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MEMORANDUM

TO: **Nechako Water Engagement Initiative Technical Working Group**

FROM: **Jonathan Abell, Ph.D., E.P. and Adam Lewis, M.Sc., R.P.Bio., Ecofish Research Ltd.**

DATE: **December 5, 2022**

FILE: **1316-09**

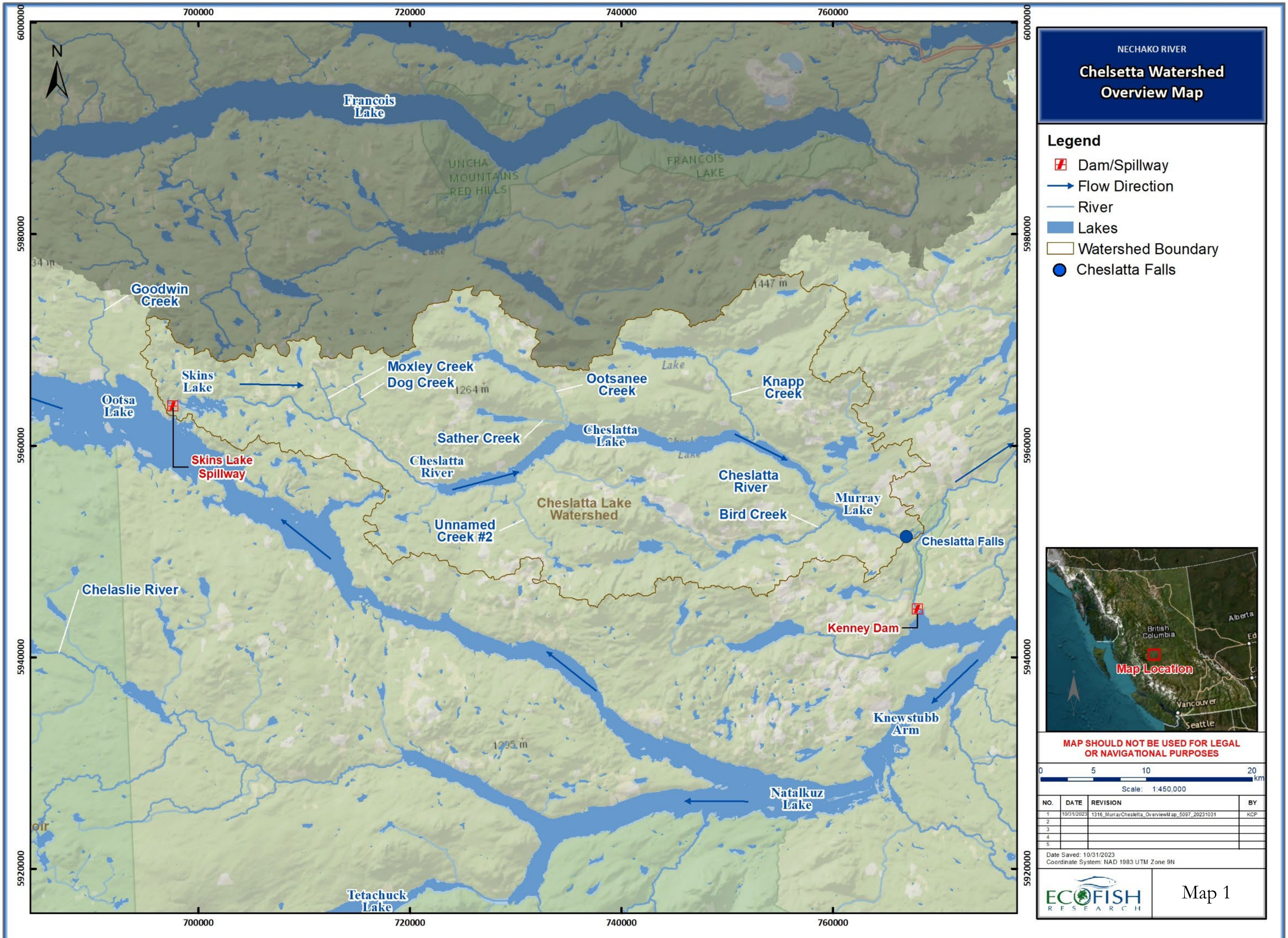
RE: **Issue #15, 16 – Cheslatta Watershed Productivity – V2**

1. INTRODUCTION

During Main Table and Technical Working Group (TWG) meetings of the Nechako Water Engagement Initiative (WEI), concerns were raised about potential effects of Rio Tinto Alcan operations on aquatic productivity. One priority is to better understand the potential impacts of changes in flow on aquatic productivity in the Cheslatta watershed, which drains into the Nechako River. The TWG asked Ecofish Research Ltd. (Ecofish) to prepare a technical memo to review this topic and develop recommendations for consideration by the WEI. Specifically, the following two issues were identified as priorities for evaluation:

- Issue #15: potential effects of changes in flow on primary and secondary productivity by periphyton, macrophytes, and macroinvertebrates; and
- Issue #16: potential effects of changes in reservoir flushing on plankton productivity.

This memo provides a review of the potential impacts of changes in flow on aquatic productivity in the Cheslatta watershed downstream of Skins Lake Spillway and upstream of Cheslatta Falls (Map 1). Recommendations are provided regarding potential performance measures to evaluate the effects of alternate flow management scenarios.



