3-4

4. Discussion

4.1 Management Question #1

The revised MQ1 that this study addresses is:

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

Table 7 shows that the critical shear stress (for τ_{*c} = 0.045) for which erosion of spawning substrate may occur is likely exceeded at discharges greater than:

- 270 m^3/s for Eagle Point, and
- 160 m^3/s for Pedestrian Bridge.

These site-specific shear stress discharge relationships are based on reach-average shear stress derived from a hydraulic model, and generally supported by field-based shear stress estimations collected by the sediment traps.

Operational impacts to flow from the WUP vs. pre-WUP (IFA) are limited to the lower end of the range of flows, below about 50 m^3/s. As such, we conclude that the implementation of the WUP has not resulted in additional erosion of spawning sediments compared with the pre-WUP condition.

4.2 Other Potential WUP Impacts to Spawning Habitat

It is important to consider other effects that WUP implementation may have had on spawning substrate, apart from erosion. As mentioned earlier, Cheakamus River fisheries monitors are of the opinion that availability of suitable spawning habitat (i.e. of a suitable surface sediment size) is not limiting. However, the quality of the sub-surface sediments has not been directly assessed, and sub-surface quality has been shown to be a limiting factor for spawning success. In particular, siltation of fine sediment into spawning redds during low flow events can lead to increased egg to fry mortality (Chapman 1988).

A local study on Steelhead in the Cheakamus River (CMSMON-3) involved the collection of physical habitat information, in particular pore depth: an estimation of fine sediment intrusion within the interstitial space of framework particles. Pore depth data were collected at many sites along lower Cheakamus River during fall 2014, and repeated at the same sites in spring 2015 (Korman and Schick 2015). The data shows that tributaries, such as Culliton Creek, are important sources of fine-grained sediment to the lower Cheakamus. In addition, the data showed that fine-grained material accumulated in interstitial space of gravel and cobbles between fall and spring sampling events.

However, this same Steelhead study (CMSMON-3) also found that egg to fry mortality does not appear to be a limiting factor for population growth. Egg to fry survival rates for Steelhead in the Cheakamus River appear to be negatively correlated with egg deposition (Korman and Schick 2015), although the sample size is limited. This is possibly a result of greater predation on Steelhead fry during emergence. There is some indication that high flows during summer and/or rapid reductions in flow during this period limited egg to fry survival rates for Steelhead, but in general the greatest mortality appears to occur after fry emergence (Korman and Schick 2015). This finding suggests that, at least for Steelhead, operational impacts to sub-surface sediment quality do not require further monitoring.

It should be noted that even if sub-surface sediment quality is assessed in future work it would not be possible to contrast current (WUP) conditions with previous conditions as the IFA-era supporting data do not exist.

Another means by which the WUP may affect spawning is in the timing of releases to meet the flow targets. During this study apparent stranding of adult spawners (Pink salmon) was noted at the Pedestrian Bridge monitoring site during the initial field visit (Sep. 16, 2015). A large number of dead adult Pink salmon were observed on gravel bar tops, at elevations of up to 1 m above the water level at the time of the site visit (36 m^3/s at WSC 08GA043). It is not known how WUP operations affect the flow levels at spawning sites, and whether there is a significant impact of operations on stranding that affects spawning success, compared with IFA conditions.

4.3 Other Considerations

It is worth noting other potential impacts that a regulated river may have on spawning habitat. As mentioned earlier, the main assumption with this study is that the erosion and the resultant degradation of spawning habitat is likely to occur when the critical shear stress has been exceeded. High sediment mobility from flood events can both scour away eggs and/or entomb the eggs (Lisle 1989).

During this study, discharge event #3 at Eagle Point (267 m^3/s) caused the deposition of ~30 cm of a sandy gravel layer on top of both sediment traps (Photo 3). A local study on Chum salmon (CMSMON-1b) postulated that the egg to fry mortality in the mainstem compared to side channels was higher due to bed scour, which resulted from several large flow events that occurred 2014 (Fell et al 2015).

In contrast, others have found that the mobilization of spawning substrate by flood flows is necessary for maintaining long-term productivity of spawning habitat (Lapointe et al 2000). Flood events causing scour and fill of sediment are a natural characteristic of gravel bed streams to which salmonid species have adapted.

Previous work evaluating the operational impact of 1960 to 1994 Cheakamus River peak flows concluded that regulation resulted in a modest reduction in peak flows:

- the 2-year return period flood was reduced by about 15%,
- the 10-year return period flood was reduced by about 9%, and
- the 100-year return period flood was reduced by about 13% (NHC, 2000).

These findings suggest that regulation has likely not resulted in a higher frequency of scour/fill events than would be experienced under no regulation. However, the construction of the Daisy Lake Dam has reduced the supply of coarse sediment to the lower Cheakamus River by half or more (NHC 2000). A more detailed study would be needed to understand the combined effect of lower peak flows and a reduced sediment supply on spawning habitat quality in the Lower Cheakamus River.

4.4 Report Submission

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May 10, 2017

This document is a copy of the sealed and signed hard copy original retained on file. The content of the electronically transmitted document can be confirmed by referring to the filed original.

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ATAL/CD/EE/abc

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Revision History

Revision #	Date	Status	Revision Description	Author
0	May 10, 2017	Final	Issued for Client	ATAL/CD/EE
A	Oct. 25, 2016	Draft	Original	ATAL/CD/EE

OQM | Organizational Quality Management Program

Appendix A:

WUP vs. Simulated IFA Discharge Comparison (2006 to 2015)

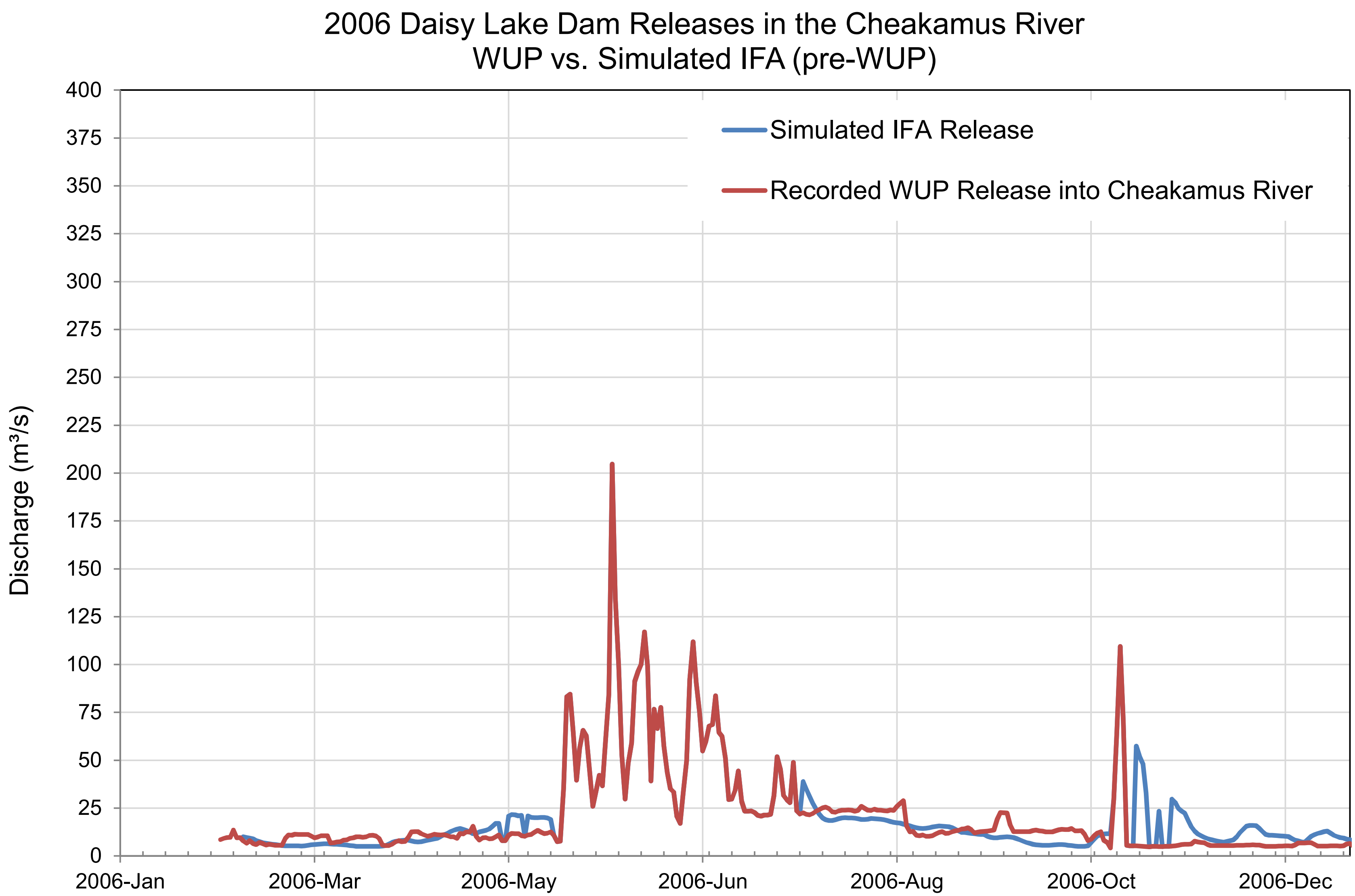

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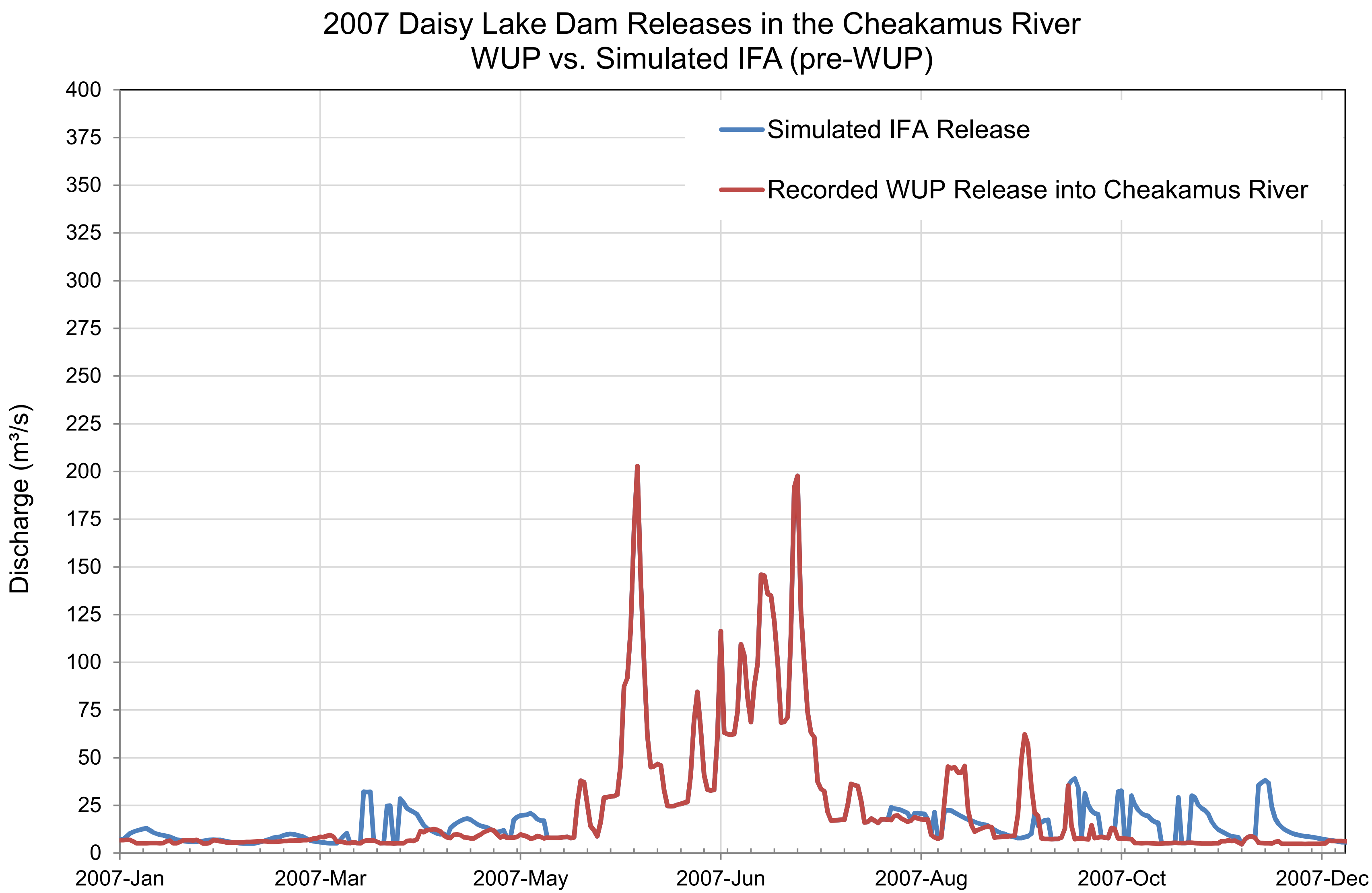
Figure A-1



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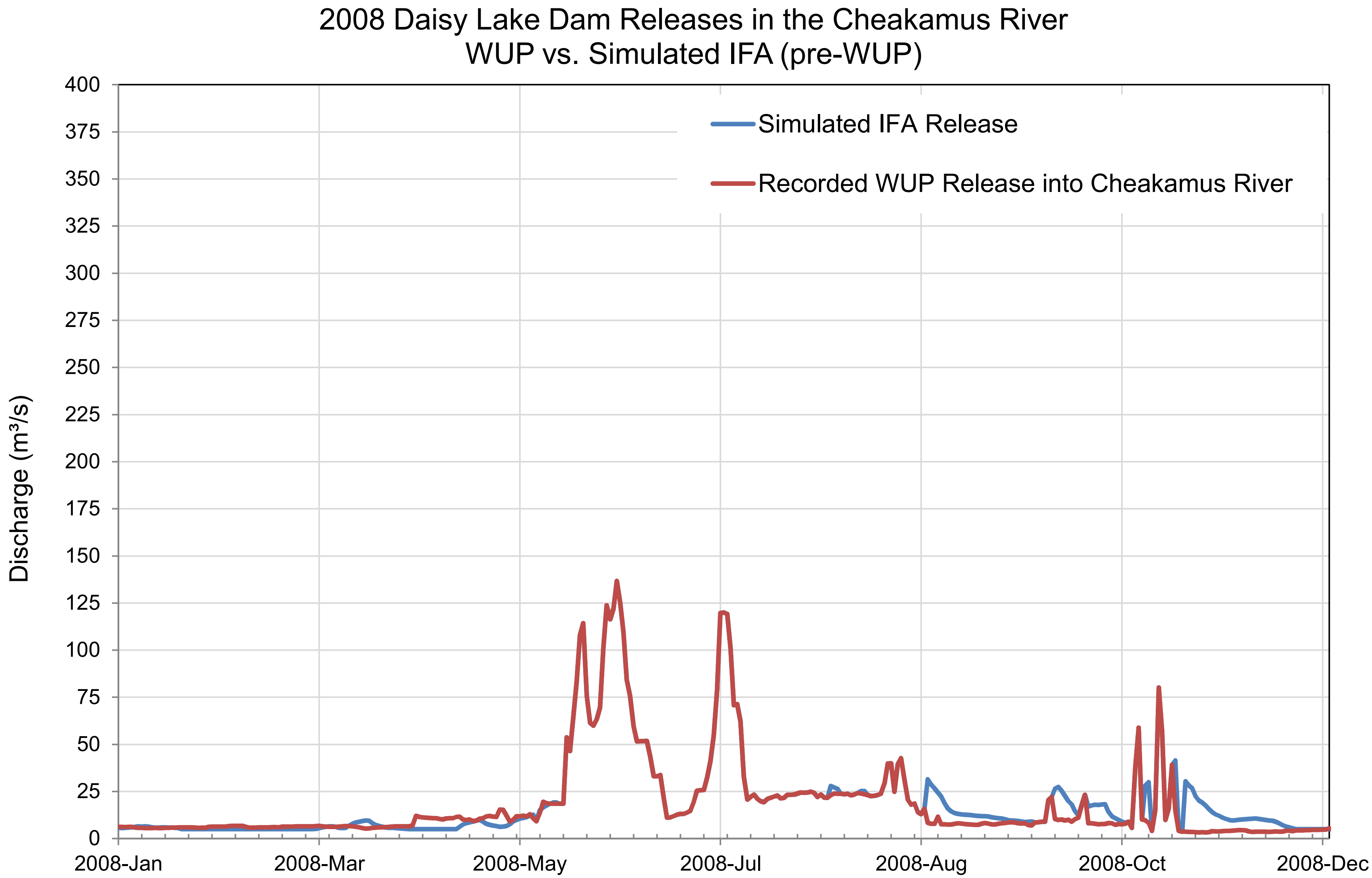

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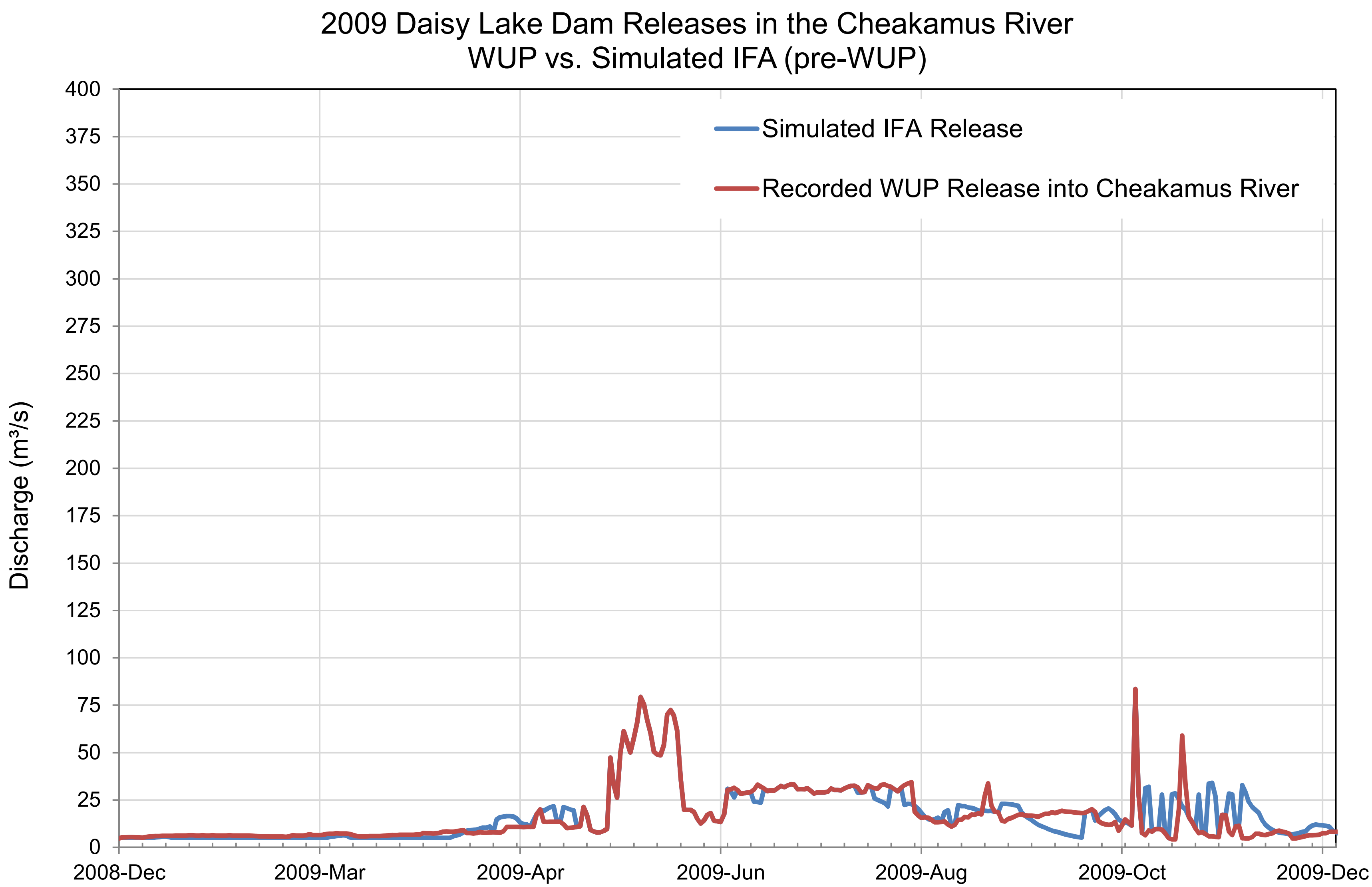

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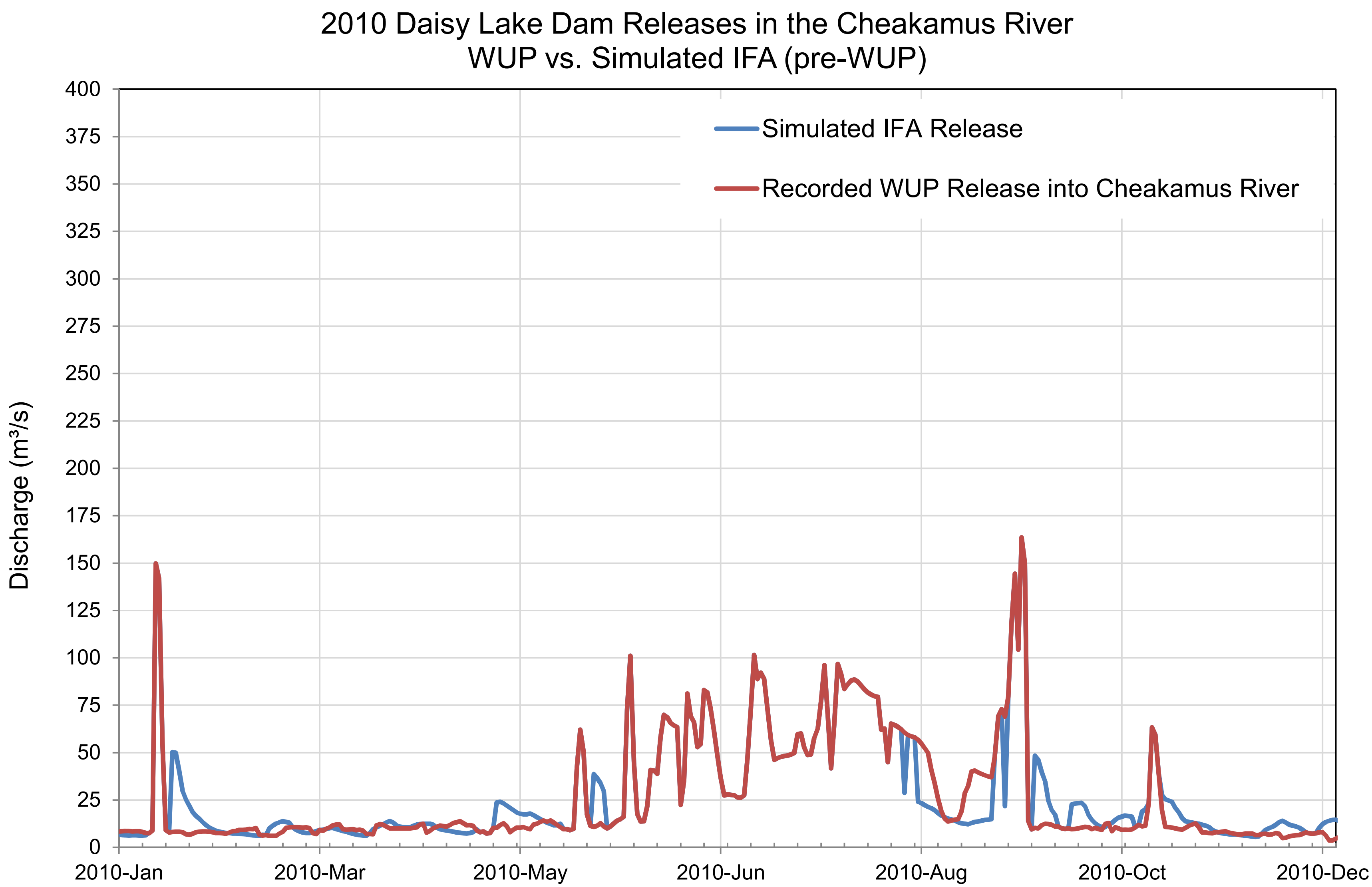

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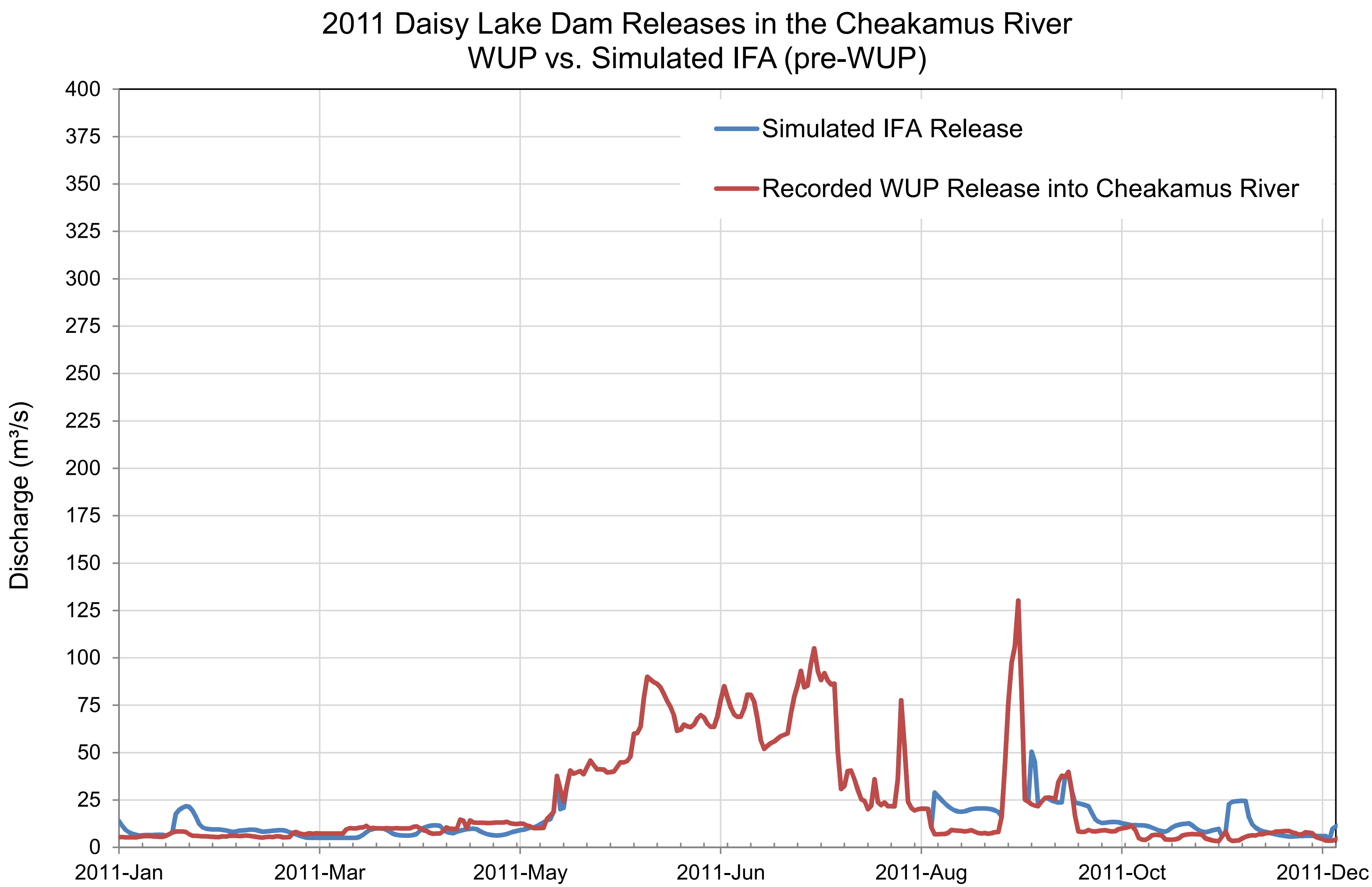

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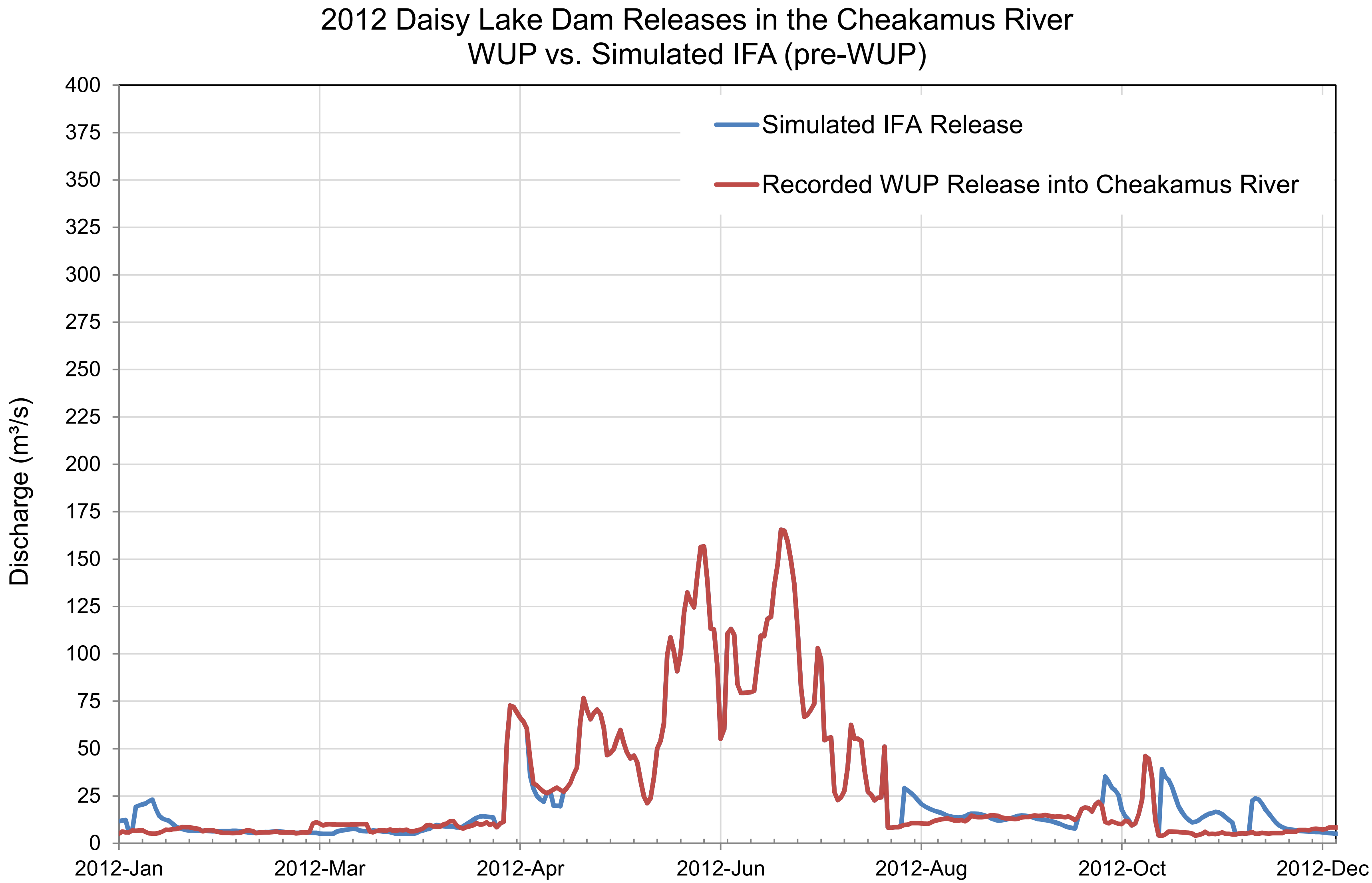

