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.

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[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*) 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*)
* 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 m³/s (September 20, 2015)	Collected captured sediment and replaced sediment traps
December 15, 2015	166 m³/s (December 4, 2015)	Collected captured sediment and replaced sediment traps
February 2, 2016	267 m³/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 m³/s (September 22, 2015)	Collected captured sediment and replaced sediment traps
December 15, 2015	107 m³/s (December 4, 2015)	Collected captured sediment and replaced sediment traps
June 17, 2016	148 m³/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.

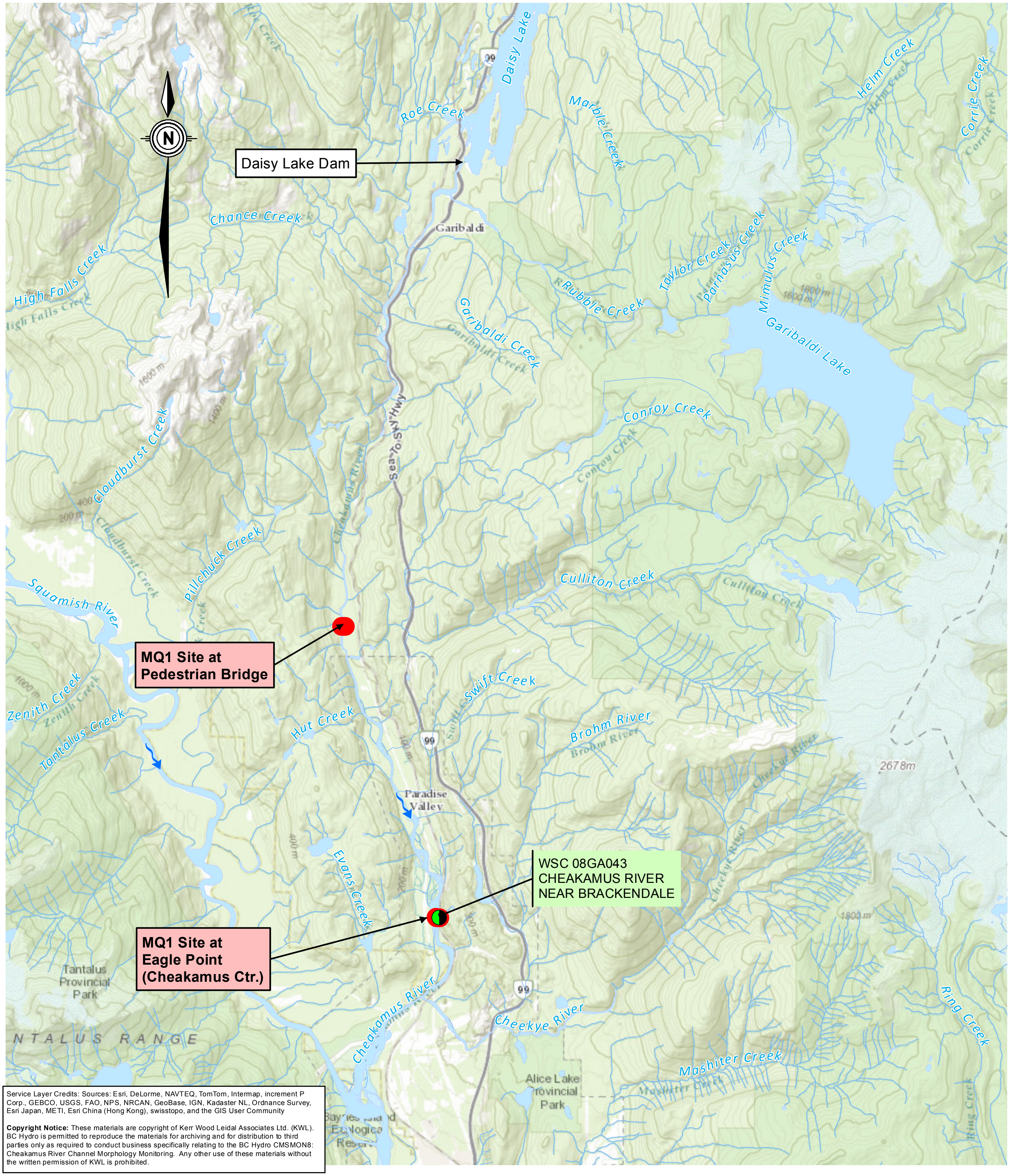
Although not necessarily accurate, this estimation creates an upper bound for comparing IFA and WUP operations above which it is assumed that discharges into the Cheakamus River are governed by flood routing and have not changed significantly from IFA to WUP periods.

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.



Service Layer Credits: Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, and the GIS User Community

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CMSMON8: Cheakamus River Channel Morphology Monitoring

Project No.	Date
478-164	November 2015

1,000 0 2,000 (m)
1:125,000

MQ1 Field Site Locations

Figure 2-1

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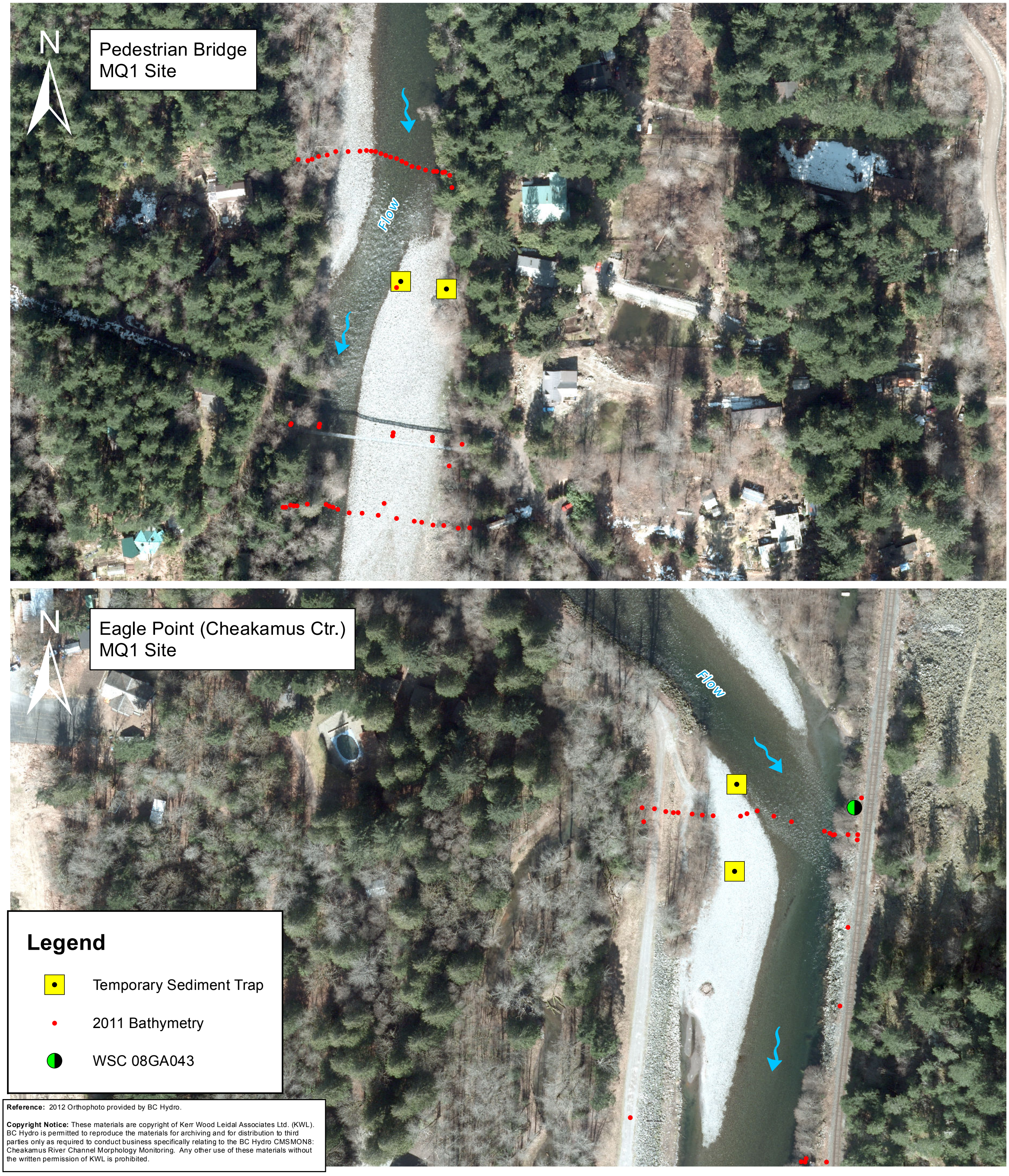
Author: EEllis



Reference: 2012 Orthophoto provided by BC Hydro.