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2. BACKGROUND

2.1. Nechako Hydroelectric System

The Nechako Reservoir is located approximately 200 km west of Prince George, British Columbia (BC) and was created to provide water for Rio Tinto Alcan's Kemano Hydroelectric Project, which was constructed in the 1950s to provide energy to operate an aluminium smelter in Kitimat, BC. The reservoir was formed by the construction of the Kenney Dam on the Nechako River (at the east end of the reservoir), which inundated a chain of six major lake and river systems (Ootsa, Whitesail, Knewstubb, Tetachuck, Natalkuz, and Tahtsa; ~420 km total length). The area of Nechako Reservoir is ~910 km^2 with a normal annual drawdown range of ~ 3 m (10'); annual minimum reservoir levels occur in late spring and annual maximum levels water occur in late summer.

There are two reservoir outflows. The powerhouse intake portal on Tahtsa Lake diverts ~70% of the annual reservoir inflow 16 km west into the Kemano River watershed. The Skins Lake Spillway on Ootsa Lake diverts the remaining flow (75 m^3/s mean annual discharge[1]) ~80 km through the Cheslatta watershed, before discharging into the Nechako River at Cheslatta Falls (Map 1). There is no discharge facility at the Kenney Dam.

Discharge at Skins Lake Spillway varies seasonally, with peak flows highest in July and August on average (Figure 1). The highest flows at Skins Lake Spillway therefore occur during the growing season, with an average growing season discharge of ~100 m^3/s[2]. Discharge during individual years can vary substantially from the longer-term average condition shown in Figure 1, e.g., see example years in Figure 2, which highlights the potential for rapid changes in discharge to occur during the growing season.

[1] Based on mean annual discharge at Skins Lake Spillway (gauge 08JA013) during 1957-2019.

[2] Average daily discharge at Skins Lake Spillway (gauge 08JA013) during May through October 1987–2019 is 102 m^3/s.

Figure 1. Mean daily discharge (1990–2020) at selected stations including Skins Lake Spillway ("SLS"), Nechako below Cheslatta Falls ("Cheslatta"), and four additional stations.

