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

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December 9, 2014

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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?"*

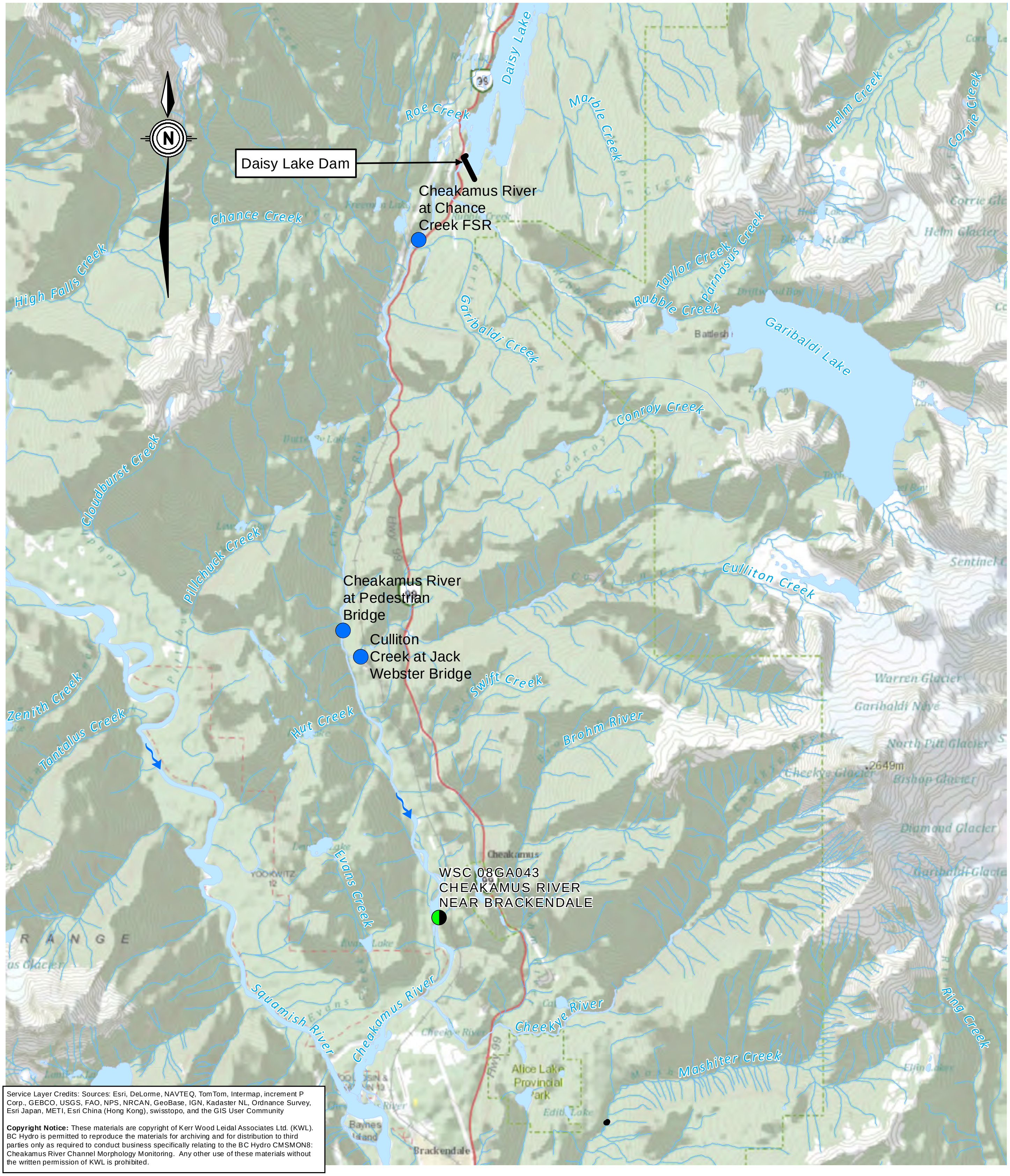
1.1 Data Sources

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

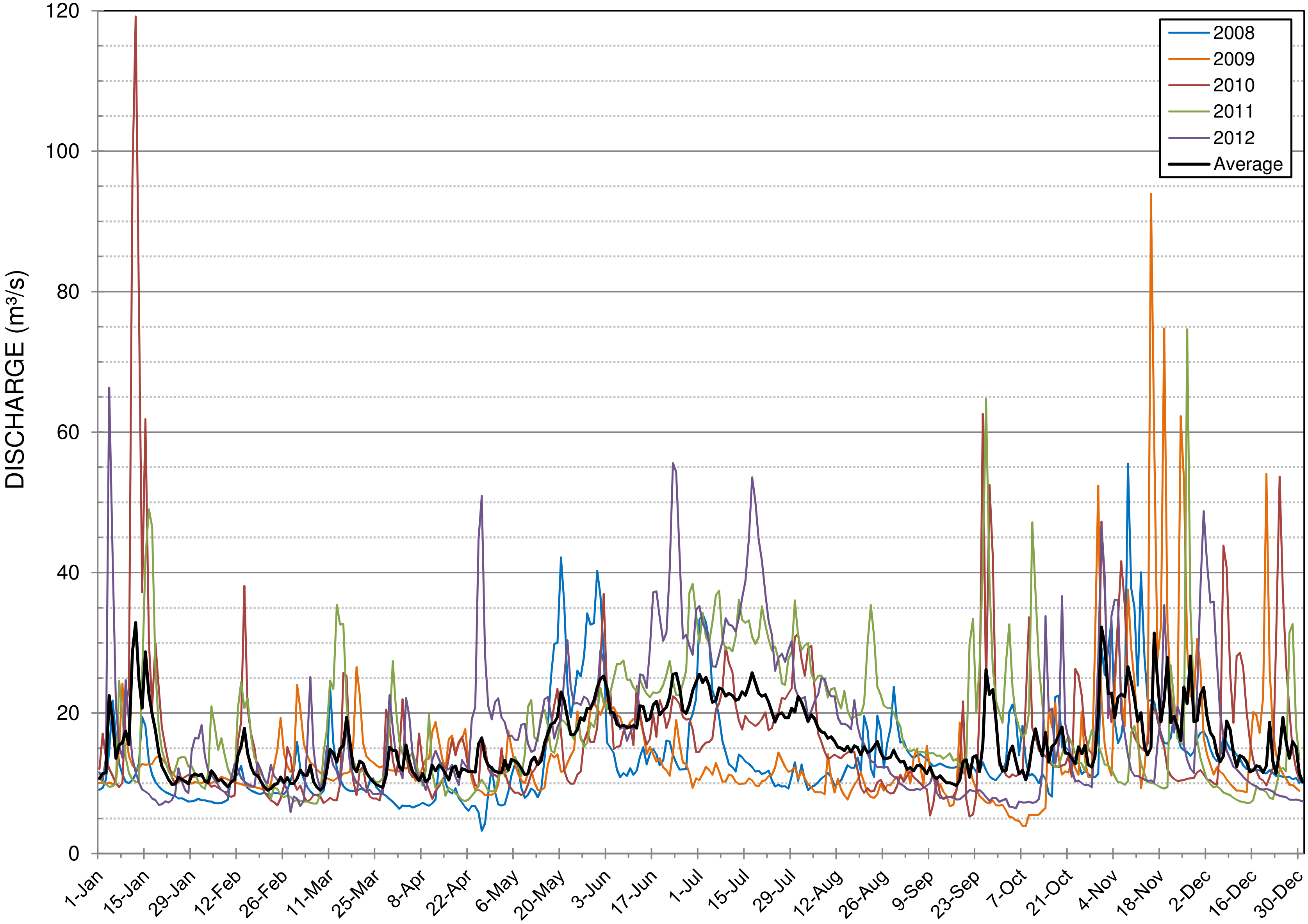

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Figure 2

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 do not 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, generally 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.

