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MEMORANDUM

TO: **Nechako Water Engagement Initiative**

FROM: **Patrick Little, M.Sc., P.Ag., Nicole Wright, Ph.D., P.Geo., Jayson Kurtz, B.Sc., R.P.Bio., P.Bio., Ecofish Research Ltd.**

DATE: **December 23, 2022**

FILE: **1316-09**

RE: **Nechako River Naturalized Flow Hydrographs**

1. INTRODUCTION

To support the Nechako Water Engagement Initiative (WEI), Ecofish Research Ltd (Ecofish) was asked by the WEI Technical Working Group to recreate naturalized hydrographs for the Nechako River at Vanderhoof. Currently, the Nechako Reservoir receives inflow from upland streams and diverts outflow to the Kemano River (out of the Nechako watershed) and to the Nechako River via the Skins Lake Spillway (SLS). The WEI is interested in understanding what flows in the Nechako River at Vanderhoof would have looked like in the absence of diversion to Kemano or other regulation of the Nechako River. This memo details the approach and methods behind the model that Ecofish developed to estimate what daily flow in the Nechako River at Vanderhoof would have been if regulation at SLS or diversion to Kemano did not take place.

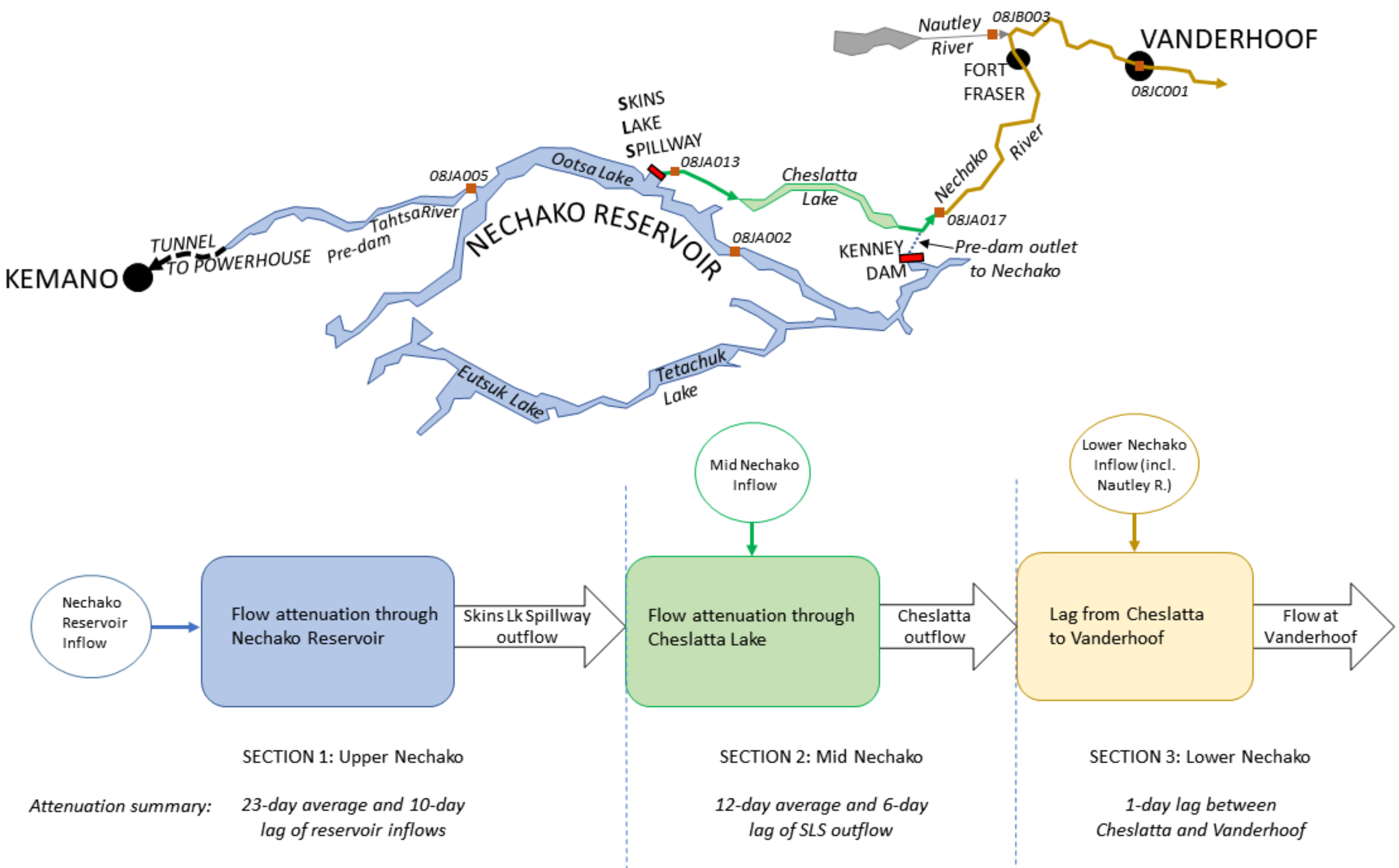
2. APPROACH

The approach consisted of constructing a coarse model that could approximate the shape, timing, and magnitude of the naturalized annual hydrograph of the Nechako River at Vanderhoof, as described above. The model assumed that flow would travel from the Nechako Reservoir through the SLS and the Cheslatta Lake system and onwards to Vanderhoof. This existing routing was chosen instead of routing through the Nechako Grand Canyon below the Kenney Dam (i.e., as if the Kenney Dam did not exist) as it represents the flow pathway using the existing release infrastructure of the SLS. To accomplish this, we used the Nechako Reservoir daily inflow timeseries provided by Rio Tinto (RT) and applied multi-day averaging and multi-day lags to represent flow attenuation at different points within the watershed. Historical flow data from the Water Survey of Canada (WSC 2021) were used to determine how much attenuation should be applied and