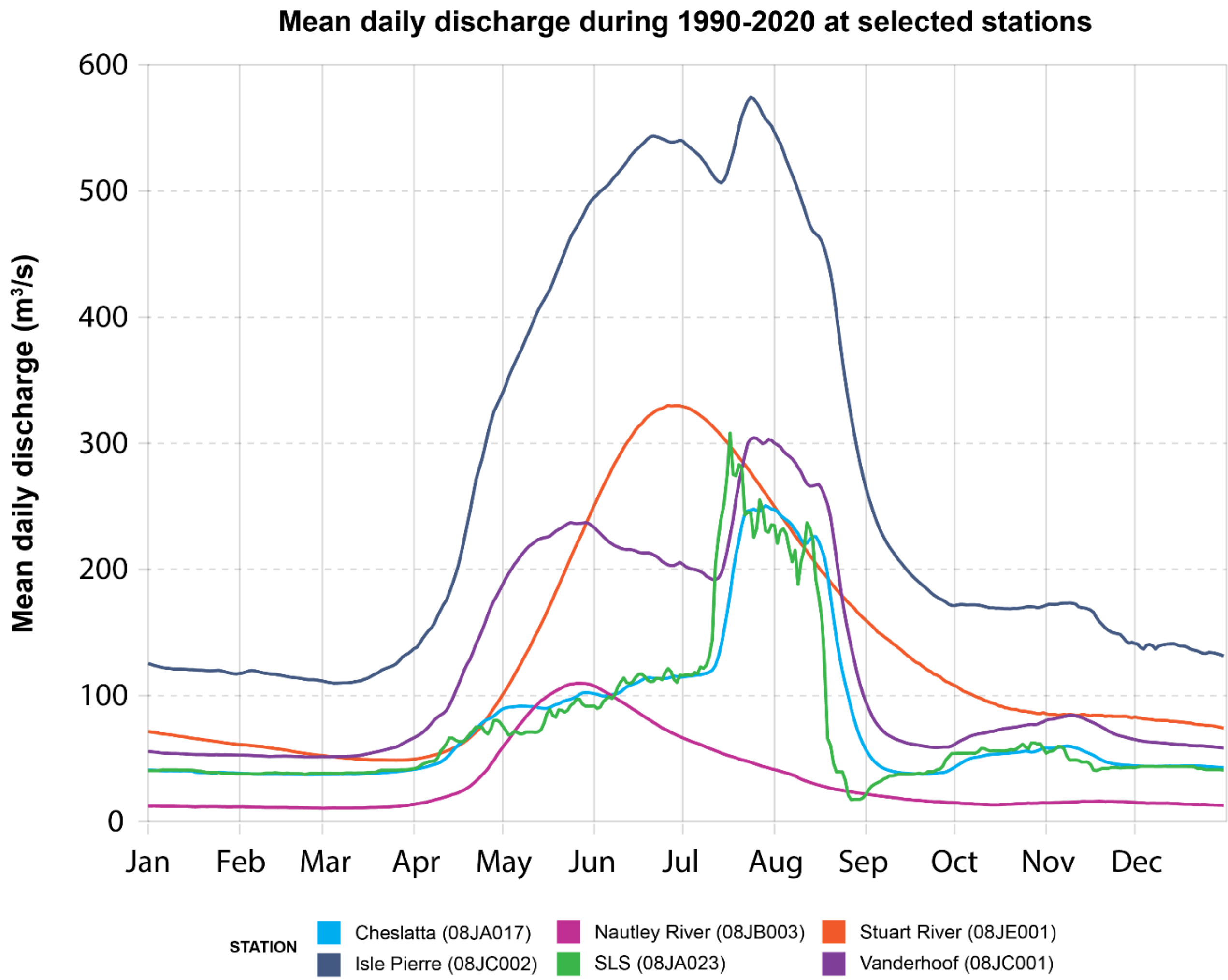
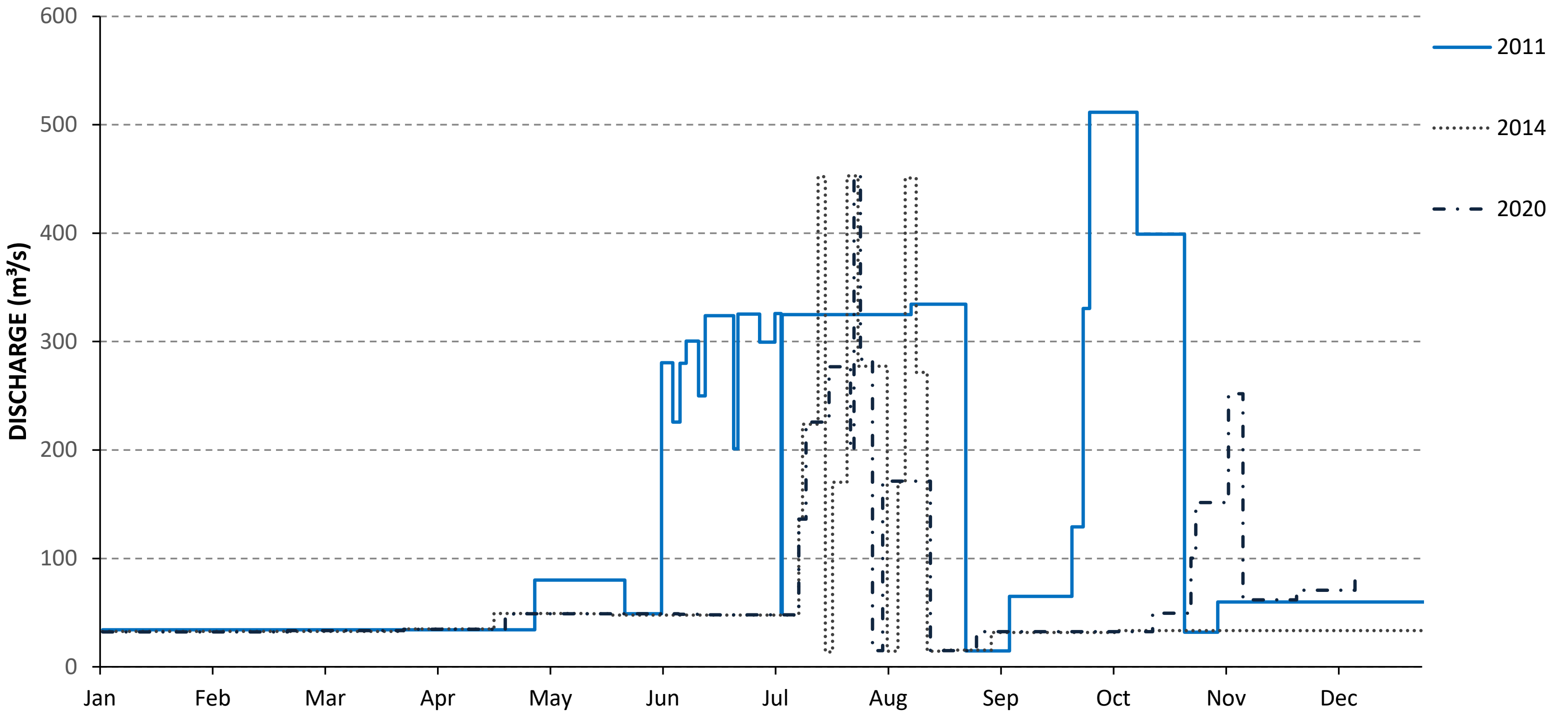


Figure 2. Skins Lake Spillway discharge in example years.



2.2. Biophysical Context

The Cheslatta watershed includes a chain of three lakes along the Cheslatta River ("Cheslatta watershed lakes") that extends from Skins Lake Spillway on the northern shoreline of Nechako Reservoir, downstream to Cheslatta Falls at the upstream end of the Nechako River (Map 1; Table 1). Outflow from the Skins Lake Spillway flows from west to east through the system (Map 1), draining an area of approximately 1,300 m^2 (Hamilton and Schmidt 2005). Skins Lake is the first lake in the chain, situated immediately downstream of the spillway. Skins Lake drains into a ~25-km-long section of the Cheslatta River that flows into Cheslatta Lake. Cheslatta Lake drains to Murray Lake, which discharges to a short (1.0 km) riverine section upstream of Cheslatta Falls.

Prior to development of Nechako Reservoir, the headwaters of Cheslatta Lake comprised a ~2-km-long section of stream at the west end of Cheslatta Lake (Lyons and Larkin 1952, cited in Hamilton and Schmidt 2005). Historically, the Cheslatta River was a small stream and the mean annual discharge of the Cheslatta watershed was ~5 m^3/s (NHCL 2000, cited in Hamilton and Schmidt 2005). Initiation of Skins Lake Spillway operations in 1956 (Hamilton and Schmidt 2005) therefore substantially affected the hydrology of the Cheslatta watershed by increasing mean annual discharge ~12-fold. Average water levels in Cheslatta Lake have increased by ~1–2 m, with an estimated increase in maximum water levels in the Cheslatta watershed lakes of up to 3.5 m, and an increase in the maximum annual range of lake water levels from 1 m to 3.5 m (Hamilton and Schmidt 2005). Cheslatta Lake was historically moderately productive (mesotrophic) whereas Murray Lake was highly productive (eutrophic) (Lyons and Larkin 1952, cited in Hamilton and Schmidt 2005). Data pertaining to existing productivity in the lakes are generally lacking but current productivity in the lakes has substantially declined (described in Section 2.3.3.1), with the unproductive (oligotrophic) surface waters in Nechako Reservoir now the current source of water to the system.