2008 Average Daily Discharge By Tributary or Tributary Reach

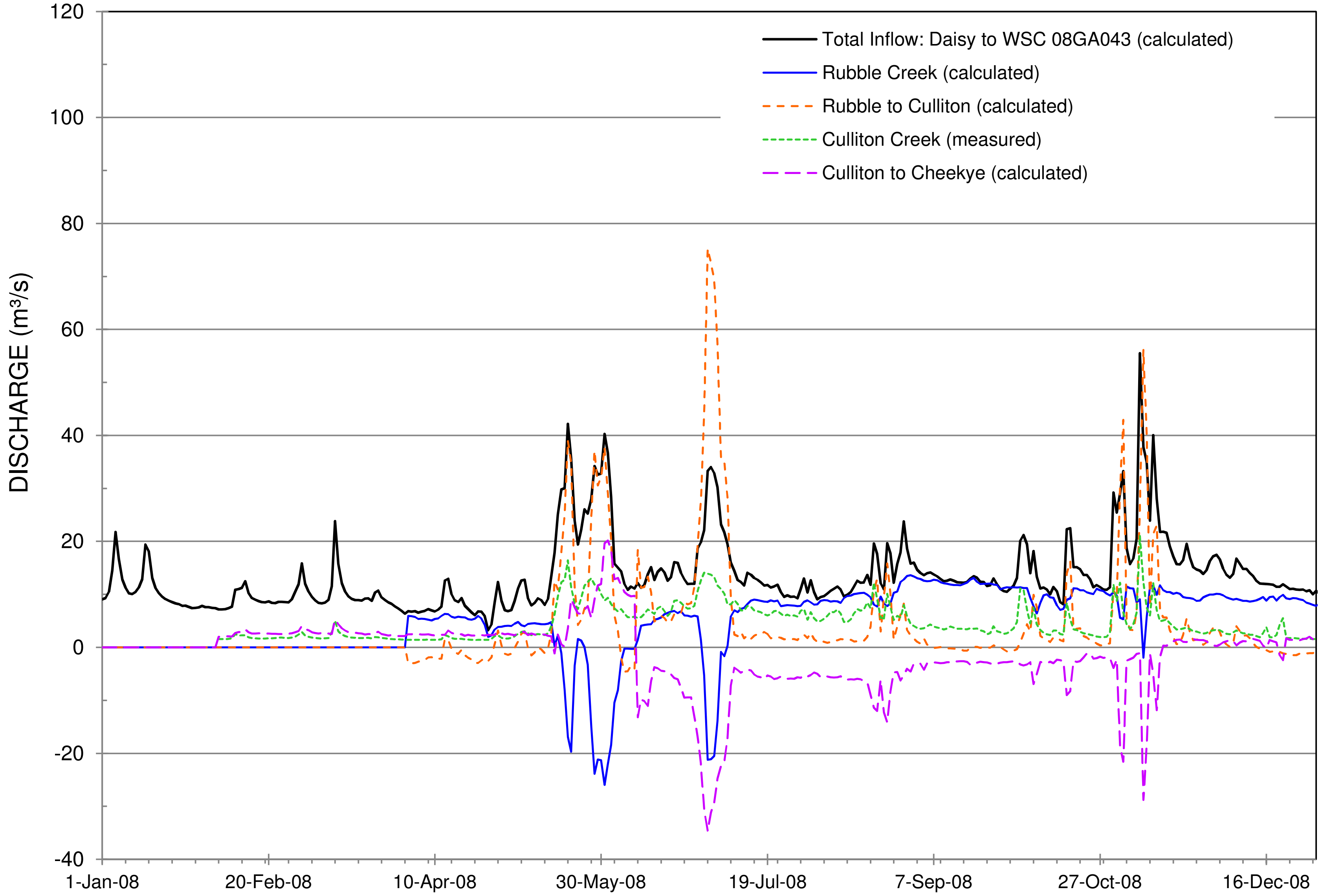

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Figure 3

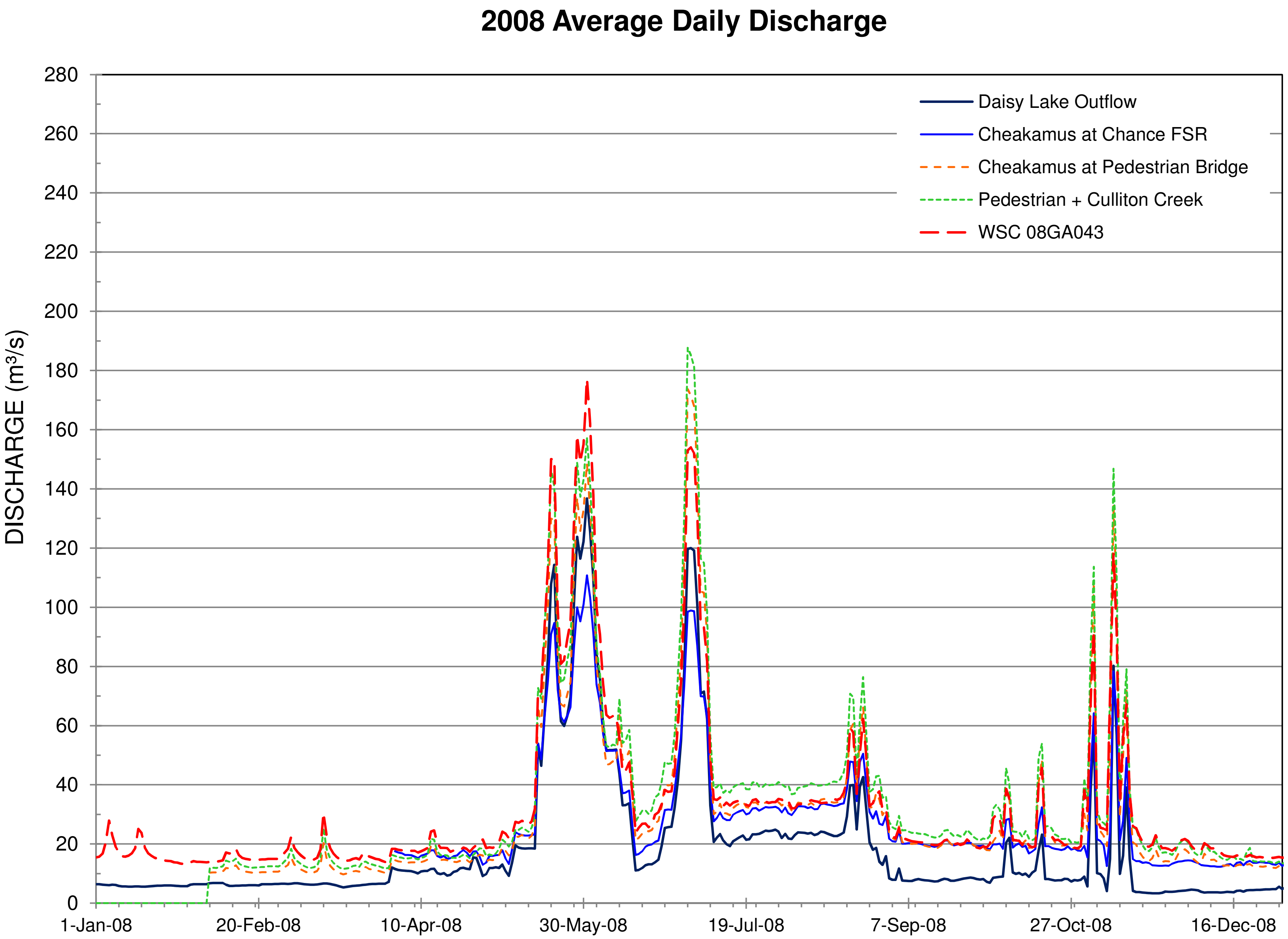

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Figure 4

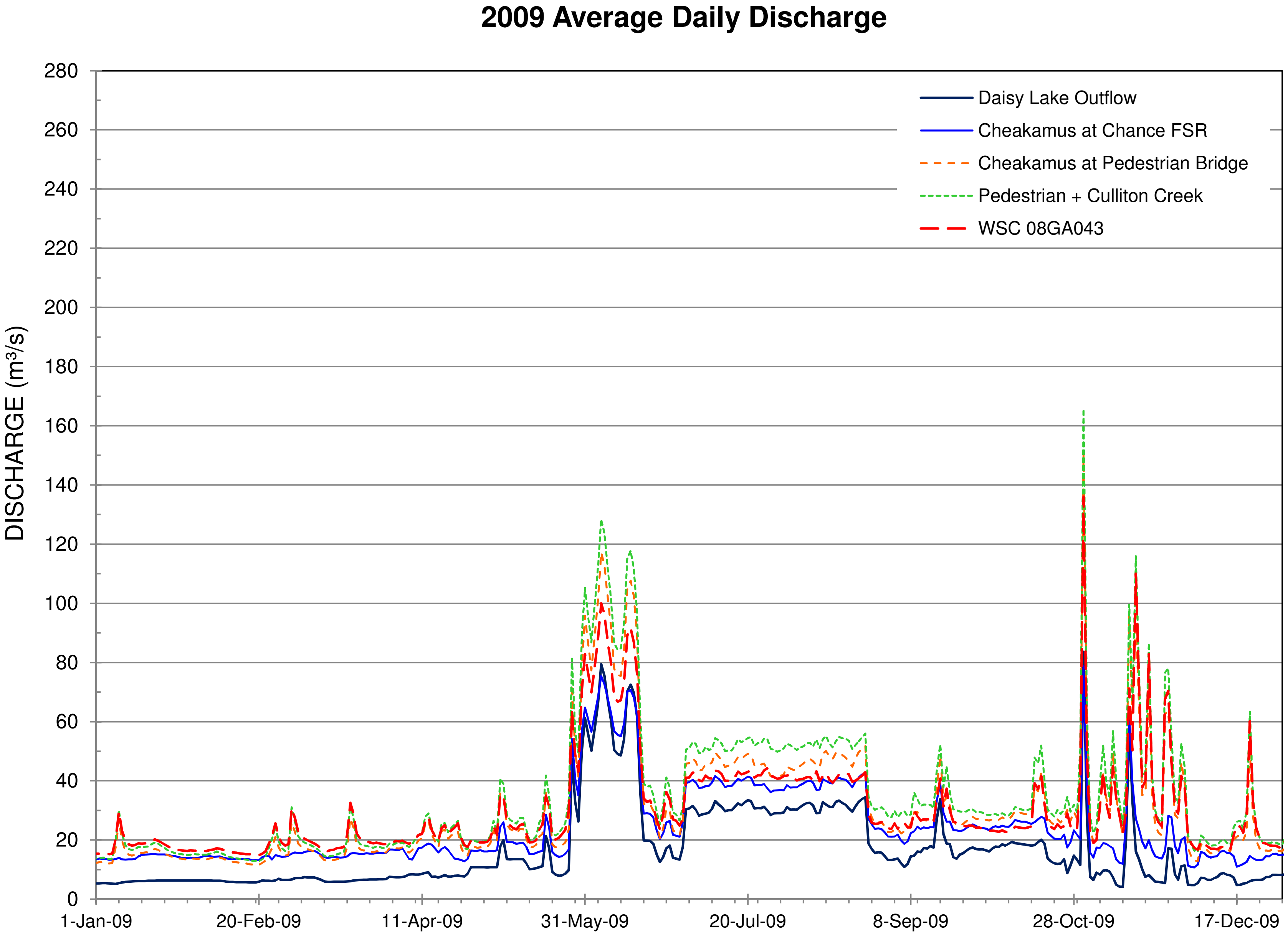