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consulting engineers

BC Hydro
CMSMON8: Cheakamus River Channel Morphology Monitoring

Project No.	Date
478-164	November 2015

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(m)
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MQ1 Field Site Layout

Figure 2-2

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Author: EEllis

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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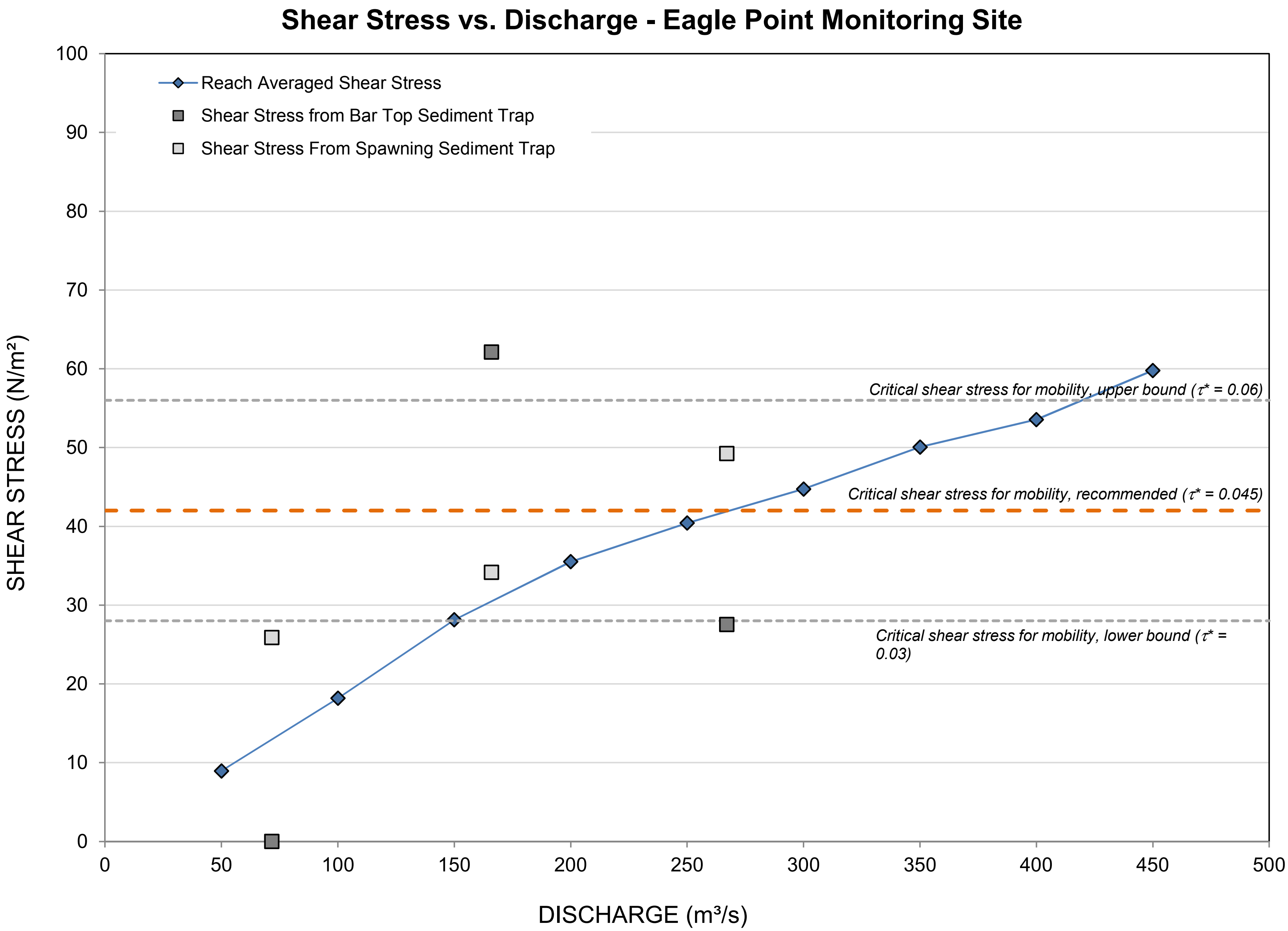