to determine inflow to the Nechako River below the reservoir. Although this approach should provide insights to the timing and magnitude of peak flows and low flows on the Nechako River, this type of analysis is coarse and not highly accurate. Therefore, the data produced are not intended to be used for further analyses that require precise timing and magnitude (e.g., flood analyses, environmental flow needs calculations), but should be useful for rough decision-making processes. If more accurate estimates of naturalized flow are required, then a hydrologic model that employs lake storage and flow routing algorithms to represent natural processes, such as the Raven model (Craig *et al.* 2020) would be recommended.

3. METHODS

The route from upland sources to Vanderhoof was conceptualized as three distinct sections based on the processes/areas that would affect streamflow calculation: Section one (Upper Nechako) includes upland inflow sources that feed into the Nechako Reservoir and are then released as outflow at the SLS; section two (Mid Nechako) includes outflow from SLS through the Cheslatta Lake system to the Nechako River below Cheslatta Falls WSC station; and section three (Lower Nechako) includes the route from Nechako below Cheslatta Falls to Nechako at Vanderhoof and includes inflows from Nautley River and other sources (Figure 1). Substantial flow attenuation and lag occurs within the first two sections along this route: first, flashy upland inflows characterized by a rapid rise and fall of the hydrograph are attenuated by the Nechako Reservoir system prior to outflow at the SLS, and second, outflow from the reservoir is attenuated by the Cheslatta Lake system prior to reporting to the Nechako River below Cheslatta Falls WSC station. To determine how much flow attenuation occurs at each of these sections and to determine the lag time and historical inflows between SLS and Nechako at Vanderhoof historical data were examined as follows.

Figure 1. Colour coded map and schematic diagram of flow naturalization model. Orange squares show approximate locations of current and past WSC hydrometric stations used in analysis.