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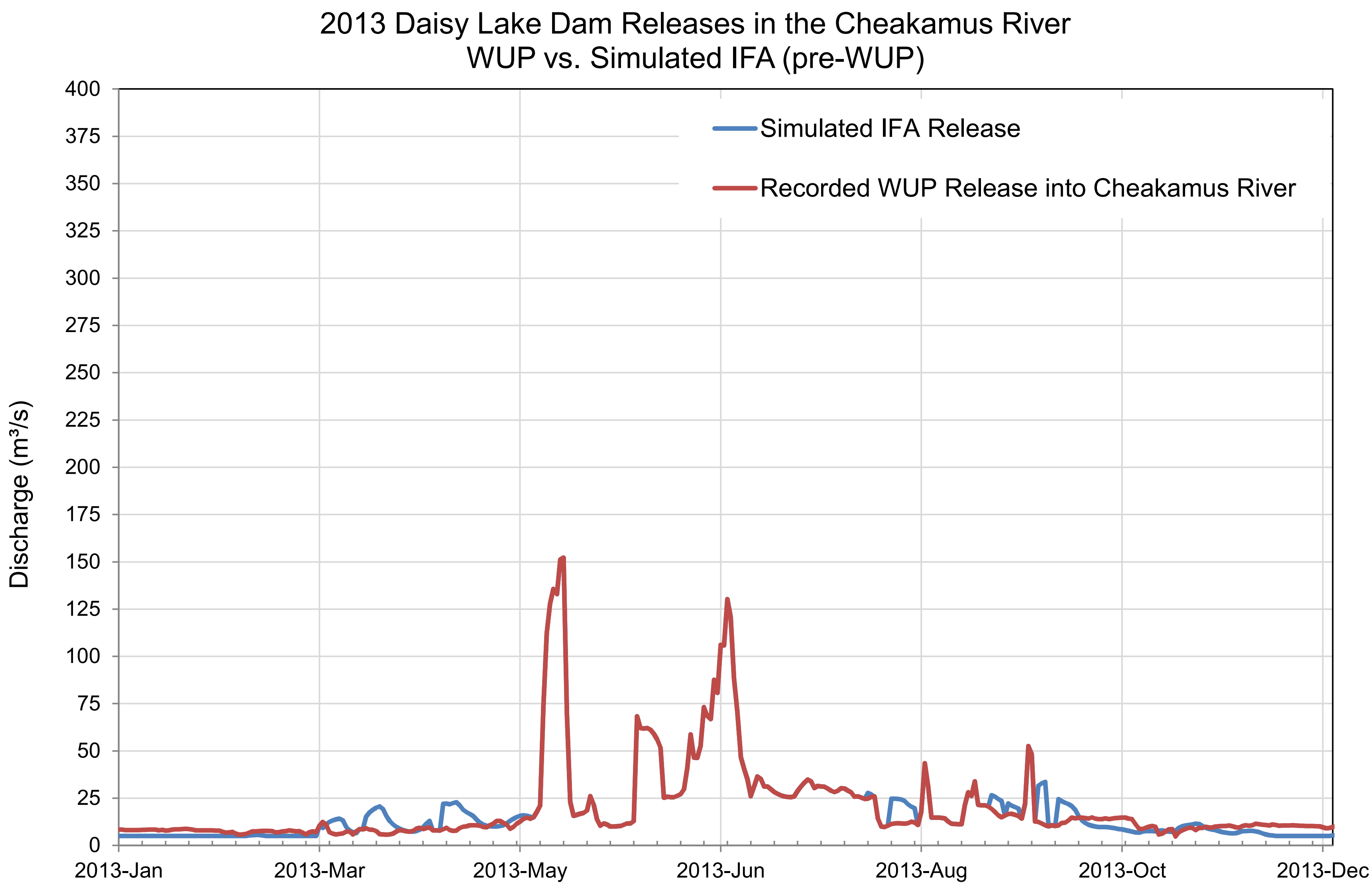

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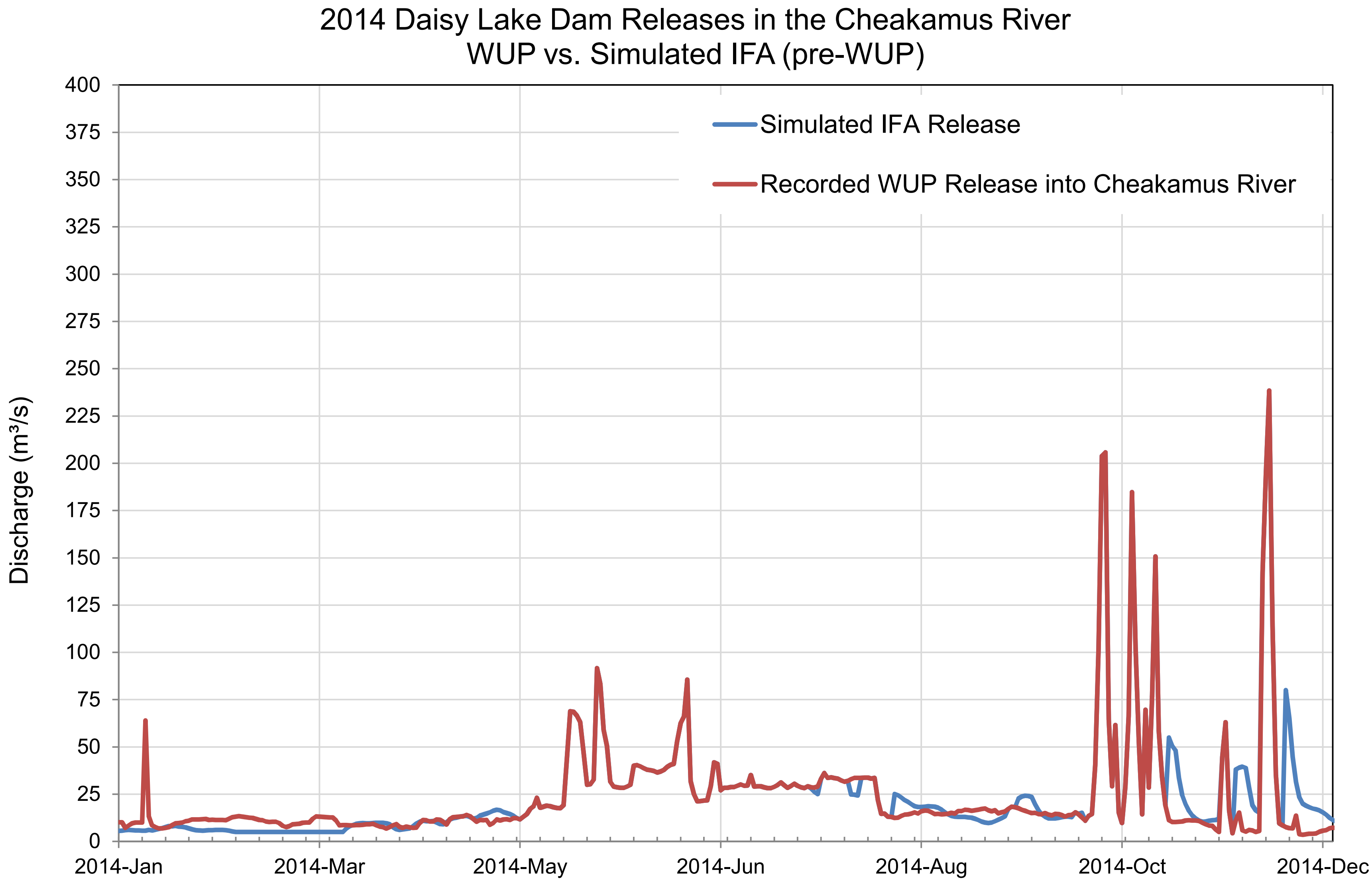

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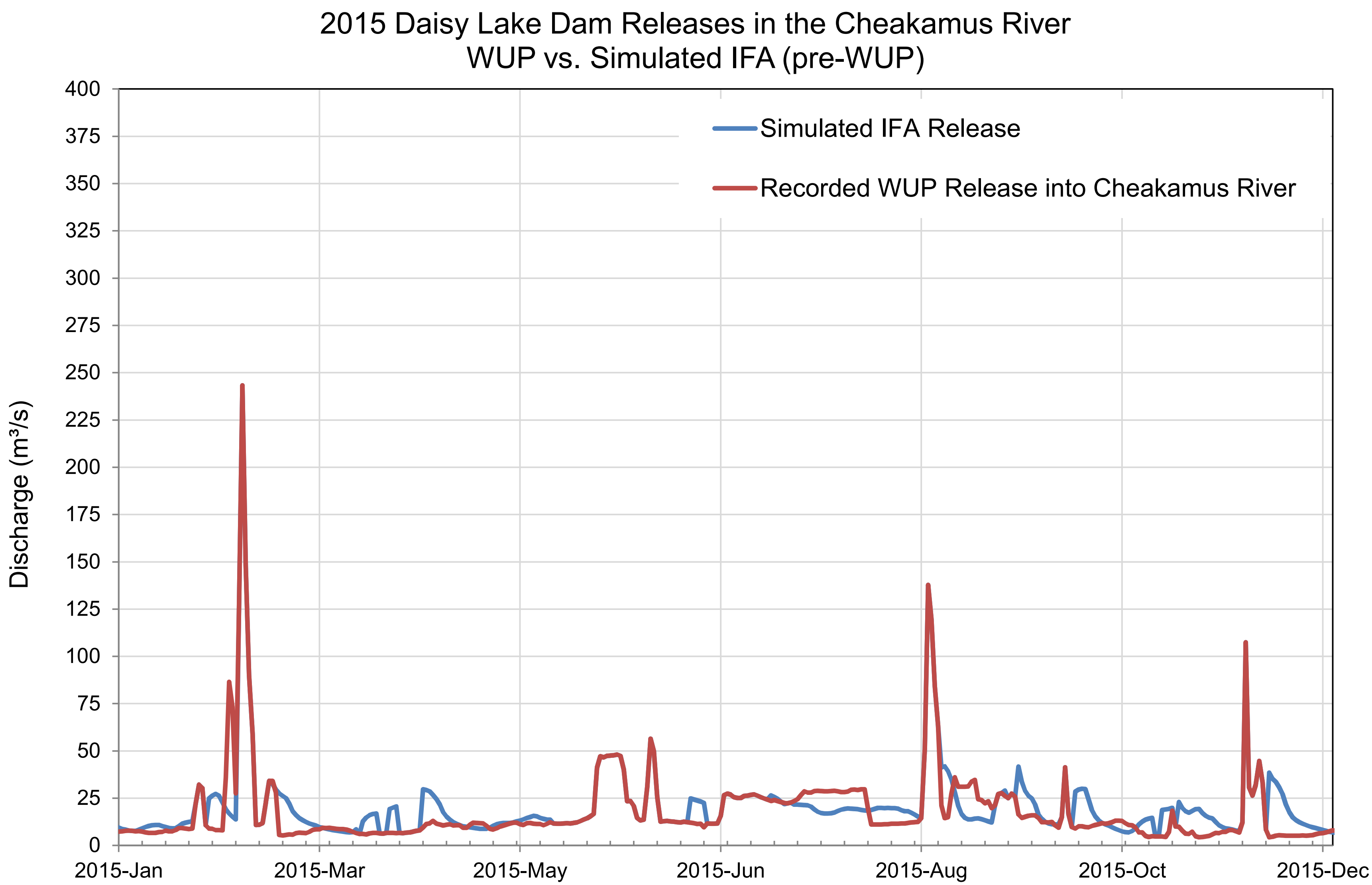

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Figure A-10

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Attachment B

CMSMON-8 MQ2 Final Report

Cheakamus Project Water Use Plan

Cheakamus River Channel Morphology Monitoring

Implementation Year 10

Reference: CMSMON-8

Annual Progress Report (FINAL)

Study Period: 2016-2017

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May 16, 2018

Contents

Figures

Tables

Appendices

Executive Summary

The Fisheries Technical Committee for the Cheakamus Water Use Plan developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the Consultative Committee, and to better inform the next Water Use Plan. CMSMON8 deals with questions related to channel morphology and tributary flows.

BC Hydro's Terms of Reference for CMSMON8 identify three management questions (MQs), which the Cheakamus River monitoring program is intended to answer. CMSMON8 is a 10-year program, and 2017 is Year 10 of the program. MQ1 was addressed in Year 8 and MQ3 was addressed in Year 6. This report summarizes the work done in addressing MQ2.

Table E-1 below summarizes MQ2, its associated Management Hypotheses, and the Year 10 status on addressing it.

Table E-1: MQ2 Summary After Year 10

Management Question	Management Hypotheses	Year 10 (2017) Status
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?	**$H_{0,2}$:** Total length (km) of connected side-channel habitat wetted at typical flows has not changed since implementation of the WUP, and **$H_{0,3}$:** The diversity of side-channel habitat as measured by the number and ratio of pool, run and riffle habitats has not changed since implementation of the WUP.	CMSMON8 concludes that following implementation of the WUP: 1. the total area of natural side channel habitat wetted at typical flows has increased (measurements of side channel area are considered more appropriate when quantifying habitat, than length); and 2. the diversity of natural, mainstem side channel habitat as measured by the area of pool, riffle, and rapid habitat units has not significantly changed. The present analysis was not able to address the question of access. This future work will be included and reported in CMSMON1b.

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) has been retained by BC Hydro to conduct monitoring work for CMSMON8: Cheakamus River Channel Morphology Monitoring. This monitoring program arose from the Water Use Plan (WUP) process that initiated in 1996 and resulted in the current WUP, accepted by the Comptroller of Water Rights in 2005. BC Hydro awarded the CMSMON8 project to KWL in August 2013. The project has a 5-year duration (2013 through 2018).

CMSMON8 is intended to answer the following management questions (MQs):

1. *Following implementation of the WUP (Water Use Plan), 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?*
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.*

KWL has addressed MQ1 and MQ3 in previous reports (KWL, 2017 and KWL, 2014). The current report addresses MQ2.

1.1 Water Use Plan

The Cheakamus River Water Use Plan (WUP) was accepted by the Comptroller of Water Rights and implemented in February 2006. The Cheakamus Consultative Committee (CC) agreed on six fundamental objectives for the Cheakamus Water Use Plan (in no particular order):

1. **Power:** Maximise economic returns from power generated at Cheakamus Generating System;
2. **First Nations:** Protect integrity of Squamish First Nation's heritage sites and cultural values;
3. **Recreation:** Maximise physical conditions for recreation;
4. **Flooding:** Minimise adverse effects of flood events through operation of the Cheakamus Generating system;
5. **Fish:** Maximise wild fish populations; and
6. **Aquatic Ecosystem:** Maximise area and integrity of the aquatic and riparian ecosystem.

The Fisheries Technical Committee developed a comprehensive monitoring plan for the Cheakamus River to address critical points of scientific uncertainty and disagreement within the CC, and to better inform the next WUP. The CC recognised that it is essential to address critical scientific uncertainties that can affect future decision making, and to comprehensively assess the response of the system to changes in the operation of the Cheakamus Generating System. CMSMON8 is one of 10[1] monitors related to the WUP.

[1] Monitors 1 through 9, with 1a and 1b considered separately.

1.2 Project Location and Description

The Cheakamus generating system was completed in 1957 (BC Hydro, 2005). Daisy Lake Dam impounds the Cheakamus River creating Daisy Lake Reservoir, located about 30 km north of Squamish, adjacent to Highway 99. From Daisy Lake Reservoir, some of the water is released via the dam to the lower Cheakamus River while some is diverted, via a tunnel, to the Cheakamus Generating Station. The water diverted for power is not returned to the lower Cheakamus River since the Cheakamus Generating Station discharges to the Squamish River. Daisy Lake Reservoir can store about 55 million m^3 of water: about 3.5% of average annual inflow (BC Hydro, 2005). The maximum capacity of the generating system is 65 m^3/s.

Cheakamus River is a 'mixed-regime' watershed, exhibiting characteristics of both rain- and snow melt-dominated streamflow regimes. The annual hydrograph contains a summer snowmelt freshet peak, but peak flows also occur the in fall and winter from intense rainstorms combined with snowmelt (BC Hydro, 2005). The fall and winter peak flows are characteristically larger than the freshet peak flows. Water Survey of Canada operates a hydrometric station on lower Cheakamus River about 5 km upstream of the confluence with Squamish River (WSC 08GA043).

The Cheakamus River provides critical habitat for many anadromous and resident fish species. A list of fish species present within the Cheakamus River is shown in Table 1-1.

Table 1-1: Anadromous and Resident Fish Species of the Cheakamus River[1]

Anadromous Species	Resident Species
Coho salmon (*Oncorhynchus kisutch*)	Rainbow trout (*O.mykiss*)
Chum salmon (*O. keta*)	Cutthroat trout (*O.clarkia*)
Chinook salmon (*O.tshawytscha*)	Bull trout (*Salvelinus confluentus*)
Pink salmon (*O.gorbuscha*)	Dolly varden (*S. malma*)
Steelhead trout (*O.mykiss*)	Brook trout (*S. fontinalis*)
	Threespine stickleback (*Gasterosteus aculeatus*)
	Coastrange sculpin (*Cottus aleuticus*)

Notes:
1. Results of a search within BC's Fisheries Information Summary System (FISS) for the Cheakamus River (2016)

1.3 Project Design

The objective of the current study report is to address the second management question posed by the Fisheries Technical Committee and Consultative Committee under WUP operations:

> *Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?*

To answer this management question, two impact hypotheses were developed by BC Hydro to test whether the morphology, and hence aquatic habitat, has been significantly altered since implementation of the WUP.

> $H_{0,2}$*: Total length (km) of connected side channel habitat wetted at typical flows has not changed since implementation of the WUP, and*

> $H_{0,3}$*: The diversity of side channel habitat as measured by the number and ratio of pool, run and riffle habitats has not changed since implementation of the WUP.*

The approach to addressing MQ2 was established in Year 1 through Year 5 of the study, which relies on repeat channel and habitat mapping from orthophotos (NHC, 2014). The main tasks in the analysis include:

- Mapping channel morphology and wetted channel habitats using morphological and habitat categories established in the first CMSMON8 monitor;
- A field visit to ground-truth morphologic channel mapping and wetted habitat classification; and
- Statistical analyses of current morphologic and channel mapping, and comparison with previous mapping.

The original mapping completed in 2008 and 2012 did not identify mainstem side channels as distinct from the main channel (NHC, 2014). This did not allow direct testing of the two management hypotheses as stated, nor did it lend itself to fully address the management question. To provide a more complete answer to MQ2, some adjustments were made to the original methodology as discussed in Section 2.

1.4 Project Team

The KWL project team and roles for this study are as follows:

- Erica Ellis – Project Manager and Professional of Record,
- David Sellars – Senior Water Resources Engineer,
- Chad Davey – Project Fluvial Geomorphologist, and
- Shayna Scott – Junior Engineer.

The following BC Hydro staff provided input to the CMSMON8 MQ2 analysis:

- Mark Sherrington – BC Hydro Contract Manager, and
- Alexis Hall – BC Hydro – Fish and Aquatic issues (Subject Matter Expert).

This project also benefited from input from other monitoring project staff and stakeholders at the annual Cheakamus River Monitoring Committee Meetings.

2. Methodology

This section describes the methods (desktop and field) used in addressing MQ2. In general, the methodology followed that of the morphological mapping and analysis carried out in Year 1 through Year 5 of the monitor (NHC, 2014), to ensure consistency in the analysis. However, to more directly address the management question and associated hypotheses, adjustments were made to the original methodology, which are discussed in the following sections.

2.1 Orthophotos

Three sets of aerial photographs (~1:5,000) covering the study area were used for the morphological mapping and analysis. The aerial photography sets used for this analysis were each flown in March/April and under similar flow conditions for the Cheakamus River (Table 2-1).

Table 2-1: Timing of Aerial Photographs and Corresponding Flow Conditions within Cheakamus River

Year	Date	Flow in Cheakamus River[1] (m^3/s)
2008	April 22	17
2012	March 24	15.5
2017	March 20	19

Notes:
1. WSC station 08GA043 Cheakamus River Near Brackendale

BC Hydro Photogrammetry Service provided KWL with the final orthophoto mosaics for each year of interest for the morphological mapping analysis. Each set of orthophotos (2008, 2012, and 2017) has a resolution of 15 cm and is referenced to UTM Zone 10N projection (NAD83 datum).

2.2 Geomorphic and Habitat Mapping

2.2.1 Year 1 and Year 5 Mapping

Geomorphic Mapping

Baseline channel morphology mapping was prepared during Year 1 of the monitor, and updated during Year 5 (NHC, 2014). Geomorphic and habitat features were digitized in ArcGIS based on orthophotography collected in 2008 and 2012.

Geomorphic mapping consisted of identifying and delineating geomorphic features including:

- bars,
- islands,
- side channels,
- floodplain, and
- wetted channels.

Bars were further classified as submerged, unvegetated or sparsely vegetated; and islands as young or mature. Unvegetated and submerged bars represent young, mobile gravel bars, while sparsely vegetated bars represent more mature bars with isolated patches of vegetation. Young islands have denser ground coverage of vegetation than sparsely vegetated bars, and may support shrubs, grasses, and small trees. Young islands, over time, evolve to become mature islands which are identified by taller stands of trees that may be coniferous or deciduous.

Side channels, both natural and engineered, were identified and delineated. Engineered channels have typically been constructed in floodplain areas off from the main channel and may be either wet or dry at typical flows. Natural side channels may be found in floodplain areas, or may be secondary "mainstem" channels split from the main channel, even at high flows, by islands. The original mapping completed in 2008 and 2012 did not identify mainstem side channels as distinct from the main channel. The original 2008 and 2012 geomorphic mapping was revised by KWL to identify and further classify natural side channels as mainstem, floodplain (wet), or floodplain (dry).

Note that while engineered side channels were included in the mapping they were excluded from the analysis as the focus of the study is on natural, connected side channels. Similarly, disconnected floodplain side channels – side channels that do not connect to the mainstem at both the upstream and downstream ends – were mapped but were not included in the analysis.

Habitat Mapping

Habitat mapping consisted of identifying and delineating habitat features within the banks of the low flow wetted channel. Habitat features include:

- riffles,
- rapids, and
- pools.

These habitat units, as defined by Church (1992), represent riffle, rapid, and pool habitat units for intermediate-sized streams, such as the Cheakamus River. Riffles are characterized by relatively shallow, fast moving water. Pools are characterized by zones of deeper flows, moving at lower velocities in comparison to riffles. Rapids have flows near critical and may be identified by the protrusion of boulders at low flows and the presence of turbulent, white water.

As mainstem side channels fall within the banks of the low-flow wetted channel, KWL could apply the original habitat mapping completed in 2008 and 2012 to the newly identified mainstem side channels. Due to the narrow width of floodplain side channels and the presence of overhanging vegetation, it was not possible to complete habitat mapping for these features.

2.2.2 Year 10 Mapping

Year 10 (2017) morphologic mapping involved delineating the same set of geomorphic and habitat features identified in Year 1 and Year 5, based on 2017 orthophotography.

Channel banks delineated in 2012 were copied and only modified where there were observable changes in the bank lines. This minimized re-digitization of bank lines that may not have undergone actual changes, but might be interpreted differently due to the appearance of shadows, tree cover, or displacement errors in the orthophotography.

Geomorphic and habitat features were also copied from the 2012 mapping and then modified to match the changes observed using the 2017 orthophotos. Mapping morphology can be subjective and, as KWL did not complete the previous mapping, there was concern that 'blind' delineation of features could introduce interpretive bias. The methods described above were intended to improve consistency between mapping periods, and to avoid situations of spurious change resulting from interpretive differences between KWL and the previous mapper.

Upon completion of the preliminary morphologic mapping, the 2017 mapping was compared to the 2012 mapping to check for consistency and identify any obvious misinterpretations. Several minor alterations were made to the 2017 mapping to eliminate discrepancies.

Examples of the geomorphic and habitat mapping are provided in Figure 2-1 and Figure 2-2, respectively.

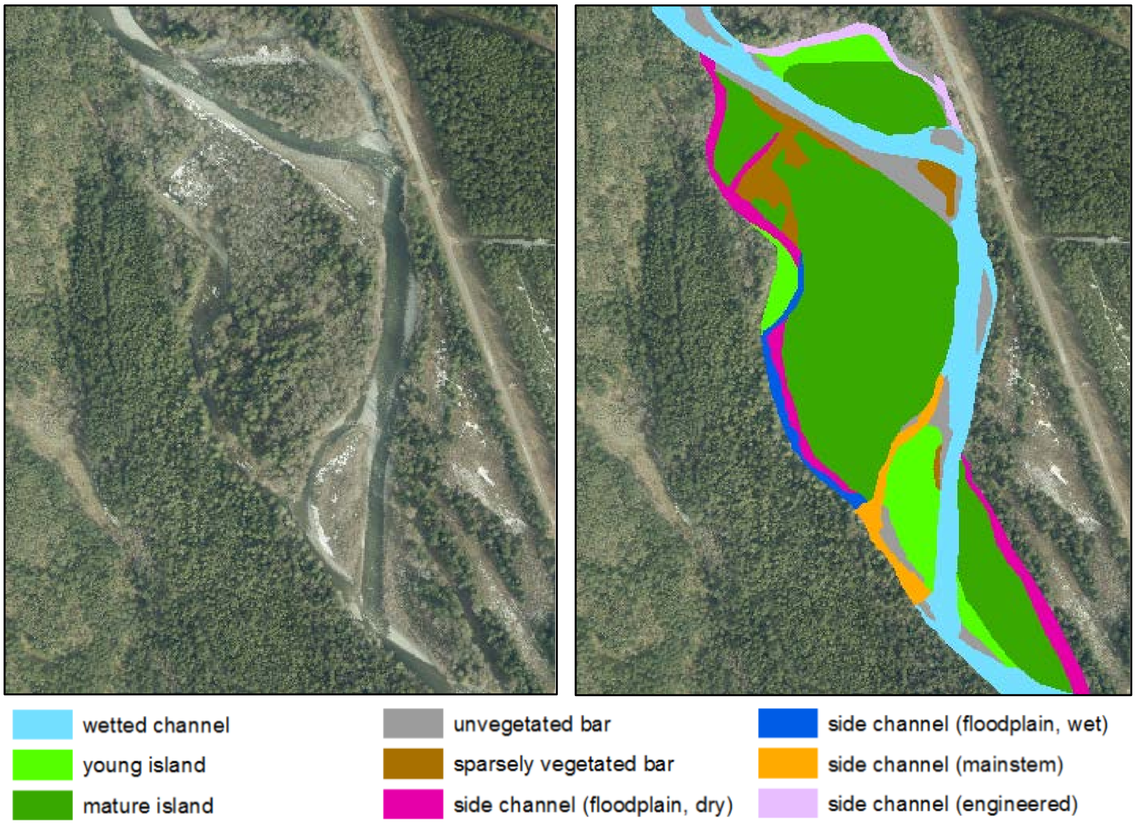

Figure 2-1: Example of 2017 Geomorphic Mapping

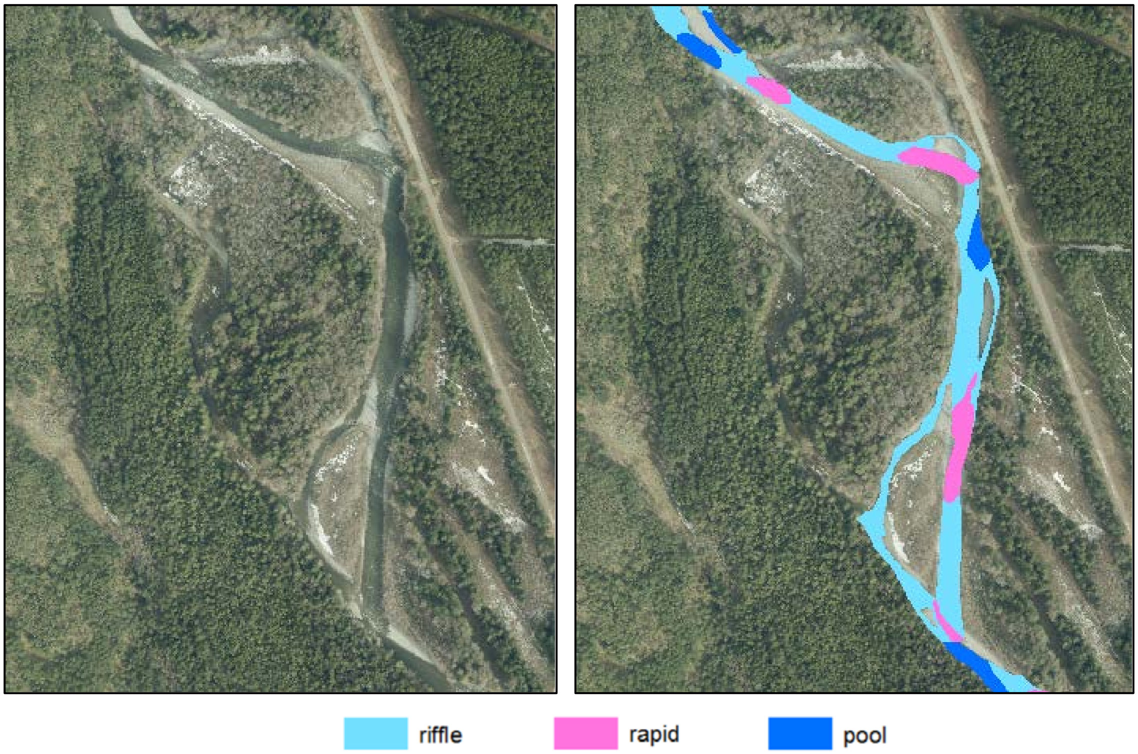

Figure 2-2: Example of 2017 Habitat Mapping

2.2.3 Field Visit (Oct. 13, 2017)

A field visit was conducted on October 13, 2017 by Chad Davey and Shayna Scott (KWL) to ground truth the completed preliminary mapping. The discharge at the time of the field visit was about 25 m^3/s based on real-time provisional data from WSC 08GA043 (Cheakamus River Near Brackendale), which is comparable to the discharge at the time the 2017 orthophotography was taken (Table 2-1).

The focus of the ground truthing was to check features that were noted during the preliminary mapping of the 2017 orthophotography as having a high degree of uncertainty in either the bounds or type of habitat or morphological unit. Most sites flagged for ground-truthing were channel features obscured by shadows or tree cover. Sites were accessed via driving and walking to the bank at various points along the mapped reach. Field notes on the type and extent of features were supplemented with photos taken at the time of ground-truthing. A subset of these photos is found in Appendix A.

2.2.4 Mapping by Reach

After updating the preliminary mapping based on information gathered during the field visit, the delineated feature polygons were split in ArcGIS using reach breaks defined in the Cheakamus River WUP. Reaches cover the channel between the confluence with the Squamish River and Daisy Lake Dam, and are the same as used by NHC (2014). Reaches 1 to 9 cover the anadromous fish segment of the river, Reach 10 is the canyon, and Reaches 11 to 14 cover the resident fish segment. The location of the 14 reaches are provided in Figure 2-3.