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Figure 5

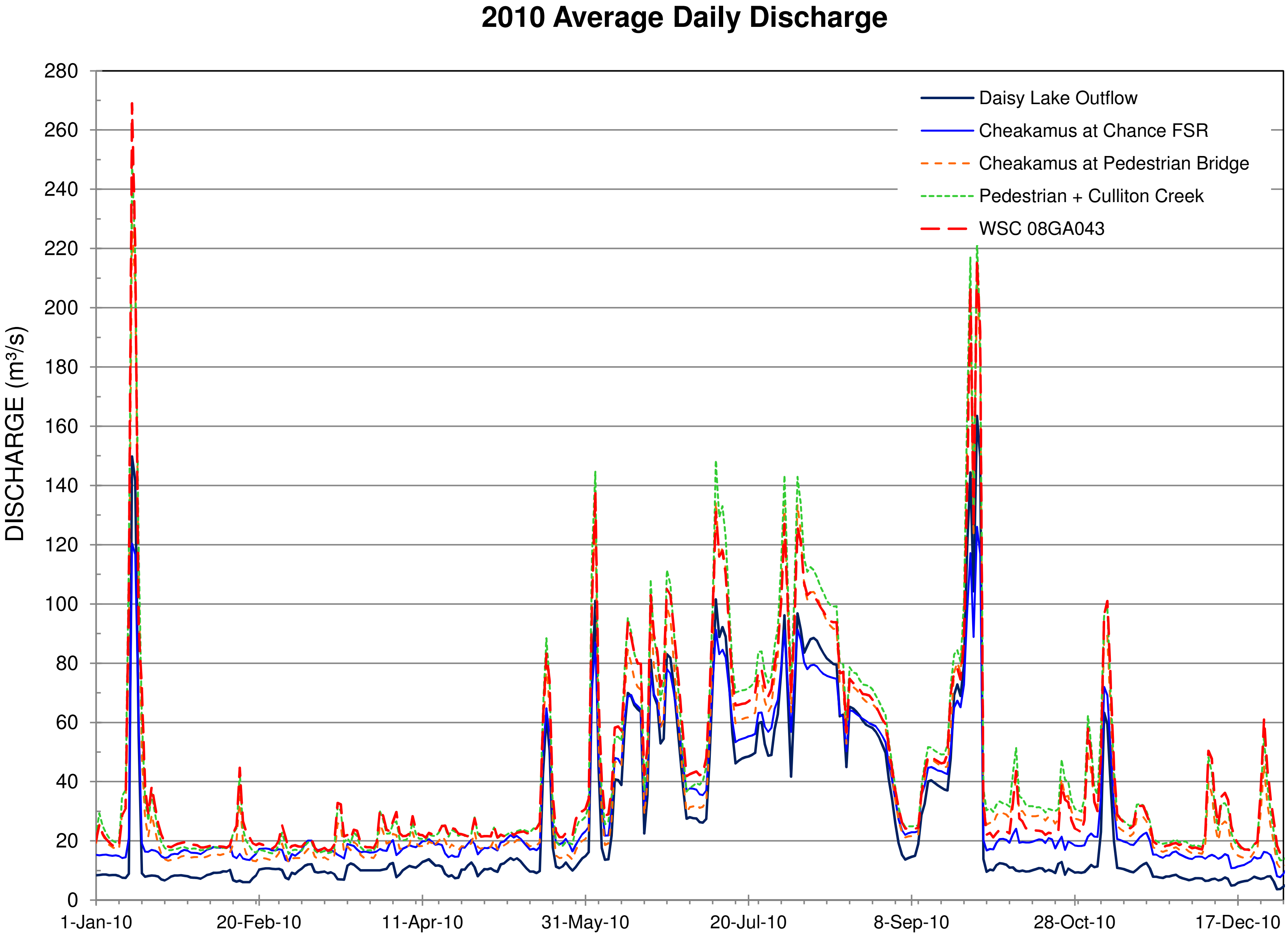

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Figure 6

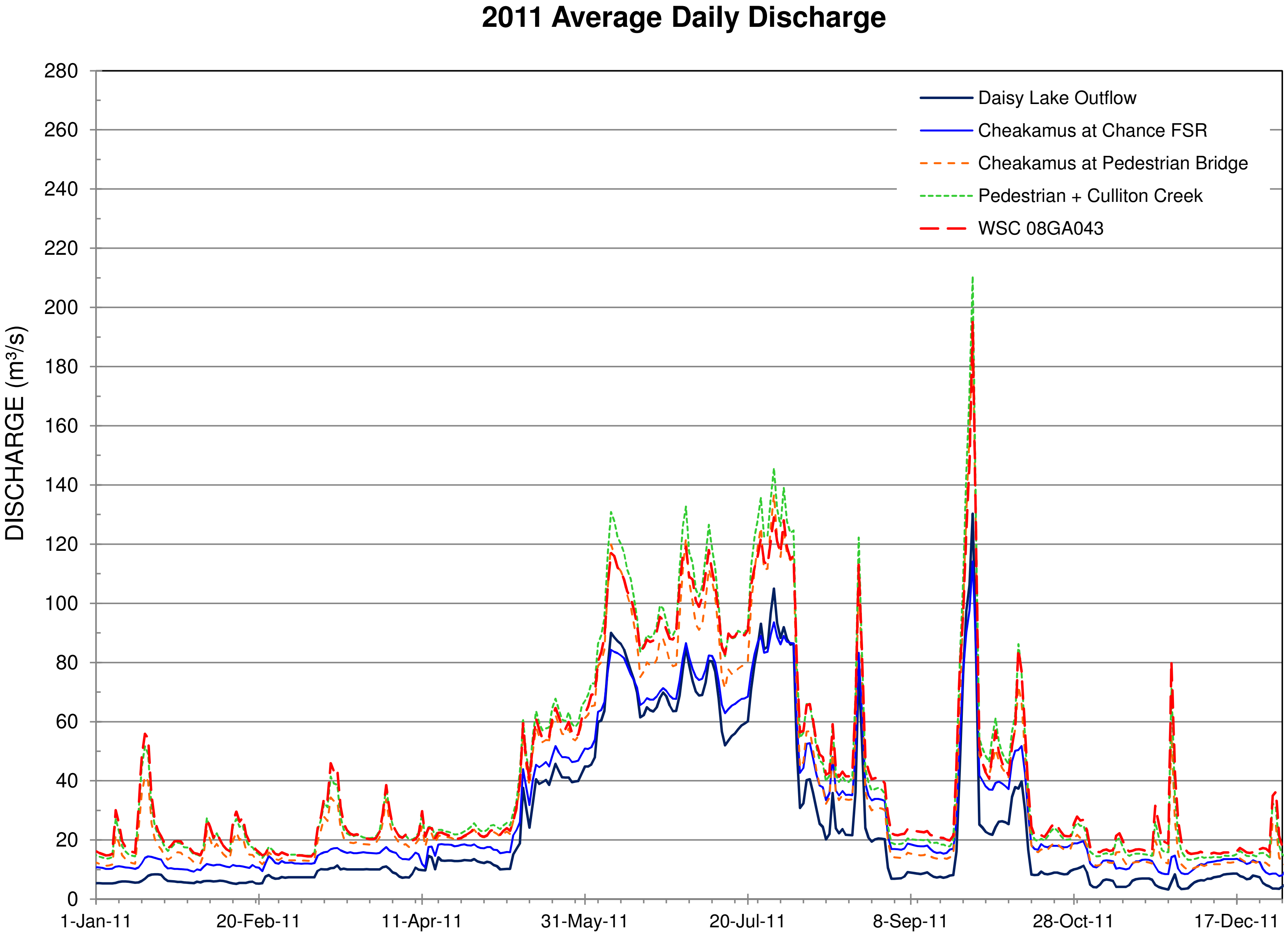

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Figure 7