Further details regarding hydrology and habitats historically present in the Cheslatta watershed are provided in Ecofish's Cheslatta Fish Habitat memo (Girard *et al.* 2022). A detailed overview of the hydrology of the Nechako watershed more broadly is provided in a separate Ecofish memo regarding hydrology (Beel *et al.* 2022).

Table 1. Physical characteristics of waterbodies in the Cheslatta watershed.

Waterbody	Length (km)*	Area (km^2)†	Maximum Depth (m)‡
Skins Lake	3.6	4.7	-
Cheslatta River	24.9	-	-
Cheslatta Lake	38.7	35.0	73
Murray Lake	8.3	5.6	26

* Linear length along the centreline, measured using Google Earth

† Skins Lake: measured using Google Earth; Murray/Cheslatta lakes: from Lyons and Larkin (1952), cited in Hamilton and Schmidt (2005)

‡ Lyons and Larkin (1952), cited in Hamilton and Schmidt (2005). Does not account for ~1–3.5 m increase in maximum lake elevation post-reservoir construction.

"-" denotes unknown values

2.3. Stockner and Slaney (2006)

2.3.1. Scope

Stockner and Slaney (2006) completed an assessment of the role of hydraulic flushing on primary productivity and ecosystem recovery on the Cheslatta watershed. Their assessment is summarized below for context as it is highly relevant to issue #16 (regarding flushing) and is also relevant to issue #15, which relates to broader effects to aquatic productivity associated with communities of periphyton, macrophytes, and macroinvertebrates (Section 1).

2.3.2. Methods

For Cheslatta and Murray lakes, the authors sought to identify optimum flows to enhance primary and secondary productivity using the following two models:

1. A phosphorus loading model developed for lakes generally (Vollenweider 1976) that links phosphorus load into a lake to average in-reservoir total phosphorus concentration; and
2. A "photosynthetic rate" model (Shortreed *et al.* 1999) that links the daily or hourly average rate of carbon fixation in a lake associated with primary productivity, with abundance and biomass of kokanee (*Oncorhynchus nerka*).

For the Cheslatta River, the authors used two stream productivity models to predict the effect of changes in flow on biological productivity:

1. A multiple regression model (Lamberti and Steinman 1997) that predicts primary production (gross carbon production per annum) based on watershed area, mean annual flow, and dissolved phosphorus concentration; and
2. Two models that predict stream salmonid biomass based on either alkalinity (Ptolemy 2005) or nitrate concentrations and cover (Rosenau and Slaney 1983).

The stream productivity models were used to evaluate the effect of flow on productivity within the upper Cheslatta River for a range of flow scenarios ranging from zero reservoir release (base flow of 0.6 m^3/s) to mean annual release of 25 m^3/s, which approximated the discharge at the time of water quality sampling (see below) and was equal to maximum mean annual release that had been proposed after construction of a proposed cold-water release facility at Kenney Dam.

To evaluate the potential for changes in wetted width due to changes in flow to affect primary productivity in the upper Cheslatta River ("flow-production area effects"), Stockner and Slaney (2006) estimated how wetted width varies between flows of 0.6–25 m^3/s by fitting a curve to observations. The authors then used a model from the literature (Lamberti and Steinman 1997) to estimate gross primary productivity in the river at different flows.

Key uncertainties identified by the authors were a lack of data regarding historical and existing productivity in the Cheslatta watershed lakes, particularly in relation to chlorophyll *a* concentrations, which provide an indicator of phytoplankton biomass and had to be estimated based on professional judgement. The authors considered spot measurements of nutrient concentrations based on sampling in March 2006; all concentrations were "exceptionally low".