Reach 1, which encompasses the Cheakamus River fan, is not included in the analysis. As well, Reach 9 and a portion of Reach 10 are not included in the analysis because they cover a section of canyon that is not considered valuable fish habitat (BC Hydro and Power Authority, 2007). The remaining portion of Reach 10 that is considered to have value from a fish habitat perspective, is included in the analysis.

Path: \\bbyfs1.kwl.ca\0000-0999\0400-0499\478-164\430-GIS\MXD-Rp\Year10_2017\478164_Fig2-3_ReachBreaks.mxd Date Saved: 11/2/2017 12:42:23 PM | Author: SScott

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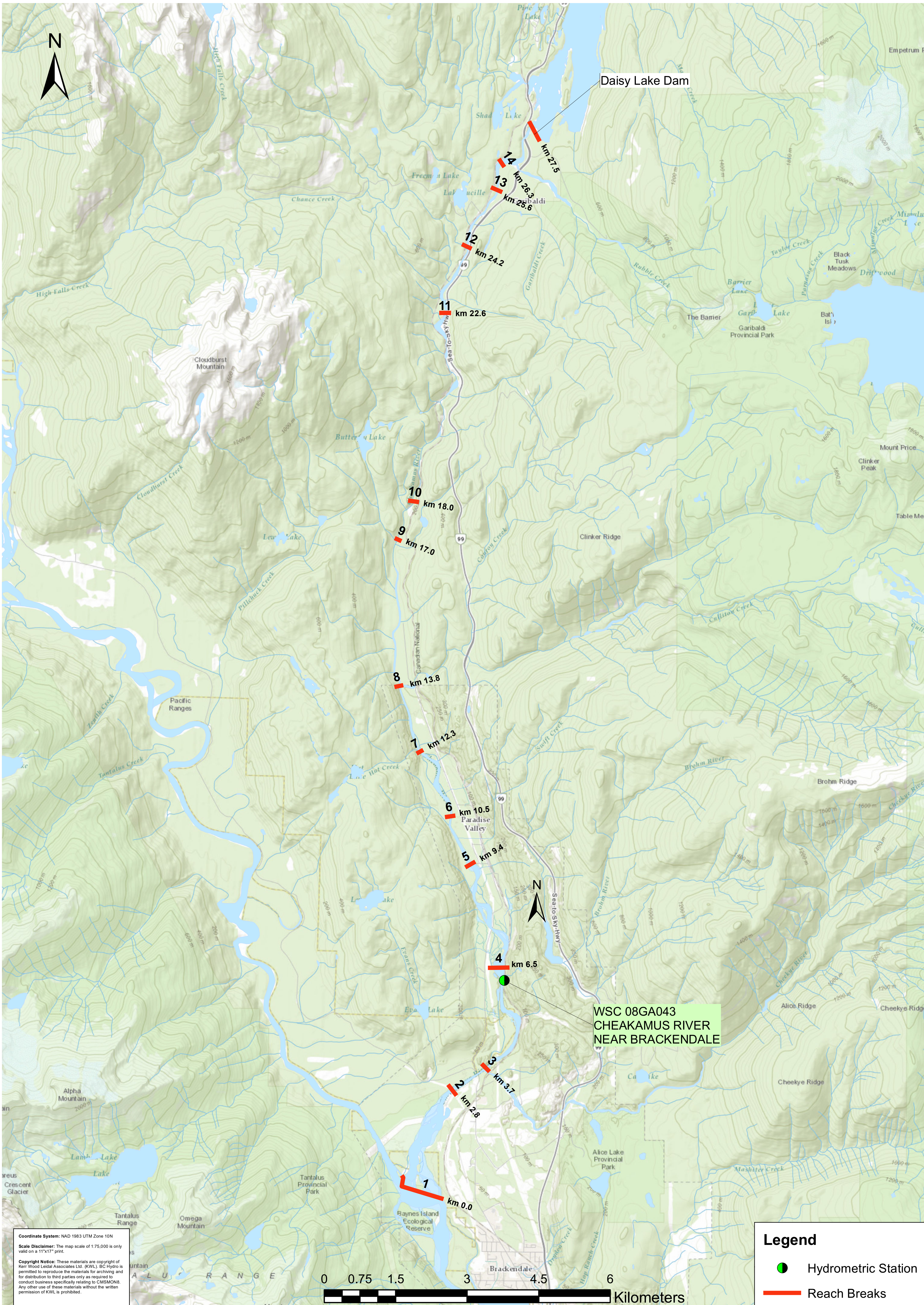
consulting engineers



Coordinate System: NAD 1983 UTM Zone 10N

Scale Disclaimer: The map scale of 1:75,000 is only valid on a 11"x17" print.

Project No. 0478-164

Date November 2017

Scale 1:75,000

Cheakamus River Reach Breaks

Figure 2-3

2.3 2008 to 2017 Flows

The daily mean flow within the Cheakamus River at the Brackendale hydrometric gauge (WSC 08GA043), is provided for the entire study period in Figure 2-4. A recent channel morphology study on the Cheakamus River indicated that flows exceeding 270 m^3/s at the Brackendale gauge result in the mobilization and transport of bed material (KWL 2017). Note that flow targets in the WUP are 38 m^3/s and lower (BC Hydro, 2005).

Flows that are capable of mobilizing and transporting sediment are generally responsible for shaping the morphology of the channel. Between 2008 and 2012, only one flow event reached the 270 m^3/s threshold (Figure 2-4). In contrast, the 270 m^3/s flow threshold was reached and/or exceeded five times between 2012 and March 2017. A direct observation of morphology change following a flow threshold event occurred in early February 2016 (267 m^3/s), where about 0.3 m of gravel material was deposited on an unvegetated bar within Reach 2 (KWL, 2017).

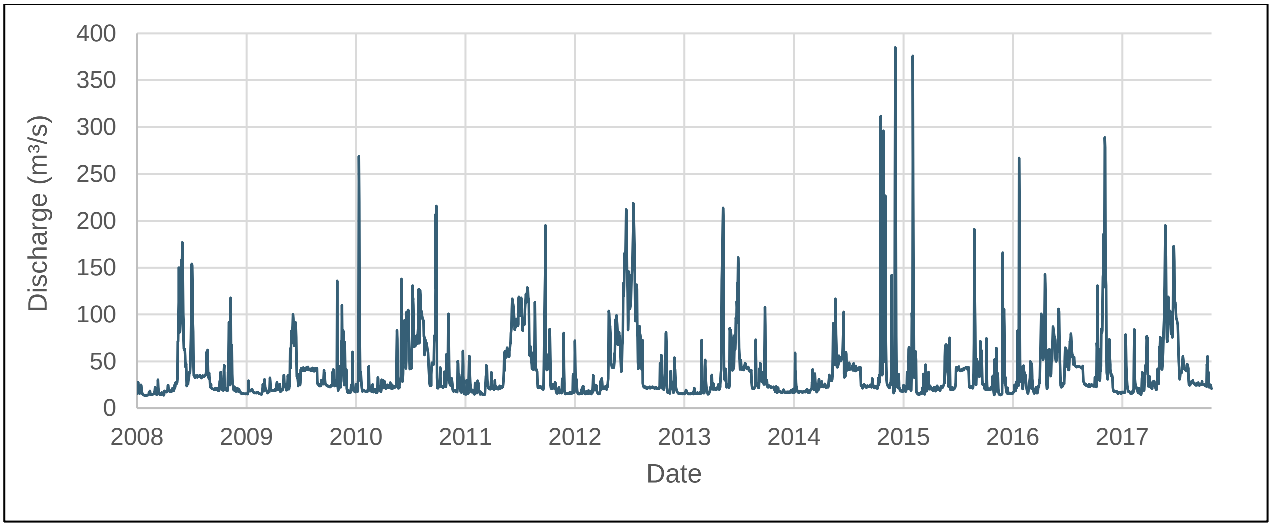


Figure 2-4: Cheakamus River Near Brackendale (08GA043) Daily Average Flows 2008 to 2017

3. Year 10 Results

3.1 Geomorphic Features

By Total Mapped Area

A summary of the mean area of each geomorphic feature as a percentage of the total mapped area for 2008, 2012 and 2017 is presented in Table 3-1 below.

The 2017 results generally match previous years (Table 3-1). The wetted channel is the dominant feature in all three years of mapping, followed by unvegetated bars. Side channels make up the smallest proportion of the mapped area. A decline in the area of unvegetated bars occurred from 2008 through to 2017. Sparsely vegetated bars increased in area from 2008 to 2012, yet decreased in 2017. An increase in young island morphology occurred from 2008 through 2017. Mature island morphology remained relatively constant from 2008 to 2012, yet increased in 2017. The percentage area of all side channel types has remained relatively constant from 2008 to 2017.

Table 3-1: Geomorphic Features as a Mean Percentage of Total Mapped Area for Each Year Mapped

Geomorphic Unit	2008	2012	2017
Wetted Channel	52%	49%	49%
Unvegetated Bar	29%	23%	18%
Sparsely Vegetated Bar	4%	7%	5%
Young Island	4%	5%	9%
Mature Island	9%	13%	17%
Mainstem Side Channel	1%	1%	1%
Floodplain Side Channel (dry)	0.5%	1%	1%
Floodplain Side Channel (wet)	1%	1%	1%

By Reach

The areal extent of all geomorphic features as a proportion of each reach for 2008, 2012, and 2017 data is presented in Appendix B. Figure 3-1 shows the change in the proportion (%) of reach area for unvegetated bars for all three years of mapping. Except for Reaches 5 and 11, the proportion of unvegetated bars declined from 2008 to 2012 for all reaches. A further decline in the proportion of unvegetated bars occurred between 2012 and 2017 for Reaches 3, 4, 5, 6, 8, 10 and 14.

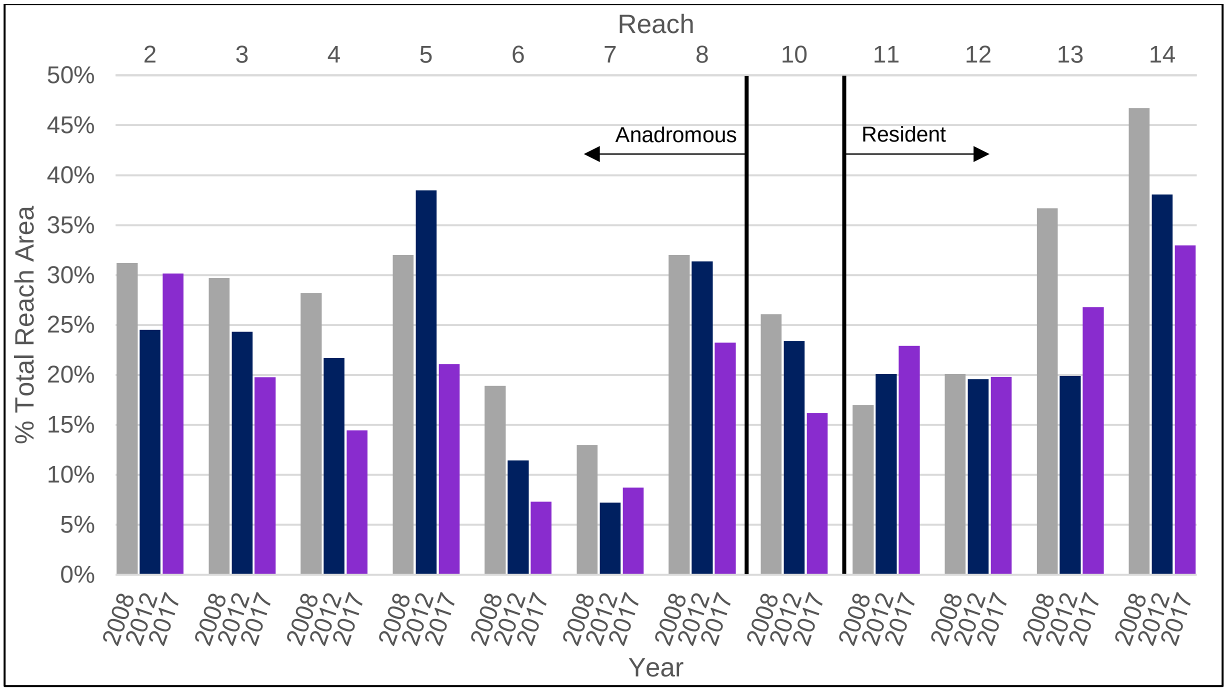


Figure 3-1: Area of Unvegetated Bars as a Percentage of Total Reach Area

Figure 3-2 shows the change in the proportion (%) of reach area for sparsely vegetated bars for all three years of mapping. Except for Reaches 11 and 12, the proportion of sparsely vegetated bars increased from 2008 to 2012 for all reaches. From 2012 to 2017, Reaches 2, 3, 4, 6, 7, 13, and 14 show a decline in the proportion of sparsely vegetated bars. An increase in the proportion of sparsely vegetated bars occurred in Reaches 5, 8, 10, 11 and 12.

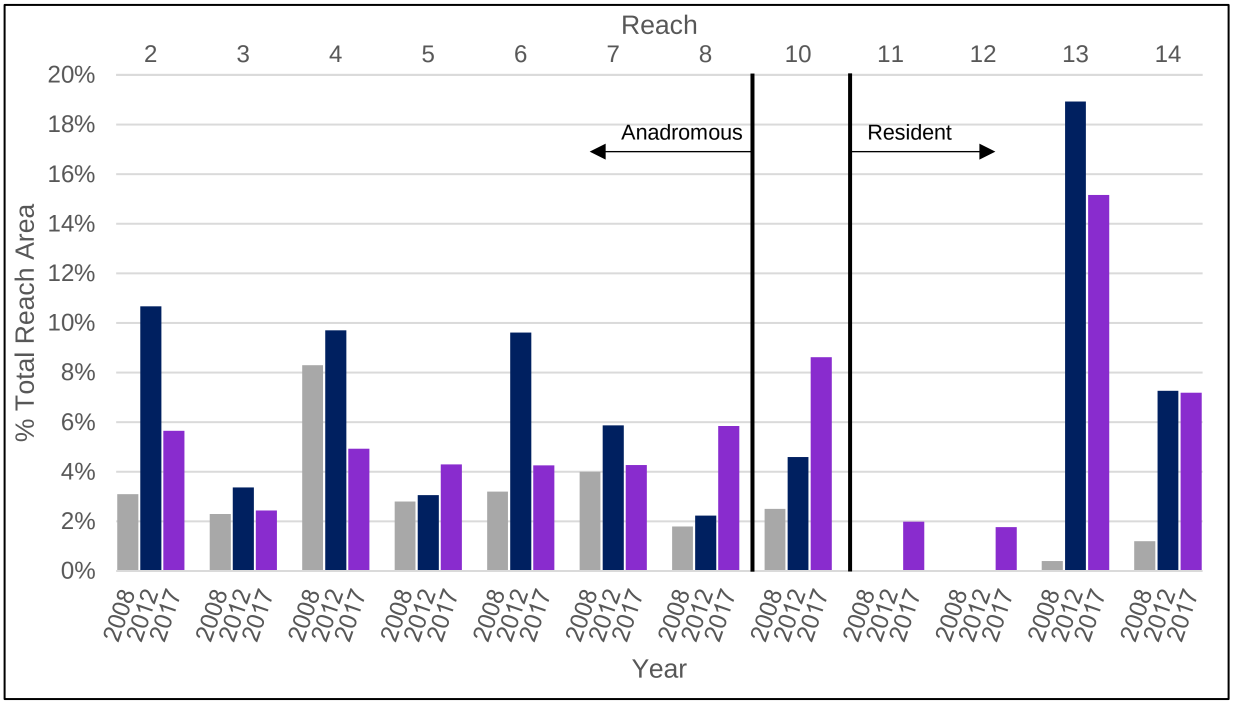


Figure 3-2: Area of Sparsely Vegetated Bars as a Percentage of Total Reach Area

Figure 3-3 shows the change in the proportion (%) of reach area for young islands for all three years of mapping. The proportion of young islands increased from 2008 to 2012 for most reaches. This includes Reaches: 3, 4, 6, 7, 8, 10, and 13. Except for Reaches 7 and 11, the proportion of young islands increased from 2012 to 2017 for all reaches.

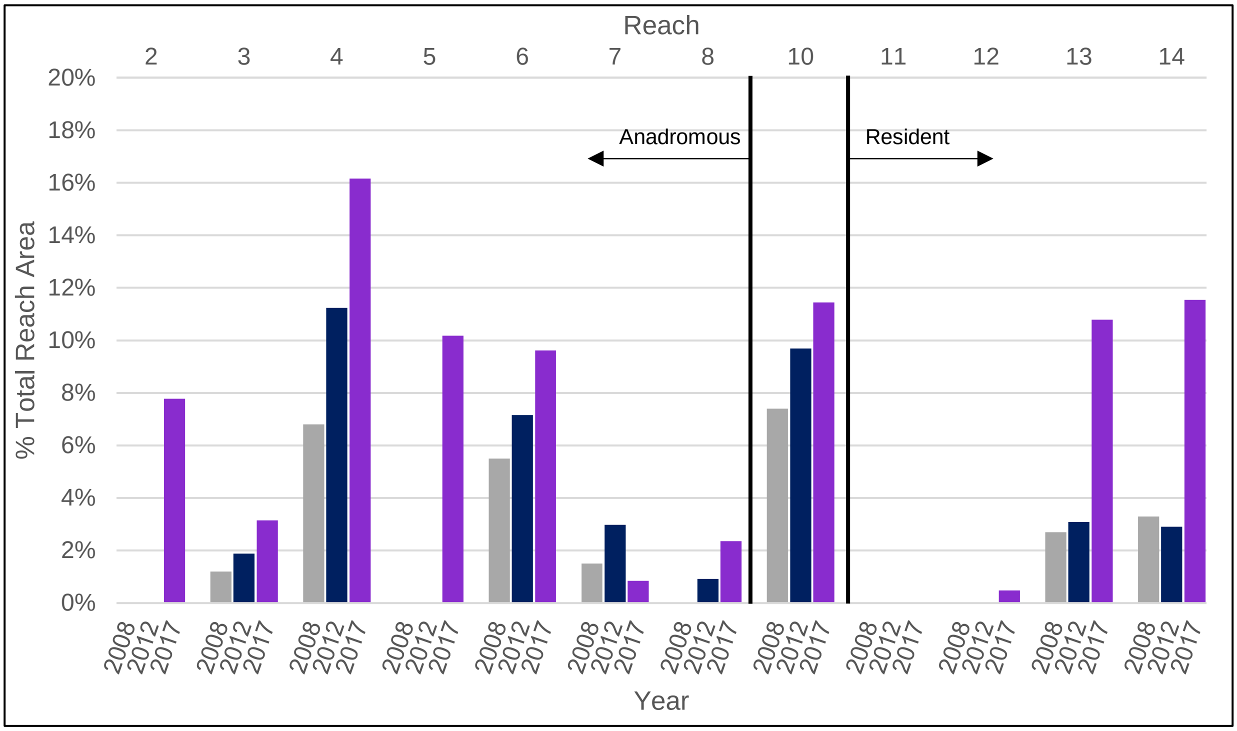


Figure 3-3: Area of Young Islands as a Percentage of Total Reach Area

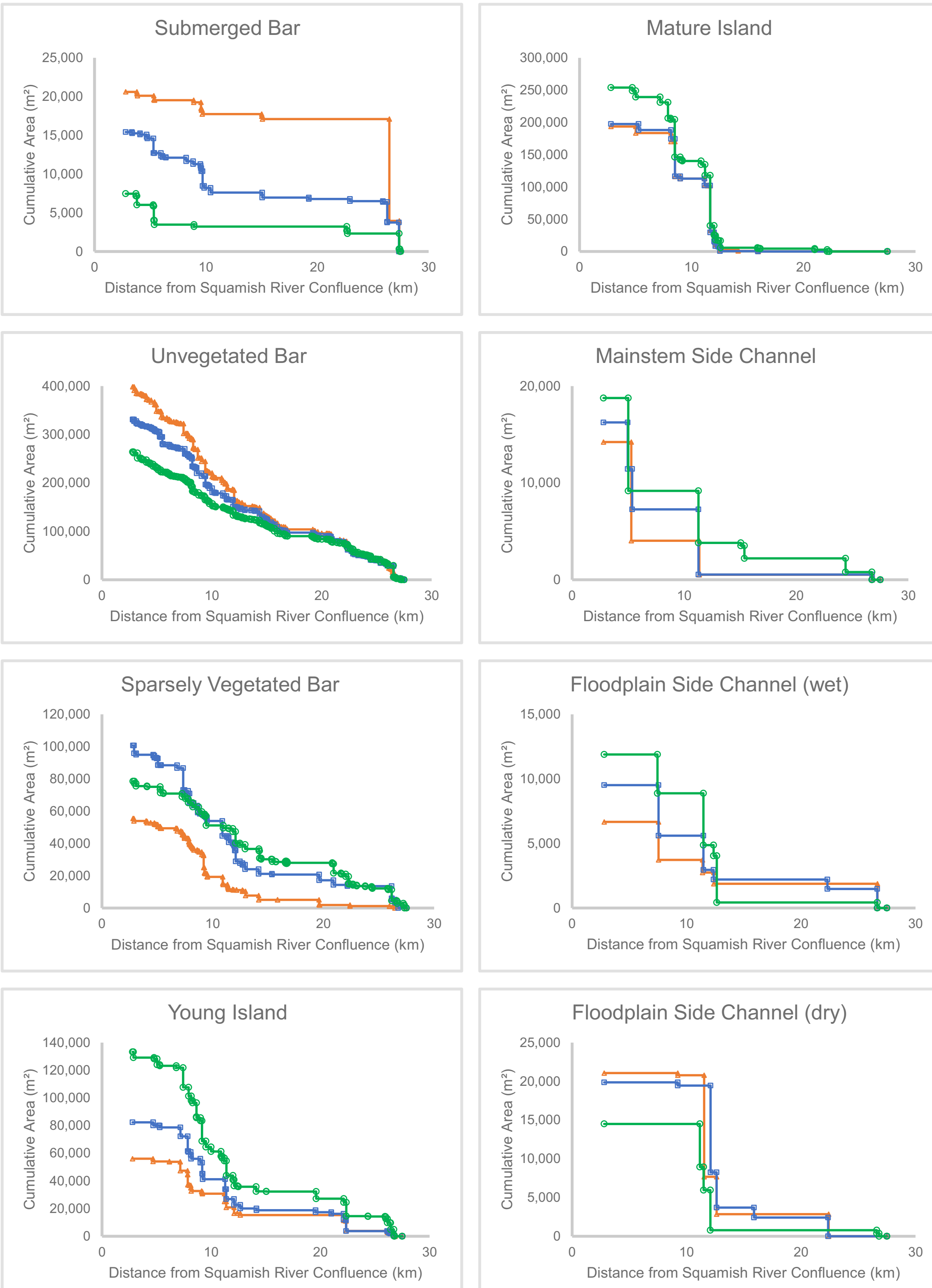
By Distance Upstream From Squamish River Confluence

To more clearly illustrate how the individual morphologies have changed over the period of study, and where these changes have occurred, the cumulative area of each geomorphic feature is plotted as a function of distance upstream from the Squamish River confluence in Figure 3-4. Refer to Figure 2-3 for the reach number and associated distance upstream from the Squamish River confluence.

The results from the morphology plots in Figure 3-4 are as follows:

- The submerged bar morphology shows a decrease in cumulative area from 2008 to 2017, with the reduction in submerged bar area occurring in Reach 14.
- The unvegetated bar morphology has steadily declined in area within Reaches 2 through 8 of the Cheakamus River study area from 2008 to 2017.
- The sparsely vegetated bar morphology shows an increase in area from 2008 compared to 2012 and 2017. In 2017, the sparsely vegetated bar shows an increase in area between Reaches 7 and 10 and a decrease in area between Reaches 2 and 4 in comparison to 2012 mapping.

- A steady increase in area of the young island morphology has occurred from 2008 to 2017, with most of the increase in area occurring in the lower reaches (2 through 6) within the anadromous section.
- The mature island morphology appears to have remained unchanged between 2008 and 2012. A slight increase in mature island morphology has occurred from 2012 to 2017 in the lower reaches (2 through 6).
- A steady increase in area of mainstem side channel morphology has occurred from 2008 to 2017.
- The floodplain side channel (wet) morphology has increased overall from 2008 to 2017; however, the area of wet side channels has decreased in Reach 14, but increased in the lower reaches (2 through 6).
- The floodplain side channel (dry) morphology appears to have remained fairly unchanged between 2008 and 2012. A decrease in dry side channel morphology has occurred from 2012 to 2017, in both the upper and lower reaches.



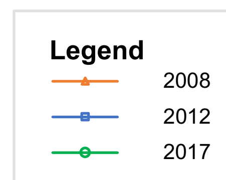


Figure 3-4:

Cumulative Area Associated with Geomorphic Features Starting at Daisy Lake and Proceeding Downstream as a Function of Chainage

3.2 Habitat Features

By Total Mapped Area

A summary of the mean area of each geomorphic habitat unit as a percentage of the mapped wetted channel for 2008, 2012 and 2017 is presented in Table 3-2. The areal extent of habitat features as a percentage of the mapped wetted channel in each reach is presented for all three years of mapping in Appendix B. Results of the habitat mapping within mainstem side channels are not presented separately as they were found to be nearly 100% riffle habitat over all three years of mapping.

A large increase in pool areas were observed between 2008 and 2012, with a small decline between 2012 and 2017 (Table 3-2). Riffle areas decreased from 2008 to 2012, then increased from 2012 to 2017. A steady decline in rapid areas occurred from 2008 through to 2017 (Table 3-2).

Table 3-2: Habitat Units as an Overall Percentage of the Wetted Channel

Habitat Unit	2008	2012	2017
Pool	13%	19%	17%
Riffle	69%	64%	71%
Rapid	18%	16%	12%

By Distance Upstream from Squamish River Confluence

The cumulative area of each geomorphic habitat unit is plotted as a function of channel chainage (distance upstream of Squamish River confluence) in Figure 3-5. Refer to Figure 2-3 for the reach number and associated chainage in kilometres.

The results from the morphology plots in Figure 3-5 are as follows:

- The area of pool habitat units has increased overall from 2008 to 2017, with a slight increase in pool area in the upper reaches (10 through 14) and a slight decrease in the lower reaches (2 through 8) from 2012 to 2017.
- The area of riffle habitat units has remained consistent in the upper reaches (10 through 14) of the Cheakamus River study area from 2008 to 2017. A slight increase in riffle area has occurred in the lower reaches (2 and 3) from 2012 to 2017.
- The area of rapid habitat units has declined in 2017 from 2008 and 2012 mapping results. Most of this decline in rapid area occurred in Reaches 11 and 12.

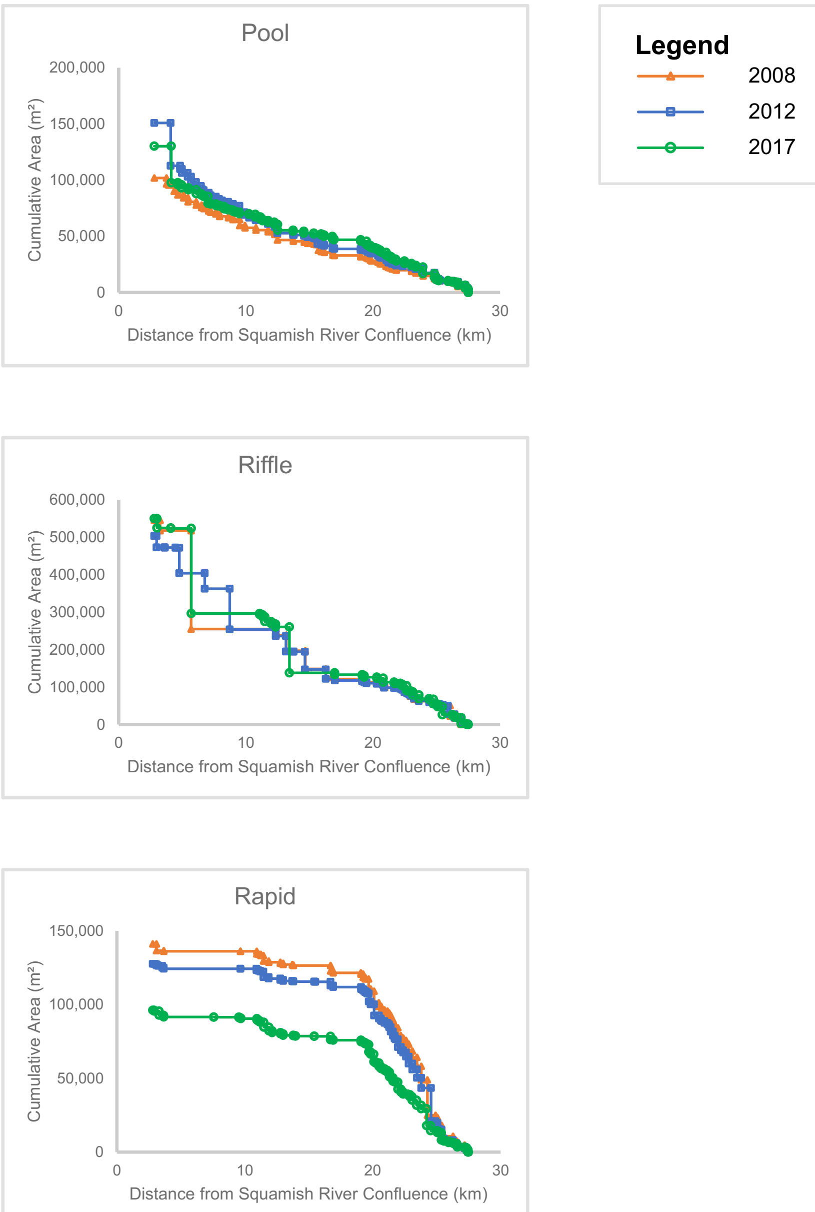


Figure 3-5: Cumulative Area Associated with Habitat Units Starting at Daisy Lake and Proceeding Downstream as a Function of Channel Chainage

3.2.1 Statistical Significance

To determine if the changes observed here are statistically significant, tests were conducted on the mean area and variance values of each morphology and habitat unit across each mapping year. The mean feature size was chosen as an indicator of morphological change, while the variance was chosen as an indicator of channel complexity. A positive change in variance indicates that the channel is becoming more complex, while a negative change indicates that the channel is becoming more homogeneous. The number and mean areal extent of each morphological unit observed in the three years of channel mapping are summarized in Table 3-3. The number and areal variance of each morphological unit are summarized in Table 3-4.

The mean and variance of each morphological unit were compared between 2008 and 2017, and 2012 and 2017. To carry out the statistical tests, the areal extent of each individual morphological unit was logarithmically transformed. Two sample t-tests and F-tests were performed on the transformed datasets and are presented in Appendix C. A summary of the statistical results comparing 2008 and 2017 is included in Table 3-3 and Table 3-4 below. As noted in Table 3-3 and Table 3-4, very few of the comparisons between mapping years were found to be statistically significant.

Note that habitat statistics are presented below for the entire wetted channel. Habitat statistics have not been separately presented for mainstem side channels as habitat was found to be nearly 100% riffles in all three years of mapping. The mean and variance of all geomorphic and habitat units are shown for comparison in Figure 3-6.