KERR WOOD LEIDAL
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Figure 3-1

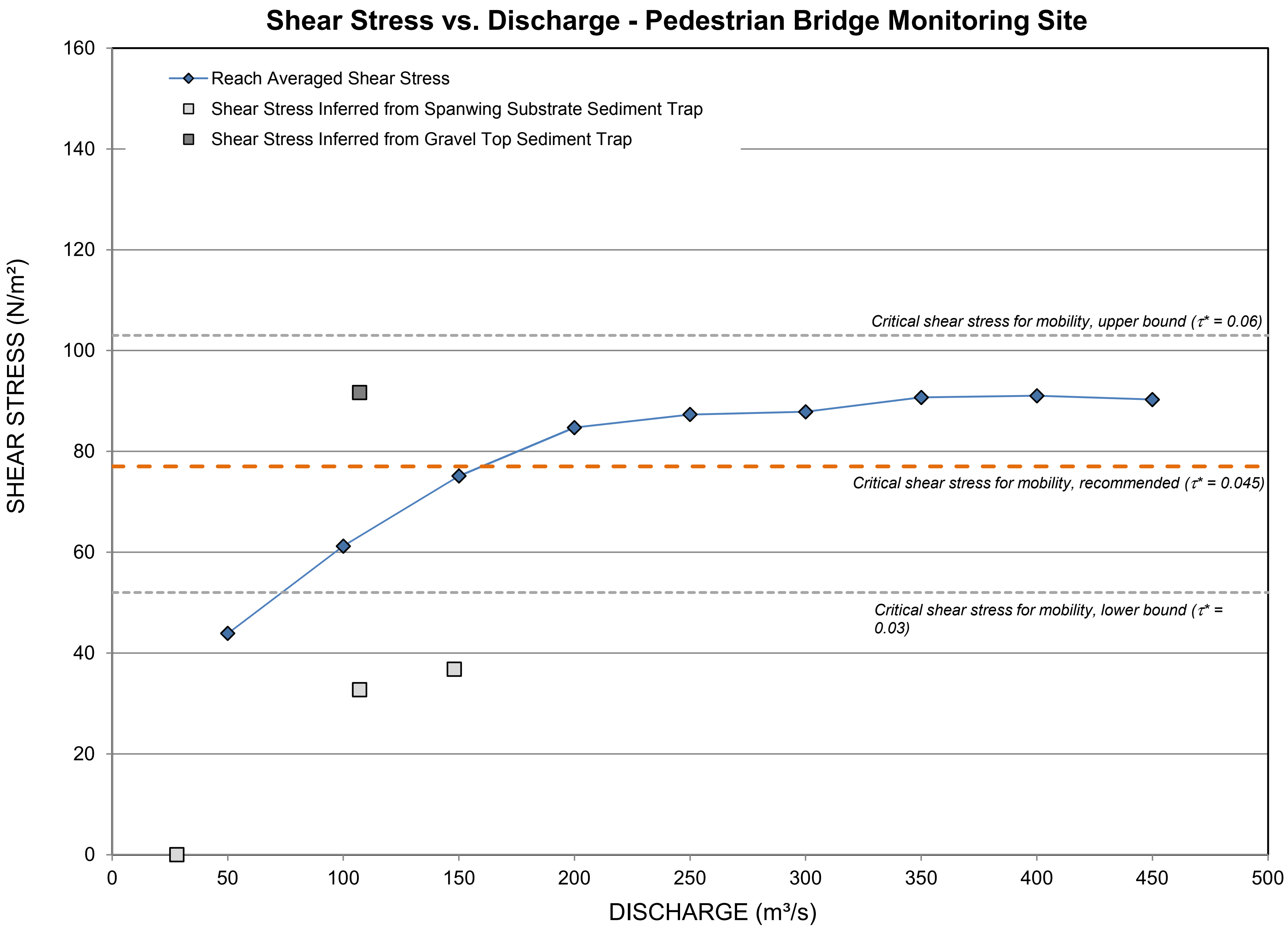

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Figure 3-2

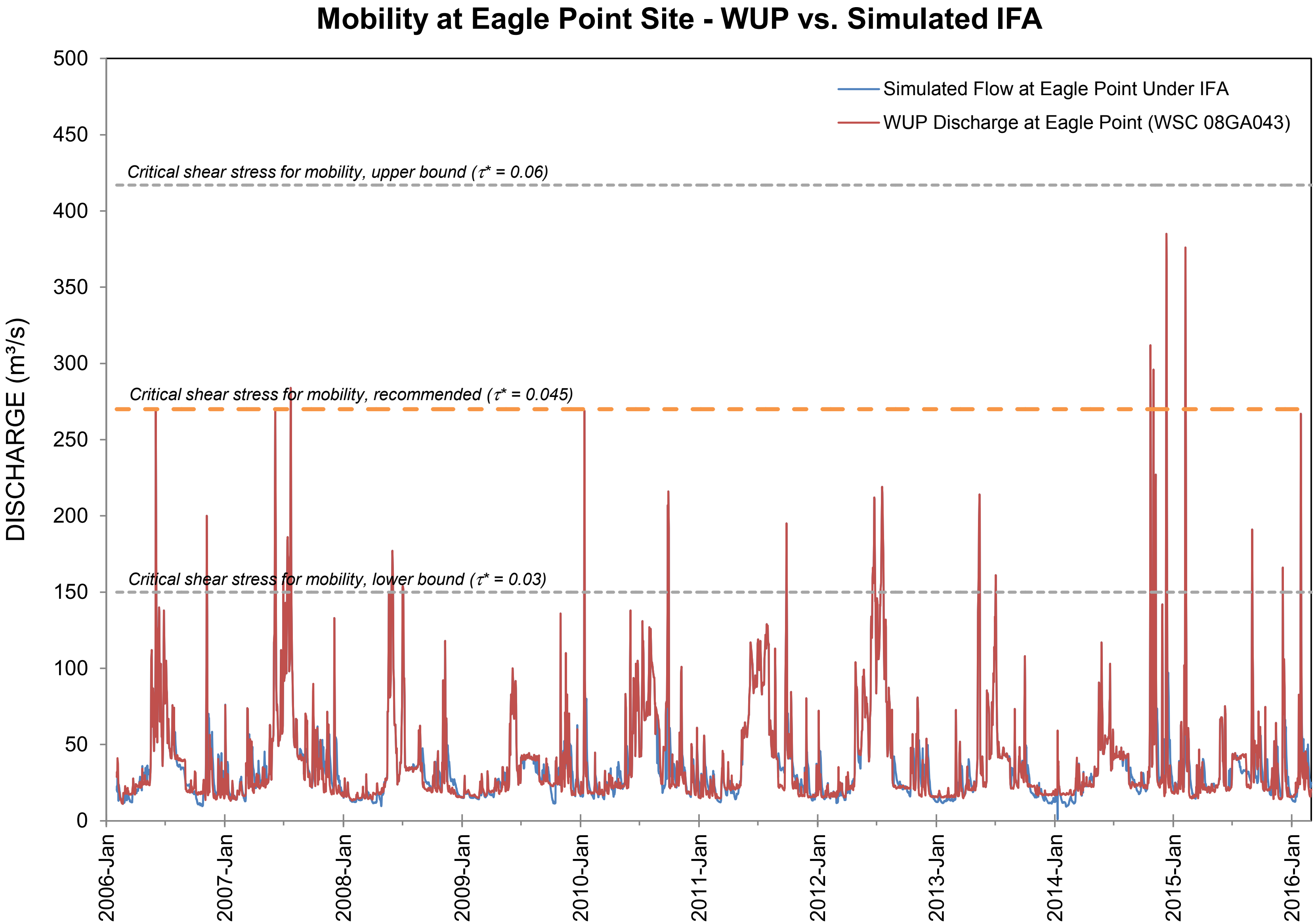

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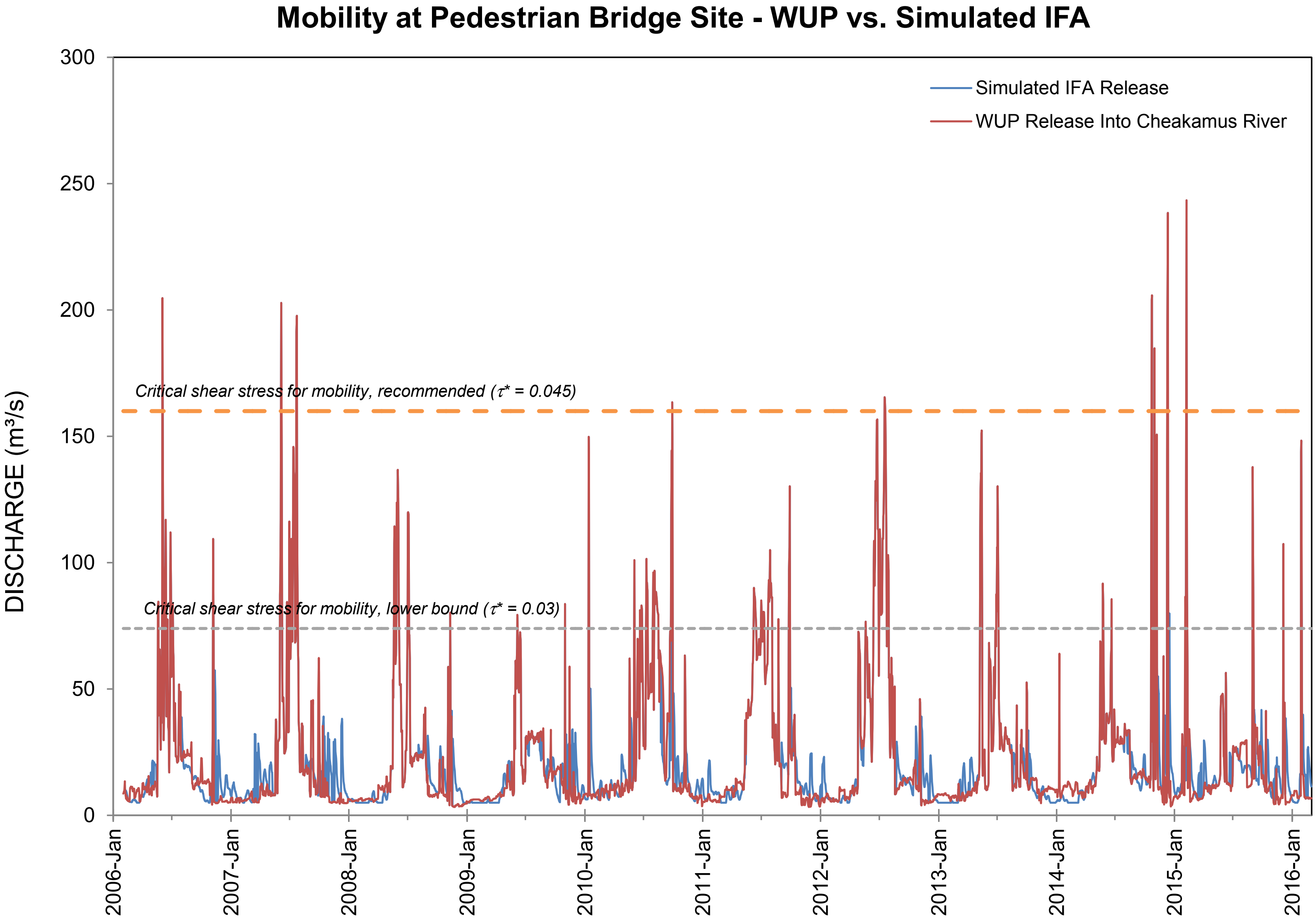
Figure 3-3



KERR WOOD LEIDAL
consulting engineers

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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

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References

BC Hydro, 2005. Cheakamus Project Water Use Plan. 12 pp + appendix.

BC Hydro, 2012. *Dam Safety – Cheakamus Dam: FLOODSiMM Inundation Modelling and Mapping Report*.

BC Hydro, 2015. Cheakamus Project Water Use Plan Monitoring Terms of Reference CMSMON8 – Channel Morphology in Cheakamus River Addendum 2. June 25, 2015.

Buffington, J.M. 1999. The legend of A.F. Shields. *Journal of Hydraulic Engineering, American Society of Civil Engineers*. 125:4. 376-387.

Bunte, K. and Abt, S.R., 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. Report prepared by the United States Department of Agriculture Forest Service Rocky Mountain Research Station. General Technical Report RMRS-GTR-74. 390 pp + appendix, references & index.