3.1. Ootsa Lake

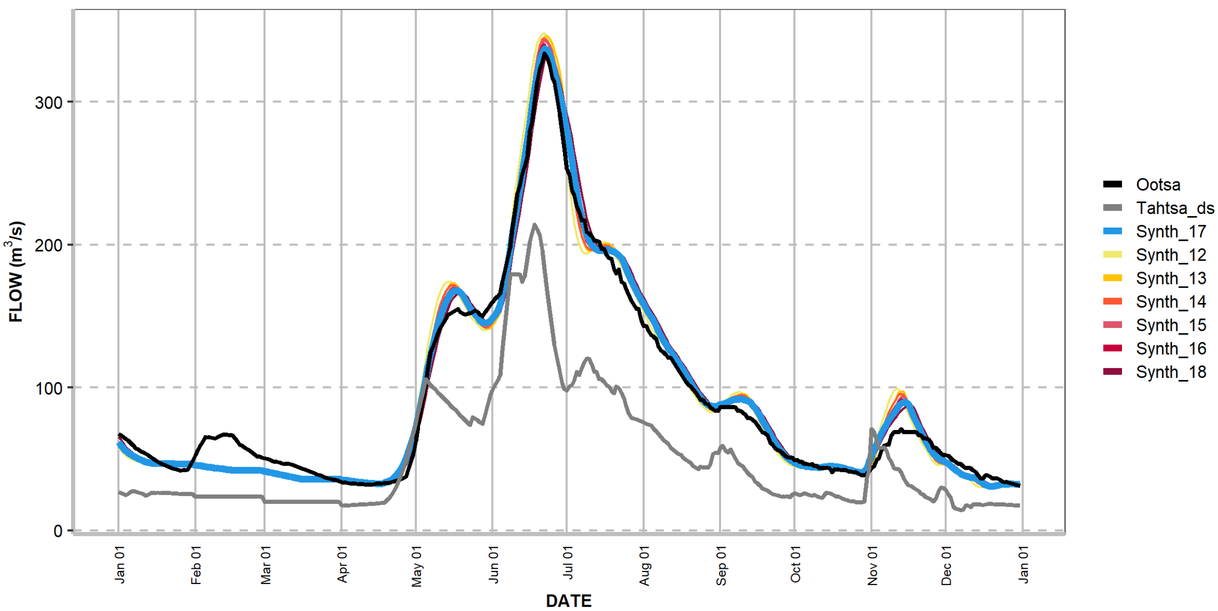
Pre-dam inflow and outflow to/from Ootsa Lake were analysed to investigate the amount of flow attenuation that would have occurred within Ootsa Lake (the largest natural lake within the Nechako Reservoir system). This pre-dam scenario was used to gain understanding of how the Nechako Reservoir would function without flow regulation, specifically, how it would attenuate and lag inflows. Tahtsa River near Ootsa Lake (WSC 08JA005; 1930-1952) data were used as a basis for inflow to Ootsa Lake and Ootsa River at Ootsa Lake (WSC 08JA002; 1930-1952) was used as outflow (WSC 2021). Tahtsa River data were manipulated by applying a multiplier[1] and multi-day averages and lags with the goal of reproducing the timing, shape, and magnitude of Ootsa Lake outflow data, with particular focus on spring freshet. Ootsa Lake inflow would have consisted of inflow from Tahtsa River (the largest inflow source to Ootsa Lake with a data record) and inflow from other minor tributaries (where no data exist). It was assumed that the timing of other inflows to Ootsa Lake would parallel the timing of Tahtsa River inflow and therefore total inflow to Ootsa Lake was approximated by multiplying Tahtsa River daily flow by a factor of 1.8. The magnitude of this multiplier was determined using trial and error (detailed below), instead of using watershed area proration because proration resulted in inflow being much larger than outflow. A variety of multi-day averages and lag times were tested by visual hydrograph comparison (Figure 2) and Nash-Sutcliffe efficiency analysis (Zambrano-Bigiarini 2021). It was determined that Ootsa Lake outflow was best approximated by a 17-day temporally centred average of Ootsa Lake inflow with a lag of 7-days. Figure 2 shows an example of several versions of the model (multi-day averages) being tested. Comparing the 17-day averaged inflow to observed daily outflow of Ootsa Lake from 1930-1952 yielded a Nash-Sutcliffe efficiency coefficient (NSE) of 0.95, which is a good approximation (the NSE can range from -Infinity to 1, with 1 being a perfect model (Zambrano-Bigiarini 2021)).