Table 3-3: Mean Area Statistics for Morphological and Habitat Features[1]

Feature	2008		2012		2017		2008 to 2017 Trend	Stat. Significant?
	N	Mean (m²)	N	Mean (m²)	N	Mean (m²)		
Morphological Features								
Submerged Bar	13	1.6E+03	25	6.2E+02	10	7.5E+02	Negative	No
Unvegetated Bar	201	2.0E+03	176	1.9E+03	171	1.5E+03	Negative	No
Sparsely Vegetated Bar	94	5.9E+02	56	1.8E+03	49	1.6E+03	Positive	**Yes**
Young Island	25	2.2E+03	28	2.9E+03	38	3.5E+03	Positive	No
Mature Island	16	1.2E+04	14	1.4E+04	25	1.0E+04	Negative	No
Mainstem Side Channel	3	4.7E+03	4	4.1E+03	6	3.1E+03	Negative	No
Floodplain Side Channel (wet)	4	1.7E+03	5	1.9E+03	5	2.4E+03	Positive	No
Floodplain Side Channel (dry)	5	8.4E+03	5	4.0E+03	5	2.9E+03	Negative	No
Habitat Features[2]								
Pool	61	1.7E+03	65	2.3E+03	65	2.0E+03	Positive	No
Riffle	31	1.8E+04	38	1.3E+04	37	1.5E+04	Negative	No
Rapid	51	2.8E+03	57	2.2E+03	63	1.5E+03	Negative	**Yes**

Notes:
1. N = sample size
2. Habitat features statistics are presented for the overall low-flow wetted channel

Table 3-4: Mean Areal Variance Statistics for Morphological and Habitat Features

Feature	2008		2012		2017		2008 to 2017 Trend	Stat. Significant?
	N	Variance	N	Variance	N	Variance		
Morphological Features								
Submerged Bar	13	0.41	25	0.32	10	0.14	Negative	No
Unvegetated Bar	201	0.47	176	0.52	171	0.43	Negative	No
Sparsely Vegetated Bar	94	0.48	56	0.49	49	0.22	Negative	**Yes[2]**
Young Island	25	0.32	28	0.44	38	0.41	Positive	No
Mature Island	16	0.50	14	0.57	25	0.75	Positive	No
Mainstem Side Channel	3	0.43	4	0.25	6	0.30	Negative	No
Floodplain Side Channel (wet)	4	0.06	5	0.11	5	0.19	Positive	No
Floodplain Side Channel (dry)	5	0.50	5	0.29	5	0.34	Negative	No
Habitat Features[3]								
Pool	61	0.12	65	0.17	65	0.15	Positive	No
Riffle	31	0.41	38	0.52	37	0.39	Negative	No
Rapid	51	0.25	57	0.28	63	0.22	Negative	No

Notes:
1. N = sample size
2. Results also statistically significant between 2012 and 2017
3. Habitat feature statistics are presented for the overall low-flow wetted channel

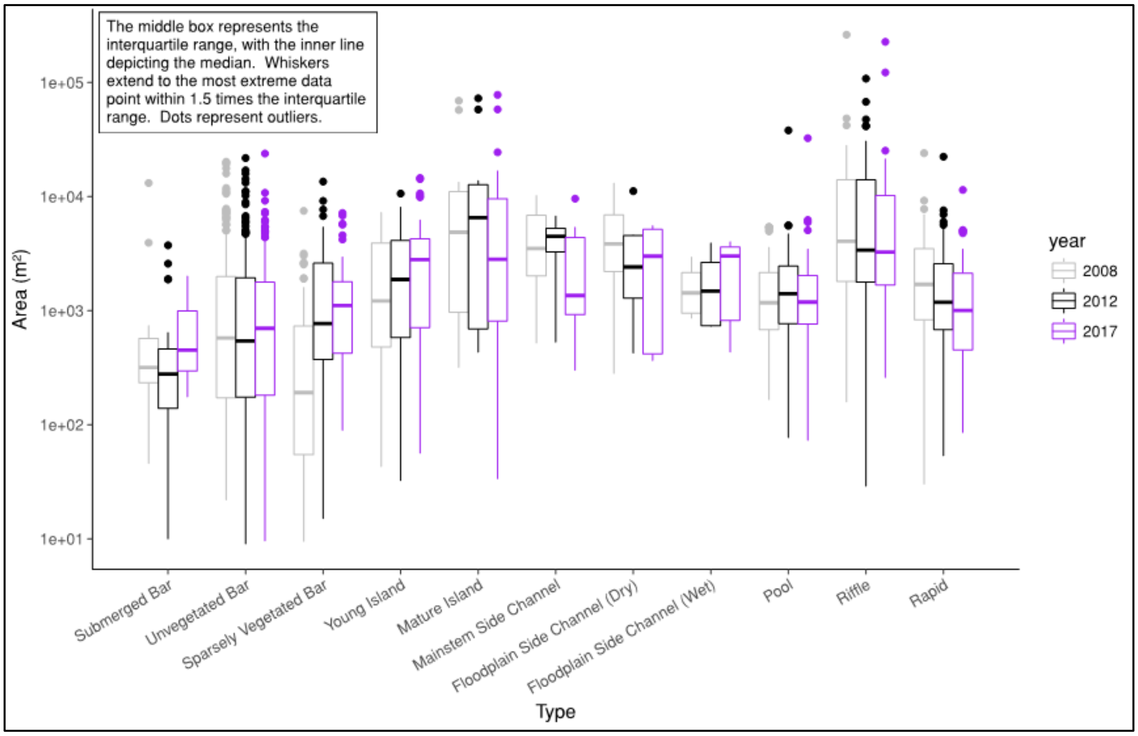


Figure 3-6: Box Plot Illustrating Area of Each Habitat and Morphological Unit in 2008, 2012 and 2017

Morphological Features

Between 2008 and 2017 the average areal extent and variance of mainstem side channels has decreased, but the number of mainstem side channels has increased. Over the same period, floodplain side channels (dry) have decreased in average areal extent and variance, while floodplain side channels (wet) have increased (Table 3-3, Table 3-4.) These changes were not found to be statistically significant.

All bar morphologies have decreased in number and areal variance over the period 2008 to 2017. Submerged and unvegetated bars have decreased in mean areal extent, while sparsely vegetated bars have increased. Only the increase in mean size of sparsely vegetated bars was found to be statistically significant.

Both young and mature island morphologies have increased in number and areal variance over the period 2008 to 2017. The mean areal extent of young islands has increased over the study period, while the mean areal extent of mature islands has decreased. These changes were not found to be statistically significant.

Habitat Features

The number of pools, riffles, and rapids identified within the low-flow wetted channel have all increased over the study period. Pools have increased in mean areal extent and variance, while riffles and rapids have decreased. Only the decrease in the mean areal extent of rapids was found to be significant; however, as mentioned previously, the decrease in areal extent of rapids is likely due to interpretive differences. When comparing the mean area of rapids from 2012 to 2017, the change was not found to be significant.

3.3 Discussion

3.3.1 Channel Morphology

The results in the Year 5 Cheakamus River channel morphology study suggested that the channel was stabilizing between 2008 and 2012 (NHC 2014). The loss of unvegetated gravel bars, and the gain in sparsely vegetated gravel bars in the lower reaches of the Cheakamus River (2 through 6), was attributed to young vegetation colonizing formerly bare bars between 2008 and 2012.

The total area of unvegetated bars has continued to decline in nearly all reaches over the 2008 to 2017 period (Figure 3-1, Figure 3-4). The reduction in unvegetated bar area could be attributed to two factors simultaneously at play:

1. stabilization of bars as vegetation continues to colonize, and
2. erosion of gravel bar material caused by high flow events.

The most likely cause of the reduction in unvegetated bar area is the colonization of vegetation over formerly unvegetated areas. While the total area of unvegetated bars has decreased over the study period, this has been paralleled with an increase in the total area of sparsely vegetated bar and young island morphologies (Figure 3-2, Figure 3-3, and Figure 3-4). The total area of sparsely vegetated bars has actually decreased slightly from 2012 to 2017 (still up from 2008), but this was met with an increase in the area of young islands (Table 3-1, Figure 3-4). The distinction between these two features is based on vegetation gradation and therefore is not as definitive as, for example, the distinction between unvegetated bars and sparsely vegetated bars. Looking at the combined area of sparsely vegetated bars and young islands, there has been an increase over both the 2012 to 2017 period, and the overall 2008 to 2017 period. The apparent increase in young island morphology that occurred from 2012 to 2017 is most likely responsible for the loss, or lack of areal increase, in sparsely vegetated bars.

Based on a visual comparison of mapping between years it was noted that some localized unvegetated bars at the edges of the main channel, or on the outskirts of larger bars and islands, were not observed in later years. The five flow events (Figure 2-4) that reached and/or exceeded the threshold to initiate the mobilization of sediment (KWL 2017) between 2012 and 2017 along the Cheakamus River support the hypothesis that localized erosion of gravel bars may have taken place. Sediment erosion from the same threshold flow events could also be partly responsible for the slight loss in area of sparsely vegetated bars. Note that this analysis does not allow us to determine whether there has been a net loss in sediment. While some gravel bars appear to have spatially eroded, it could be that the sediment has been vertically redistributed within the channel.

The total area of submerged bars has declined from 2008 to 2017 (Figure 3-4). It is possible that bars previously identified as submerged were not identified as such in later mapping due to differences in flows at the time orthophotos were taken (Table 2-1). Whether this trend is real or observed, submerged bars make up only a small fraction of the channel and therefore the loss of even a single bar can have a large effect on the measured area of this feature.

The total area and number of mainstem side channels has increased over the study period (Figure 3-4, Table 3-3). This increase is further evidence of channel stabilization; as bars vegetate and become islands, this results in the formation of mainstem side channels (i.e. as opposed to flow simply dividing around a gravel bar).

The total area of floodplain side channels (wet) has increased from 2008 to 2017, while the total area of floodplain side channels (dry) has declined from 2008 to 2017 (Figure 3-4) the combined area of wet and dry floodplain side channels has remained relatively constant over the study period (Figure 3-4).

The change in total area of wet versus dry floodplain side channels may be a result of differences in flows at the time of orthophotography (Table 2-1). This is supported by Table 3-3 as there has been an increase in the mean area of wet floodplain side channels and a decrease in the mean area of dry floodplain side channels, but the number of features has remained nearly constant.

Although it is hypothesized that high flow events that occurred between 2012 and 2017 may have contributed to localized erosion and loss of bare gravel bar area, it is likely that the overall reduction of unvegetated bar area can be attributed to the gradual colonization of vegetation as evidenced by the increased area of sparsely vegetated bars, young and mature islands, and mainstem side channels. This reinforces the trend identified in the Year 5 Geomorphology Report that the overall stability of the channel is increasing.

3.3.2 Habitat Units

Riffles made up the largest proportion of the wetted channel in all three years of mapping (Table 3-2). The total area of riffle habitat has not changed significantly over the study period. Riffle features are found in long, uninterrupted stretches, particularly in the river valley (Reach 2 to Reach 8) where the channel gradient is lower. Since the majority of mainstem side channels are found in Reach 2 to Reach 8, it follows that riffles are the primary habitat found within these features.

The total area of rapids within the wetted channel has decreased over the study period (Figure 3-5). Rapids are most prevalent in the bedrock canyon (located in the steep upper reaches of the channel), and limited in the lower reaches, particularly in Reaches 3 through 5. The total areal extent of rapids has declined by nearly a third from 2008 to 2017, though this decline is localized to Reaches 11 and 12 in the bedrock canyon (Figure 3-5). Due to shadows, habitat mapping of the narrow canyon was difficult. It is likely that the apparent decline in rapid areas for Reaches 11 and 12 is mostly due to interpretive differences, and not related to actual habitat morphology changes. The statistically significant decrease in the mean areal extent of rapids is likely associated with this interpretive error (Table 3-3).

In the upper reaches of the channel (10 to 14), pools are generally found downstream of rapids and span the width of the wetted channel; in the lower reaches (2 to 8), pools are more often isolated features found along one side of the channel. Since 2012, the total area of pools has increased in the upper reaches (10 to 14), but decreased in the lower reaches (2 to 8) (Figure 3-5). This finding could be explained by a gradual downstream transfer of sediment, which may have been initiated by the threshold flow events that occurred through the period 2012 to 2017.

3.3.3 Review of MQ2

As mentioned previously, the original methodology developed in Years 1 and 5 of the monitor did not lend itself to directly addressing MQ2. Adjustments were made to the original methodology to attempt to provide a more complete answer, but some gaps still exist. This section relates the analysis presented above back to the management question:

> *Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?*

Total length of natural side channel habitat was not analyzed as part of this study; however, total area of side channels was analyzed from year to year, and is thought to be a better indicator of habitat availability than length. For example, vegetation encroachment may decrease the area of available side channel habitat, while total length may remain unchanged. **From the analysis presented above it may be concluded that the total area of natural side channel habitat has increased following implementation of the WUP (Figure 3-4).**

Natural side channel habitat was mapped for mainstem side channels, which are located within the main wetted channel. Riffles were found to be the primary habitat present within mainstem side channels for all three years of mapping. The narrow width of floodplain side channels, and presence of overhanging vegetation, meant that identification of individual habitat units was not possible for these features. **Based on the review of the mapping for all three years, the diversity of natural, mainstem side channel habitat has remained nearly 100% riffle habitat and has therefore not changed significantly following implementation of the WUP.**

Access to natural side channel habitat cannot be determined by the methodology followed in this study. Orthophotos were taken at relatively similar flows in order to ensure consistency in the analysis between years. Therefore, the flows at which side channels become activated, and how this may have changed over the period of study, cannot be directly addressed. As such, the question of changes in side channel access related to WUP vs. IFA flow regimes may warrant future work.

KWL previously estimated the required flows for sediment mobilization (KWL, 2017). Channel forming flows are estimated to exceed 270 m^3/s, while WUP flow targets are 38 m^3/s and less. Considering this finding, it is unlikely that erosion of channel features is because of WUP flows. However, not all morphological changes may be caused by high erosive flows. For example, colonization of shrubs may be impeded by sustained inundation at lower flows during the growing season. Conclusions about whether the WUP flow targets may have had such an effect on morphological changes is beyond the scope of this study.

This work provides a partial answer to MQ2, and provides valuable information about morphological changes and availability of fish habitat.

4. Summary and Conclusions

Year 10 of the CMSMON8 project set out to answer the following management question:

Following implementation of the WUP, has there been a change in the total length, diversity and access of natural side channel habitat from the present state, and if so, can this change be clearly attributed to Daisy Lake Dam operations or to other environmental or anthropogenic factors?

To answer this question, the areal extent of geomorphic and habitat features was delineated in 2008, 2012, and 2017, and compared using statistical analysis methods to determine whether changes since implementation of the WUP could be considered significant. The present study adjusts the original mapping methodology to more directly address MQ2.

4.1 Summary

Findings of the analysis include the following:

- The total area and number of mainstem side channels has increased over the study period (Figure 3-4, Table 3-3).
- The total area of floodplain side channels (wet) has increased from 2008 to 2017, while the total area of floodplain side channels (dry) has declined; the combined area of wet and dry floodplain side channels has remained relatively constant (Figure 3-4). Differences in the proportion of wet vs. dry floodplain side channels may be due to differences in flows at the time of orthophotography (Table 2-1).
- Riffles are the most dominant habitat unit by area (Table 3-2); the overall area of riffles has remained relatively constant over the study period (Figure 3-5).
- Riffles make up nearly 100% of the habitat found within mainstem side channels; this trend has remained constant over the study period (Section 3.2).
- The total area and mean areal extent of rapids has decreased over the study period (Figure 3-5, Table 3-3); however, this is believed to be related to interpretive error due to poor orthophoto image quality in the canyon areas.
- Since 2012, the area of pools has increased in the upper reaches (10 to 14) and decreased in the lower reaches (2 to 8), which is indicative of downstream sediment transfer initiated through threshold flow events (Figure 3-5, Figure 2-4).
- The decrease in total area and number of bar features, and the increase in total area and number of young and mature islands, and mainstem side channels, suggests that the Cheakamus River continues to stabilize over time (Figure 3-4, Figure 3-5, and Table 3-3).
- The increase in the mean areal extent and decrease in mean areal variance of sparsely vegetated bars were found to be statistically significant over the study period (Table 3-3, Table 3-4) which is indicative of consolidation of features and further evidence of channel stabilization.
- Five flow events between 2012 and 2017 that exceeded the 270 m^3/s threshold for mobilization (KWL 2017), in combination with the observed loss in area of unvegetated gravel bars, suggest that erosion of gravel material in the lower reaches of the Cheakamus River may have occurred.

4.2 Conclusion

Based on the statistical analyses of the geomorphic and habitat mapping, and supported by the findings listed above, CMSMON8 concludes that following implementation of the WUP:

- the total area of natural side channels has increased; and
- the diversity of natural, mainstem side channels as measured by the area of pool, riffle, and rapid habitat units has not significantly changed.

The question of whether access to natural side channel habitat may have changed as a result of the WUP could not be answered by the current study, but will be further investigated in CMSMON1b and the CMS Stranding Protocol work.

Report Submission

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This document is a copy of the sealed and signed hard copy original retained on file. The content of the electronically transmitted document can be confirmed by referring to the filed original.

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Revision History

Revision #	Date	Status	Revision	Author
0	May 16, 2018	FINAL	Issued as final	SMS

OQM CERTIFIED

References

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Appendix A

Photos – Site Visit (Oct 13, 2017)

Photo A-1: Rapids with protruding boulders

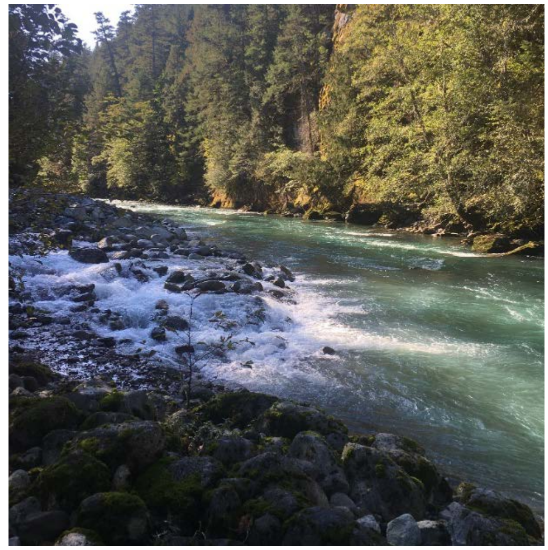

Photo A-2: An unvegetated bar (left) adjacent to a riffle section

Photo A-3: A riffle section

Photo A-4: Channel encroaching on floodplain, but no evidence of erosion

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Appendix B

Detailed Tables and Figures

Table B-1: Geomorphic Mapping by Reach

Reach	Wetted Channel	Un-vegetated Bar	Sparsely Vegetated Bar	Young Island	Mature Island	Mainstem Side Channel	Floodplain Side Channel (wet)	Floodplain Side Channel (dry)
2008 Data								
2	66%	31%	3%	0%	0%	0%	0%	0%
3	54%	31%	2%	1%	6%	6%	0%	0%
4	39%	36%	11%	9%	5%	0%	1%	0%
5	65%	32%	3%	0%	0%	0%	0%	0%
6	22%	20%	3%	6%	42%	1%	0%	5%
7	65%	13%	4%	1%	10%	0%	1%	6%
8	64%	32%	2%	0%	2%	0%	0%	0%
10	62%	26%	2%	7%	0%	0%	0%	2%
11	83%	17%	0%	0%	0%	0%	0%	0%
12	80%	20%	0%	0%	0%	0%	0%	0%
13	60%	37%	0%	3%	0%	0%	0%	0%
14	46%	47%	1%	3%	0%	1%	2%	0%
Average	59%	29%	3%	3%	5%	1%	0%	1%
2012 Data								
2	65%	25%	11%	0%	0%	0%	0%	0%
3	59%	26%	4%	2%	5%	5%	0%	0%
4	31%	22%	10%	12%	23%	0%	1%	0%
5	58%	38%	3%	0%	0%	0%	0%	0%
6	19%	12%	10%	8%	43%	3%	1%	5%
7	68%	7%	6%	3%	9%	0%	1%	6%
8	64%	32%	2%	1%	0%	0%	0%	1%
10	60%	23%	5%	10%	0%	0%	0%	2%
11	80%	20%	0%	0%	0%	0%	0%	0%
12	80%	20%	0%	0%	0%	0%	0%	0%
13	58%	20%	19%	3%	0%	0%	0%	0%
14	49%	38%	7%	3%	0%	1%	2%	0%
Average	58%	24%	6%	3%	7%	1%	0%	1%
2017 Data								
2	56%	30%	6%	8%	0%	0%	0%	0%
3	60%	21%	3%	3%	8%	5%	0%	0%
4	32%	15%	5%	17%	30%	0%	1%	0%
5	64%	21%	4%	10%	0%	0%	0%	0%
6	20%	8%	4%	10%	49%	2%	2%	5%
7	66%	9%	4%	1%	15%	0%	5%	0%
8	66%	23%	6%	2%	1%	1%	0%	0%
10	61%	16%	9%	11%	3%	0%	0%	0%
11	75%	23%	2%	0%	0%	0%	0%	0%
12	75%	20%	2%	0%	0%	2%	0%	0%
13	47%	27%	15%	11%	0%	0%	0%	0%
14	45%	33%	7%	12%	0%	1%	1%	1%
Average	56%	21%	6%	7%	9%	1%	1%	1%

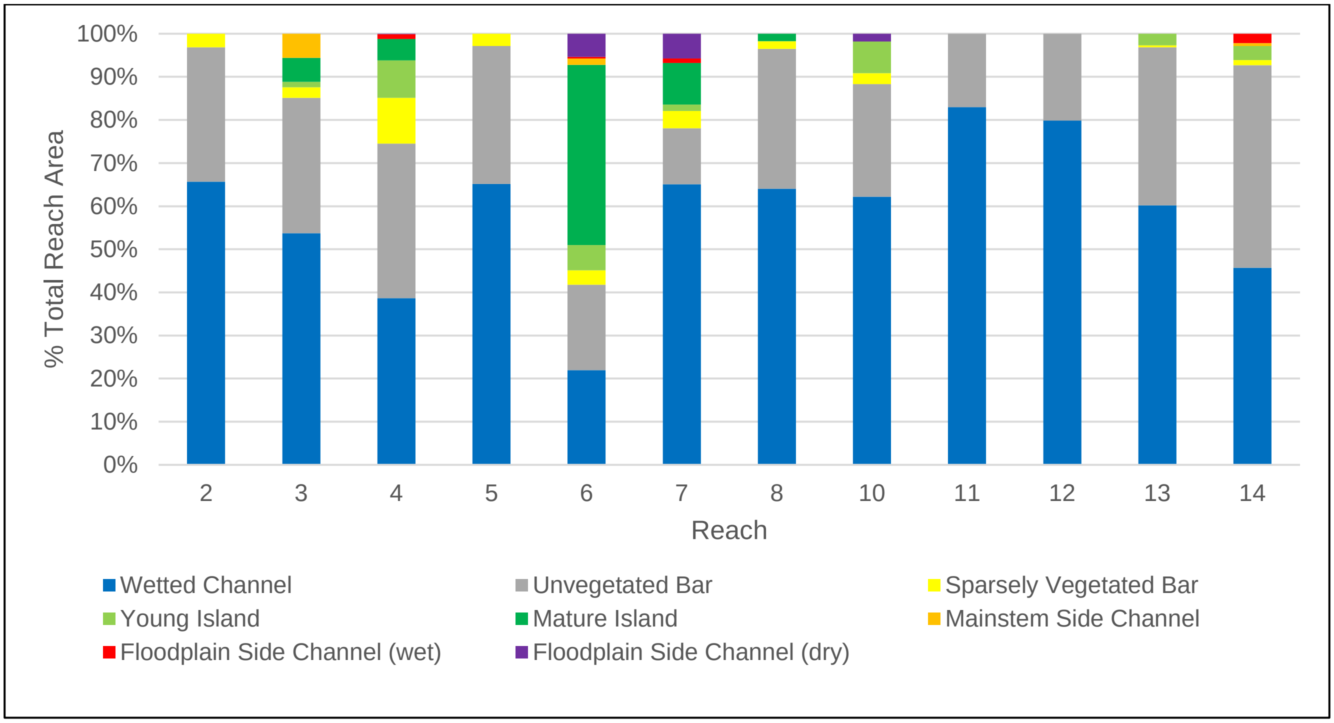

Figure B-1: 2008 Cheakamus River Geomorphic Mapping

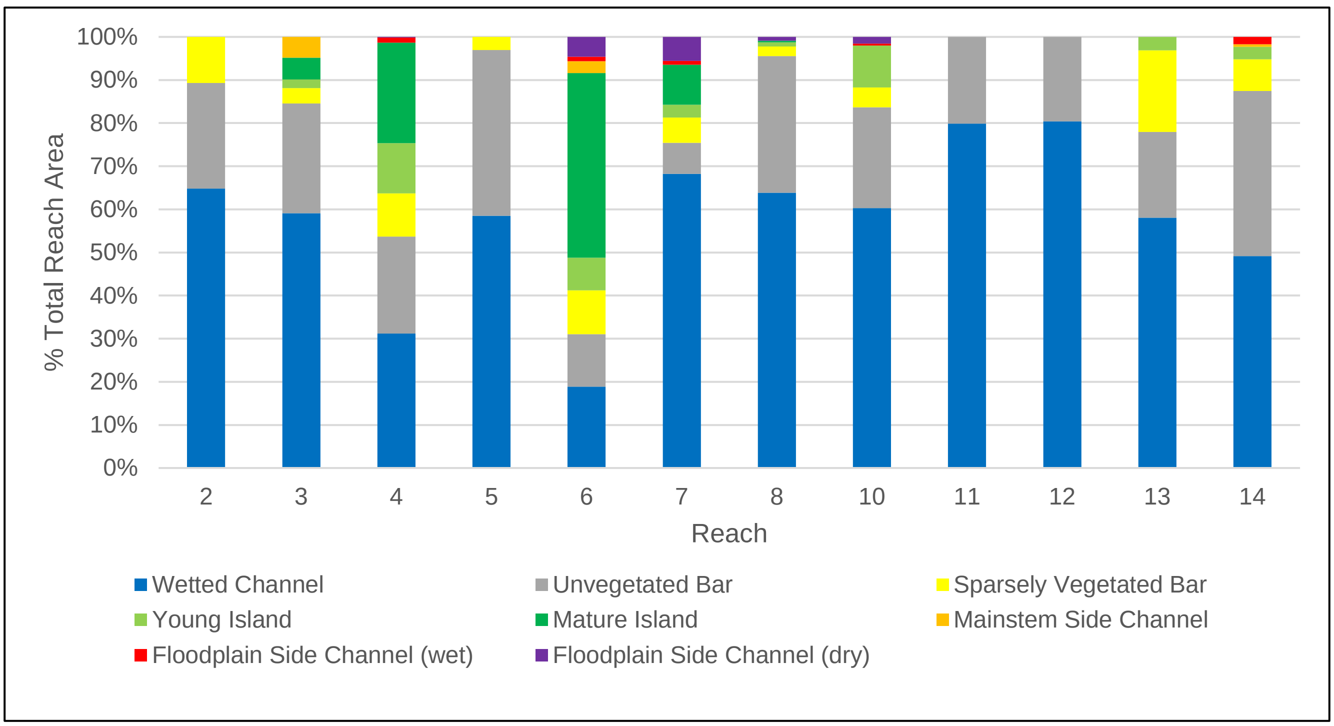

Figure B-2: 2012 Cheakamus River Geomorphic Mapping

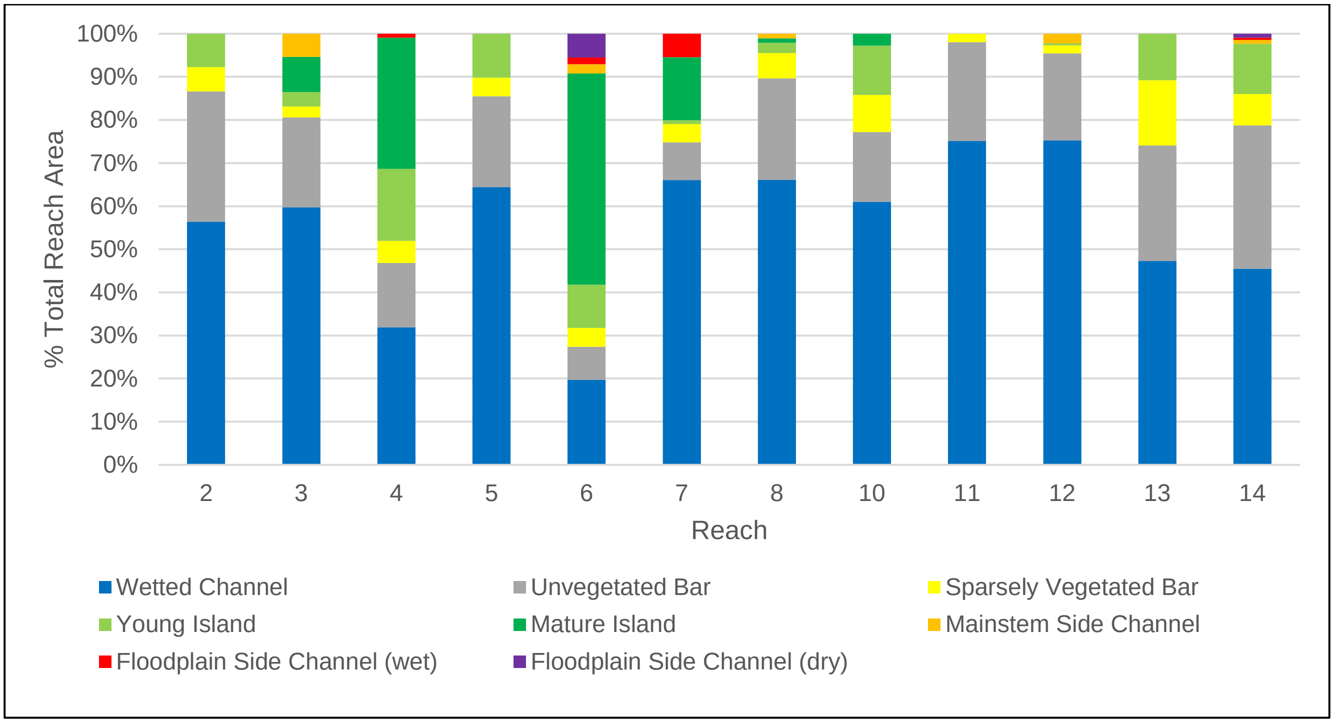

Figure B-3: 2017 Cheakamus River Geomorphic Mapping

Table B-2: Summary of Habitat Units by Reach

Reach	Pool	Riffle	Rapid
2008 Data			
2	2%	83%	15%
3	21%	79%	0%
4	11%	89%	0%
5	15%	85%	0%
6	9%	79%	12%
7	11%	86%	3%
8	14%	81%	6%
10	14%	37%	50%
11	9%	40%	52%
12	8%	33%	59%
13	4%	92%	4%
14	23%	54%	24%
Average	12%	70%	19%
2012 Data			
2	1%	90%	10%
3	46%	54%	0%
4	16%	84%	0%
5	24%	76%	0%
6	14%	75%	11%
7	13%	84%	3%
8	13%	82%	4%
10	17%	33%	50%
11	10%	41%	49%
12	14%	30%	56%
13	3%	93%	4%
14	22%	61%	17%
Average	16%	67%	17%
2017 Data			
2	1%	84%	15%
3	34%	66%	0%
4	15%	85%	0%
5	4%	94%	2%
6	15%	69%	16%
7	11%	86%	3%
8	8%	89%	3%
10	22%	39%	39%
11	17%	53%	30%
12	12%	55%	33%
13	5%	88%	7%
14	24%	61%	15%
Average	14%	72%	14%