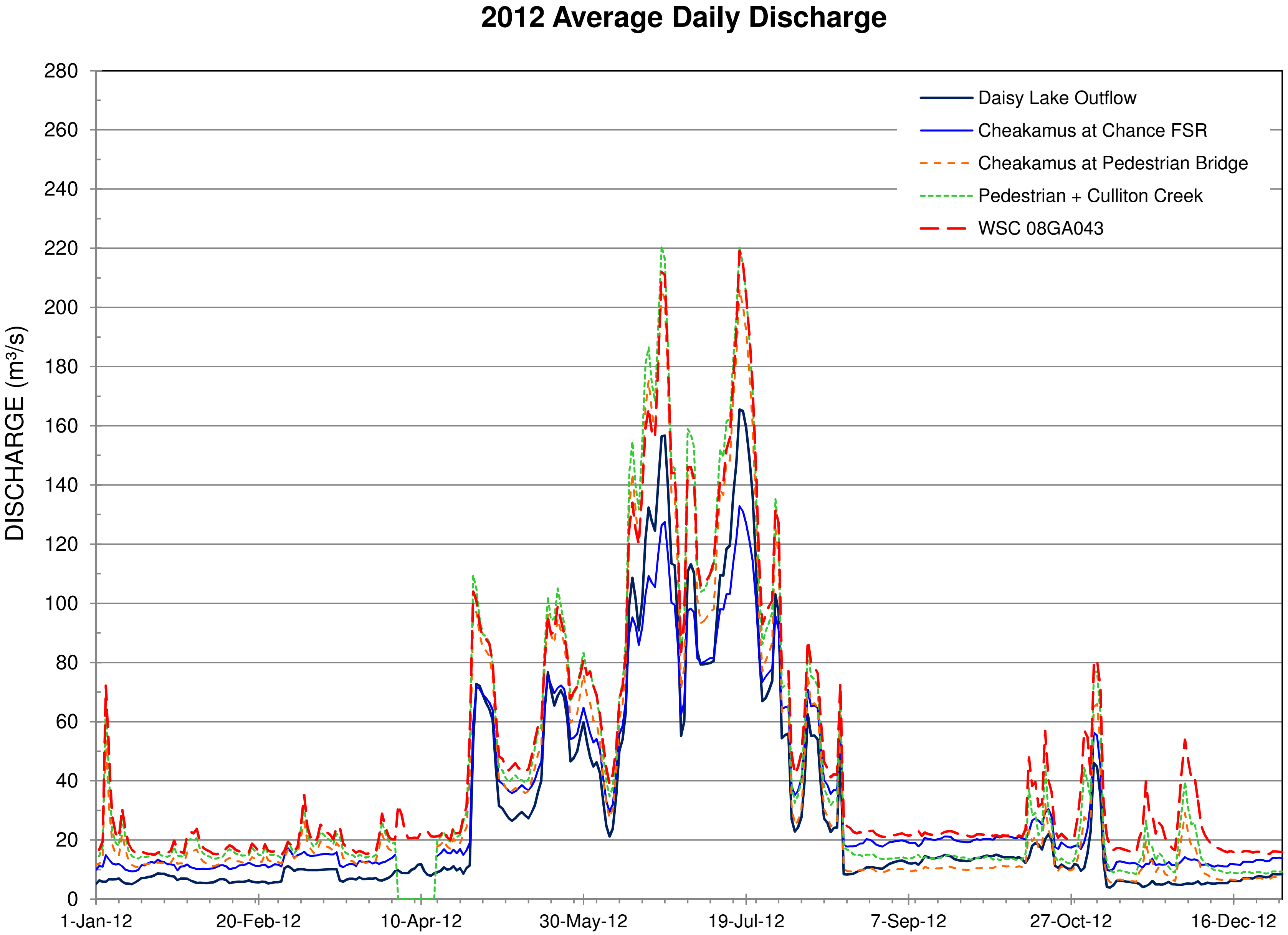

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Figure 8

February 2012 Average Daily Discharge

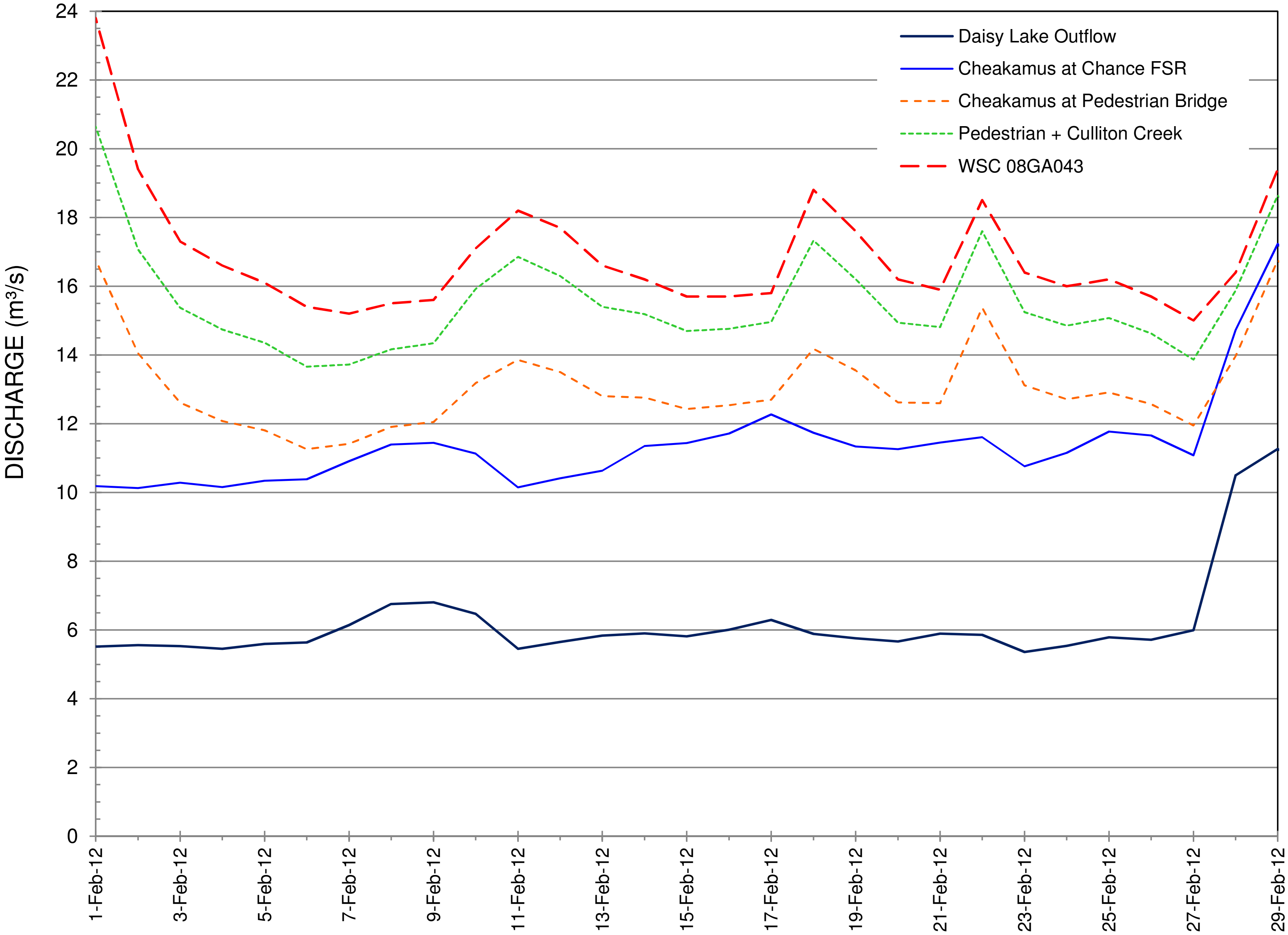

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Figure 9

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.