The Nechako Reservoir system is larger (910 km^2 surface area) than Ootsa Lake (<250 km^2 surface area) and therefore it is expected that the attenuation of inflow would be greater, and a longer multi-day average of Nechako Reservoir inflow would better approximate natural outflow. In Section 3.2 below, attenuation in the Cheslatta Lake system (52 km^2 surface area) was found to be best approximated by a 12-day average with a 6-day lag. Ootsa Lake is approximately 5 times the surface area of Cheslatta Lake system, and the length of the multiday average is 5-days longer. Nechako Reservoir is approximately 4 times the surface area of Ootsa Lake, thus it is expected that the length of the multiday average would be similarly 5-7 days - longer. Therefore, 6 days were added to the multi day averaging so that a 23-day average with a 10-day lag was used to represent attenuation

[1]Since Tahtsa River is not the only source of inflow to Ootsa Lake, a multiplier was applied so that the rough volume of inflow was equal to outflow.

of inflow through Nechako Reservoir. A 10-day lag was selected based on the Ootsa Lake lag which was equal to half the multi-day average of Ootsa Lake (i.e., 17 days) minus 1.5 days.

Figure 2. Example plot (1931) of pre-dam inflow to Ootsa Lake (Tahtsa_ds) and outflow from Ootsa Lake (Ootsa) as well as several multi-day averages applied to inflow data (Synth_12 to Synth_18). Synth_xx represents a xx-day rolling average of 1.8xTahtsa_ds, (e.g., Synth_12 represents a 12-day rolling average). A 17-day rolling average (Synth_17) showed the best correspondence (highest NSE score) to Ootsa lake outflow over the 1930-1952 period of record.



3.2. Downstream of Cheslatta Falls

Daily outflow data from Skins Lake Spillway (SLS) (WSC 08JA013) were examined alongside Nechako River below Cheslatta Falls (WSC 08JA017) to determine the amount of flow attenuation that occurs in this mid-section of the model. After testing a range of multi-day averages and lag times it was found that applying a 12-day average with a 6-day lag to SLS flow yielded the best approximation of Nechako River below Cheslatta Falls daily flow. This timeseries is labelled Synth_12 in the example plot shown in Figure 3. Comparing the 12-day averaged and 6-day lagged SLS daily flow (Synth_12) to observed daily flow of Nechako below Cheslatta Falls from 1981-2018 (the entire period of record at this gauge) yielded an NSE of 0.97.

It is evident from examining annual hydrographs that this section also receives inflow that is characterized by a gradual and small freshet (relative to the main freshet) that generally occurs prior to the main freshet at Nechako River below Cheslatta Falls and is likely due to low elevation snowmelt in the early spring (the main freshet is driven by controlled releases from SLS and the timing is generally later than the natural freshet). An example of this is shown in Figure 4 where flow at Nechako at Cheslatta starts to rise at the beginning of April prior to SLS releases increasing. To calculate inflow, the Synth_12 daily data were subtracted from daily flow at Nechako River below Cheslatta Falls. The resulting timeseries (labelled Inflow_raw in Figure 4) is smooth and gradual prior to freshet each year (i.e., during the times when SLS flow was constant) but is highly flashy during Summer Temperature Management Program (STMP) flows (i.e., when SLS flow is flashy) and can even be negative during that period. This is because the timeseries is capturing both the real inflows within this section as well as the residuals (positive or negative) that are artifact of the inadequacy of Synth_12 to predict flow at Nechako River below Cheslatta Falls. To diminish these artifacts a variety of multi-day averages were applied to the Inflow_raw timeseries. A 20-day average (called Inflow_20 in Figure 4) of Inflow_raw was selected to represent Mid-Nechako inflow. Although this approximation of Mid-Nechako Inflow may not be highly accurate (especially from ~July-September) it is such a small component of the overall hydrograph of Nechako at Vanderhoof that it was deemed adequate for the purposes of this coarse naturalization study.