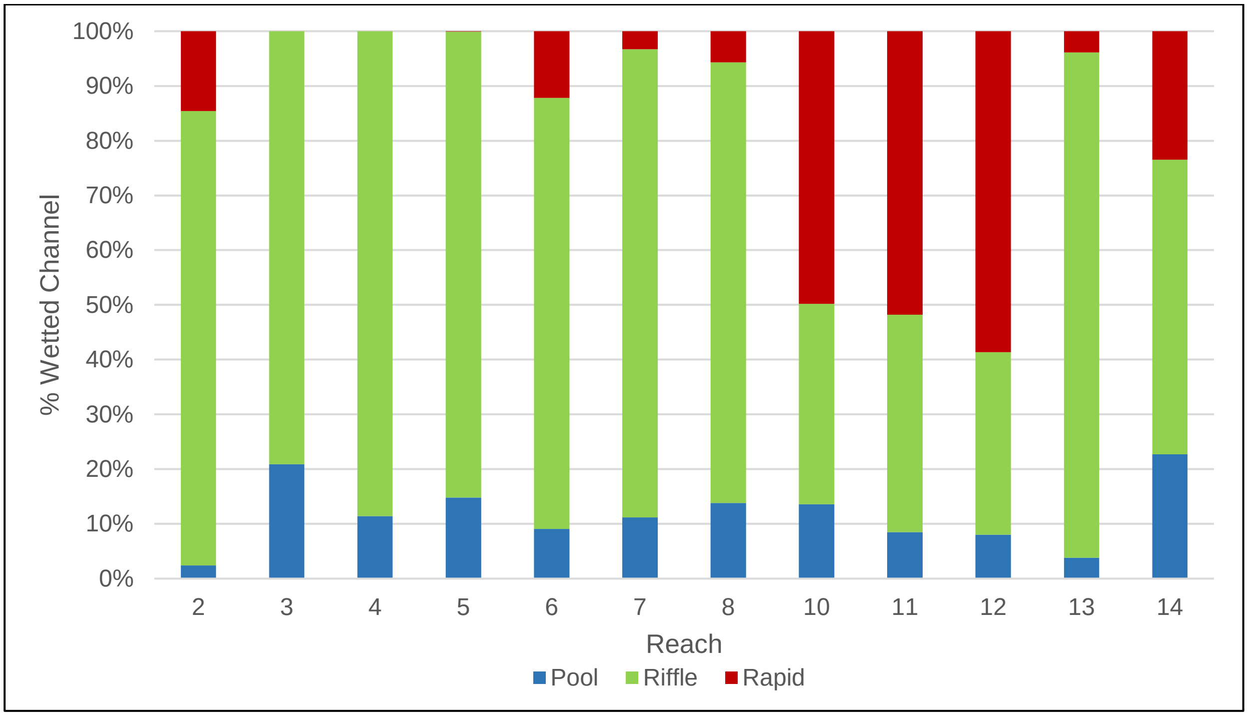

Figure B-4: 2008 Cheakamus River Habitat Units

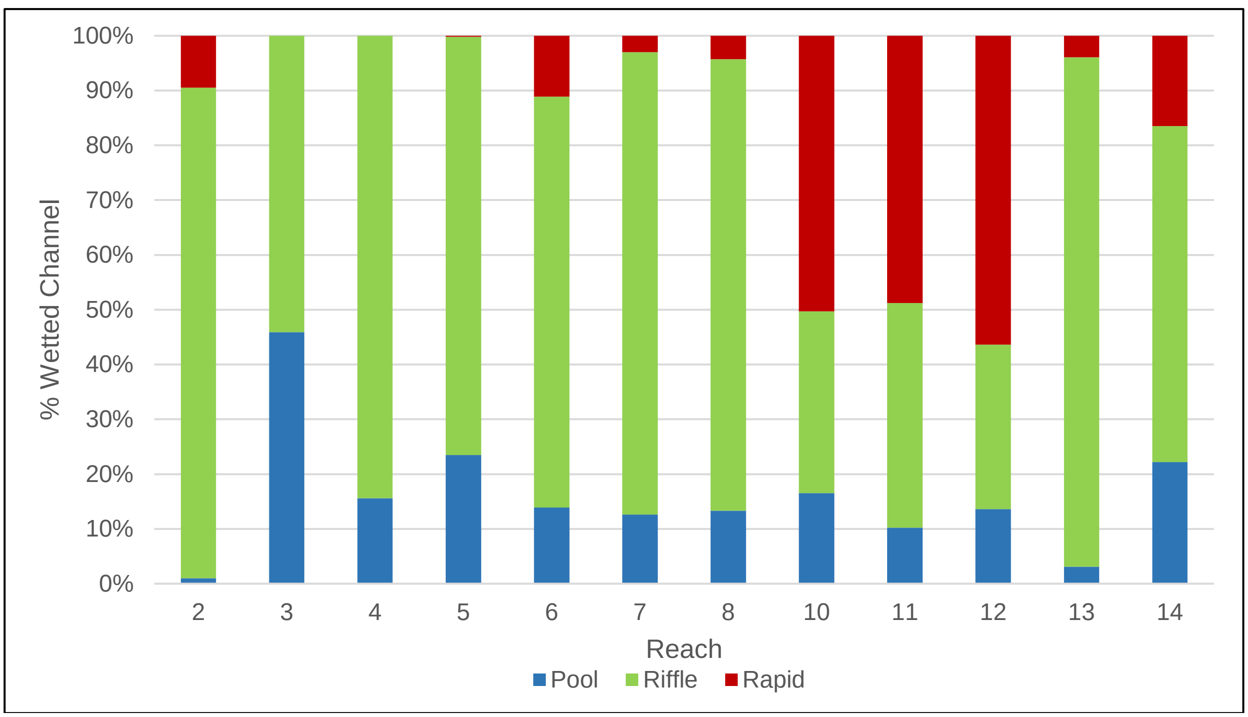

Figure B-5: 2012 Cheakamus River Habitat Units

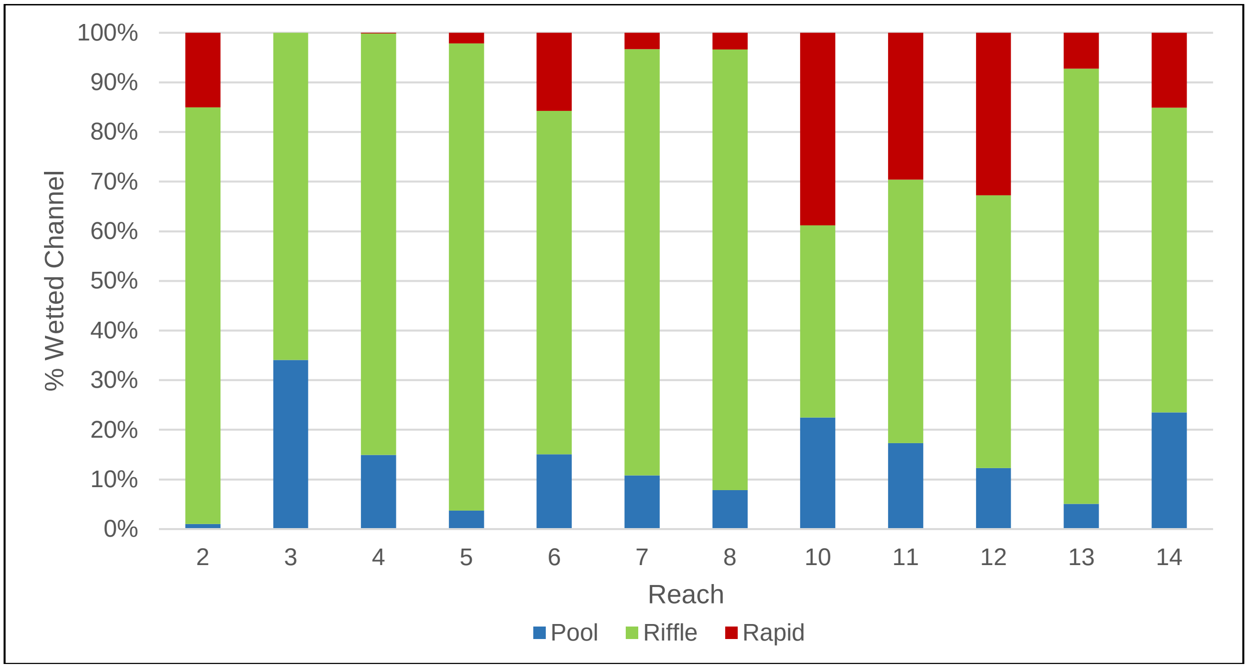

Figure B-6: 2017 Cheakamus River Habitat Units

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Appendix C

Statistical Output

Submerged Bars

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	2.624098782	2.724894216
Variance	0.412301906	0.136275678
Observations	13	10
Pooled Variance	0.294004951	
Hypothesized Mean Difference	0	
df	21	
t Stat	-0.44194813	
P(T<=t) two-tail	0.663044463	
t Critical two-tail	2.079613845	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	2.624098782	2.724894216
Variance	0.412301906	0.136275678
Observations	13	10
Hypothesized Mean Difference	0	
df	20	
t Stat	-0.47335314	
P(T<=t) two-tail	0.641086947	
t Critical two-tail	2.085963447	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	2.624098782	2.724894216
Variance	0.412301906	0.136275678
Observations	13	10
df	12	9
F	3.025498845	
P(F<=f) two-tail	0.104557715	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	2.445672005	2.724894216
Variance	0.322023607	0.136275678
Observations	25	10
Pooled Variance	0.271365081	
Hypothesized Mean Difference	0	
df	33	
t Stat	-1.43254728	
P(T<=t) two-tail	0.1613928	
t Critical two-tail	2.034515297	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	2.445672005	2.724894216
Variance	0.322023607	0.136275678
Observations	25	10
Hypothesized Mean Difference	0	
df	26	
t Stat	-1.714973	
P(T<=t) two-tail	0.098247158	
t Critical two-tail	2.055529439	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	2.445672005	2.724894216
Variance	0.322023607	0.136275678
Observations	25	10
df	24	9
F	2.363030669	
P(F<=f) two-tail	0.180745147	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

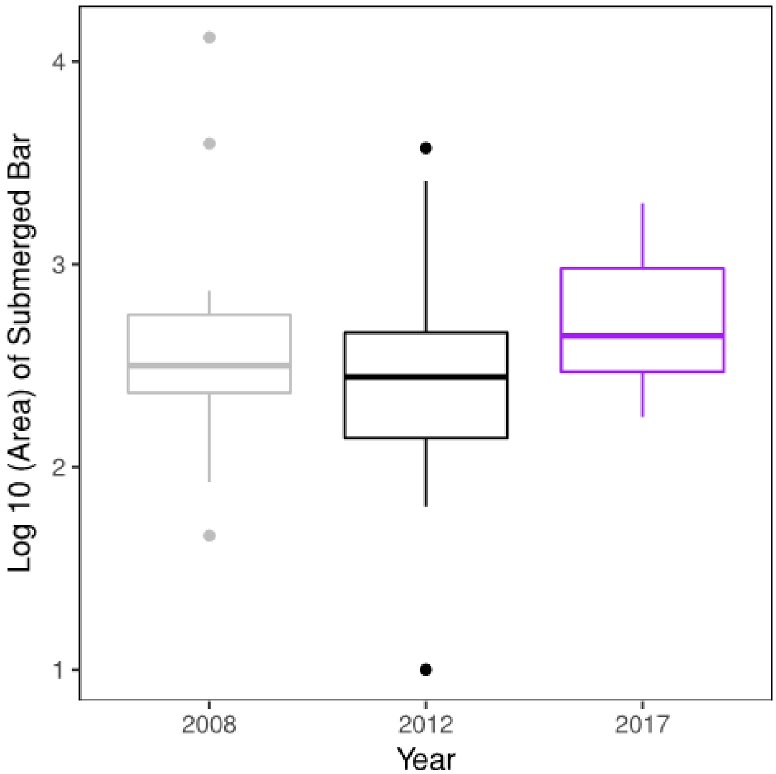

Figure C-1: Box Plot of log (10) Area of Submerged Bars

Unvegetated Bars

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	2.796023607	2.768977193
Variance	0.467788525	0.429089458
Observations	201	171
Pooled Variance	0.450007873	
Hypothesized Mean Difference	0	
df	370	
t Stat	0.387546895	
P(T<=t) two-tail	0.698574215	
t Critical two-tail	1.966396196	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	2.796023607	2.768977193
Variance	0.467788525	0.429089458
Observations	201	171
Hypothesized Mean Difference	0	
df	365	
t Stat	0.388901452	
P(T<=t) two-tail	0.697575817	
t Critical two-tail	1.966484596	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	2.796023607	2.768977193
Variance	0.467788525	0.429089458
Observations	201	171
df	200	170
F	1.090188808	
P(F<=f) two-tail	0.562074922	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	2.759199898	2.768977193
Variance	0.524930036	0.429089458
Observations	176	171
Pooled Variance	0.477704244	
Hypothesized Mean Difference	0	
df	345	
t Stat	-0.13174338	
P(T<=t) two-tail	0.895264069	
t Critical two-tail	1.966863909	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	2.759199898	2.768977193
Variance	0.524930036	0.429089458
Observations	176	171
Hypothesized Mean Difference	0	
df	343	
t Stat	-0.13193477	
P(T<=t) two-tail	0.89511324	
t Critical two-tail	1.966904281	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	2.759199898	2.768977193
Variance	0.524930036	0.429089458
Observations	176	171
df	175	170
F	1.223358033	
P(F<=f) two-tail	0.187052657	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

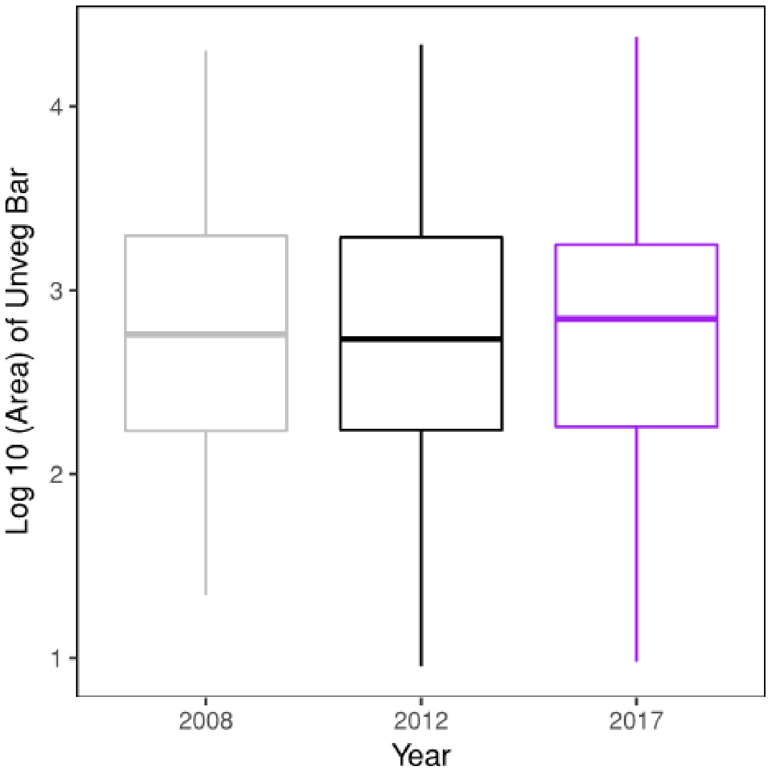

Figure C-2: Box Plot of log (10) Area of Unvegetated Bars

Sparsely Vegetated Bars

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	2.288185139	2.975644851
Variance	0.480680532	0.223551245
Observations	94	49
Pooled Variance	0.393147157	
Hypothesized Mean Difference	0	
df	141	
t Stat	-6.222481727	
P(T<=t) two-tail	5.25386E-09	
t Critical two-tail	1.976931489	

Reject Null Hypothesis because p < 0.05 (means are not the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	2.288185139	2.975644851
Variance	0.480680532	0.223551245
Observations	94	49
Hypothesized Mean Difference	0	
df	131	
t Stat	-6.988785701	
P(T<=t) two-tail	1.26731E-10	
t Critical two-tail	1.978238539	

Reject Null Hypothesis because p < 0.05 (means are not the same)

F-Test: Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	2.288185139	2.975644851
Variance	0.480680532	0.223551245
Observations	94	49
df	93	48
F	2.150202887	
P(F<=f) two-tail	0.004215449	

Reject Null Hypothesis because p < 0.05 (variances are not equal)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	2.848268194	2.975644851
Variance	0.487967612	0.223551245
Observations	56	49
Pooled Variance	0.36474445	
Hypothesized Mean Difference	0	
df	103	
t Stat	-1.078184052	
P(T<=t) two-tail	0.283470199	
t Critical two-tail	1.983264145	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	2.848268194	2.975644851
Variance	0.487967612	0.223551245
Observations	56	49
Hypothesized Mean Difference	0	
df	97	
t Stat	-1.105494509	
P(T<=t) two-tail	0.271679802	
t Critical two-tail	1.984723186	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	2.848268194	2.975644851
Variance	0.487967612	0.223551245
Observations	56	49
df	55	48
F	2.182799798	
P(F<=f) two-tail	0.006577205	

Reject Null Hypothesis because p < 0.05 (variances are not equal)

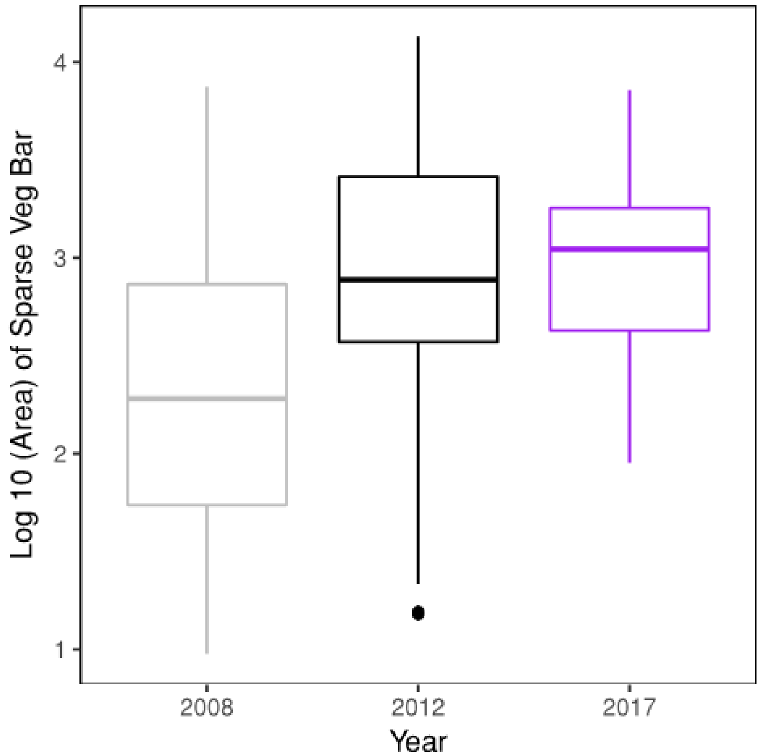

Figure C-3: Box Plot of log (10) area of Sparsely Vegetated Bars

Young Islands

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.066748232	3.223020545
Variance	0.32139284	0.411583051
Observations	25	38
Pooled Variance	0.376098378	
Hypothesized Mean Difference	0	
df	61	
t Stat	- 0.989516037	
P(T<=t) two-tail	0.326319641	
t Critical two-tail	1.999623585	

Cannot Reject Null Hypothesis because $p > 0.05$ (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.066748232	3.223020545
Variance	0.32139284	0.411583051
Observations	25	38
Hypothesized Mean Difference	0	
df	56	
t Stat	- 1.015379559	
P(T<=t) two-tail	0.314291936	
t Critical two-tail	2.003240719	

Cannot Reject Null Hypothesis because $p > 0.05$ (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.066748232	3.223020545
Variance	0.32139284	0.411583051
Observations	25	38
df	24	37
F	0.780869958	
P(F<=f) two-tail	0.529487768	

Cannot Reject Null Hypothesis because $p > 0.05$ (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.150180917	3.223020545
Variance	0.439064113	0.411583051
Observations	28	38
Pooled Variance	0.423176624	
Hypothesized Mean Difference	0	
df	64	
t Stat	-0.449578699	
P(T<=t) two-tail	0.654533202	
t Critical two-tail	1.997729654	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.150180917	3.223020545
Variance	0.439064113	0.411583051
Observations	28	38
Hypothesized Mean Difference	0	
df	57	
t Stat	-0.447349048	
P(T<=t) two-tail	0.656318473	
t Critical two-tail	2.002465459	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.150180917	3.223020545
Variance	0.439064113	0.411583051
Observations	28	38
df	27	37
F	1.066769178	
P(F<=f) two-tail	0.842917544	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

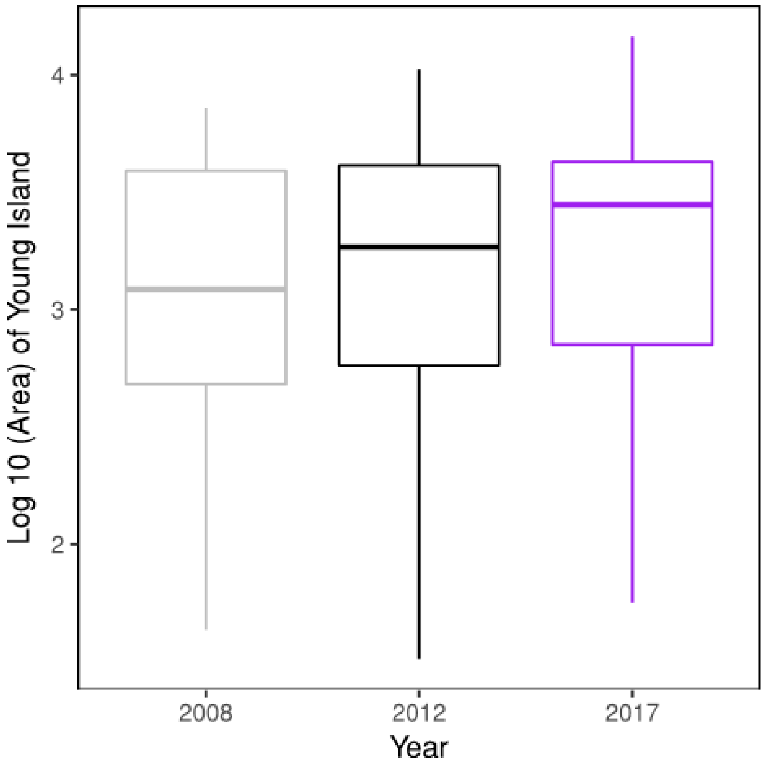

Figure C-4: Box Plot of log (10) Area of Young Islands

Mature Islands

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.587309182	3.379469052
Variance	0.504393843	0.754925344
Observations	16	25
Pooled Variance	0.658567074	
Hypothesized Mean Difference	0	
df	39	
t Stat	0.799958514	
P(T<=t) two-tail	0.42858077	
t Critical two-tail	2.02269092	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.587309182	3.379469052
Variance	0.504393843	0.754925344
Observations	16	25
Hypothesized Mean Difference	0	
df	37	
t Stat	0.836586236	
P(T<=t) two-tail	0.408195988	
t Critical two-tail	2.026192463	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.587309182	3.379469052
Variance	0.504393843	0.754925344
Observations	16	25
df	15	24
F	0.668137382	
P(F<=f) two-tail	0.421705731	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.636852162	3.379469052
Variance	0.567504081	0.754925344
Observations	14	25
Pooled Variance	0.68907463	
Hypothesized Mean Difference	0	
df	37	
t Stat	0.928856516	
P(T<=t) two-tail	0.358983908	
t Critical two-tail	2.026192463	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.636852162	3.379469052
Variance	0.567504081	0.754925344
Observations	14	25
Hypothesized Mean Difference	0	
df	30	
t Stat	0.967762846	
P(T<=t) two-tail	0.340900531	
t Critical two-tail	2.042272456	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test: Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.636852162	3.379469052
Variance	0.567504081	0.754925344
Observations	14	25
df	13	24
F	0.751735368	
P(F<=f) two-tail	0.602856282	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

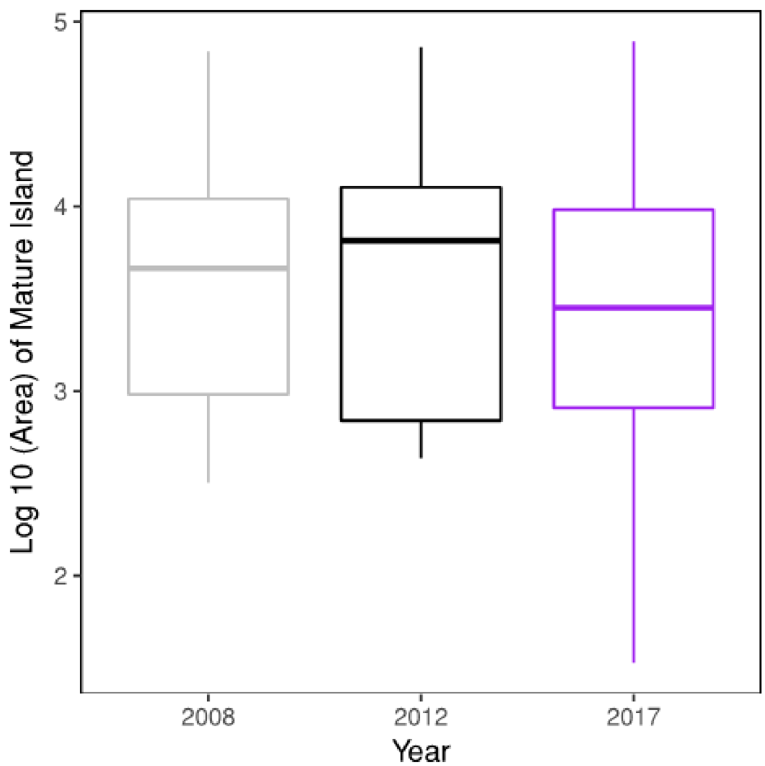

Figure C-5: Box Plot of log (10) Area of Mature Islands

Mainstem Side Channels

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.423170288	3.225668352
Variance	0.428460407	0.301904831
Observations	3	6
Pooled Variance	0.338063567	
Hypothesized Mean Difference	0	
df	7	
t Stat	0.480382491	
P(T<=t) two-tail	0.645604546	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.423170288	3.225668352
Variance	0.428460407	0.301904831
Observations	3	6
Hypothesized Mean Difference	0	
df	3	
t Stat	0.449405034	
P(T<=t) two-tail	0.683622647	
t Critical two-tail	3.182446305	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.423170288	3.225668352
Variance	0.428460407	0.301904831
Observations	3	6
df	2	5
F	1.419190299	
P(F<=f) two-tail	0.649963754	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.46385388	3.225668352
Variance	0.250516571	0.301904831
Observations	4	6
Pooled Variance	0.282634233	
Hypothesized Mean Difference	0	
df	8	
t Stat	0.694078528	
P(T<=t) two-tail	0.507283462	
t Critical two-tail	2.306004135	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.46385388	3.225668352
Variance	0.250516571	0.301904831
Observations	4	6
Hypothesized Mean Difference	0	
df	7	
t Stat	0.708726647	
P(T<=t) two-tail	0.501408125	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.46385388	3.225668352
Variance	0.250516571	0.301904831
Observations	4	6
df	3	5
F	0.829786559	
P(F<=f) two-tail	0.936230312	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

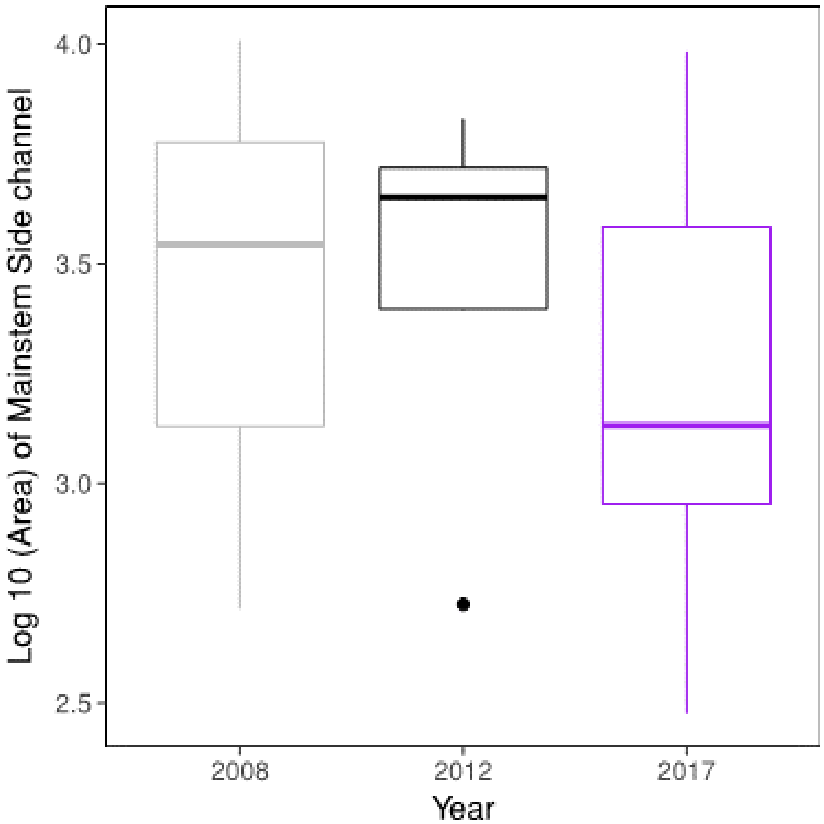

Figure C-6: Box Plot of log (10) Area of Mainstem Side Channels

Floodplain Side Channels (wet)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.167317118	3.238409582
Variance	0.062871003	0.189727312
Observations	4	5
Pooled Variance	0.135360322	
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.288052479	
P(T<=t) two-tail	0.78164862	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.167317118	3.238409582
Variance	0.062871003	0.189727312
Observations	4	5
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.30689176	
P(T<=t) two-tail	0.76785379	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.167317118	3.238409582
Variance	0.062871003	0.189727312
Observations	4	5
df	3	4
F	0.331375603	
P(F<=f) two-tail	0.39102498	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.183711976	3.238409582
Variance	0.106894711	0.189727312
Observations	5	5
Pooled Variance	0.148311011	
Hypothesized Mean Difference	0	
df	8	
t Stat	-0.22456994	
P(T<=t) two-tail	0.827943456	
t Critical two-tail	2.306004135	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.183711976	3.238409582
Variance	0.106894711	0.189727312
Observations	5	5
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.22456994	
P(T<=t) two-tail	0.828728246	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.183711976	3.238409582
Variance	0.106894711	0.189727312
Observations	5	5
df	4	4
F	0.56341235	
P(F<=f) two-tail	0.592008833	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