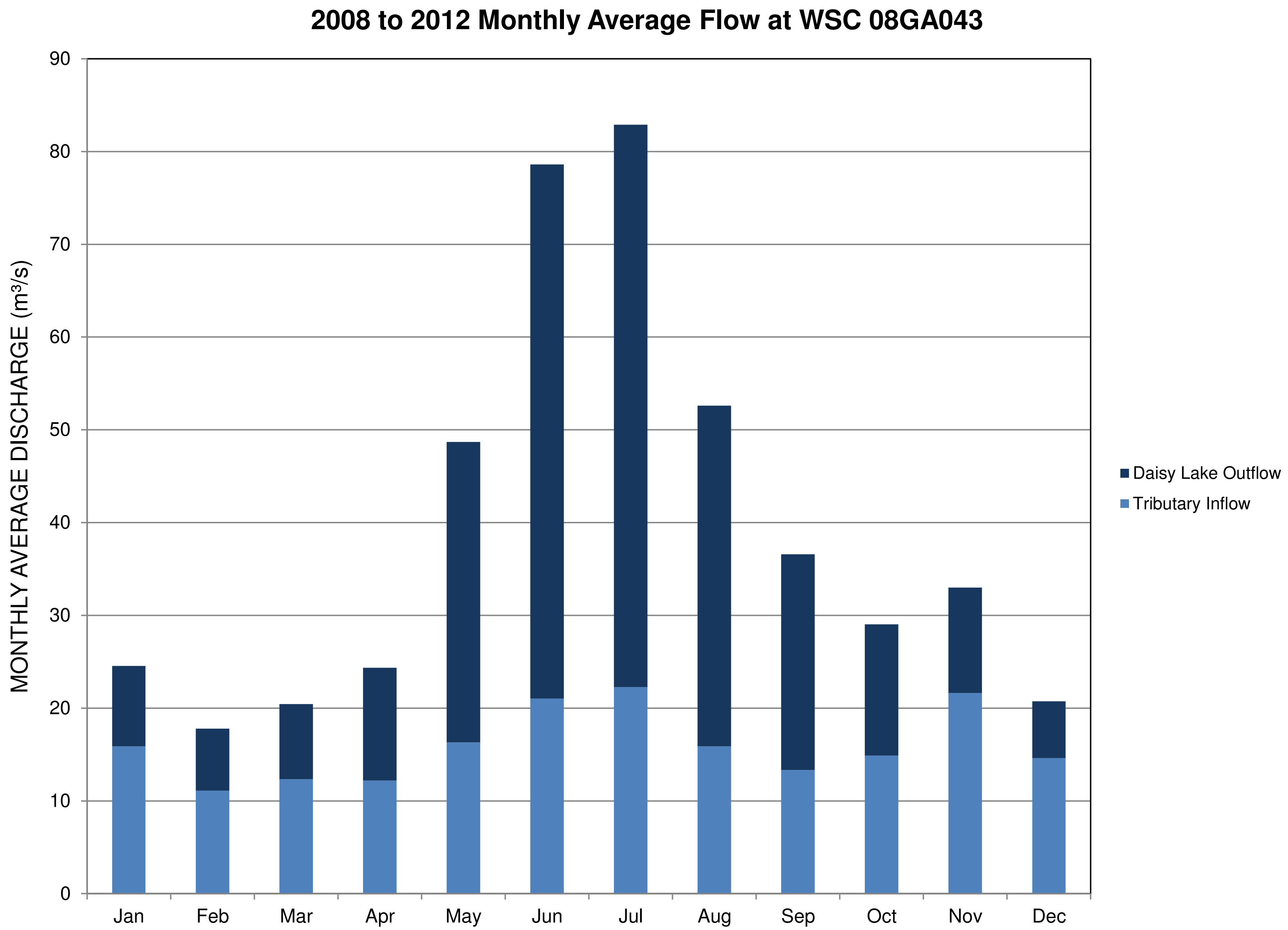

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Figure 10

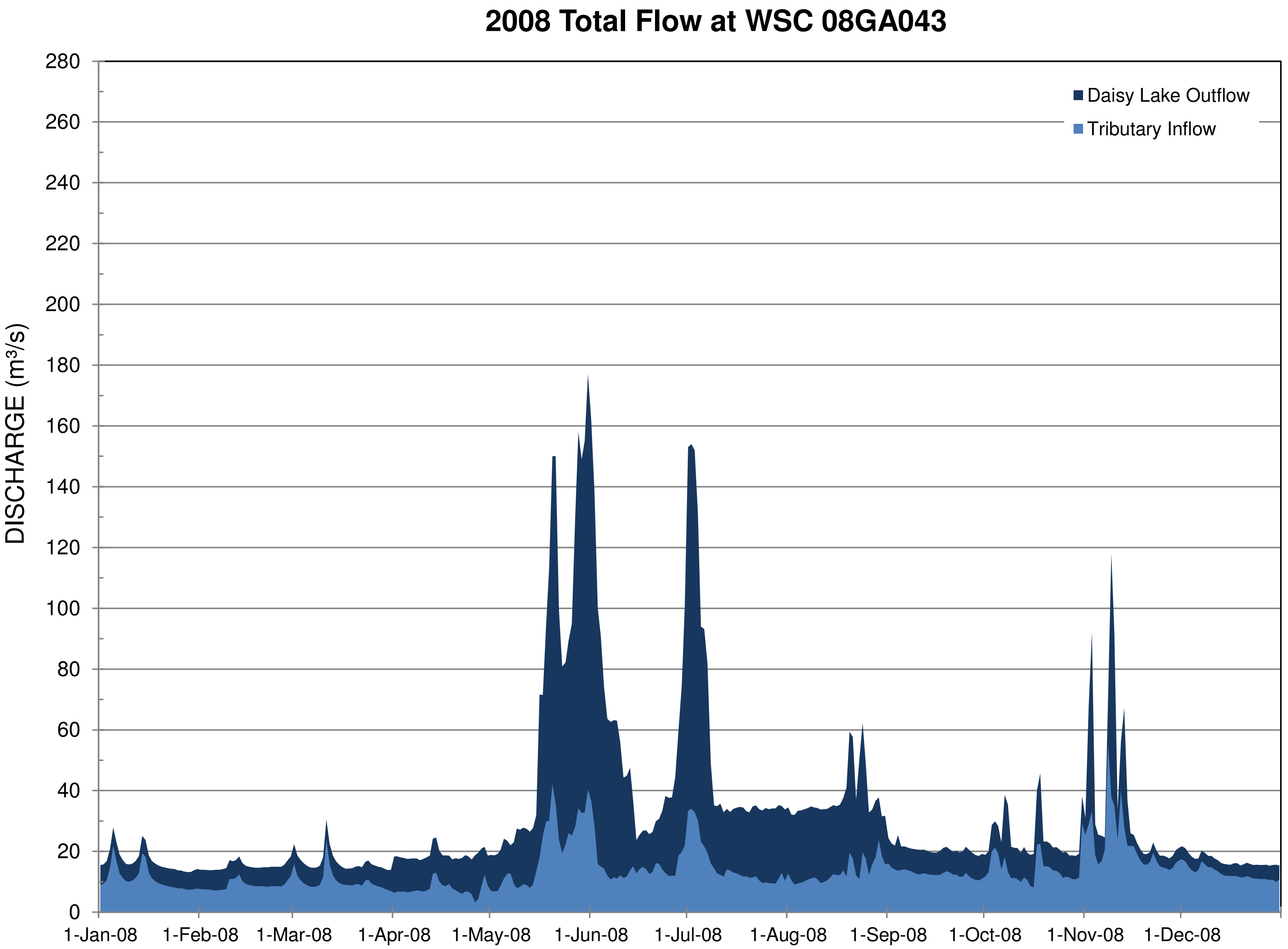

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Figure 11

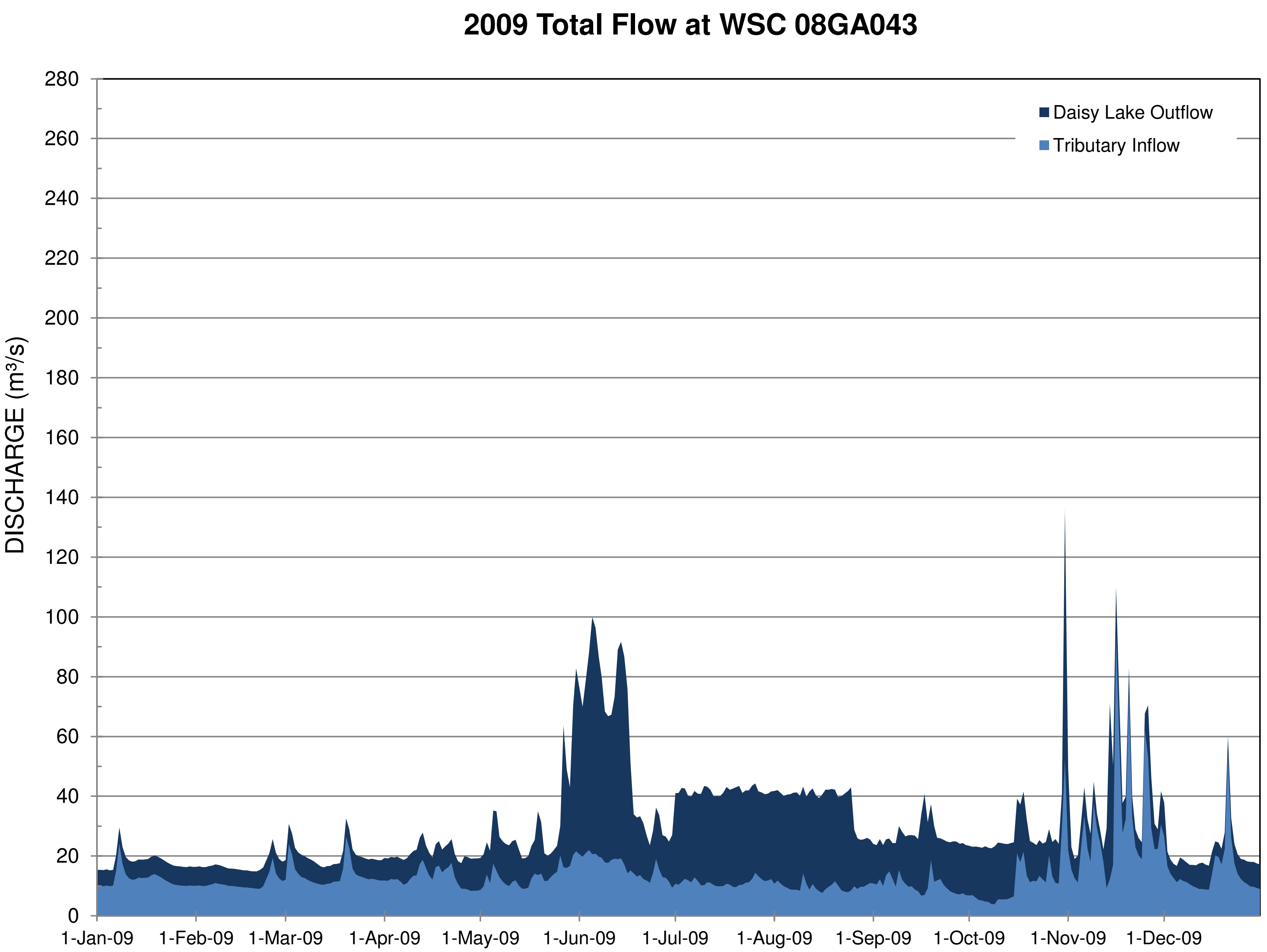

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Figure 12

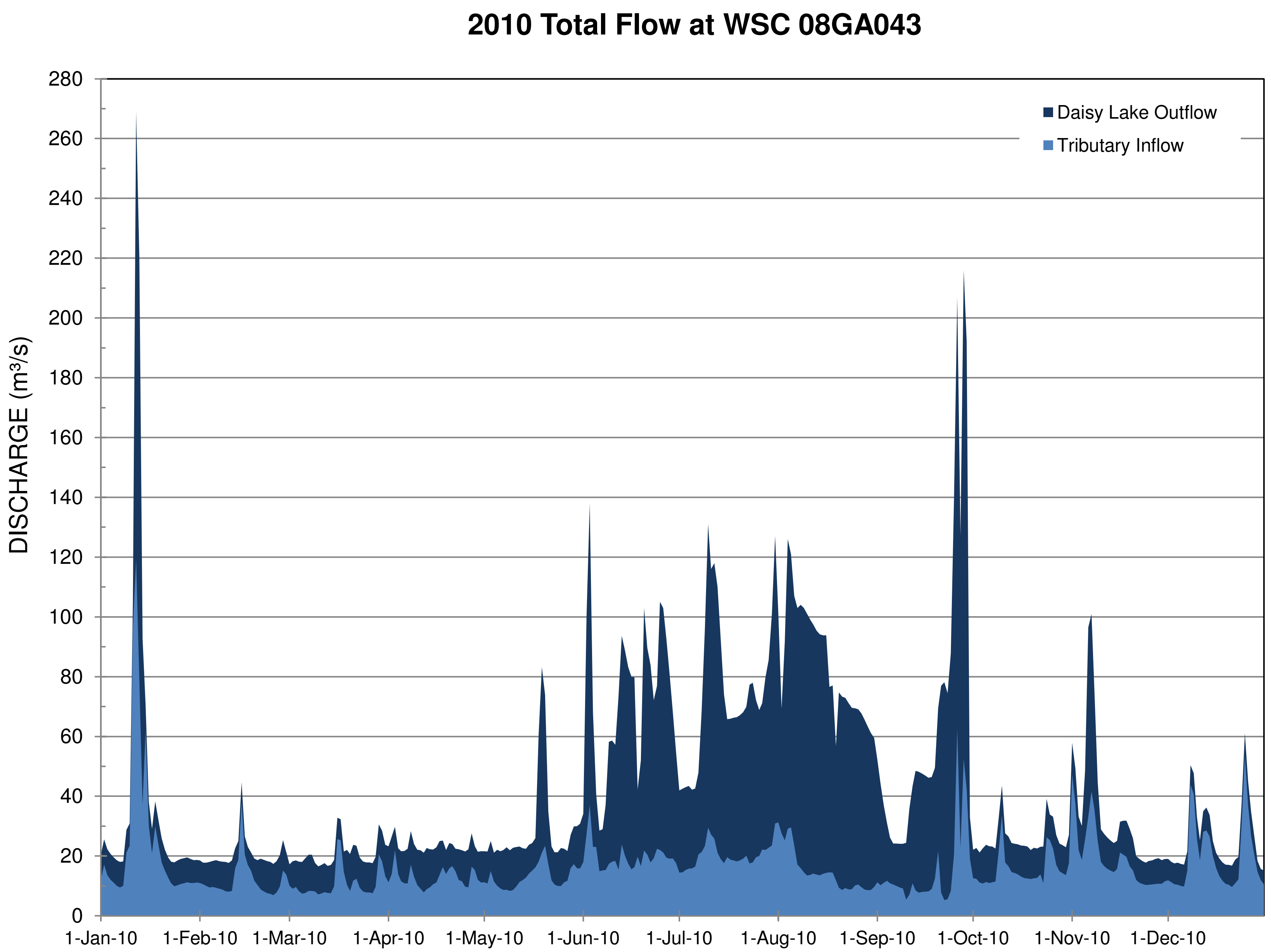