Figure 3. Example plot (2007) of Nechako Reservoir outflow from Skins Lake Spillway along with several multi-day averages applied to this data which are meant to represent the flow at Nechako below Cheslatta. Synth_xx represents a x-day rolling average (e.g., Synth_09 represents a 9-day rolling average). Synthesized data with a 12-day rolling average (Synth_12) showed the best correspondence (highest NSE score) to Nechako below Cheslatta over the 1981-2018 period of record.

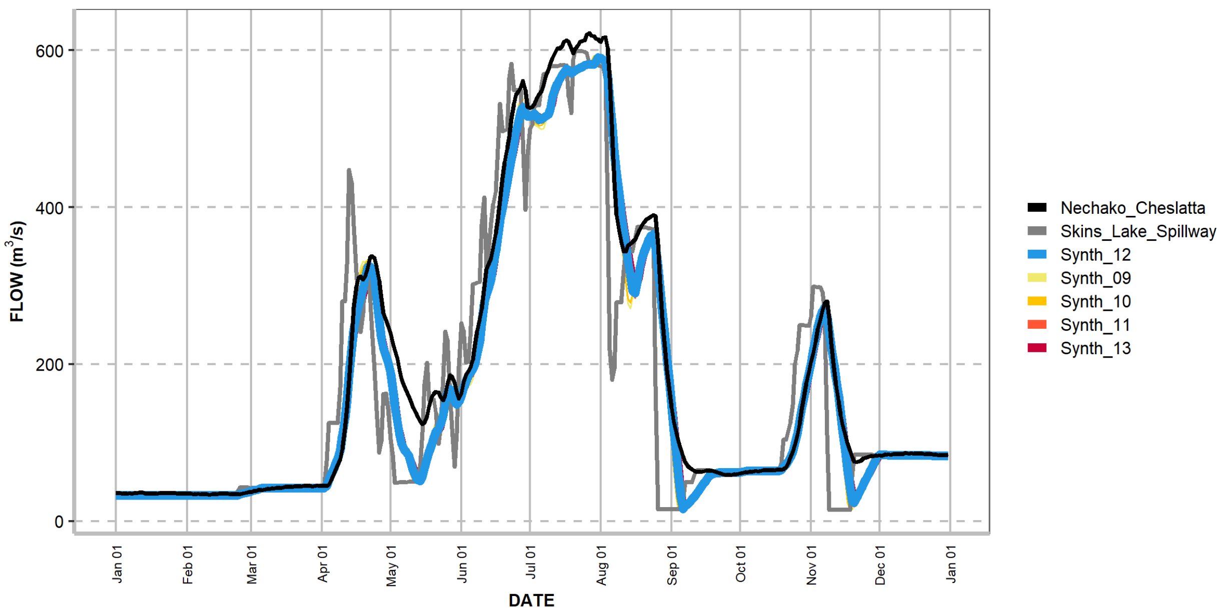
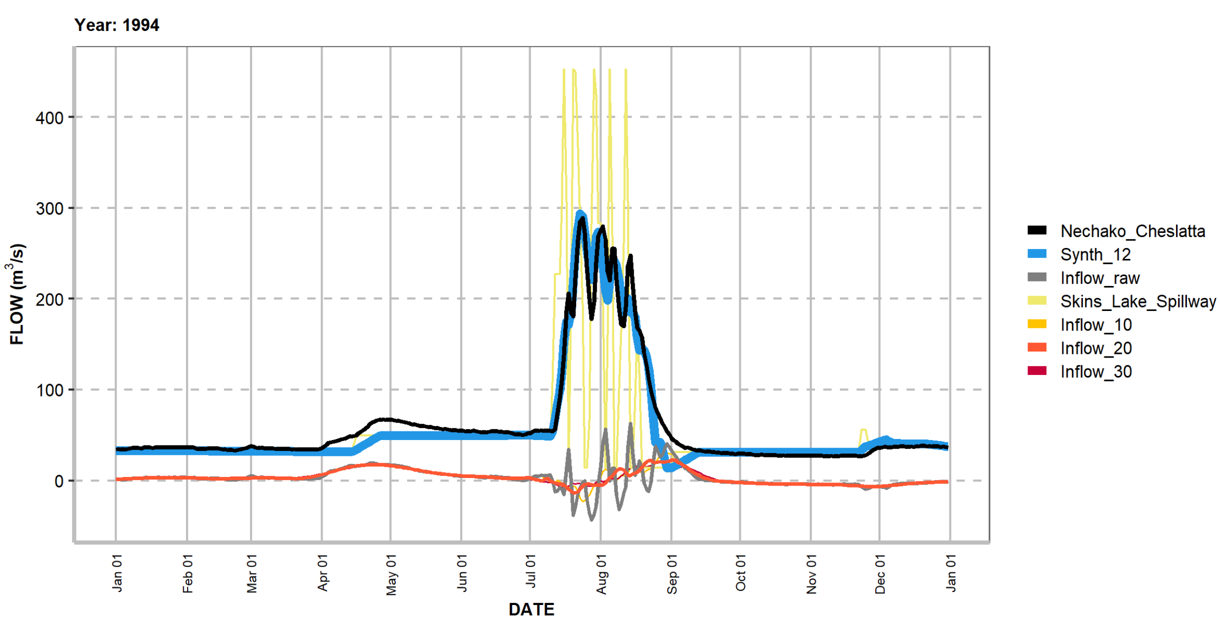