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonid populations in streams. Trans. Am. Fish. Soc. 117:1-21.

Church, M., 2006. Bed Material Transport and the Morphology of Alluvial Channels. *Annu. Rev. Earth Planet. Sci.* 34:325-54.

C. Fell, D.J.F. McCubbing, L.J. Wilson and C.C. Melville. 2015. Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey, Implementation Year 8 (Reference: CMSMON-1B). Prepared for B.C. Hydro Power Authority. November 10, 2015.

Knighton, D., 1998. Fluvial Forms and Processes: A New Perspective. London: Arnold.

Komar, P.D. 1996. Entrainment of Sediments form Deposits of Mixed Grain Sizes and Densities. In. Carling, P.A. and Dawson M.R. (eds). Advances in Fluvial Dynamics and Stratigraphy. Wiley, Chichester, pp. 127-81.

Kondolf, M.G., and M.G. Wolman. 1993. The Sizes of Salmonid Spawning Gravels. Water Resources Research. 29: 2275–2285.

Korman, J. and J. Schick. 2015. Cheakamus River Steelhead Adult Abundance, Fry Emergence Timing, and Juvenile Habitat Use and Abundance Monitoring, Implementation Year 7 (Reference: CMSMON-03). Prepared for B.C. Hydro Power Authority. November 4, 2015.

KWL, 2014. Cheakamus River Channel Morphology Monitoring Year 1 to Year 5 Flow Synthesis Report. Report prepared for BC Hydro.

Lapointe, M., B. Eaton., S. Driscoll., and C. Latulippe. 2000. Modelling the probability of salmonid egg pocket scour due to floods. Can. J. Aqua. Sci. 57: 1120-1130.

Lisle, T.E. 1989. Sediment Transport and Resulting Deposition in Spawning Gravels, North Coastal California. Water Resources Research, 25: 1303-1319.

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

Petit, F., Houbrechts, G., Peeters, A., Hallot, E., Van Campenhout, J., and Denis, A., 2015. Dimensionless Critical Shear Stress in Gravel-bed Rivers. Geomorphology. 250: 308-320.

Wolman, M.G. 1954. A method of sampling coarse river bed material. Transactions, American Geophysical Union, Volume 35, Issue 6, p. 951-956.

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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)

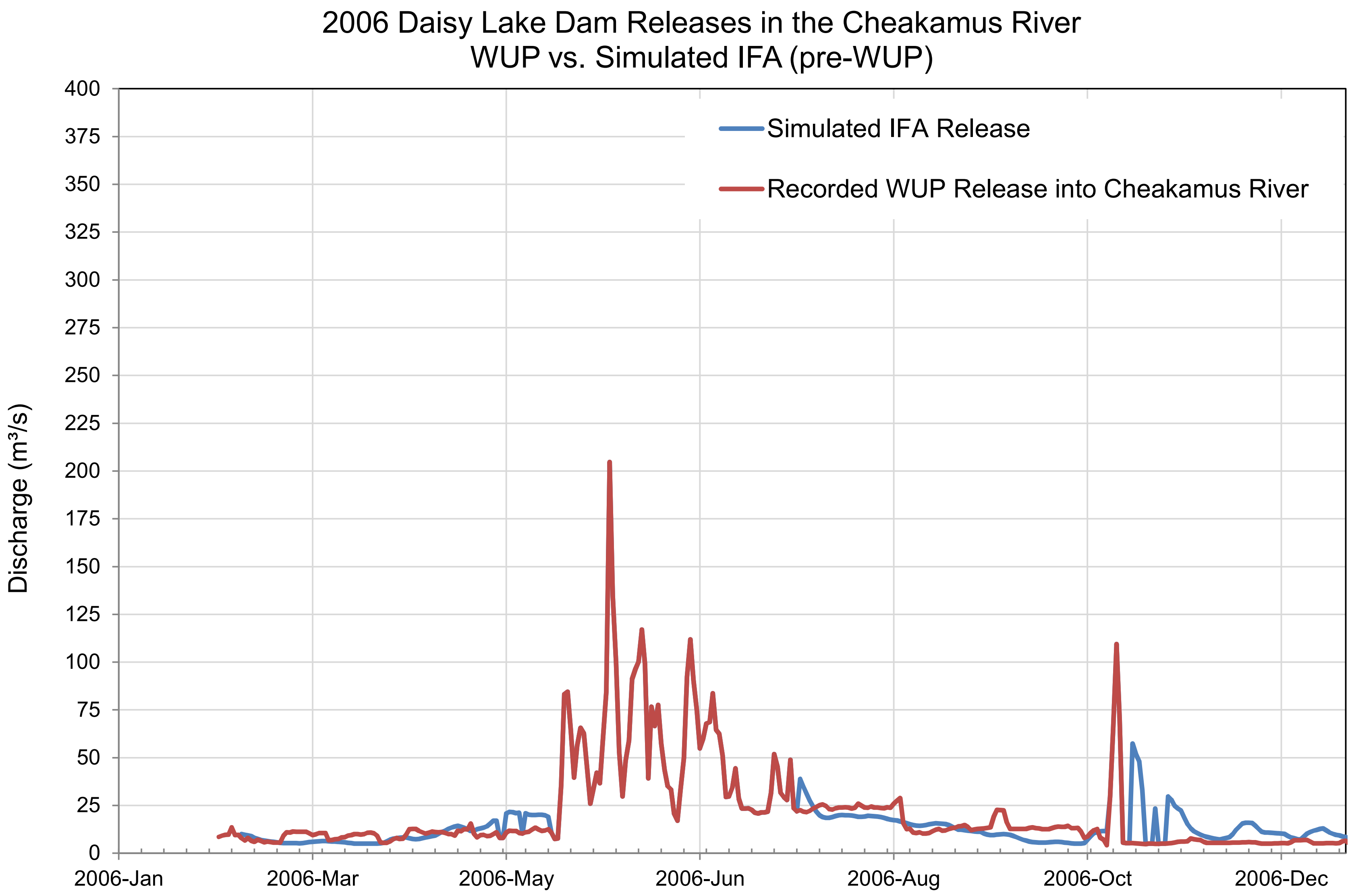
2006 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)

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Figure A-1

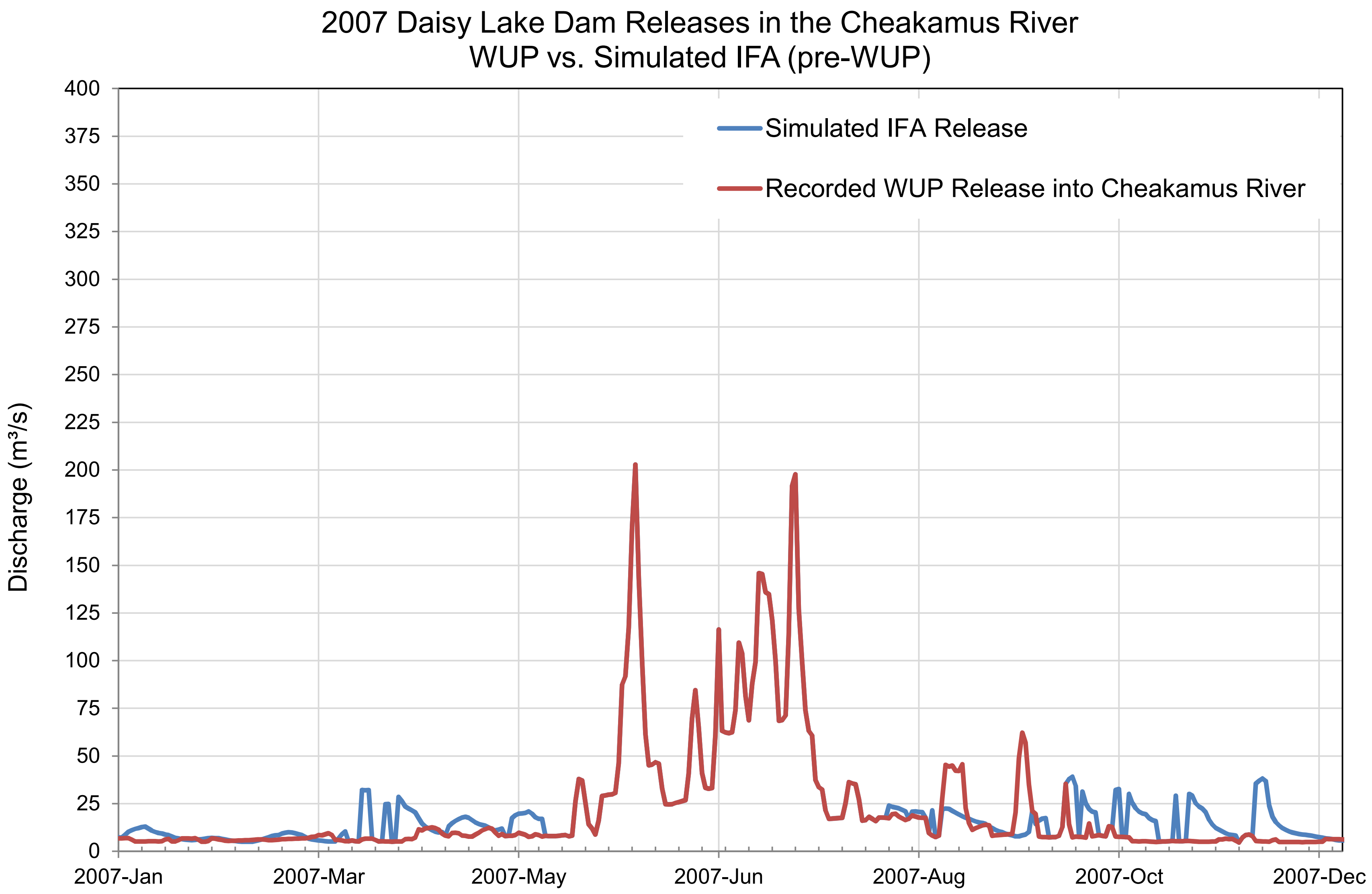
2007 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)
Simulated IFA Release
Recorded WUP Release into Cheakamus River
Discharge (m³/s)
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
2007-Jan
2007-Mar
2007-May
2007-Jun
2007-Aug
2007-Oct
2007-Dec