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Figure 13

2011 Total Flow at WSC 08GA043

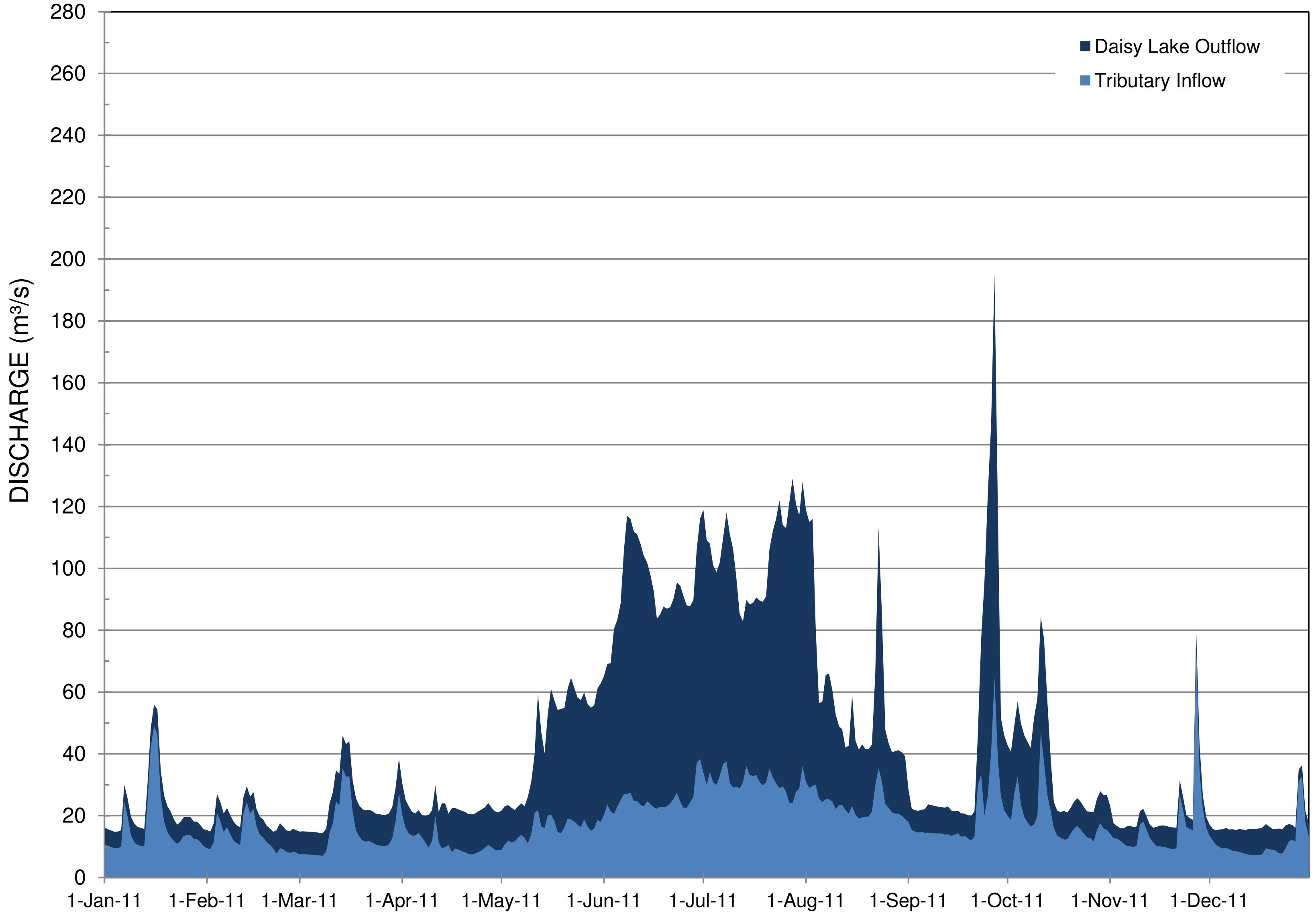

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Figure 14

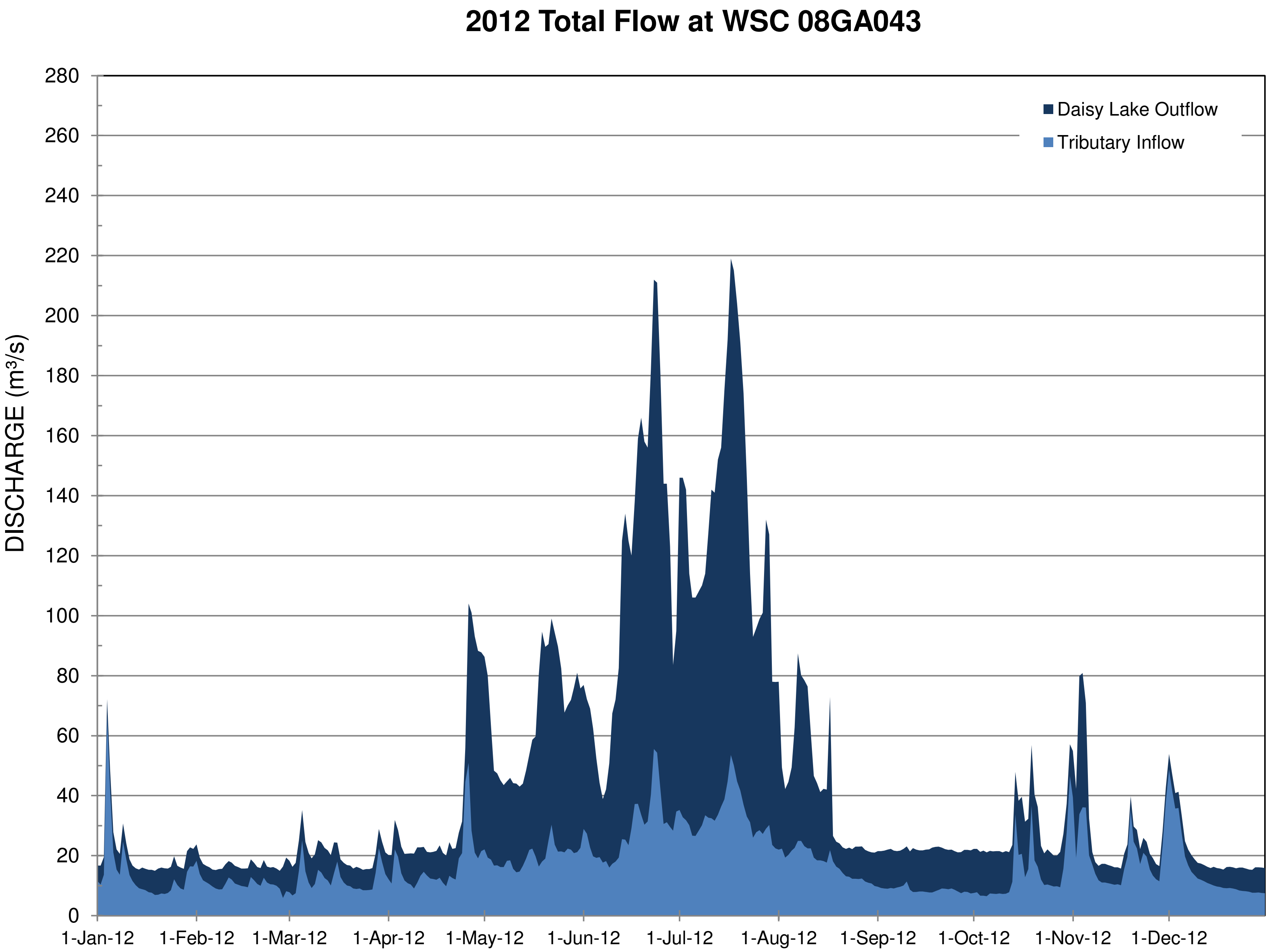

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Figure 15

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)

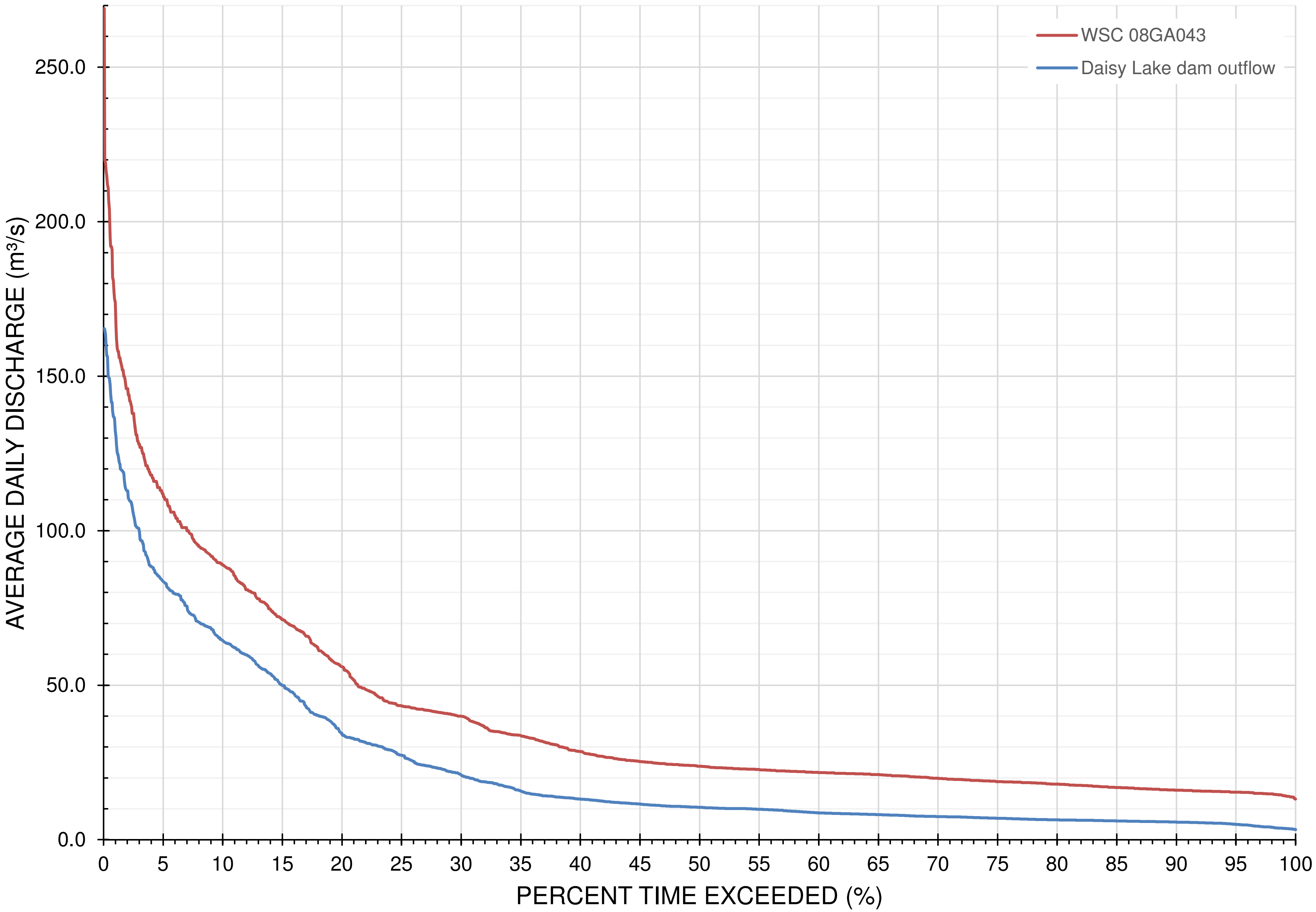

Figure 16

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, the difference in flow that would need to be measured is on the same order as the associated uncertainty of the measurement. 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.

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:

Dec 09, 2014
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Senior Water Resources Engineer

EE/la

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Revision History

Revision #	Date	Status	Revision Description	Author
2	December 9, 2014	Final	Final.	EE
1	December 4, 2014	Draft	Revised based on client review.	EE
B	November 13, 2014	Draft	Draft for client review.	EE
A	November 7, 2014	Draft	Draft for internal review.	EE