2.3.3. Results

2.3.3.1. Murray and Cheslatta Lakes

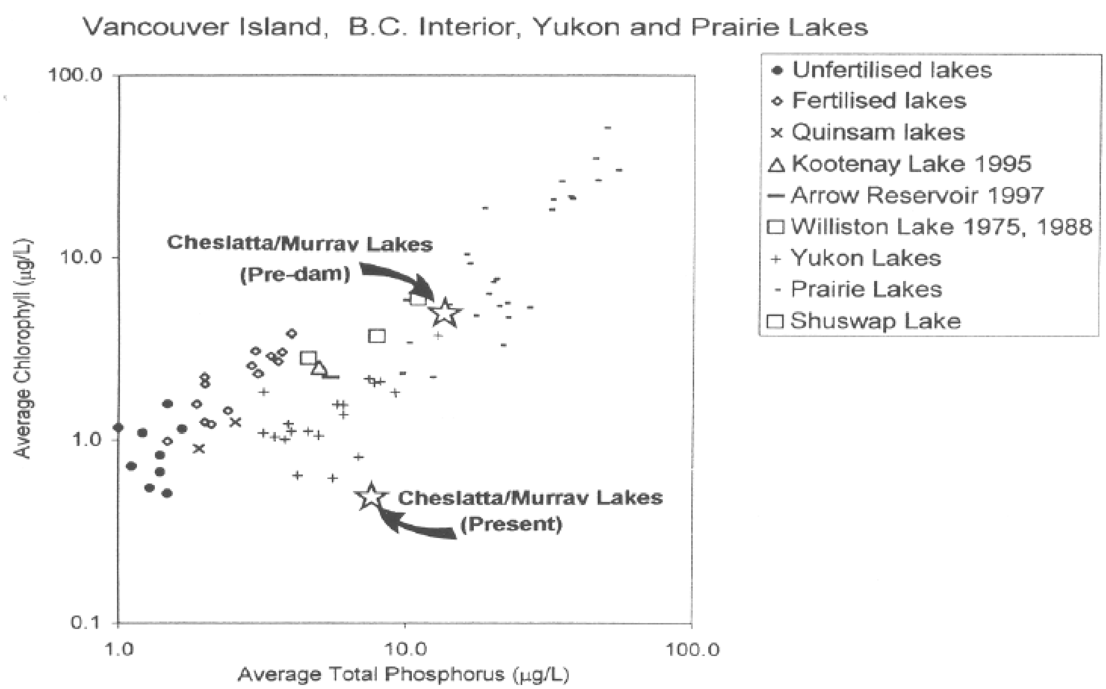
Evaluation of estimated average chlorophyll *a* and total phosphorus concentrations showed substantial declines in productivity in Murray and Cheslatta lakes due to the construction and operation of Skins Lake Spillway (Figure 3). Estimated current mean chlorophyll *a* concentrations (0.5 μg/L) were lower than concentrations for a suite of comparable lakes that included lakes in the Yukon and lakes that were subsequently fertilized to enhance productivity (Figure 3).

Predictions with the photosynthetic rate model indicated that Skins Lake Spillway operations have led to major declines in primary production in the Cheslatta watershed due to reduced total phosphorus concentrations that are associated with large increases in flushing rate. Specifically, the predictions indicated that the capacity of the lakes to support pelagic fish had reduced by approximately seven-fold in Cheslatta Lake and ten-fold in Murray Lake.

Consideration of water residence time showed that, prior to reservoir construction, the annual residence time was approximately six years in Cheslatta Lake and six months in Murray Lake. Based on approximate mean annual discharge at Skins Lake Spillway (68 m^3/s), annual water residence time was estimated to be 4–5 months in Cheslatta Lake and a few weeks in Murray Lake. These residence times were estimated to result in complete replacement of the epilimnion[3] six times during the growing season in Cheslatta Lake and 45 times in Murray Lake, indicating rapid flushing with a detrimental effect on aquatic productivity. Based on a model from the literature (Prairie 1988), Stockner and Slaney (2006) estimated that phosphorus retention was 70–90% in the lakes before reservoir production, but only ≤10–15% subsequently.

Overall, Stockner and Slaney (2006) concluded that lower spring freshet flows would result in higher aquatic productivity in Murray and Cheslatta lakes.

Figure 3. Comparison of estimated average chlorophyll *a* concentration (an indicator of phytoplankton biomass) and estimated total phosphorus concentration in Murray and Cheslatta lakes before and after construction of Nechako Reservoir. Figure reproduced from Stockner and Slaney (2006), prepared for the Nechako Enhancement Society.



[3] The epilimnion is the surface mixed layer of stratified lakes where primary production by phytoplankton predominantly occurs.

2.3.3.2. Upper Cheslatta River

Stockner and Slaney (2006) postulated that, prior to reservoir construction, water chemistry in the upper Cheslatta River would have been similar to existing water chemistry in tributaries to the river, which are unaffected by reservoir construction. Thus, based on this assumption and evaluation of water chemistry measured in late March 2006, the authors suggested that existing total alkalinity and total dissolved solid concentrations are ~20% of historical values, whereas existing nutrient concentrations are ~3–5% of historical values, indicating a substantial decline in the productivity of the upper Cheslatta River due to reservoir construction.

Application of stream productivity models further showed that productivity in the upper Cheslatta River had greatly declined due to reservoir construction. Specifically, salmonid standing crop (biomass) was estimated to have been 2.3–3.7 times higher under historical flows (0.6 m^3/s) compared to flows of 25 m^3/s. However, consideration of changes in wetted width showed that the estimated decline in fish productivity would be partially offset by increased gross primary productivity associated with increased wetted width, although the cumulative outcome of the two mechanisms (i.e., reduced productivity due to lower nutrient concentrations and increased productivity due to greater wetted area) was a general decline in fish productive capacity due to increased flow associated with reservoir production.

2.3.4. Recommendations

Based on the results of their analysis, Stockner and Slaney (2006) recommended that average discharge of 10–20 m^3/s should be targeted for the Cheslatta watershed, with values at the low end of this range preferable to support an objective to achieve moderately high fish production in Murray and Cheslatta lakes.

For the upper Cheslatta River, the authors suggested that discharge of 10–15 m^3/s would be adequate to maintain satisfactory productivity, whereas discharge of 25 m^3/s "is excessive in terms of productivity losses".

3. METHODS

A background review was completed to summarize potential interactions between Skins Lake Spillway operations and aquatic productivity in the Cheslatta watershed. Literature was considered regarding the potential effects of flow management operations on aquatic productivity generally (e.g., Furey *et al.* 2004, 2006; Zohary and Ostrovsky 2011), including research undertaken elsewhere in BC as part of Water Use Plan monitoring studies (e.g., Hocking *et al.* 2017; Sneep *et al.* 2020). Such information was then used to define potential pathways of effect, which were evaluated in the context of watershed-specific information.