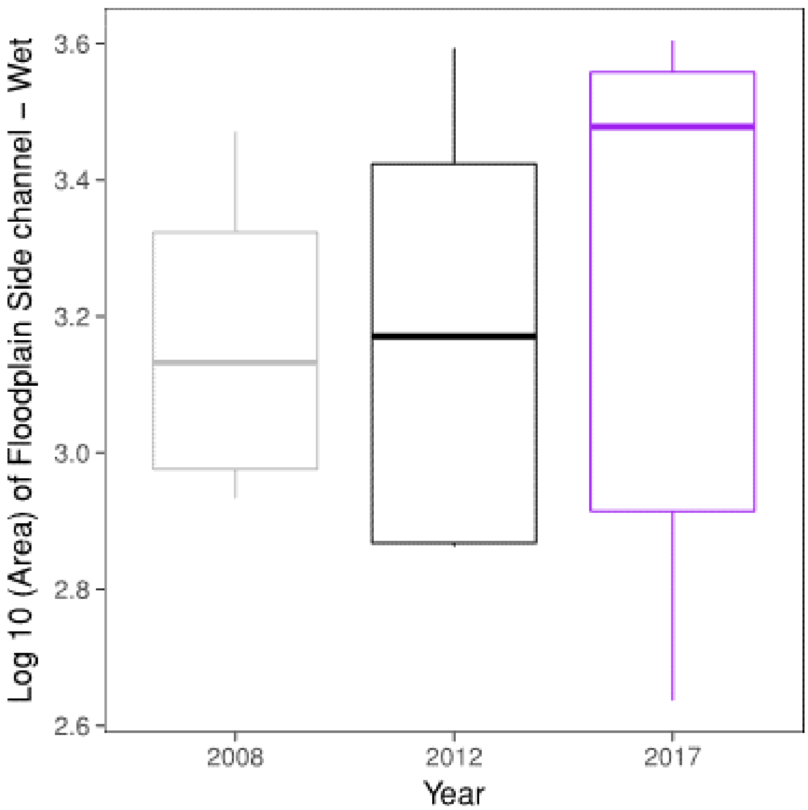

Figure C-7: Box Plot of log (10) Area of Floodplain Side Channels (wet)

Floodplain Side Channels (dry)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	Variable 1	*Variable 2*
Mean	3.426653141	3.223600961
Variance	0.499506715	0.343907672
Observations	4	5
Pooled Variance	0.410592976	
Hypothesized Mean Difference	0	
df	7	
t Stat	0.472384503	
P(T<=t) two-tail	0.651024992	
t Critical two-tail	2.364624252	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.426653141	3.223600961
Variance	0.499506715	0.343907672
Observations	4	5
Hypothesized Mean Difference	0	
df	6	
t Stat	0.461412862	
P(T<=t) two-tail	0.660756534	
t Critical two-tail	2.446911851	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.426653141	3.223600961
Variance	0.499506715	0.343907672
Observations	4	5
df	3	4
F	1.452444231	
P(F<=f) two-tail	0.706502443	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.365616679	3.223600961
Variance	0.290516103	0.343907672
Observations	5	5
Pooled Variance	0.317211888	
Hypothesized Mean Difference	0	
df	8	
t Stat	0.398686649	
P(T<=t) two-tail	0.700553918	
t Critical two-tail	2.306004135	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.365616679	3.223600961
Variance	0.290516103	0.343907672
Observations	5	5
Hypothesized Mean Difference	0	
df	8	
t Stat	0.398686649	
P(T<=t) two-tail	0.700553918	
t Critical two-tail	2.306004135	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.365616679	3.223600961
Variance	0.290516103	0.343907672
Observations	5	5
df	4	4
F	0.844750281	
P(F<=f) two-tail	0.874061653	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

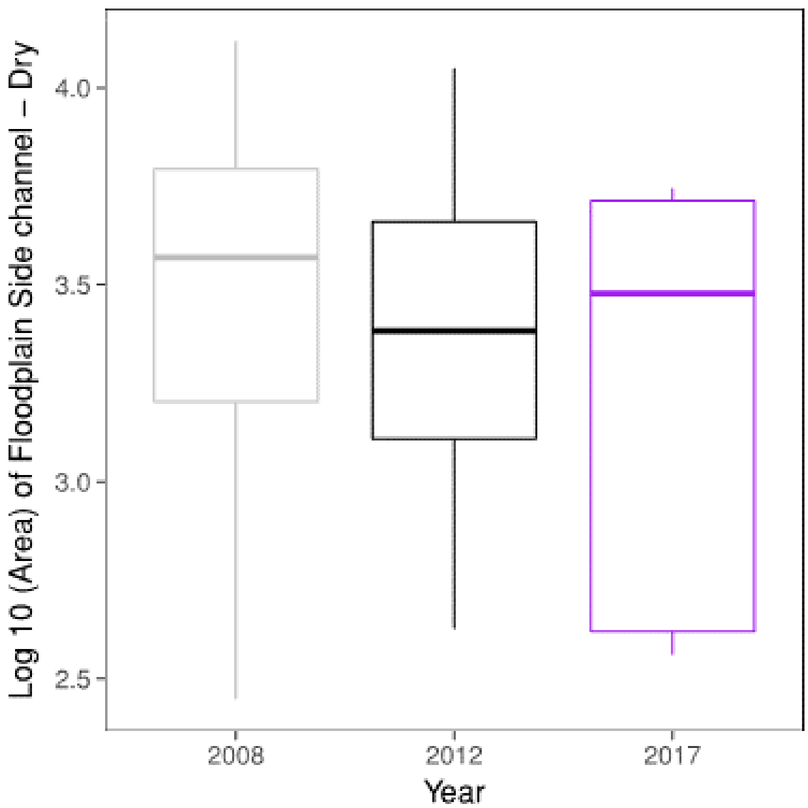

Figure C-8: Box Plot of log (10) Area of Floodplain Side Channels (dry)

Pools

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.093317888	3.080717147
Variance	0.121180701	0.152088377
Observations	61	65
Pooled Variance	0.13713305	
Hypothesized Mean Difference	0	
df	124	
t Stat	0.190880409	
P(T<=t) two-tail	0.848931463	
t Critical two-tail	1.979280117	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.093317888	3.080717147
Variance	0.121180701	0.152088377
Observations	61	65
Hypothesized Mean Difference	0	
df	124	
t Stat	0.191572543	
P(T<=t) two-tail	0.848390396	
t Critical two-tail	1.979280117	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.093317888	3.080717147
Variance	0.121180701	0.152088377
Observations	61	65
df	60	64
F	0.796778181	
P(F<=f) two-tail	0.375848495	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.137178541	3.080717147
Variance	0.168333854	0.152088377
Observations	65	65
Pooled Variance	0.160211116	
Hypothesized Mean Difference	0	
df	128	
t Stat	0.804168319	
P(T<=t) two-tail	0.422790789	
t Critical two-tail	1.97867085	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.137178541	3.080717147
Variance	0.168333854	0.152088377
Observations	65	65
Hypothesized Mean Difference	0	
df	128	
t Stat	0.804168319	
P(T<=t) two-tail	0.422790789	
t Critical two-tail	1.97867085	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.137178541	3.080717147
Variance	0.168333854	0.152088377
Observations	65	65
df	64	64
F	1.106816027	
P(F<=f) two-tail	0.686006216	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

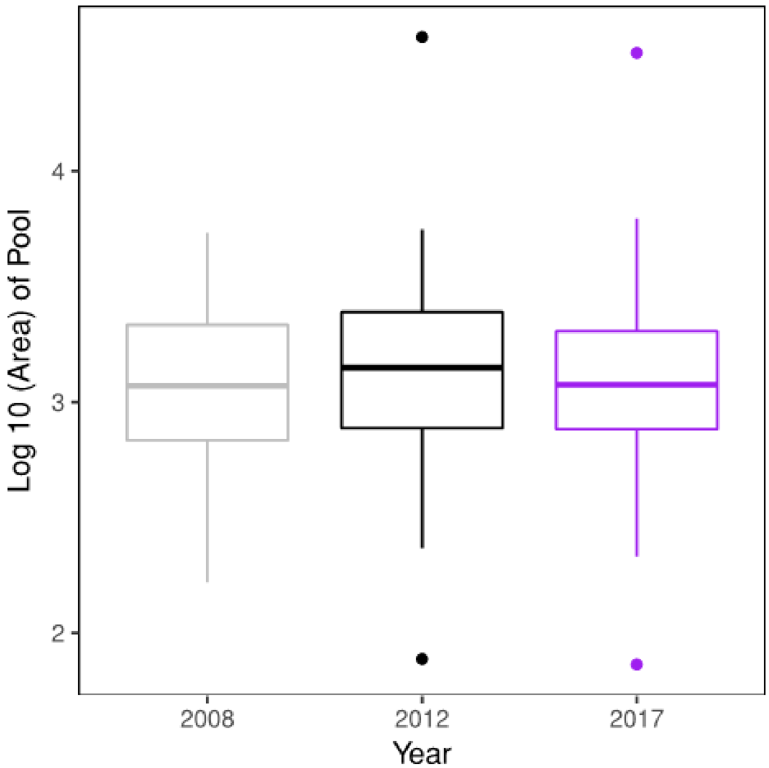

Figure C-9: Box Plot of log (10) Area of Pools

Riffles

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.701377567	3.604353325
Variance	0.41273838	0.394598353
Observations	31	37
Pooled Variance	0.40284382	
Hypothesized Mean Difference	0	
df	66	
t Stat	0.627825798	
P(T<=t) two-tail	0.532284421	
t Critical two-tail	1.996564419	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.701377567	3.604353325
Variance	0.41273838	0.394598353
Observations	31	37
Hypothesized Mean Difference	0	
df	63	
t Stat	0.62656347	
P(T<=t) two-tail	0.533209308	
t Critical two-tail	1.998340543	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.701377567	3.604353325
Variance	0.41273838	0.394598353
Observations	31	37
df	30	36
F	1.045970863	
P(F<=f) two-tail	0.889995493	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.633064124	3.604353325
Variance	0.515664959	0.394598353
Observations	38	37
Pooled Variance	0.455960879	
Hypothesized Mean Difference	0	
df	73	
t Stat	0.184095643	
P(T<=t) two-tail	0.85444886	
t Critical two-tail	1.992997126	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.633064124	3.604353325
Variance	0.515664959	0.394598353
Observations	38	37
Hypothesized Mean Difference	0	
df	72	
t Stat	0.184426873	
P(T<=t) two-tail	0.854197063	
t Critical two-tail	1.993463567	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.633064124	3.604353325
Variance	0.515664959	0.394598353
Observations	38	37
df	37	36
F	1.306809709	
P(F<=f) two-tail	0.423976476	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

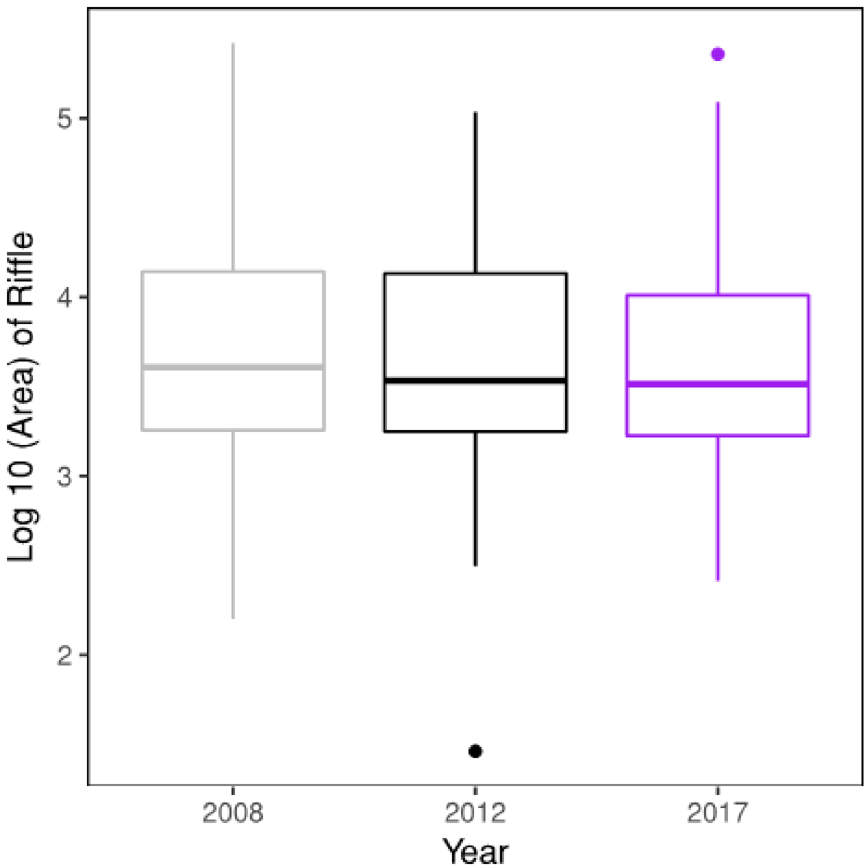

Figure C-10: Box Plot of log (10) Area of Riffles

Rapids

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2008	*2017*
Mean	3.195935145	2.949186898
Variance	0.249601382	0.224106977
Observations	51	63
Pooled Variance	0.235488408	
Hypothesized Mean Difference	0	
df	112	
t Stat	2.69943109	
P(T<=t) two-tail	0.008022689	
t Critical two-tail	1.981371815	

Reject Null Hypothesis because p < 0.05 (means are not the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2008	*2017*
Mean	3.195935145	2.949186898
Variance	0.249601382	0.224106977
Observations	51	63
Hypothesized Mean Difference	0	
df	105	
t Stat	2.684044976	
P(T<=t) two-tail	0.008453474	
t Critical two-tail	1.982815274	

Reject Null Hypothesis because p < 0.05 (means are not the same)

F-Test Two-Sample for Variances	α	0.05
	2008	*2017*
Mean	3.195935145	2.949186898
Variance	0.249601382	0.224106977
Observations	51	63
df	50	62
F	1.113759981	
P(F<=f) two-tail	0.682308325	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

t-Test: Two-Sample Assuming Equal Variances	α	0.05
	2012	*2017*
Mean	3.076880624	2.949186898
Variance	0.275892262	0.224106977
Observations	57	63
Pooled Variance	0.248683044	
Hypothesized Mean Difference	0	
df	118	
t Stat	1.400759424	
P(T<=t) two-tail	0.16391028	
t Critical two-tail	1.980272249	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

t-Test: Two-Sample Assuming Unequal Variances	α	0.05
	2012	*2017*
Mean	3.076880624	2.949186898
Variance	0.275892262	0.224106977
Observations	57	63
Hypothesized Mean Difference	0	
df	113	
t Stat	1.39346275	
P(T<=t) two-tail	0.166214673	
t Critical two-tail	1.981180359	

Cannot Reject Null Hypothesis because p > 0.05 (means are the same)

F-Test Two-Sample for Variances	α	0.05
	2012	*2017*
Mean	3.076880624	2.949186898
Variance	0.275892262	0.224106977
Observations	57	63
df	56	62
F	1.231073952	
P(F<=f) two-tail	0.424225128	

Cannot Reject Null Hypothesis because p > 0.05 (variances are the same)

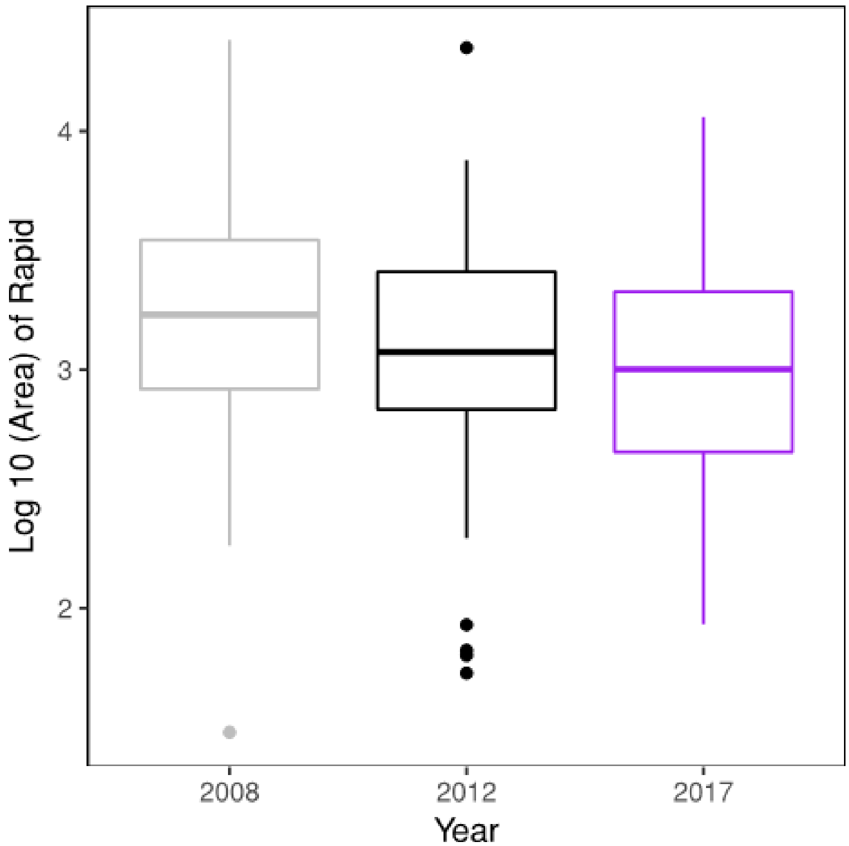

Figure C-11: Box Plot of log (10) Area of Rapids

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Attachment C

CMSMON-8 MQ3 Final Report

Cheakamus Project Water Use Plan

Cheakamus River Channel Morphology Monitoring

Implementation Year 6

Reference: CMSMON-8

Year 1 to Year 5 Flow Synthesis Report

Study Period: 2014

Kerr Wood Leidal Associates Ltd.
200 - 4185A Still Creek Drive
Burnaby BC V5C 6G9
604-294-2088

December 9, 2014

KERR WOOD LEIDAL
consulting engineers

Greater Vancouver
200 - 4185A Still Creek Drive
Burnaby, BC V5C 6G9
T 604 294 2088
F 604 294 2090

Technical Memorandum

DATE: December 9, 2014

TO: Darin Nishi, BC Hydro

CC: Alexis Hall, BC Hydro

FROM: Erica Ellis, M.Sc., P.Geo.

RE: **CMSMON8 CHEAKAMUS RIVER CHANNEL MORPHOLOGY MONITORING**
Final Year 1 to Year 5 Flow Synthesis Report
Our File 478.164-300

1. Introduction

Kerr Wood Leidal Associates Ltd. (KWL) has been retained by BC Hydro (BCH) to conduct monitoring work for CMSMON8: Cheakamus River Channel Morphology Monitoring. 2013-2014 is the first year that KWL has been involved in CMSMON8, which was awarded in August 2013. 2013-2014 is Year 6 of CMSMON8.

The goal of CMSMON8 is to address three Management Questions posed by the Consultative Committee (CC) of the Water Use Plan (WUP). The questions are intended to address critical points of scientific uncertainty, and to better inform the next WUP

The purpose of the current technical memorandum is to summarize an analysis of hydrometric data collected in Years 1 through 5 of CMSMON8 and to attempt to answer the following Management Question (#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?"

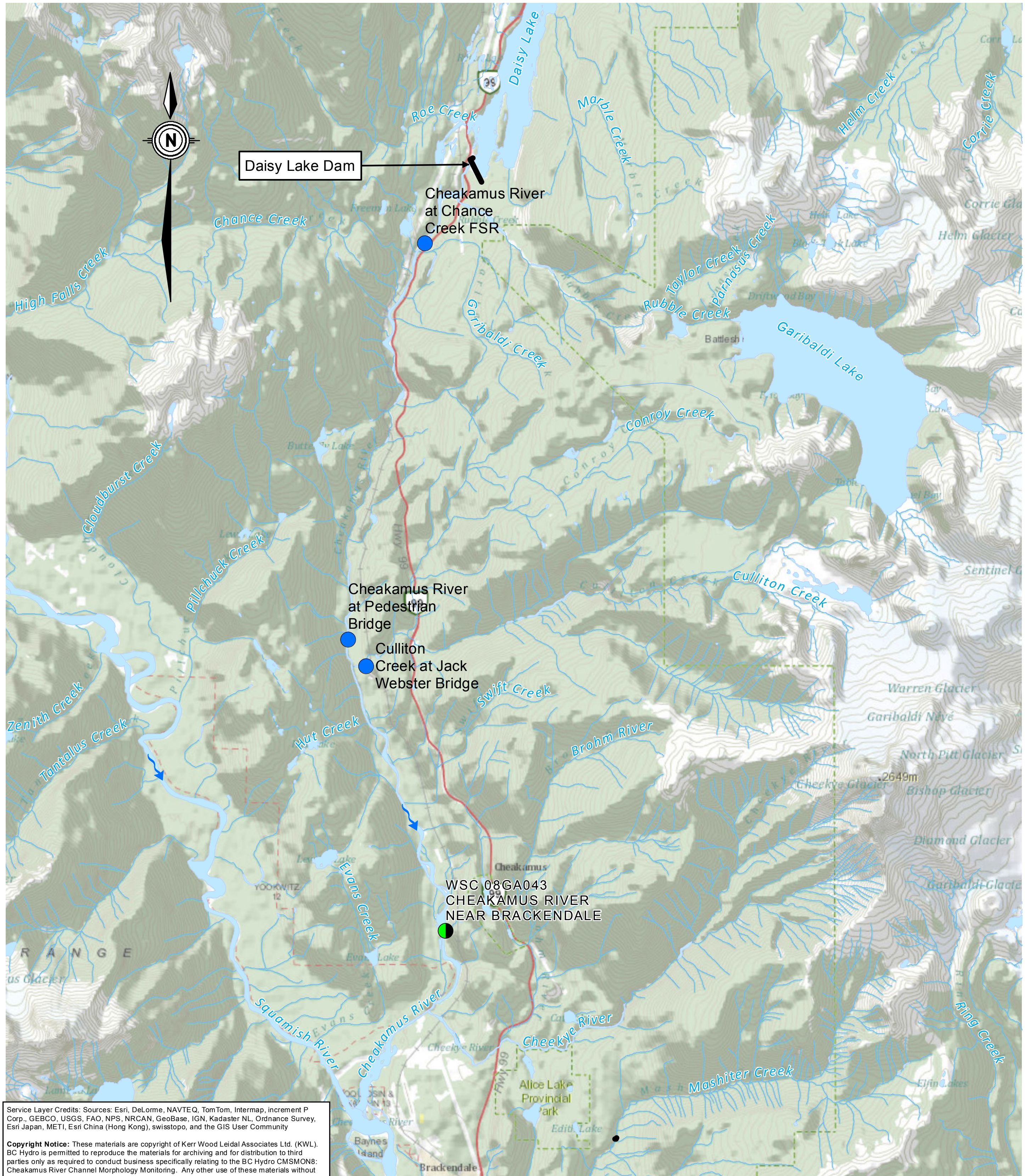
1.1 Data Sources

The analysis is based on data from the following sources:

- Daisy Lake dam outflow (data provided by BC Hydro);
- Water Survey of Canada (WSC) Cheakamus River near Brackendale (08GA043) (archived data publically available for download); and
- Hydrometric stations installed in Year 1 of CMSMON8 and operated through Year 5, including:
  - Cheakamus River at Chance Creek Forest Service Road;
  - Cheakamus River at the Pedestrian Bridge; and
  - Culliton Creek.

Figure 1 shows the locations of the data sources listed above.

An analysis based on the Year 1 (Y1) through Year 5 (Y5) period is preferred (2008-2012), compared to more recent monitoring data, because the WSC data have been reviewed for quality-assurance and are no longer provisional and subject to change.



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BC Hydro
CMSMON8: Cheakamus River Channel Morphology Monitoring

Project No.
478-164

Date
December 2014

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Hydrometric Data Sources for CMSMON8 Flow Synthesis

Figure 1

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Author: EEllis

2. Inflow Downstream of Daisy Lake Dam

The upstream limit of the reach of interest for CMSMON8 is Daisy Lake dam. The dam regulates the flow of Cheakamus River and varying amounts of flow are either released or spill to the downstream reach, depending on the time of year and the upstream precipitation inputs. BC Hydro has provided hourly data of flow releases downstream of the dam, which have been converted into daily average flows.

For the purposes of this analysis, the downstream limit of the CMSMON8 reach of interest is at the Cheakamus River near Brackendale hydrometric station (08GA043), operated by WSC. The archived daily average flow data have been downloaded from the WSC website.

2.1 Total Inflow

Total inflow to the CMSMON8 reach of interest is simply the difference of the flow measured at WSC 08GA043 and the Daisy Lake outflows. This flow represents all tributary flow that enters the reach downstream of the dam, from all sources.

A time series of annual total inflow to the reach is plotted in Figure 2. Summary statistics of the total inflow are presented in Table 1 below.

Table 1: Summary of 2008 to 2012 Total CMSMON8 Inflow

Statistic	Total Inflow (m^3/s)
Minimum	3
Maximum	119
Average	16

Total Inflow To Cheakamus River Between Daisy Lake Dam & WSC 08GA043

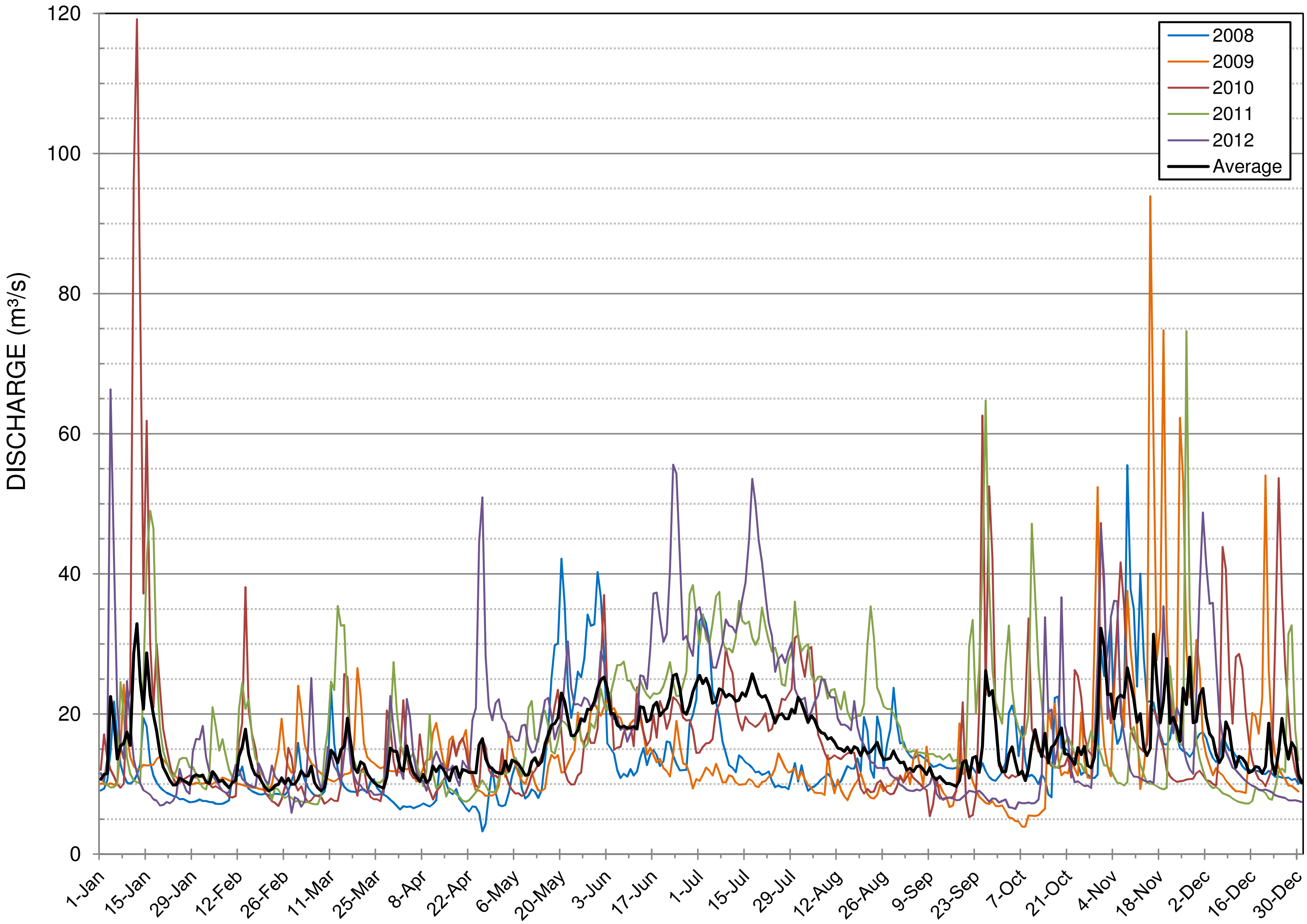

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Figure 2

2.2 Individual Tributaries and Sub-reach Inflows

Using the additional CMSMON8 hydrometric station data, it is possible to estimate the proportion of inflow that is delivered by individual tributaries or sub-reaches of the total reach of interest, either based on direct measurement (e.g., Culliton Creek) or through calculation.

The following tributary inflows can be estimated:

Rubble Creek	• estimated as the difference between Cheakamus River flow at Chance Creek FSR and the Daisy Lake outflow
Sub-reach: Rubble to Culliton	• estimated as the difference between Cheakamus River flow at the Pedestrian Bridge and at Chance Creek FSR
Culliton Creek	• data from Culliton Creek hydrometric station
Sub-reach: Culliton to Cheekye	• estimated as the difference between Cheakamus River flow at WSC 08GA043 and the sum of the Pedestrian Bridge flow and Culliton Creek flow

An example of the measured and calculated time series of tributary and sub-reach inflows is presented in Figure 3, for the 2008 data. As is evident in Figure 3, attempting to calculate tributary inflows based on the available data is problematic since the resulting flows are sometimes negative.

Rather than attempting to resolve individual tributary (or tributary reach) contributions, Figure 4 through Figure 8 plot the measured discharge data for each year from the various points of interest along the Cheakamus River, as follows:

- Daisy Lake outflow,
- Cheakamus River at Chance Creek FSR,
- Cheakamus River at the Pedestrian Bridge,
- Cheakamus River at the Pedestrian Bridge + Culliton Creek, and
- WSC 08GA043.

What we would expect to see is that the time series lines are stacked: outflow from Daisy Lake dam is the lowest, flow measured at WSC 08GA043 is the highest and the other stations fall into place between these two stations as:

$$Q_{Daisy} < Q_{Chance\ FSR} < Q_{Pedestrian} < Q_{(Pedestrian\ +\ Culliton)} < Q_{08GA043}$$

If the time series data <u>do not</u> display this behaviour then we may have the following issues:

- **If the lines cross**, this would imply that we are losing flow with distance downstream, which is not a reasonable assumption.
- **If the lines overlap**, this would imply that there is no runoff being contributed for some distance downstream, which also is unlikely.

As is shown in the time series figures, there are crossed and overlapping lines for much of the 2008 to 2012 period. However, as an example, the data for February 2012, presented in Figure 9, <u>generally</u> display the expected pattern of increasing flow with distance downstream.

2.3 Uncertainty in Data Sources

For the purposes of this analysis it has been assumed that both the BC Hydro flows and the WSC flows are known with low associated error. This is a reasonable expectation considering WSC's mandate to provide high-accuracy data (±7-10%), and BC Hydro's desire to have good quantitative estimates of flows for the purposes of power generation estimates.

Under this assumption, unreasonable calculated flows, or unreasonable downstream trends in flow, must result from issues associated with the shorter-term CMSMON8 stations:

- In the case of the calculated Rubble Creek flow, negative flows are clearly associated with individual higher-flow events, suggesting that the problem lies in uncertainty associated with the higher end of the Chance Creek FSR rating curve.
- For the Rubble to Culliton sub-reach flows, both the Chance Creek FSR and Pedestrian Bridge records may contribute to uncertainty, and similarly for the Culliton to Cheekye sub-reach.
- The Culliton Creek flows appear reasonable (i.e., non-negative, and generally following the pattern of the estimated total inflow), but there is likely to be uncertainty associated with the higher flows for which the rating curve is being extrapolated beyond the limits of existing measurements.