Figure A-2

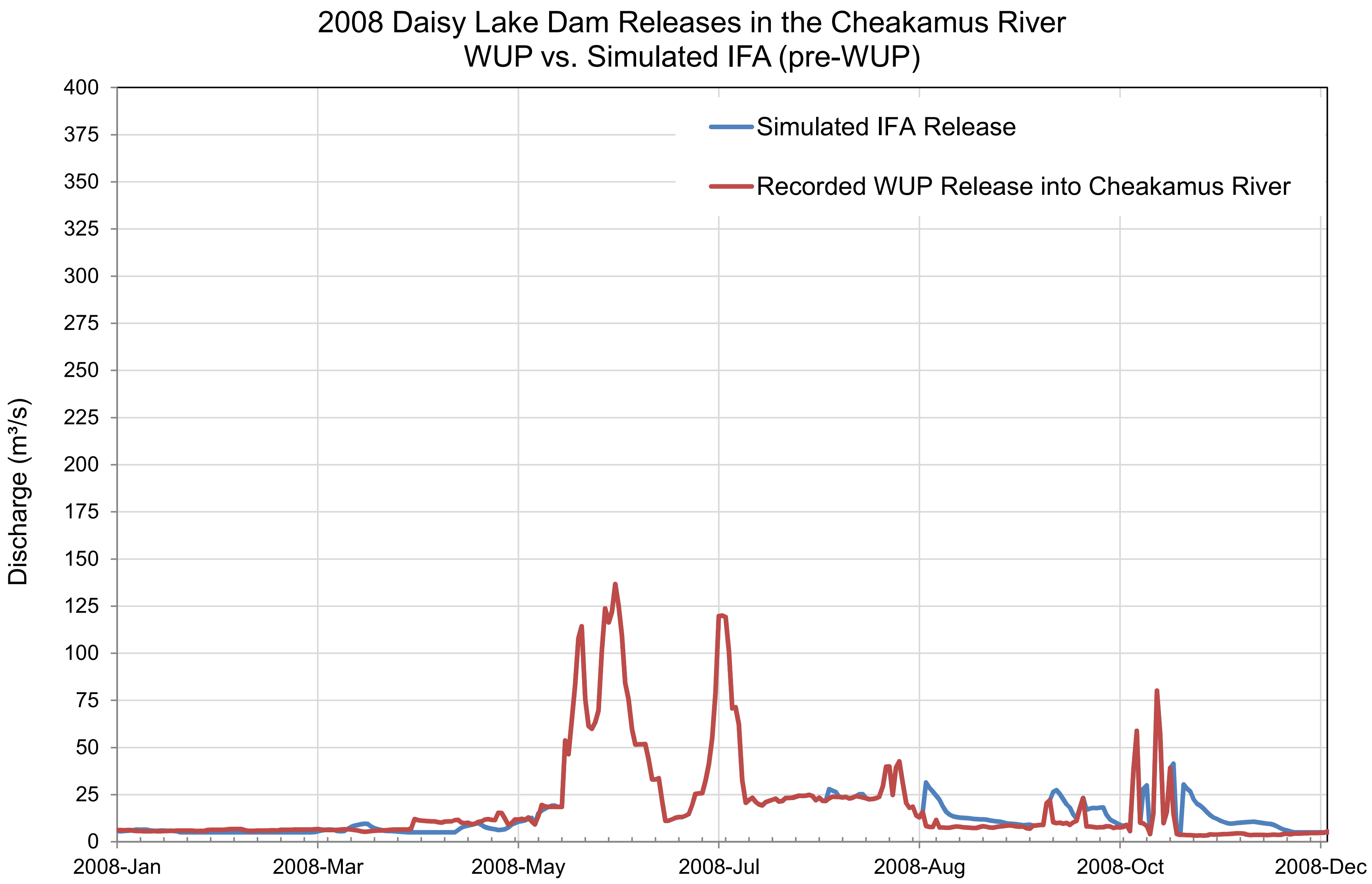

Figure A-3

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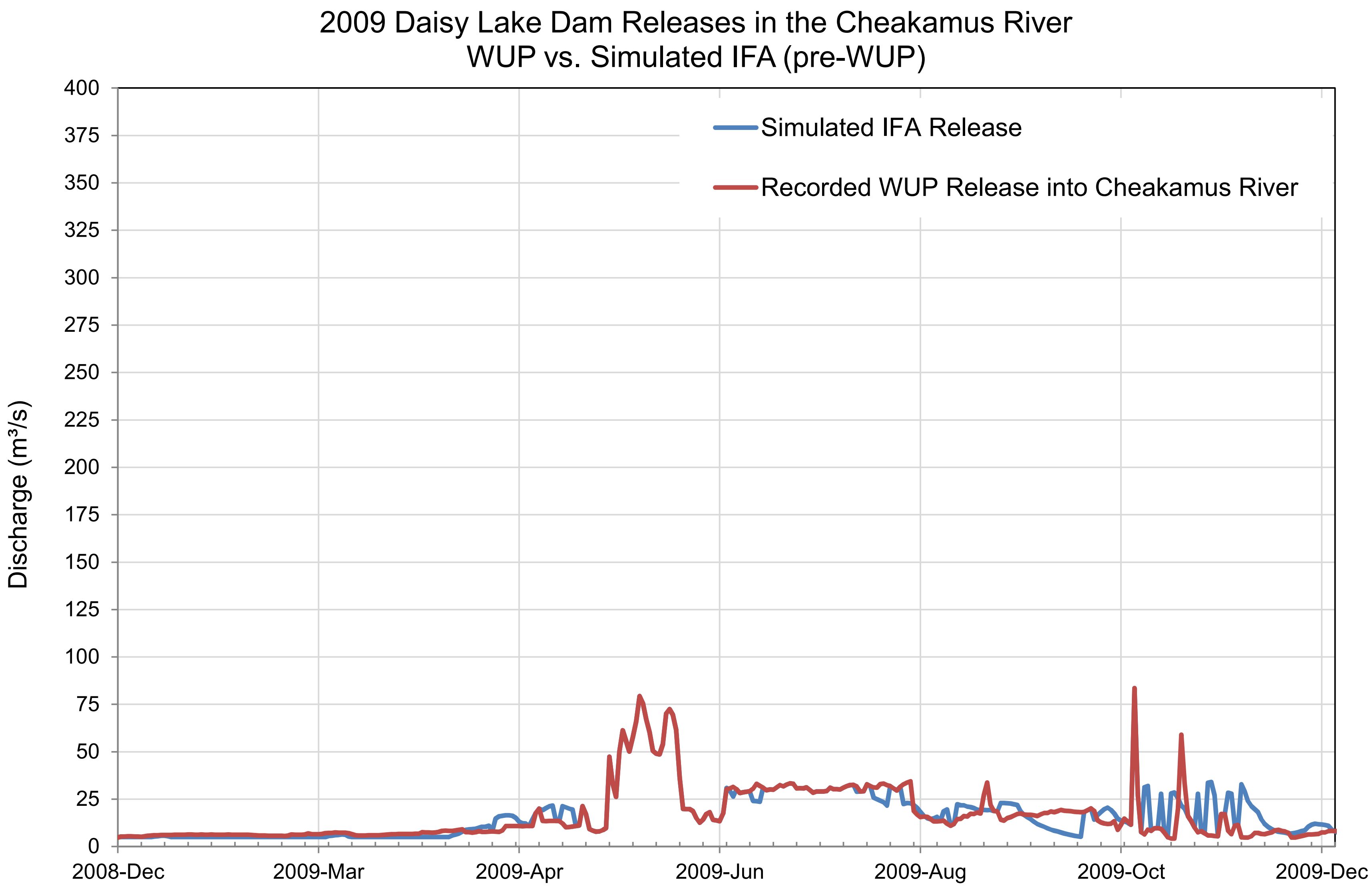