Literature was identified by consulting the provincial Ecological Reports Catalogue (Province of BC 2022) and Ecofish files, including an electronic library relating to the Nechako system that is maintained to support the WEI. Key watershed-specific studies considered were Stockner and Slaney (2006; see Section 2.3) and the background information report prepared by Hamilton and Schmidt (2005), which summarized geomorphological, biological, and hydrological information regarding the Cheslatta watershed, with a focus on interactions with water management.

Based on the review, the potential for each pathway to influence aquatic productivity in the Cheslatta watershed was evaluated and uncertainties were identified. Potential performance measures, operational considerations, and management options aside from flow management were also evaluated.

4. RESULTS

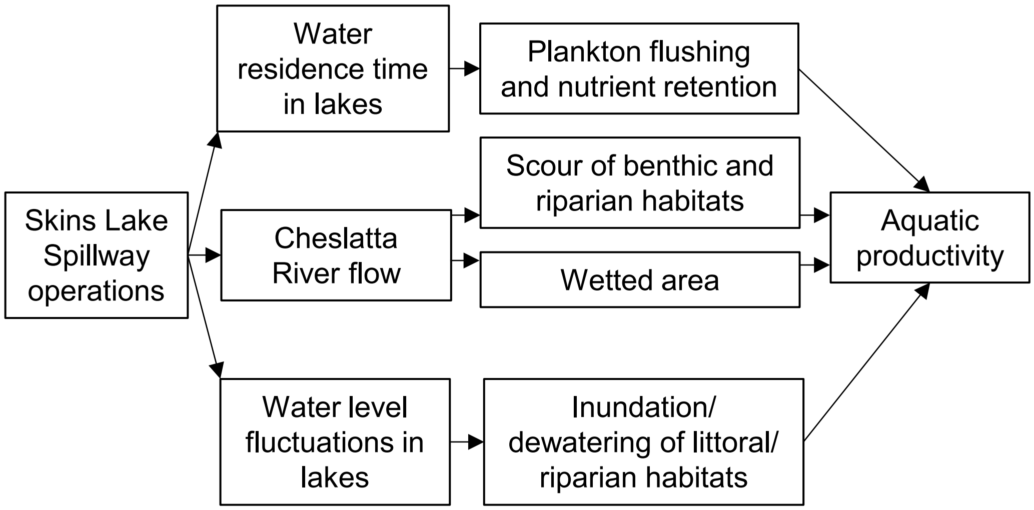
4.1. Overview of Potential Pathways of Effect

Key pathways that were identified by which Skins Lake Spillway operations could potentially affect aquatic productivity in the Cheslatta watershed (Figure 4) can be summarized as follows:

- Increased plankton flushing and reduced nutrient retention due to reduced water residence time as a consequence of increased flows, relative to historical conditions (directly applicable to lakes);
- Scour of benthic and riparian habitats due to high freshet flows (which include Summer Temperature Management Program flows; pathway directly applicable to riverine habitats);
- Increased wetted area due to increased flows, relative to historical conditions (most applicable to riverine habitats); and
- Inundation and dewatering of riparian and littoral habitats due to increased water level fluctuations, relative to historical conditions (most applicable to lakes).

The first pathway listed above (flushing) applies to issue #16, whereas the other three pathways apply to issue #15 (issues are defined in Section 1). Pathways are evaluated individually in the subsections below.

Figure 4. Pathways of effect relevant to changes in aquatic productivity associated with flow management in the Cheslatta watershed.



4.2. Flushing

Operation of Skins Lake Spillway has greatly increased flow through the Cheslatta watershed relative to historical conditions (Section 2.2). Increased flows through the lakes in the watershed have reduced water residence time, which can be calculated as lake volume divided by mean outflow to approximate the average time that a parcel of water is retained in a lake (water residence time is the inverse of flushing rate). Reduction to water residence time has potential to reduce pelagic productivity of plankton by increasing "transport losses" (Lucas *et al.* 2009), i.e., increasing the rate at which planktonic organisms are flushed from a lake. High flushing rates have been shown to depress plankton productivity in small lakes in BC (Dickman 1969), and the effect of altered water residence time on fisheries is an issue of management interest elsewhere, e.g., for diversion lakes in the Campbell River watershed (Hocking *et al.* 2017).

With regards to plankton flushing, a key point is that this effect pathway is only relevant if flushing is sufficiently high to reduce water residence time to low values that are comparable with the intrinsic growth rates of plankton. For phytoplankton (suspended algae), the maximum intrinsic growth rate in natural environments (i.e., accounting for losses) is typically 0.1–1/day (Reynolds 2006 and references therein). Thus, increased flushing is not expected to significantly affect phytoplankton productivity unless water residence time is reduced to the order of days to weeks, and a water residence time of 20 days has been proposed as an appropriate threshold below which flushing has potential to exert a substantive effect on phytoplankton biomass (Hamilton and Dada 2016). Zooplankton (suspended invertebrates) have longer generation times and are therefore more sensitive to flushing effects. The effect of flushing on zooplankton production is variable but flushing can exert a significant effect in some systems such as rapidly flushed impoundments. In general, decreasing water residence time to less than several months can reduce production of crustacean zooplankton with long generation times, and biologically significant declines in zooplankton biomass are most likely to occur when water residence time is less than approximately two months (Campbell *et al.* 1998; Walz and Melker 1998; Obertegger *et al.* 2007).