The CMSMON8 hydrometric station data will be discussed further in Section 5.

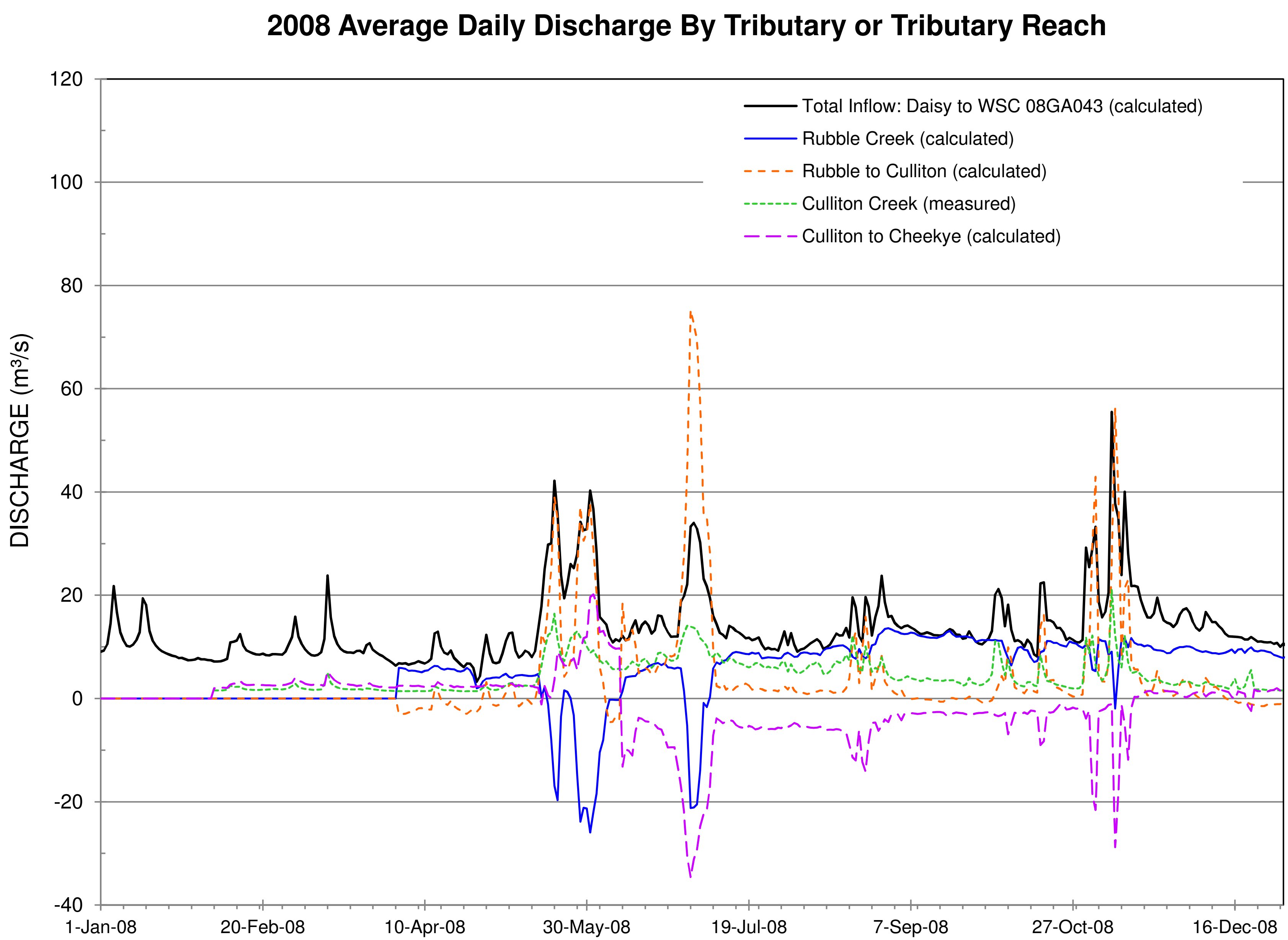

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Figure 3

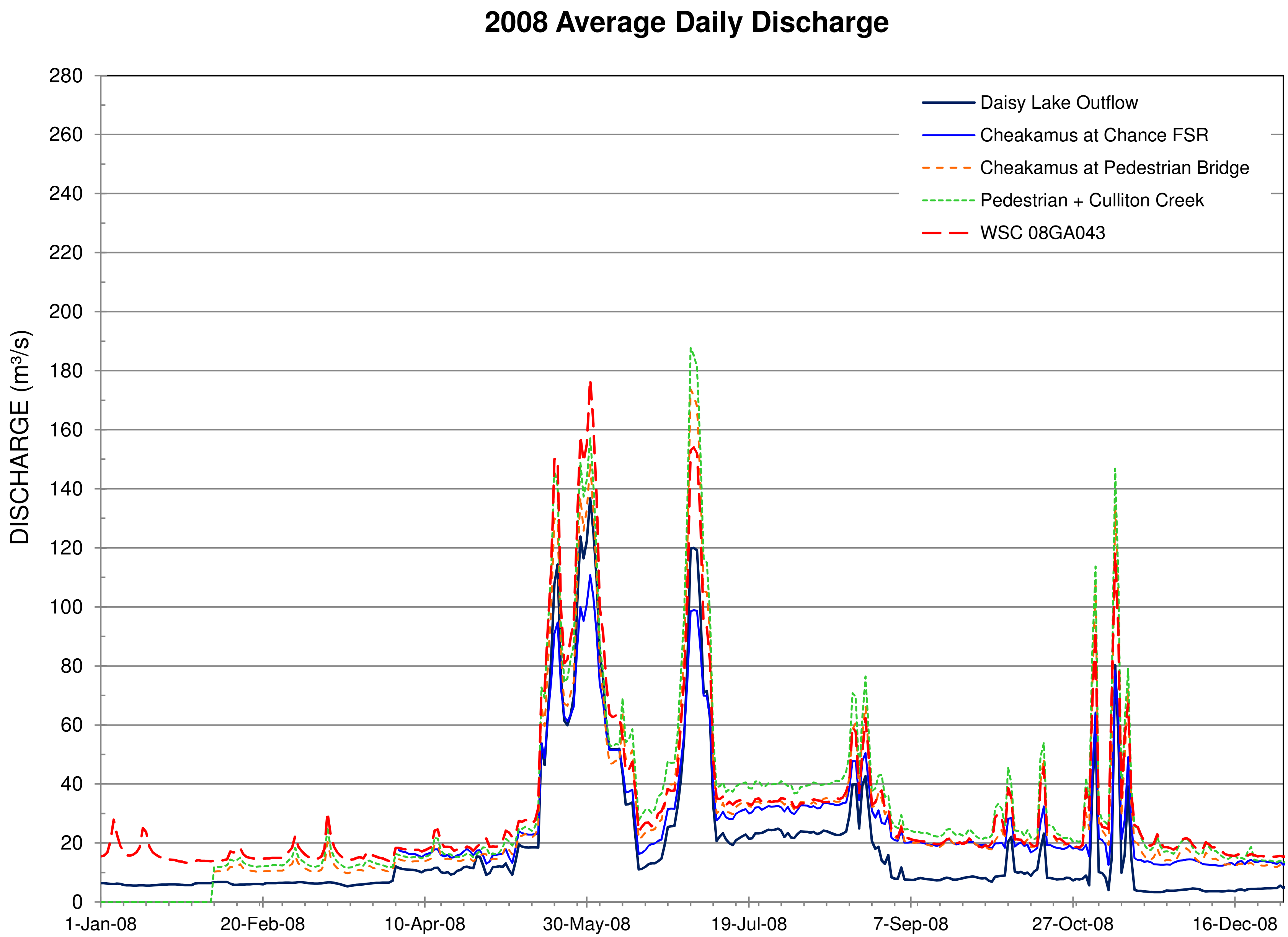

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Figure 4

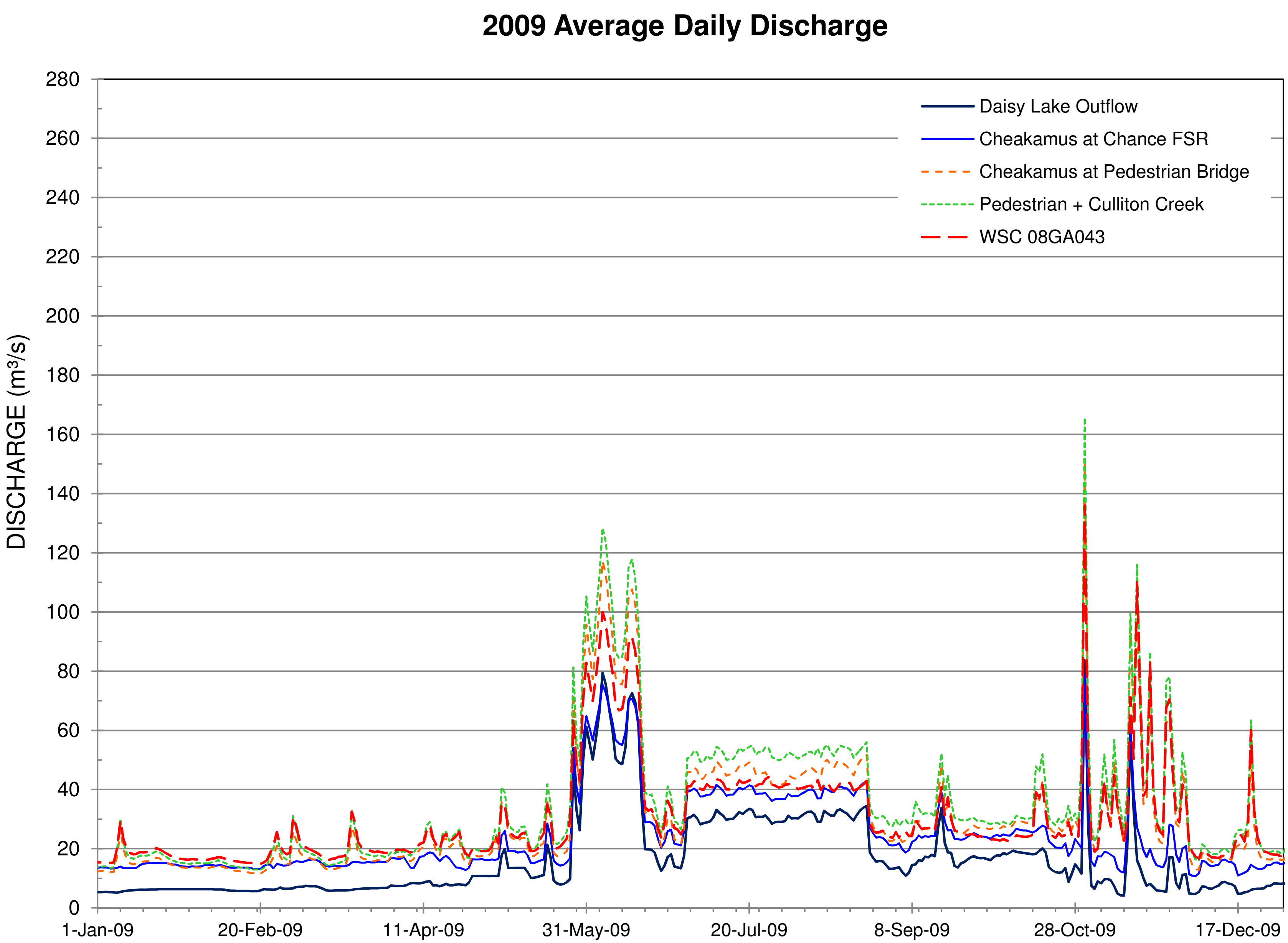

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Figure 5

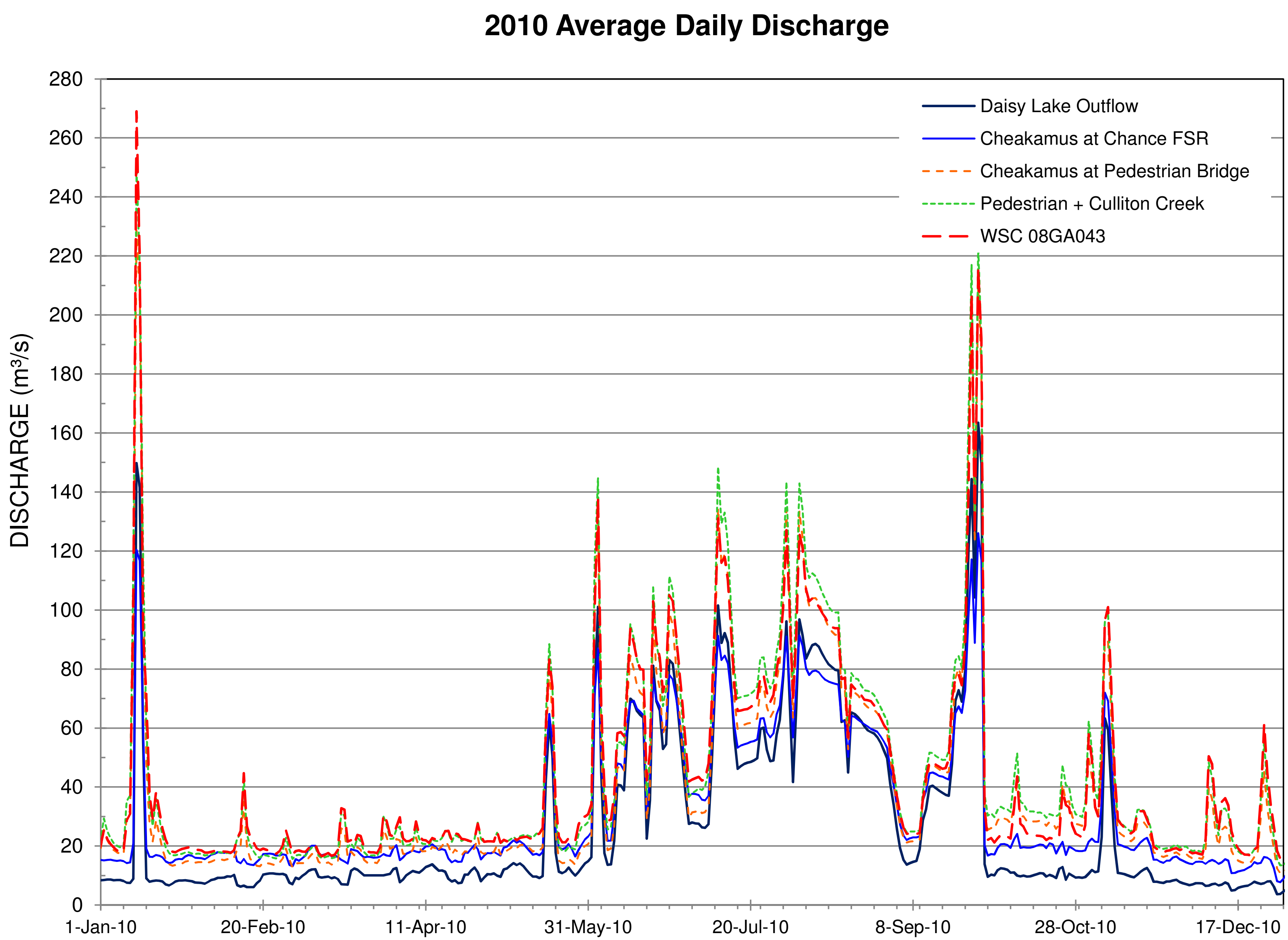

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Figure 6

2011 Average Daily Discharge

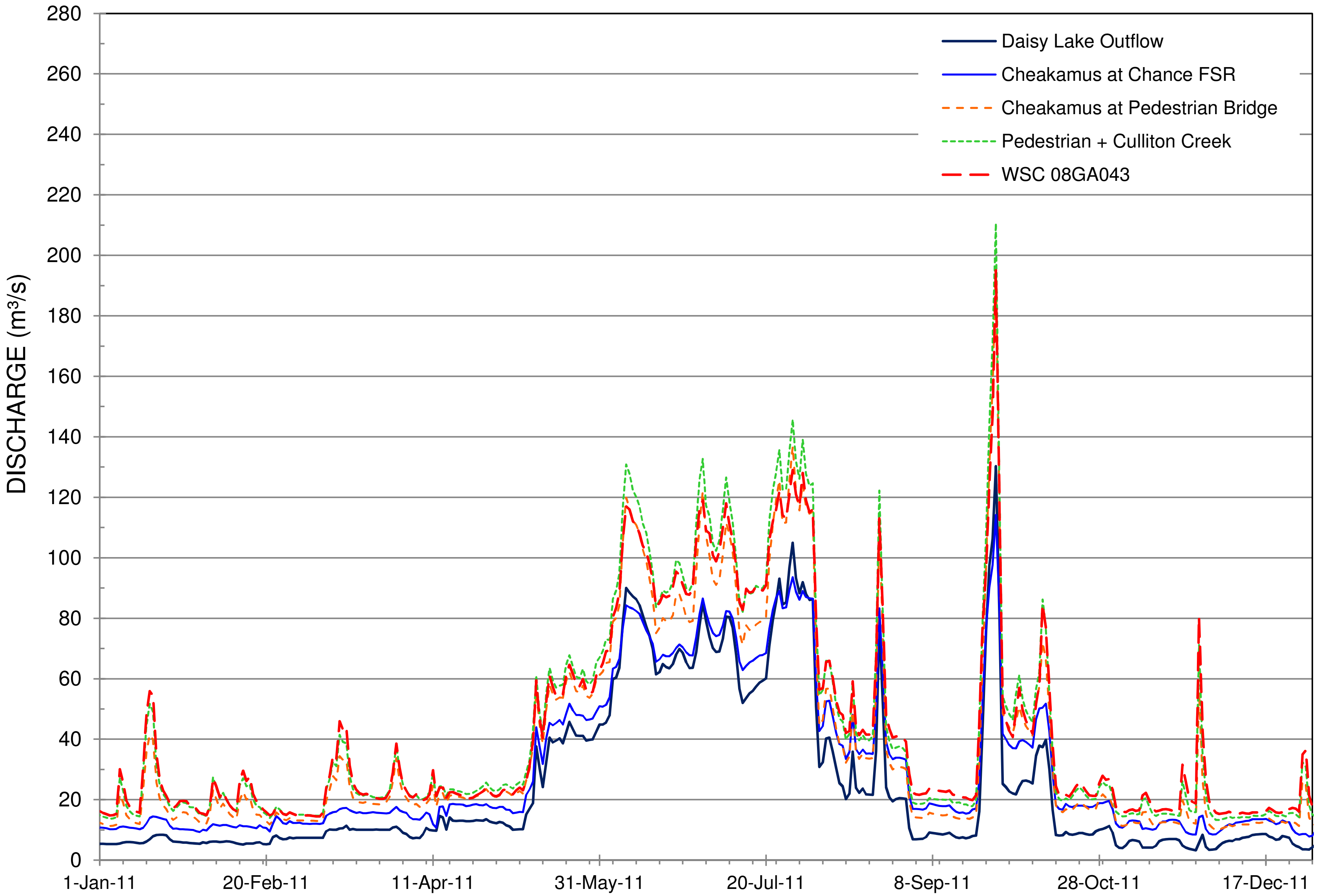

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Figure 7

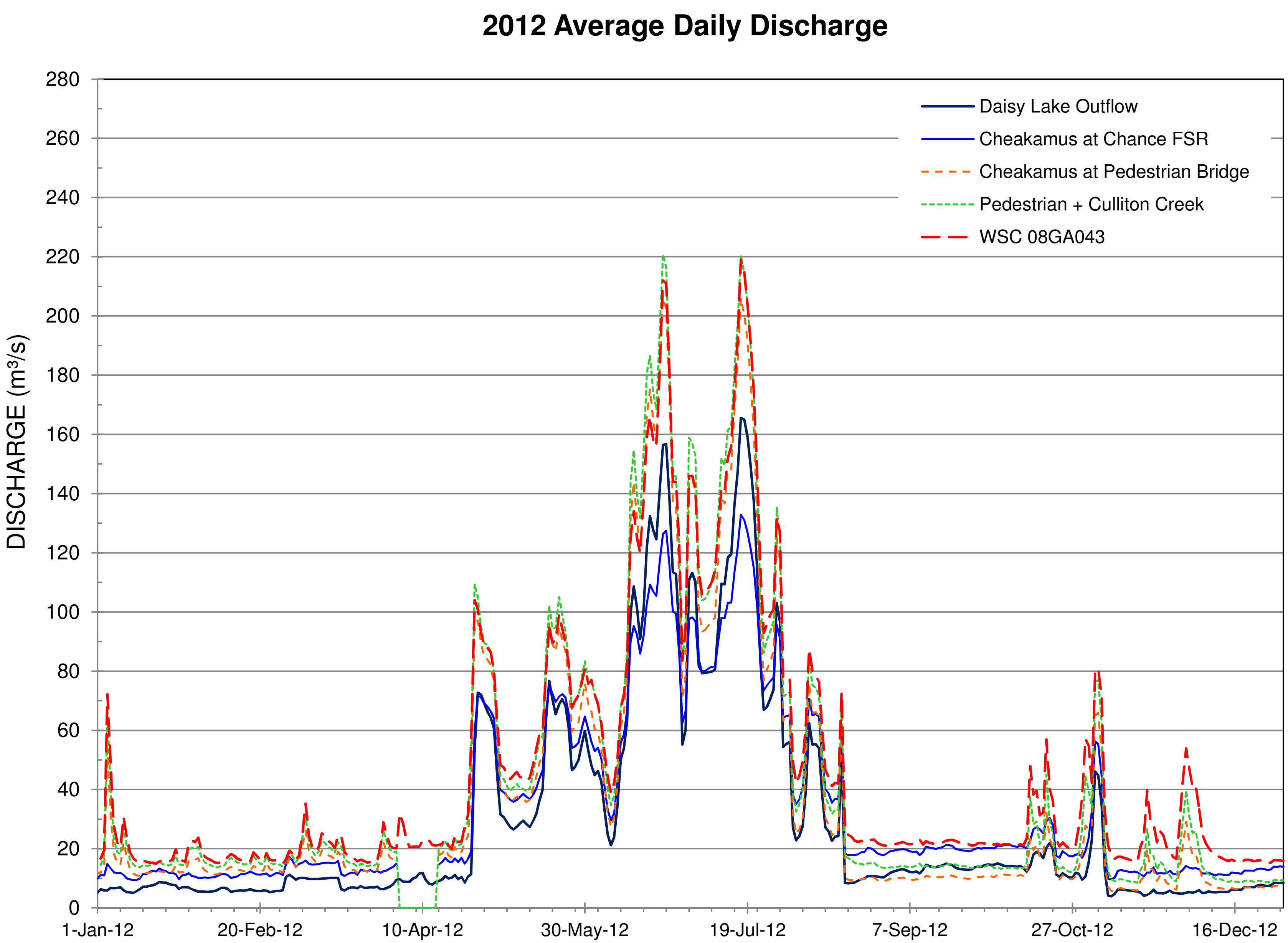

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Figure 8

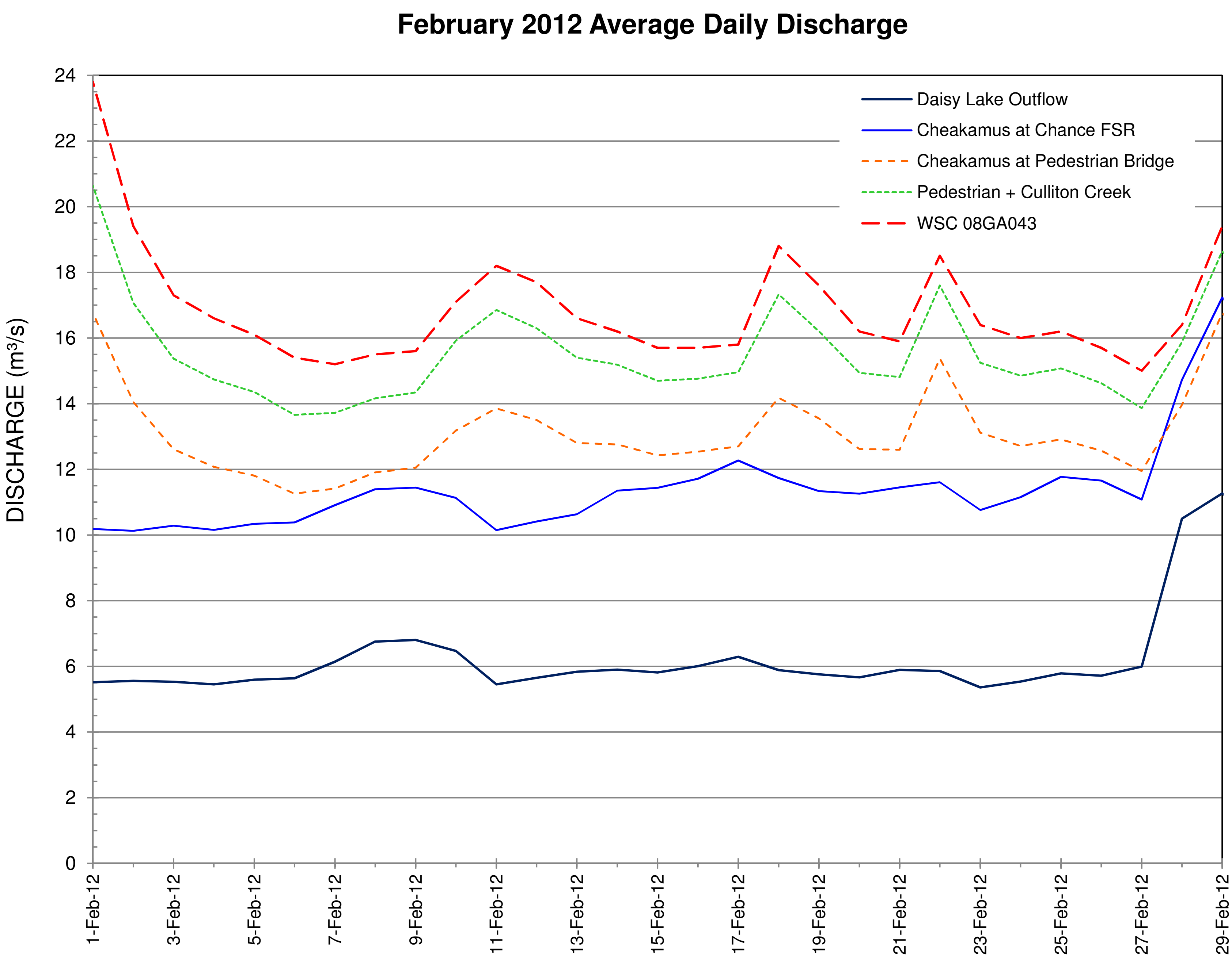

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Figure 9

3. Attenuation of Daisy Lake Dam

The Management Question is specifically concerned with how tributary flows “attenuate”, or reduce the effect of, the operation of Daisy Lake dam:

> “*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?*”

Immediately downstream of the dam, Cheakamus River flow is entirely a result of outflow from Daisy Lake dam. However, some 19 km downstream at WSC 08GA043, Cheakamus River flow is larger than simply the dam outflow since the drainage area has increased by 185 km^2 and runoff from this area downstream of the dam has increased the flow in the channel. “Attenuation” in this context is assumed to be the increase in flow downstream of Daisy Lake dam, i.e. the degree to which the flow in Cheakamus River is increased beyond the dam outflow.

For the purposes of this analysis, attenuation has been quantified by three methods:

1. estimating the absolute (i.e., m^3/s) increase in flow from Daisy Lake dam to WSC 08GA043;
2. estimating the relative (i.e., %) increase in flow from Daisy Lake dam to WSC 08GA043; and
3. a comparison of flow duration curves for Daisy Lake dam outflows and WSC 08GA043.

3.1 Increase in Flow Downstream of Daisy Lake Dam

The total inflow downstream of the dam can be presented as absolute values (m^3/s) and also as increases relative to the dam outflow (%), explained as follows:

- The *absolute* tributary inflow is the amount of flow (in m^3/s) being contributed by the drainage area downstream of the dam and upstream of WSC 08GA043.
- The *relative* increase takes the absolute tributary inflow downstream of the dam and normalizes it to the dam outflow (i.e. tributary inputs equivalent to the dam outflow would equal a 100% increase).

Table 2 summarizes the absolute and relative increases into monthly averages over the period 2008 to 2012. Similarly, Figure 10 presents the total flow at WSC 08GA043 (Brackendale) as monthly averages, with the Daisy Lake outflow and tributary inflow separated out for ease of visual comparison.

Table 2: Monthly Average Outflow from Daisy Lake Dam And Downstream Tributary Inflow

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.

As indicated in Table 2, for the Y1 to Y5 period, the average inflow in any given month has been at least 11 m^3/s, and as much as 22 m^3/s. Inflows are lowest in the late winter/early spring months and greatest in mid-summer, which is consistent with regional precipitation and climate patterns. Relatively high inflows are also apparent in some fall and winter months, reflecting the occurrence of large rain or rain-on-snow events in the lower catchment of the Cheakamus River.

As a percentage of Daisy Lake outflow, in any given month the tributary inflow ranges from 40% to almost 300% of the outflow. In seven of 12 months, the tributary inflow is equal or greater than the outflow (i.e., > 100%). In three of 12 months, the tributary inflow is double to almost triple the dam outflow. The percentage increase is greatest in fall and winter months, when outflows are lowest. Late spring, summer, and early fall are when the percentage increases are lowest, but this is because the outflows are already relatively high (and therefore the higher tributary inflows have less of an effect, proportionately).

Figure 11 through Figure 15 present the annual time series of the total flow at WSC 08GA043 with the Daisy Lake outflow and tributary inflow components identified.