Figure 4. Example plot (1994) of Mid-Nechako inflow. Inflow_raw is the calculated inflow prior to smoothing (i.e., Synth_12 subtracted from Nechako_Cheslatta). Inflow_10 to Inflow_30 show a 10, 20, or 30-day average that has been applied to Inflow_raw to reduce the artefacts introduced by Synth_12 residuals.



3.3. Vanderhoof

For the third section, visual assessment of peaks showed that there is 1-day lag in flow from Nechako River below Cheslatta Falls to Nechako River at Vanderhoof (WSC 08JC001). A NSE of 0.96 was calculated by comparing 1-day lagged Nechako River below Cheslatta Falls + daily Nautley River near Fort Fraser flow (WSC 08JB003) to Nechako River at Vanderhoof flow for 1981-2018 (the period of record at Nechako River below Cheslatta Falls).

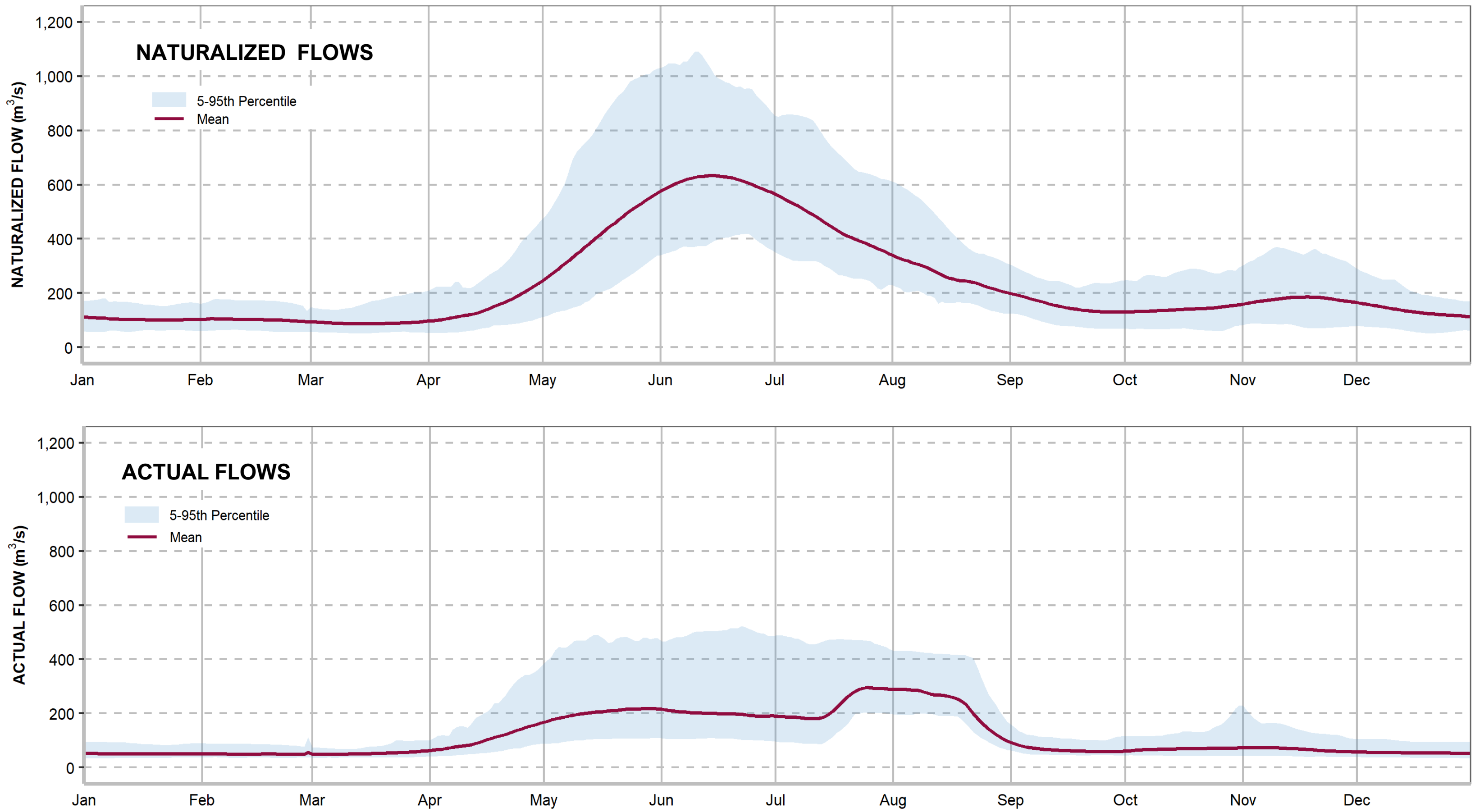
In addition to determining a lag time from Cheslatta to Vanderhoof, Lower Nechako inflows were also calculated. These include any inflow to the Nechako River from below Cheslatta Falls to Vanderhoof (including Nautley River inflows) and were calculated by subtracting the 1-day lagged version of Nechako River below Cheslatta Falls from the Nechako River at Vanderhoof timeseries.

3.4. Naturalized Flow Model

Combining the above findings, the Naturalized Nechako River at Vanderhoof flow model was constructed as follows and is represented by Figure 5:

1. A 23-day average with a 10-day lag of Nechako Reservoir Inflow was calculated to represent Naturalized SLS Outflow.
2. A 12-day average and 6-day lag was applied to the Naturalized SLS outflow.