Stockner and Slaney (2006) estimated that the annual water residence time had decreased from approximately six years to 4–5 months in Cheslatta Lake, and from six months to a few weeks in Murray Lake, based on approximate current mean annual discharge at Skins Lake Spillway of 68 m^3/s (Section 2.3.3.1). Current water residence time is lower during the growing season when discharge at Skins Lake Spillway is highest (Figure 1). Thus, based on the context above, it is expected that operation of Skins Lake Spillway has directly adversely affected plankton productivity in lakes in the watershed due to flushing, most notably in Murray Lake. Mean discharge of 20 m^3/s could be considered a reasonable threshold at which plankton flushing effects are substantially reduced relative to approximate existing conditions; Stockner and Slaney (2006) estimated that, at 20 m^3/s, water residence time would be 1.5 years in Cheslatta Lake and a few months in Murray Lake, equating to a complete exchange of the epilimnion once every ~90 days in the growing season in Cheslatta Lake and once every ~2 weeks in Murray Lake (although Stockner and Slaney (2006) identified that discharge of 10–15 m^3/s would be preferable for the river).

In addition to the direct flushing effects described above, reduced water residence time decreases nutrient retention (Vollenweider 1976), further reducing aquatic productivity. The modelling by Stockner and Slaney (2006) provides the best available insight into interactions between flow and nutrient retention (Section 2.3.3.1).

In summary, increases in flow within the Cheslatta watershed are expected to reduce nutrient retention in lakes (i.e., increase nutrient loss) as lakes are flushed with highly unproductive water that originates from the surface layer of Nechako Reservoir.

4.3. Scour

In the upper Cheslatta River, flow diversion over Skins Lake Spillway has historically caused major physical effects, resulting in the channel becoming highly entrenched and confined, with increased bankfull width (75 to 150 m), bank erosion, and substantial bedload movement (Hamilton and Schmidt 2005). Further details regarding such historical changes to fish habitat in the Cheslatta watershed are described in Ecofish's Cheslatta Fish Habitat memo (Girard *et al.* 2022) and are not considered further here.

On an annual basis, high flows can cause physical scour of periphyton (attached algae) and benthic invertebrates, reducing aquatic productivity during the growing season in rivers (e.g., Biggs and Close 1989). For example, ongoing research in the Lower Bridge River watershed near Lillooet, BC has shown that peak flows >100 m^3/s in that watershed result in low densities of fish food organisms due to physical scouring effects (Sneep *et al.* 2020). Given the high magnitude of flows during the growing season (Figure 1), and the historically small size of the Cheslatta River (Section 2.2), it is likely that physical scouring also occurs on an annual basis, reducing aquatic productivity in the Cheslatta watershed. However, the magnitude of such effects and corresponding flow thresholds at which effects occur are unknown.

4.4. Changes to Wetted Area

Increases to flow increase the wetted area (i.e., habitat availability) that aquatic organisms such as periphyton and benthic invertebrates can colonize in rivers. Thus, higher growing season flows can potentially increase aquatic productivity, although this effect can be moderated by scour at high flows (Section 4.3 above), habitat dewatering caused by water level fluctuations (Section 4.5 below), and changes to habitat suitability (e.g., for benthic invertebrates) associated with changes to depth and velocity (Jowett and Duncan 1990). Such effects are more applicable to the riverine sections within the Cheslatta watershed than to the lentic sections because changes in flow have a greater potential to cause changes in aquatic habitat area in rivers than in lakes.

The modelling by Stockner and Slaney (2006) provides the best available insight into interactions between changes in wetted area and aquatic productivity in the Cheslatta River. As summarized in Section 2.3.3.2, their analysis indicated that, in isolation, increases in flow within the range 0.6–25 m^3/s could increase gross primary productivity in upper Cheslatta River by increasing wetted area; however, such increases would not offset the negative effects associated with increased flushing and associated reduced nutrient retention. The flow range considered by Stockner and Slaney (2006) was lower than the range of existing mean daily discharge (i.e., ~40–190 m^3/s; Figure 1), and it is expected that changes in aquatic productivity are less sensitive to changes in flow at this higher flow range as wetted width will be at near-bankfull or bankfull conditions. Of note, flow management intended to improve habitat availability and rearing conditions for resident fish (Girard *et al.* 2022) would also generally be expected to enhance primary and secondary productivity in the upper Cheslatta River.

4.5. Inundation and Dewatering

Water management activities that increase the frequency and magnitude of water level fluctuations in lakes can cause adverse effects to aquatic productivity due to repeated wetting and drying of nearshore littoral and riparian areas, which can lead to reduced primary productivity of macrophytes and periphyton, and reduced secondary productivity of associated invertebrate communities, e.g., due to desiccation (Wilcox and Meeker 1991; Zohary and Ostrovsky 2011). Construction and operation of

Skins Lake Spillway has increased the maximum annual range of water levels in the Cheslatta watershed lakes from approximately 1–3.5 m (Hamilton and Schmidt 2005). Water levels in the lakes are expected to typically increase during summer freshet in the approximate mid part of the growing season in July (Figure 1), with a larger decrease in approximately late August as freshet wanes. Relative to pre-reservoir conditions, the increase in the annual range of water levels is likely to have reduced littoral productivity in the lakes due to less hydrologically stable conditions in the littoral zone.