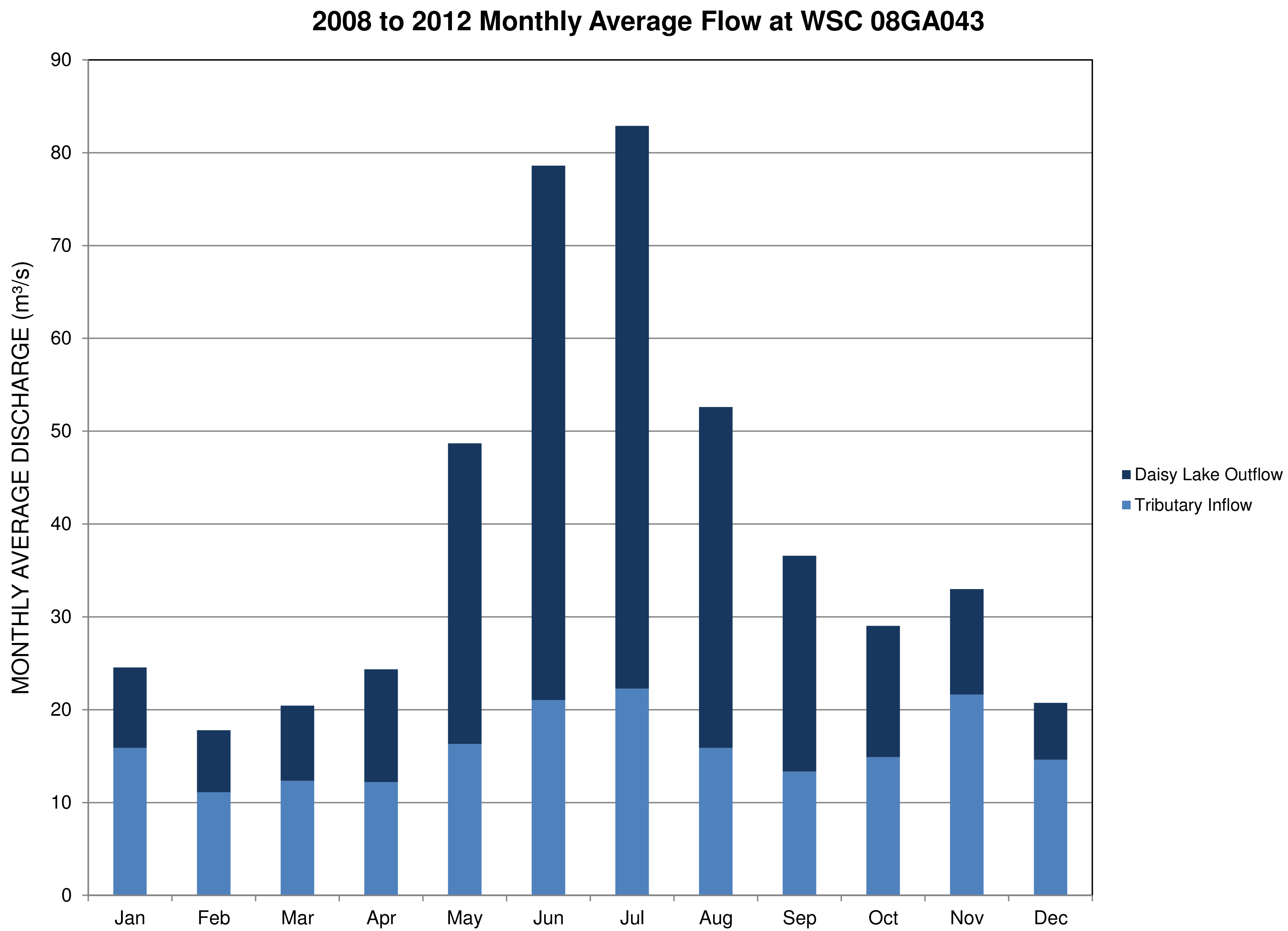

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Figure 10

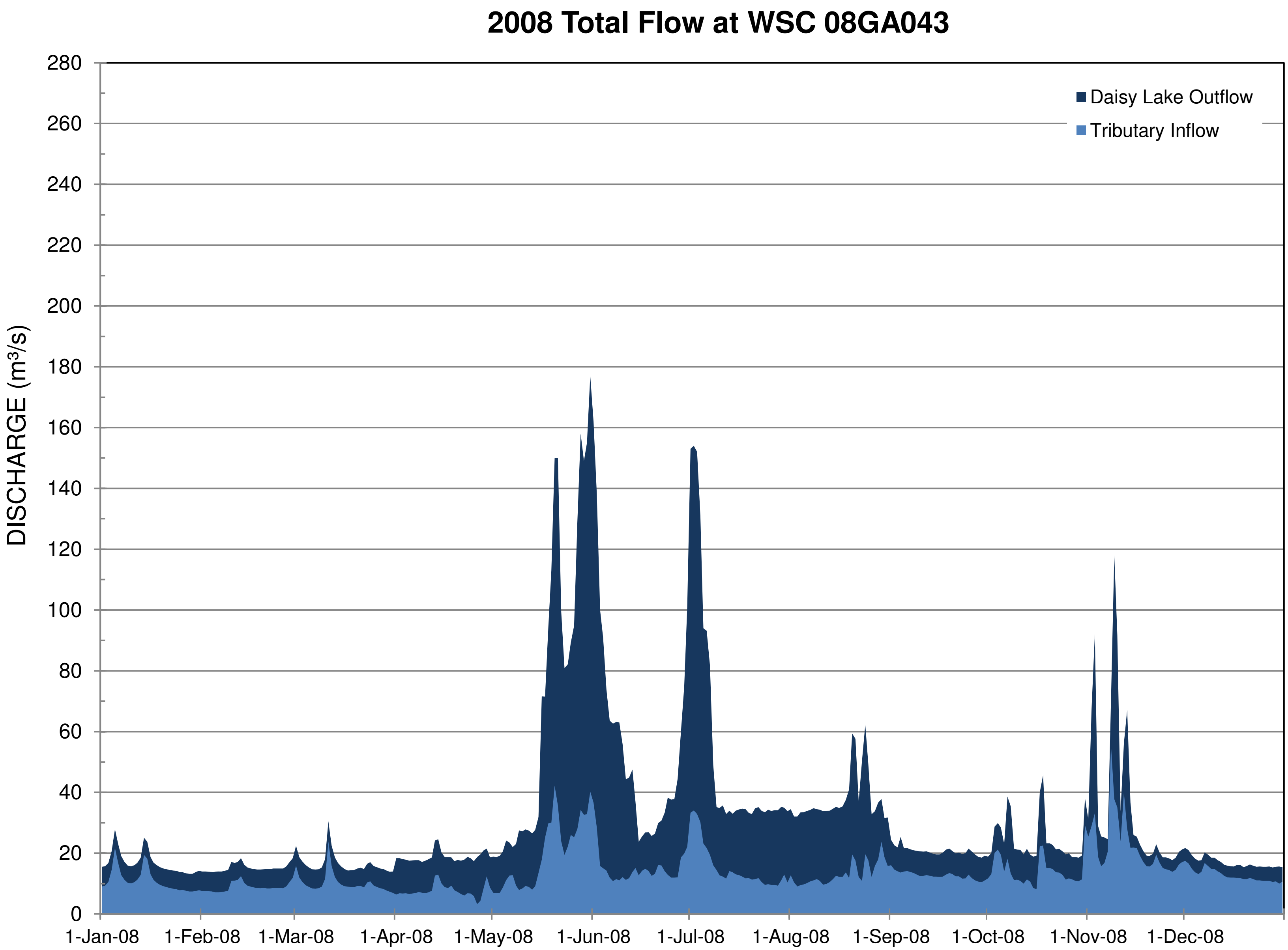

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Figure 11

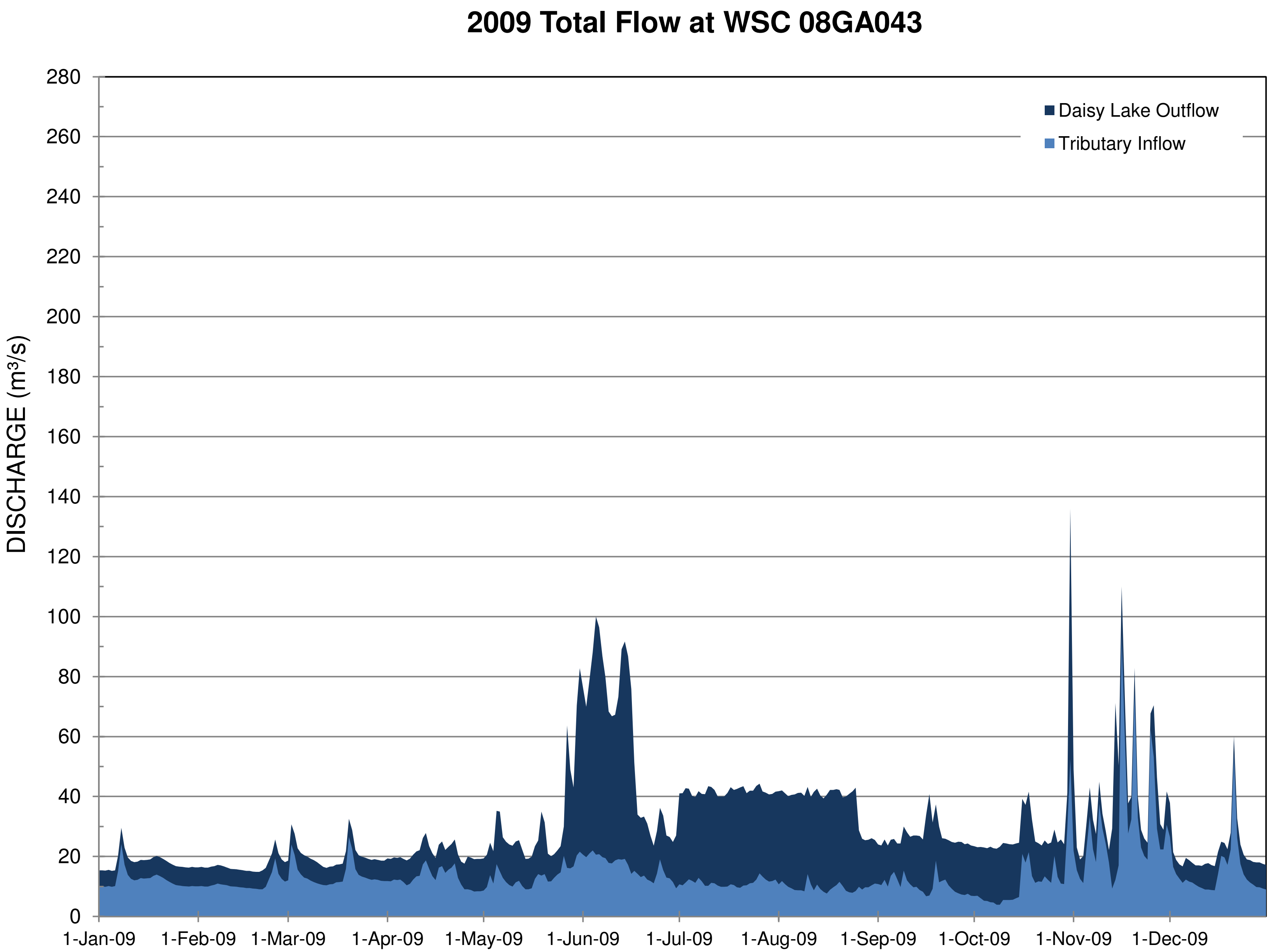

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Figure 12

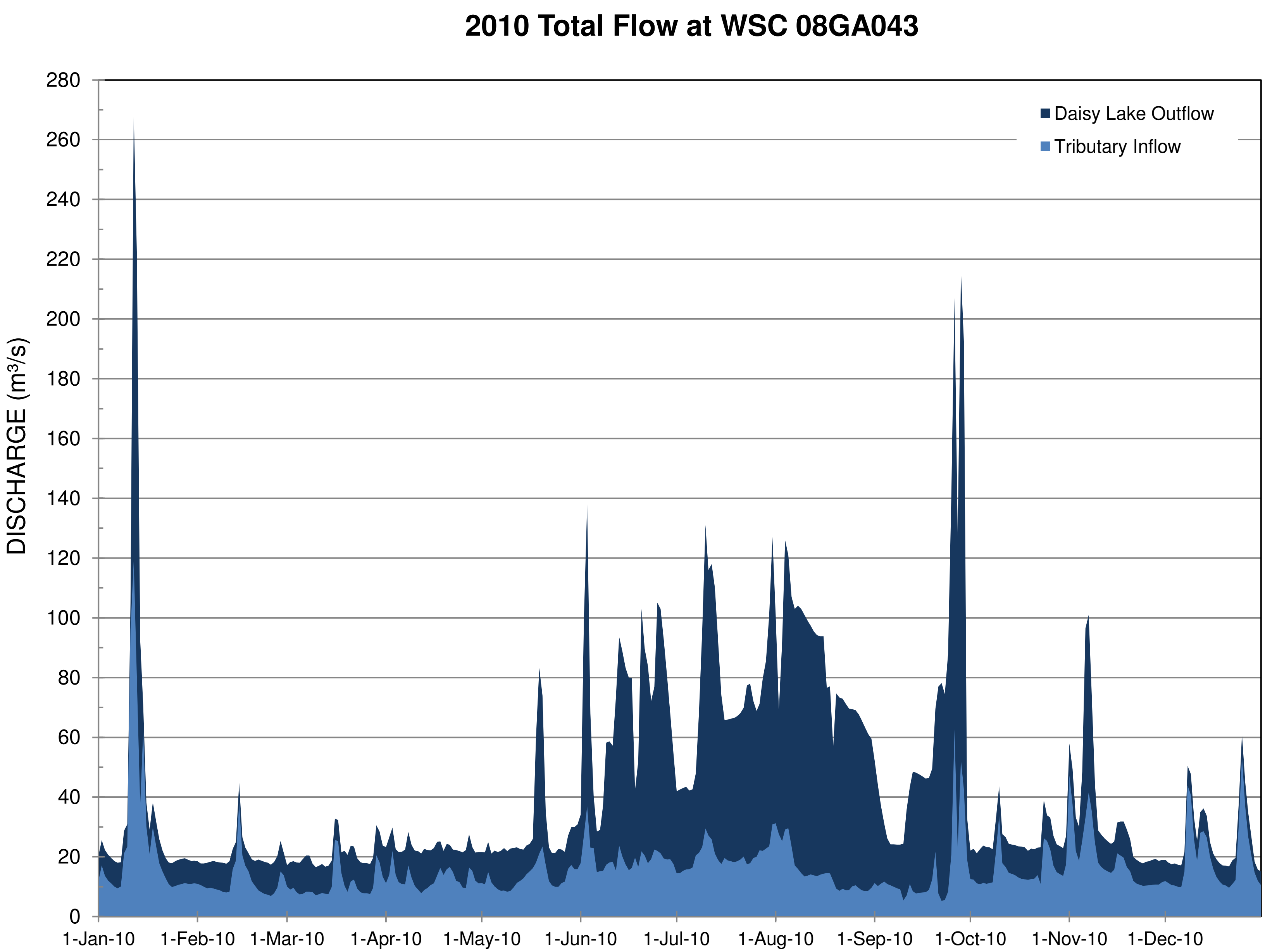

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Figure 13

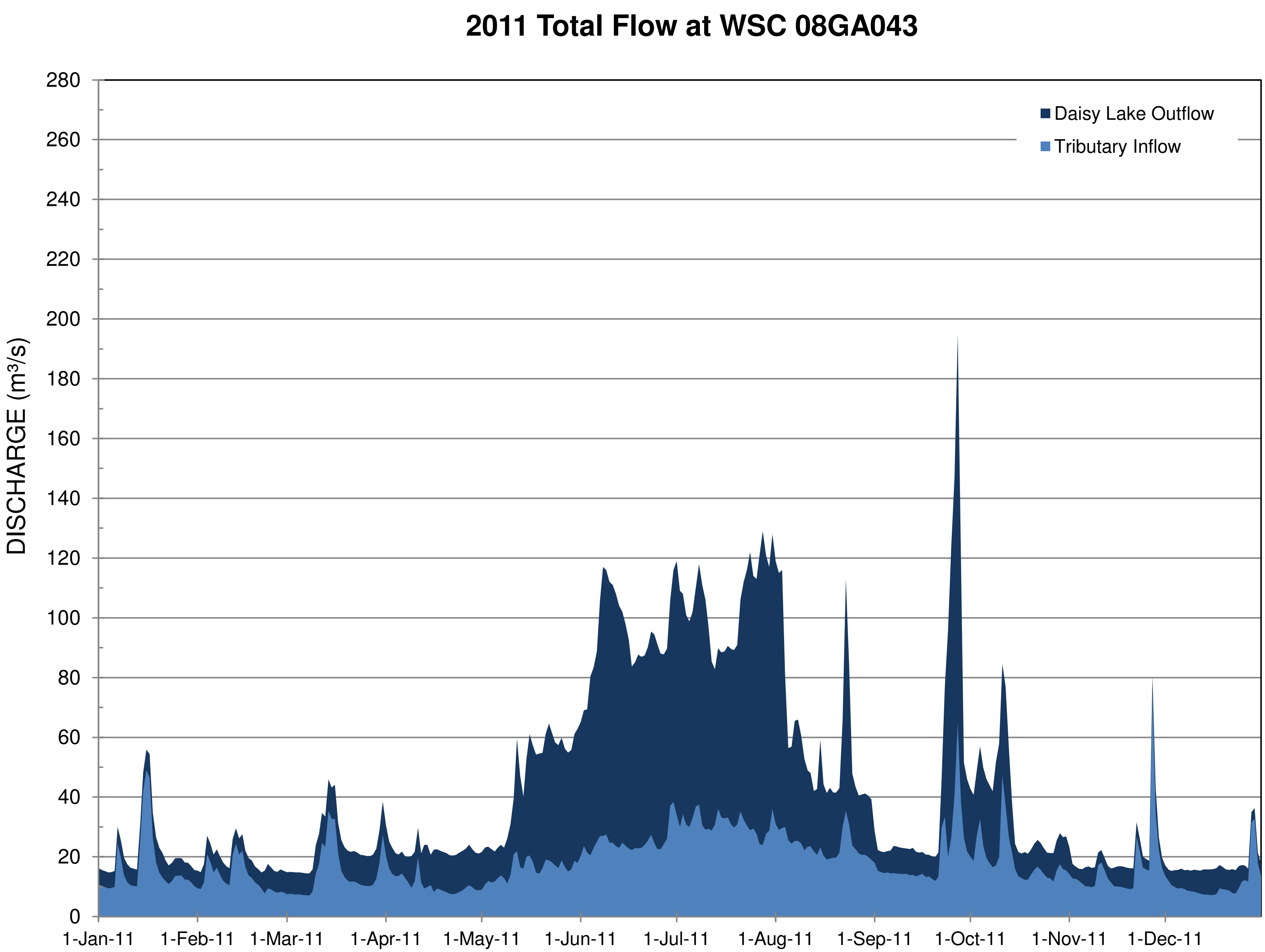

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Figure 14

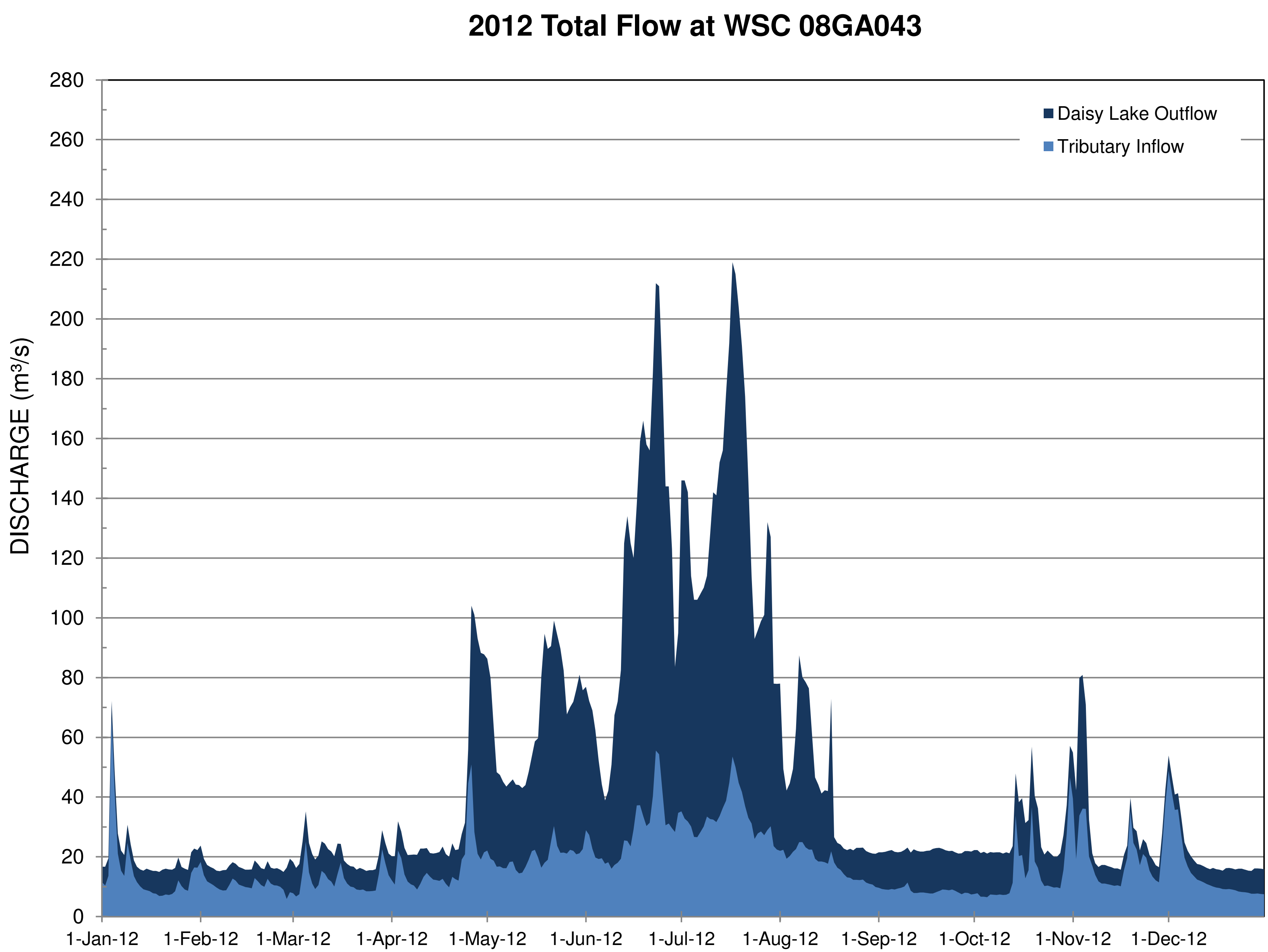

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Figure 15

3.2 Flow Duration Curves

Flow duration curves express the percentage of time that the flow is equalled or exceeded over the period of record. Higher flows have a lower percentage of exceedance because they occur less often, while the lowest flows are almost always exceeded.

Figure 15 presents flow duration curves for the Daisy Lake dam outflows and WSC 08GA043 for the Y1 (2008) to Y5 (2012) period of record.

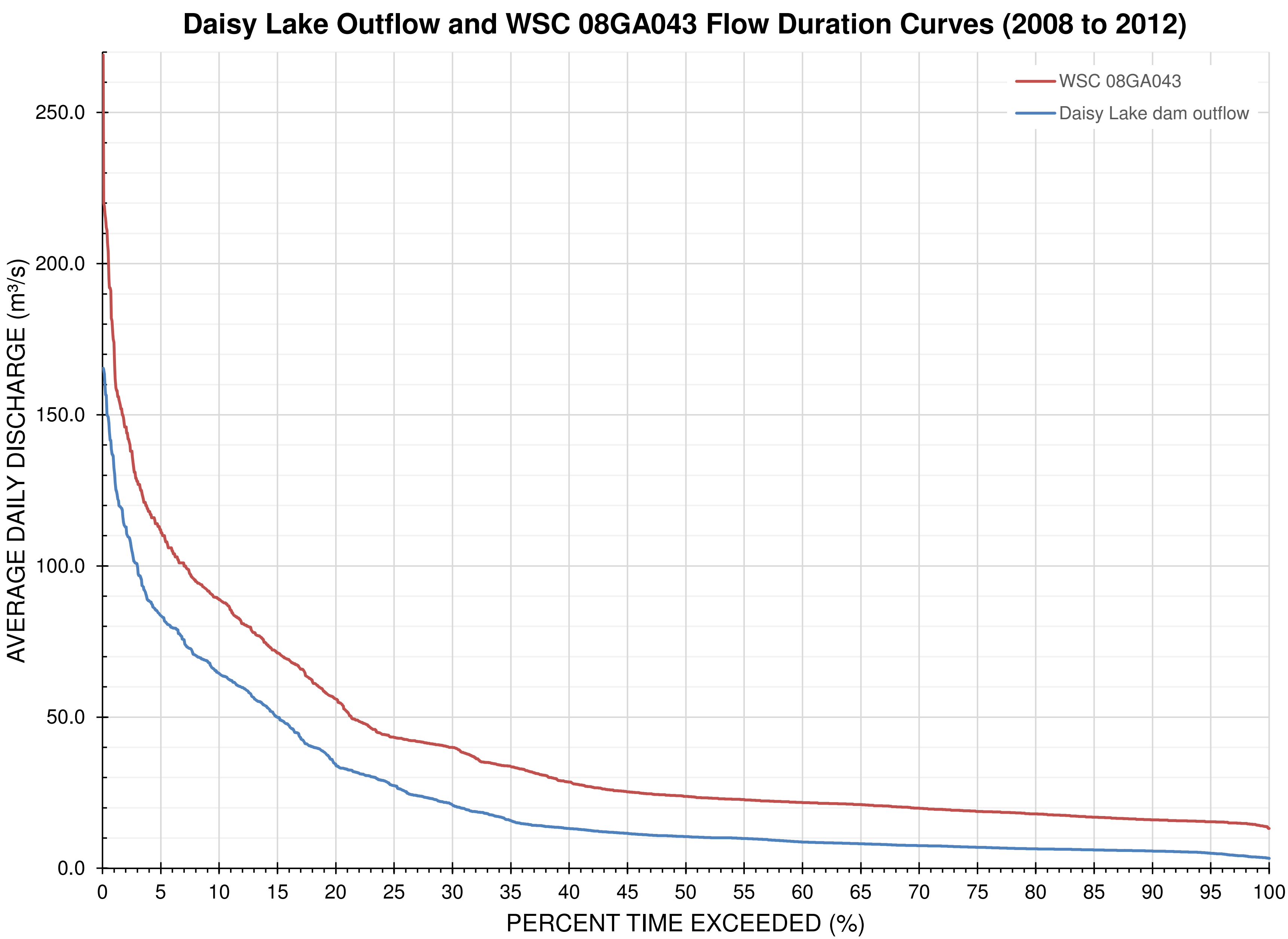
A visual comparison of the flow durations curves indicates the following conclusions:

- As expected, WSC 08GA043 flows for all percent exceedences are larger than the Daisy Lake dam outflows (due to the tributary inflow).
- The difference between the two curves is largest for the relatively rarely occurring flows (i.e., the higher flows) and less for the more regularly occurring flows (the lower flows).

Table 3 provides a comparison of the Daisy Lake outflow and WSC 08GA043 flow for various percent exceedences, as well as the calculated difference. As indicated in Table 3, for the more regularly-occurring flows (i.e., percent time exceeded ≥ 50%), the difference between WSC 08GA043 and Daisy Lake dam outflow is in the range of 10 m^3/s to 13 m^3/s.

Table 3: Daisy Lake Outflow and WSC 08GA043 Flow for Various Percent Exceedences

Percent Time Exceeded (%)	Daily Average Outflow Daisy Lake Dam (m^3/s)	Daily Average WSC 08GA043 (m^3/s)	Difference (m^3/s)
5	84	112	28
10	65	89	24
15	50	71	21
20	34	56	22
25	27	43	16
30	21	40	19
35	16	34	18
40	13	28	15
45	12	25	14
50	11	24	13
55	9.8	23	13
60	8.7	22	13
65	8.1	21	13
70	7.5	20	12
75	6.9	19	12
80	6.4	18	12
85	6.1	17	11
90	5.7	16	10
95	4.9	15	10



Daisy Lake Outflow and WSC 08GA043 Flow Duration Curves (2008 to 2012)
WSC 08GA043
Daisy Lake dam outflow
AVERAGE DAILY DISCHARGE (m³/s)
250.0
200.0
150.0
100.0
50.0
0.0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
PERCENT TIME EXCEEDED (%)

Figure 16

4. Summary

The goal of the current analysis is to answer the following Management Question:

> *"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?"*

Based on discussions with BC Hydro, the Management Question can be interpreted as a question related to general tributary inputs downstream of Daisy Lake dam. "Attenuation" speaks to the degree to which the tributary inputs downstream of the dam increase the Cheakamus River flow beyond what is released from Daisy Lake.

Using the CMSMON8 Y1 to Y5 data, the following statements can be made which speak to both the general hydrology of lower Cheakamus River, and also the degree to which the tributary inflows attenuate the effects of Daisy Lake dam:

- Average daily tributary inflow over this 5-year period 16 m^3/s, with a range from 3 m^3/s to 119 m^3/s.
- On average, the tributary inflow results in about a 138% increase in flow between Daisy Lake dam and WSC 08GA043 (i.e. tributary inflow is about 1.4 times the dam outflows).
- Monthly average tributary inflow ranges from a minimum of 11 m^3/s in February, to a maximum of 22 m^3/s, which occurs in both July and November.
- Tributary inflow is consistently larger during the summer months, as an absolute value.
- However, the largest *relative* increases (i.e., as a percentage of the dam outflow) occur during in fall and winter months, when dam outflows are lowest. During fall and winter the relative inflow downstream of the dam ranges from 95% to 294% as a monthly average (i.e. the tributary inflow is equivalent to almost triple the dam outflow).
- For the more regularly-occurring flows (i.e., those that are equalled or exceeded for more than 50% of the Y1 to Y5 record), the difference between the WSC 08GA043 and Daisy Lake dam outflow is in the range of 10 m^3/s to 13 m^3/s.
- Uncertainties associated with the additional CMSMON8 hydrometric station data mean that it is difficult to accurately assess how much flow is being contributed by specific tributaries (or sub-reaches).

5. Conclusions

The foregoing sections have presented an analysis of hydrometric data aimed at addressing CMSMON8 Management Question 3. The general hydrology of the lower Cheakamus has been characterized, and tributary inputs to the CMSMON8 reach as a whole have been quantified. In addition, the attenuation effect of the tributary inputs has also been assessed and quantified. All of the foregoing has been accomplished *solely based* on BC Hydro and WSC discharge data.

Tributary inflows downstream of the dam have a large impact on the Cheakamus River flow downstream of the dam. Over the CMSMON8 study reach, the average tributary inflow from 2008 to 2012 was about 138% of dam outflow. As represented by the *relative* increase in flow (i.e., %), the attenuating effect of tributary inflow is felt most strongly during fall and winter months. However, absolute tributary inflow is highest during summer months but this is when dam outflow is also higher, so the relative impact of the tributary inflows is less.

The CMSMON8 hydrometric stations located between Daisy Lake dam and WSC 08GA043 do not appear to provide a great deal of additional value when attempting to answer the Management Question. Attempts to resolve the flow contributions from specific tributaries or tributary sub-reaches using data from these stations results in unrealistic flows (e.g. negative flows) or unrealistic downstream trends in flows (e.g., loss of flow downstream, or reaches with no runoff).

Using the existing WSC 08GA043 station and Daisy Lake dam outflows, it is possible to quantify tributary inflow to the reach downstream of the dam as a whole, as this analysis has demonstrated. It is assumed that the additional CMSMON8 hydrometric stations were intended to provide a greater degree of spatial resolution, and increase understanding of how the tributary inflows might vary through the reach downstream of the dam. However, there are two main challenges associated with this premise:

1. During much of the year, the total tributary inflow downstream of the dam is 20 m^3/s or less. In rough terms, this would imply that the flow difference to be resolved between the three CMSMON8 stations would be in the order of about 7 m^3/s or less. This is a very high level of precision relative to the expected average uncertainty associated with the rating curves for the stations. In other words, <u>the difference in flow that would need to be measured is on the same order as the associated uncertainty of the measurement</u>. Therefore, this measurement of flow difference appears impractical to attempt to achieve.
2. During peak flow events, water levels rise above the range of existing measurements and therefore in order to calculate a discharge the rating curve was extrapolated. Extrapolation of the rating curve can lead to a large increase in associated uncertainty.

In the case of (1) above, there is little that can be done to address this challenge. In the case of (2), the degree of associated uncertainty can be reduced by obtaining additional high flow measurements to reduce the extrapolation in the event of peak flows, but it is unlikely that extrapolation could be eliminated completely for large events.

We trust that the foregoing report is sufficient for your purposes. Please do not hesitate to contact the undersigned should you have any questions.

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Revision History

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