3. The output of step 2 was added to Mid-Nechako Inflow (calculated as described in Section 3.2) to represent Naturalized Nechako River below Cheslatta Falls flow.
4. A 1-day lag was applied to the Naturalized Nechako River below Cheslatta Falls flow.
5. The output of step 4 was added to the Lower Nechako Inflows (calculated as described in Section 3.3) to yield a daily timeseries of Naturalized Nechako River at Vanderhoof flow.

Figure 5. Visual representation of the naturalized hydrograph compared to the actual hydrograph 1981-2018 (mean, 5th and 95th percentiles).



4. CONCLUSION

An interactive plot (html file) is provided and shows the resulting naturalized hydrographs alongside actual hydrographs from 1981-2018. These provide insight into the approximate shape, magnitude, and timing of flow at Nechako River at Vanderhoof in the absence of diversion to Kemano or regulation at Skins Lake Spillway. The approach taken for this analysis was coarse and, as stressed in Section 2, the data produced are not intended to be used for further analyses such as flood frequency or magnitude analyses, environmental flow needs, or other detailed analyses. If more accurate estimates of naturalized flow are required, then Ecofish recommends undertaking a more rigorous approach such as using a hydrologic model (e.g., Raven) that would employ lake storage and flow routing algorithms to represent natural processes in the Nechako watershed.

Yours truly,

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EGBC Permit #1002952

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Disclaimer:

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