2009 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)
Discharge (m³/s)
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
2008-Dec
2009-Mar
2009-Apr
2009-Jun
2009-Aug
2009-Oct
2009-Dec
Simulated IFA Release
Recorded WUP Release into Cheakamus River

Figure A-4

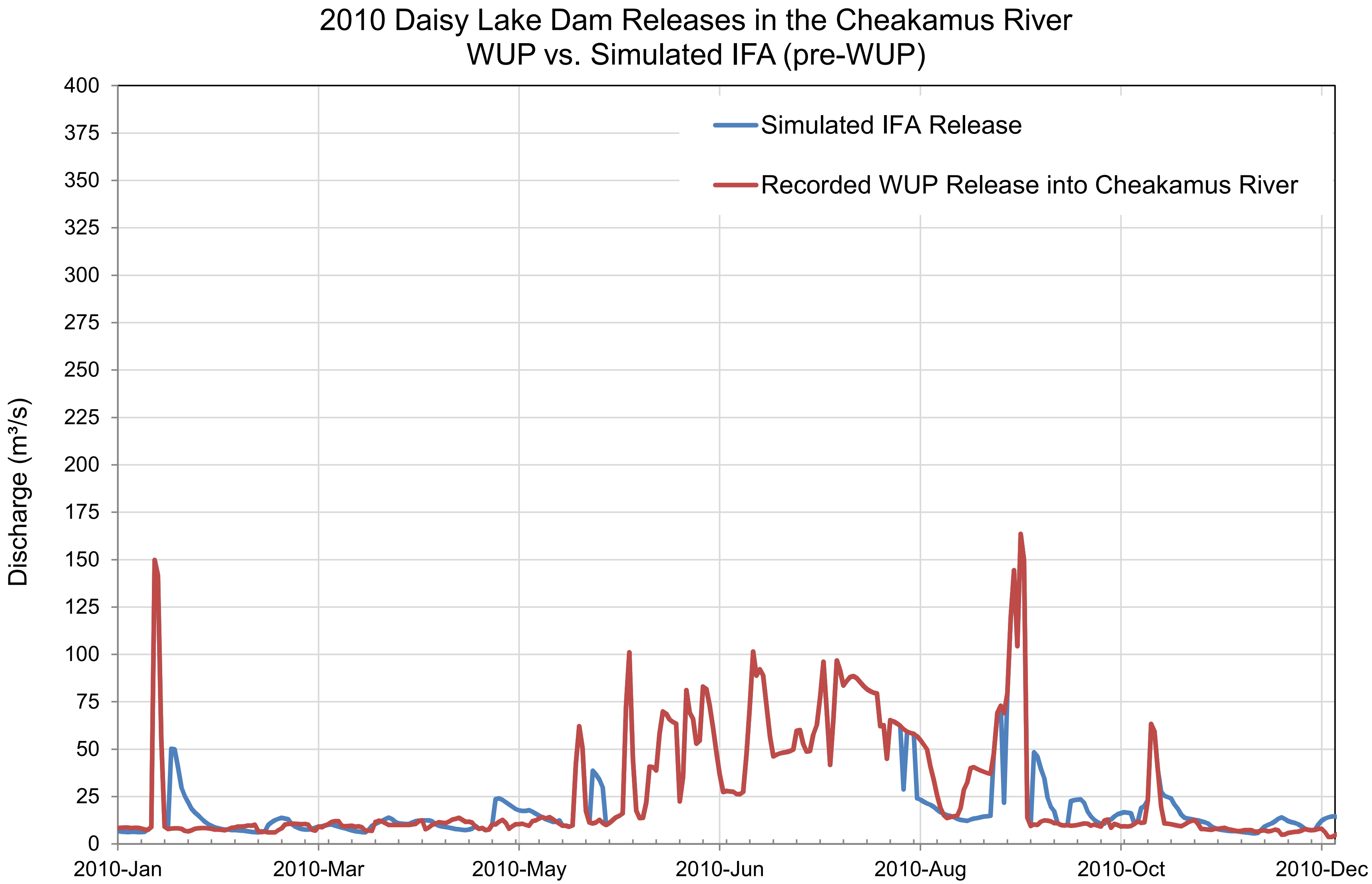
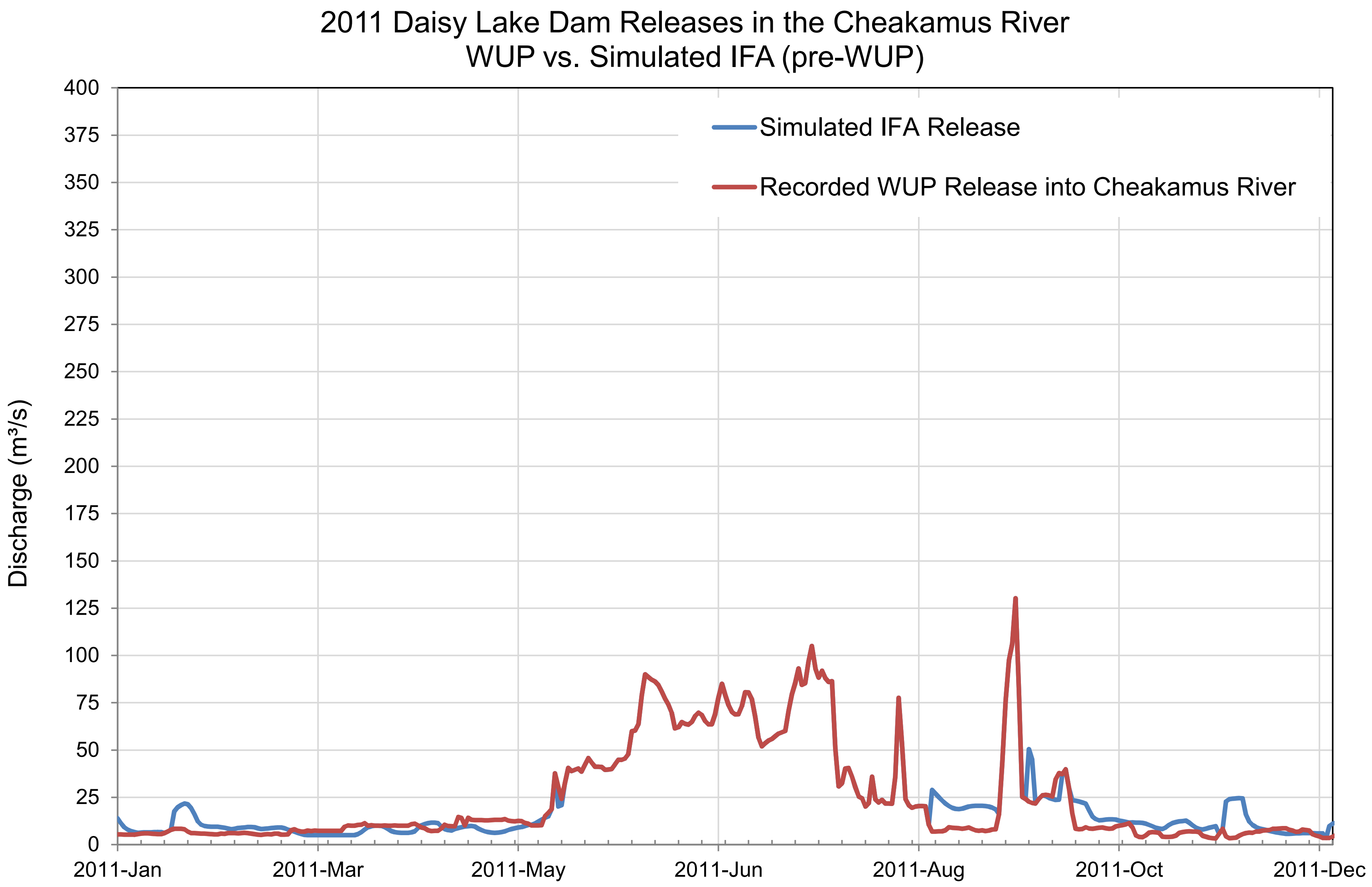

2010 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)
Discharge (m³/s)
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
2010-Jan
2010-Mar
2010-May
2010-Jun
2010-Aug
2010-Oct
2010-Dec
Simulated IFA Release
Recorded WUP Release into Cheakamus River

Figure A-5



2011 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)

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Figure A-6

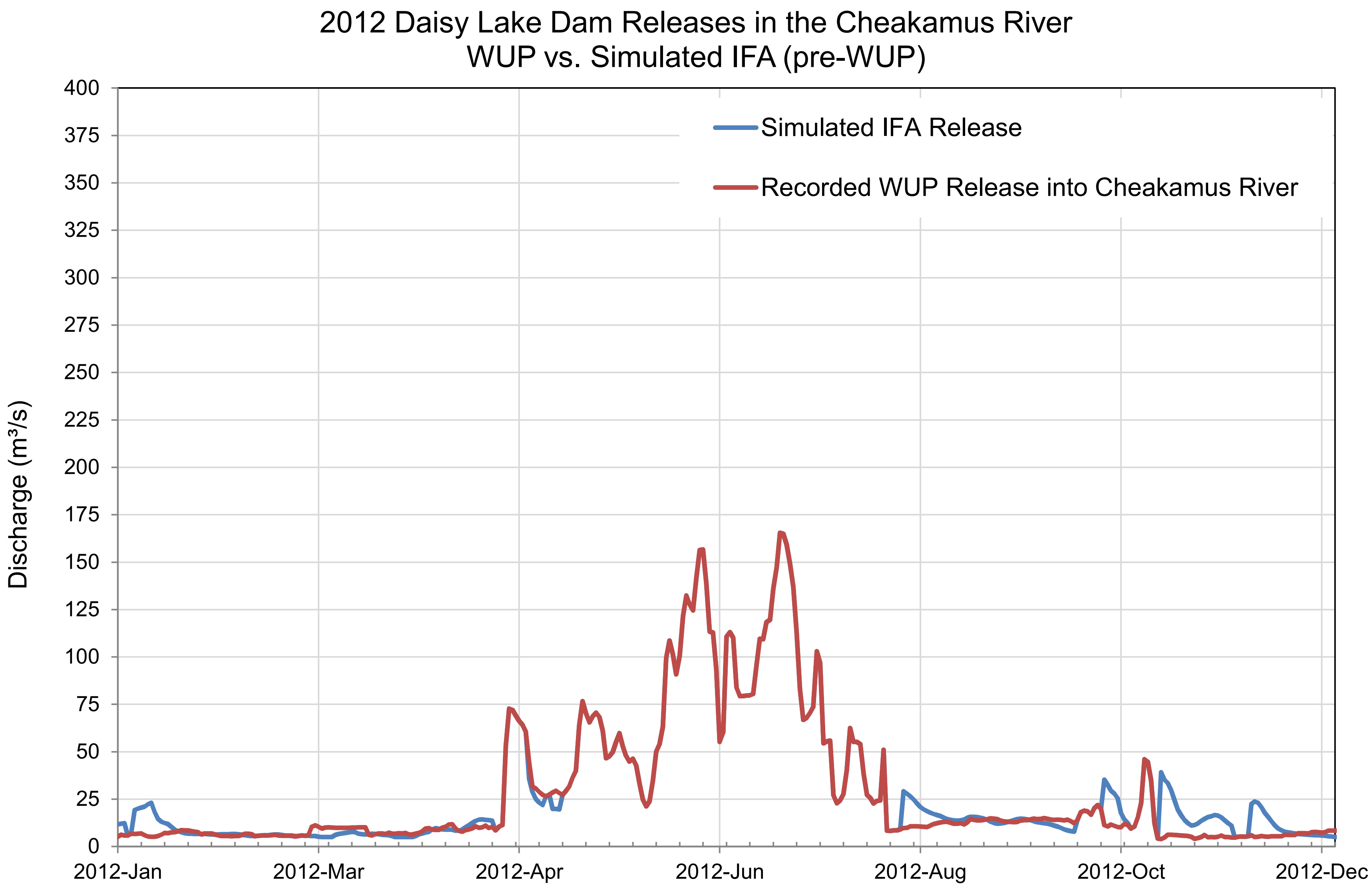
2012 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)

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Figure A-7

2013 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)

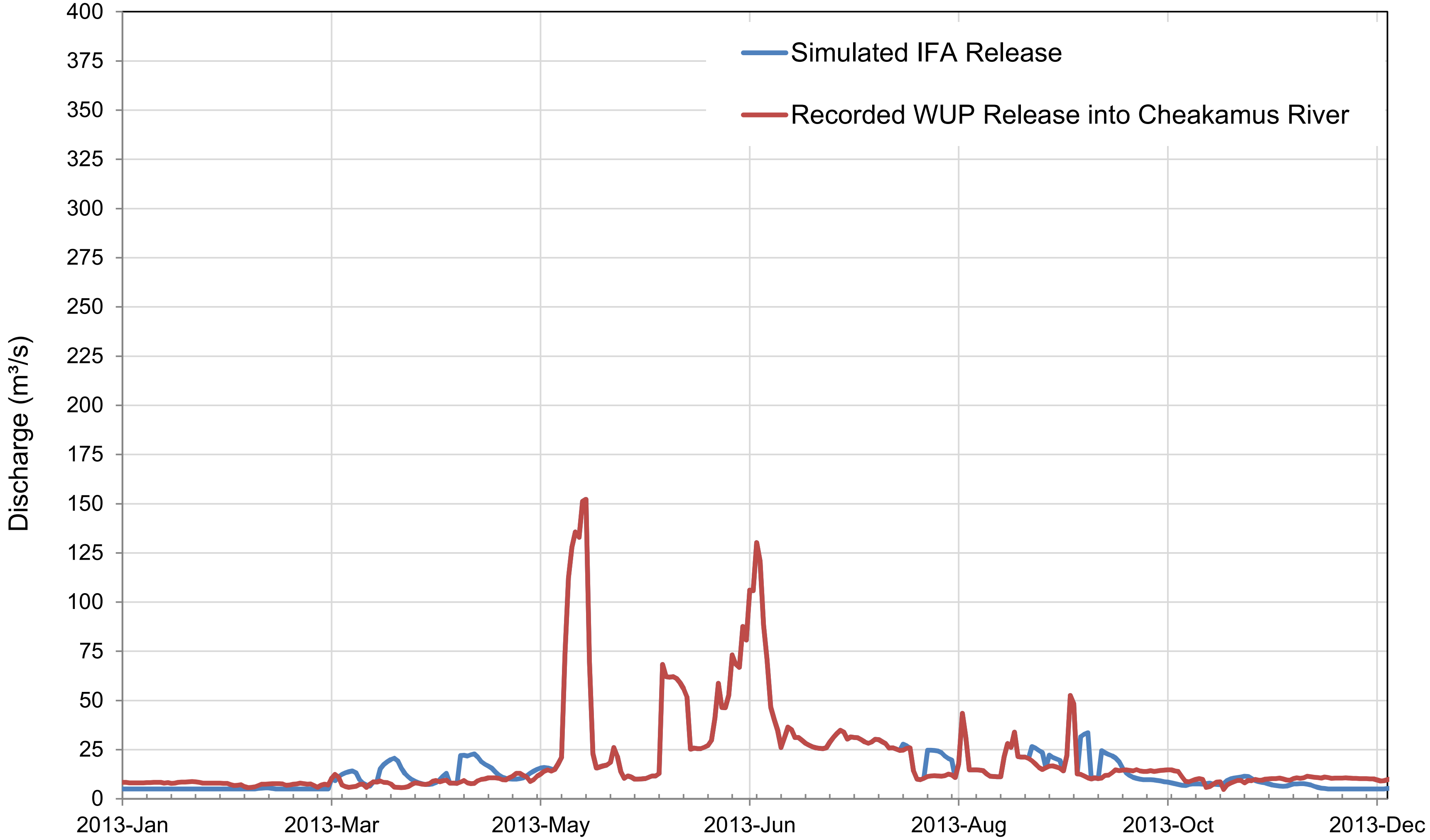

Figure A-8

2014 Daisy Lake Dam Releases in the Cheakamus River
WUP vs. Simulated IFA (pre-WUP)

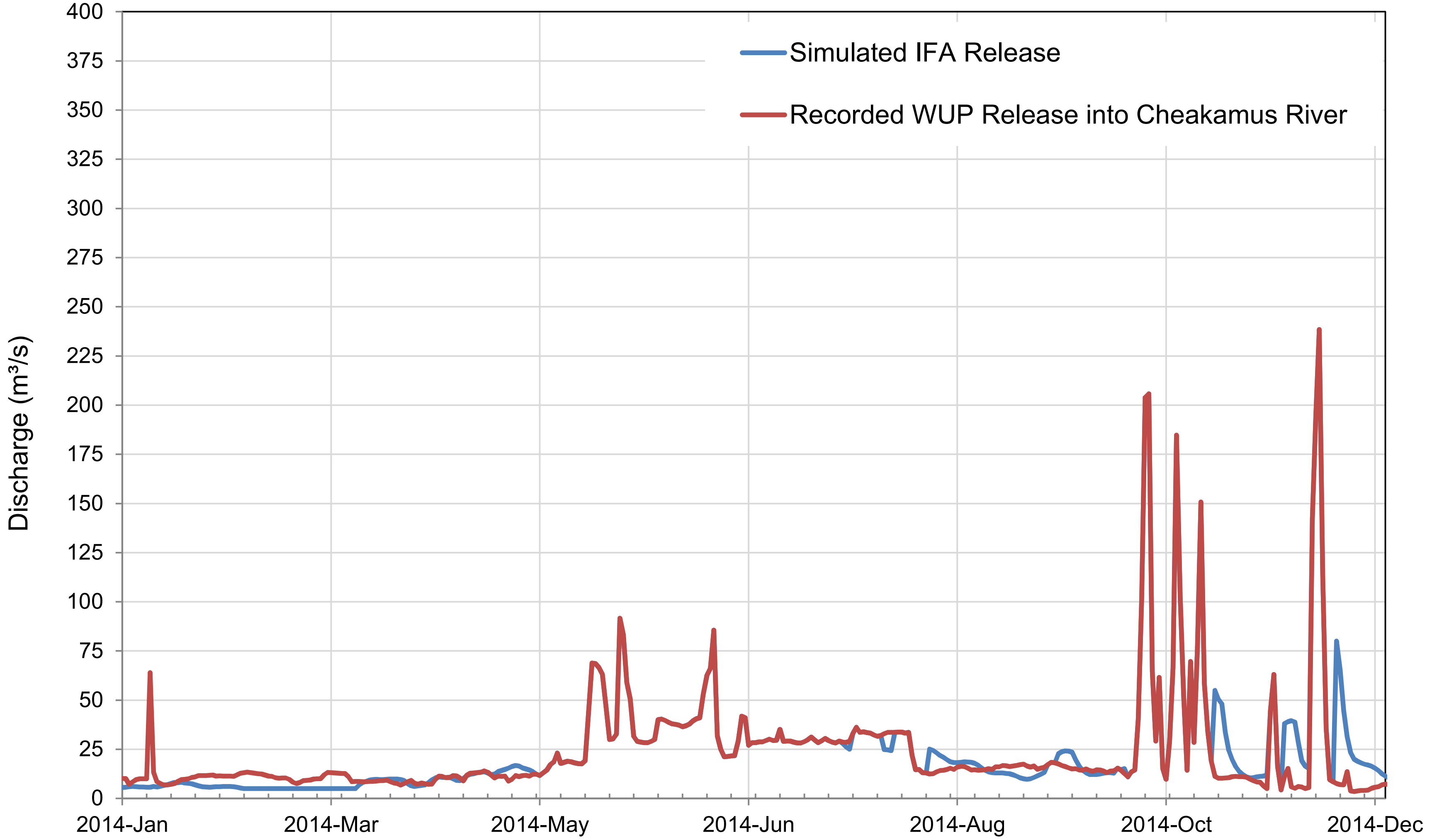

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Figure A-9

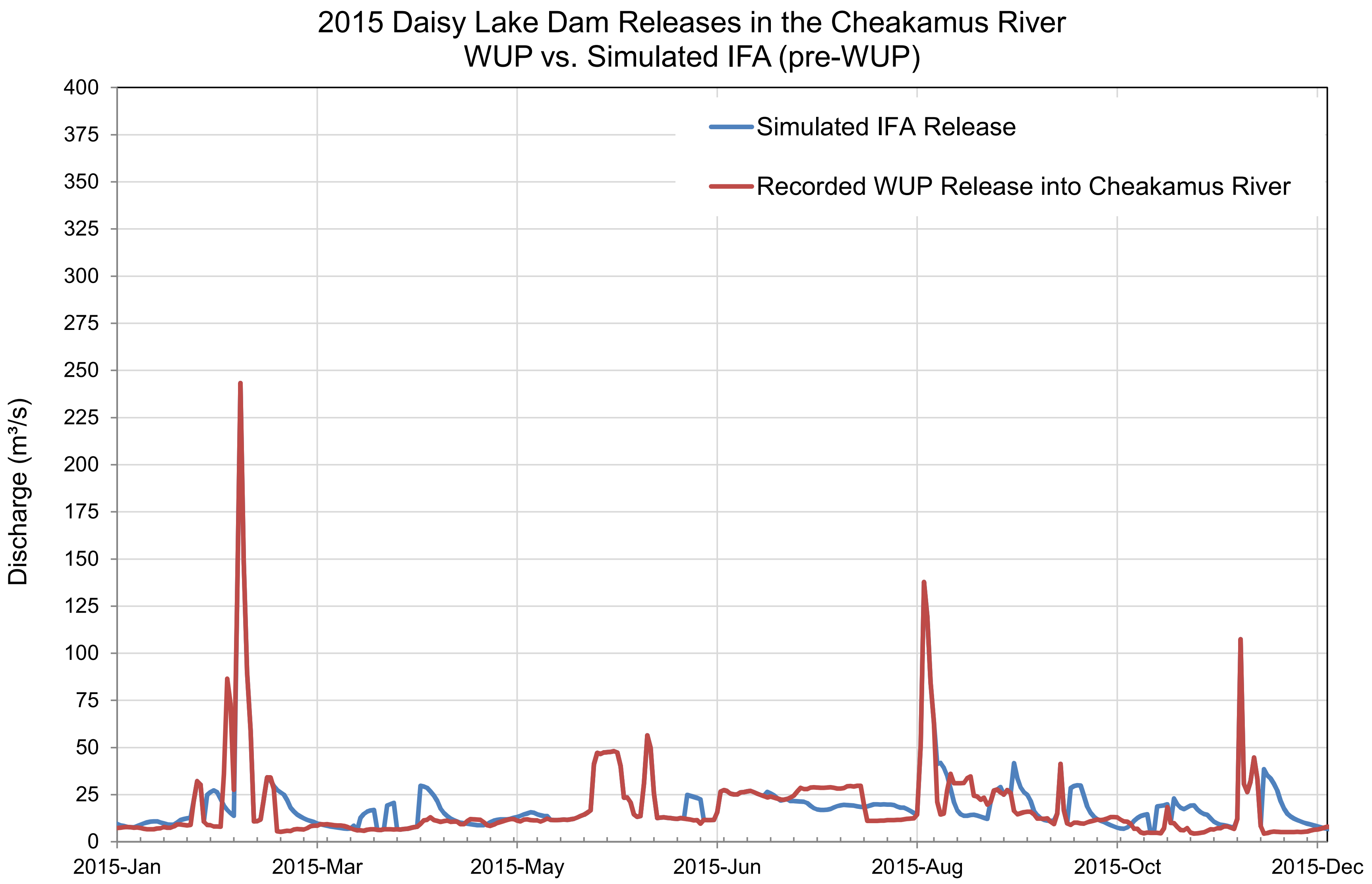

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Figure A-10