There is limited information to evaluate the biological significance of this pathway or the associated interaction with flow management. However, review of aerial imagery indicates the presence of an unproductive drawdown zone at Cheslatta Lake that generally lacks riparian vegetation, which is not apparent in aerial imagery of other lakes in the region that are not regulated. Additionally, evaluation of discharge at Skins Lake Spillway (Figure 2) indicates that lake levels can fluctuate throughout the growing season, as opposed to more gradually increasing and decreasing in association with freshet, as would be expected for unregulated lakes in the region. Such fluctuations cause repeated wetting and drying of littoral zones, which is associated with decreased littoral productivity in lakes (Zohary and Ostrovsky 2011). Thus, this pathway is expected to have an adverse effect on aquatic productivity in the Cheslatta watershed lakes, although a mitigating factor is that the lakes are part of a run-of-river system, and therefore, the drawdown range is expected to be lower than in typical storage reservoirs, where such effects are more typically a concern. Additionally, the deep characteristic of Cheslatta Lake (i.e., the largest lake in the chain; Table 1) indicates that pelagic productivity (only indirectly affected by this pathway) is of greater importance than littoral productivity (directly affected by this pathway). Thus, the biological significance of this pathway of effect is expected to be lower than the flushing pathway described above (which directly affects pelagic productivity); however, additional information about littoral/riparian productivity, lake bathymetry, and seasonal variability in lake levels could reduce uncertainty associated with this pathway.

5. DISCUSSION

5.1. Limiting Factors

Following construction of Skins Lake Spillway, increased flushing in the Cheslatta watershed has reduced aquatic productivity due to reduced nutrient retention, increased flushing of plankton, and influx of highly unproductive water from Nechako Reservoir. Of the four pathways considered (Section 4.1), flushing is expected to be the most biologically important, as supported by the assessment by Stockner and Slaney (2006). This pathway is directly related to flow management at Skins Lake Spillway, with lower flows during the growing season expected to be beneficial.

Limited information means there is moderate to high uncertainty with assessing the relative biological importance of the other three pathways considered. Nonetheless, physical scour of riverine habitats due to high flows during freshet (including Summer Temperature Management Program flows) is likely the second-most important pathway, given that summer flows are now many times greater than historical flows (Section 4.3). Specific flow ranges at which scour effects potentially occur are unknown, although lower peak freshet flows are generally expected to be beneficial.

Increased inundation and dewatering of littoral and riparian areas is likely to have contributed to reduced aquatic productivity since construction of Skins Lake Spillway because water management has increased the range of lake level fluctuations (Section 4.5). Information to evaluate this pathway is limited; however, as for the scour pathway, lower peak freshet flows are generally expected to be beneficial because they correspond to lower magnitude of lake level fluctuations during the growing season. Reduced frequency of fluctuations during the growing season, which cause repeated wetting and drying of littoral zones, is also beneficial.

Unlike the other three pathways, increases in aquatic productivity associated with the fourth pathway (changes to wetted area) are positively correlated with flow. However, the analysis by Stockner and Slaney (2006) showed that increases to aquatic productivity associated with this pathway at higher flows are outweighed by adverse effects associated with the flushing pathway. Furthermore, although flow-habitat relationships are lacking, it is likely that this pathway is of low biological importance, unless flows are much lower than the existing flow range (Figure 1) and wetted width is well below bankfull width.

5.2. Data Gaps

Key data gaps identified are as follows:

- Information about the productivity of the Cheslatta watershed is lacking; Stockner and Slaney (2006) noted there "is an urgent need to gather some limnological information on the 'present' state of the lakes". Thus, further data regarding water chemistry, algal productivity, bathymetry, and littoral habitats in lake habitats in the watershed would be beneficial.
- Information about the productivity of riverine habitats would also be beneficial. This gap includes a lack of information about the flow ranges at which physical scour of periphyton and invertebrates in benthic habitats occurs. Collecting such information would require sampling at a range of flows throughout the growing season, potentially as part of an adaptive management framework, e.g., see details of Water Use Plan monitoring in the Lower Bridge River for context (Sneep *et al.* 2020).
- Analysis of relationships between flow and lake level would be beneficial and could be incorporated into hydrological analysis undertaken of flow management scenarios, e.g., to provide time series of lake levels in Murray and Cheslatta lakes to support evaluation of scenarios during water use planning.

- Quantitative relationships between flow and habitat availability (e.g., for benthic invertebrates) in the Cheslatta watershed are lacking. Such relationships could be developed as part of an instream flows study that focuses of quantifying relationships between flows and fish habitat availability in the watershed (Girard *et al.* 2022).

5.3. Potential Performance Measures

Performance measures are metrics for evaluating how changes in flow affect a particular interest or issue. We have identified preliminary performance measures for the WEI to consider as part of the structured decision-making process. Additionally, suggestions are provided regarding how preliminary performance measures could be further developed if the WEI wishes to consider issues in greater detail. Potential performance measures are described below in relation to each pathway of effect. It is important to recognize that the potential performance measures presented here might be revised, replaced, or ignored depending on the specific needs and interests of the WEI.

Flushing: scenarios that result in lower average discharge at Skins Lake Spillway during the growing season are expected to increase aquatic productivity in the Cheslatta watershed lakes by increasing nutrient retention and reducing plankton flushing, in association with a shift towards more lacustrine (lake-like) conditions (Section 4.2). Accordingly, PM1 below is proposed for initial consideration by the WEI:

- PM1: Mean growing season discharge at Skins Lake Spillway.

PM1 will be calculated by calculating the mean growing season discharge for each scenario, i.e., the overall mean of mean values for individual years in the timeseries simulated. Lower values will correspond to preferable conditions.

To support with comparing scenarios, mean growing season discharge could be standardized to a scale from 0 (no benefit) to 1 (highest benefit). Scenarios could be assigned a value of 0 for PM1 if they correspond to mean growing season discharge equal to or greater than the current mean value (~100 m^3/s; Section 2.2)[4]. Scenarios could be assigned a value of 1 for PM1 if they correspond to mean growing season discharge equal to or less than 15 m^3/s, based on recommendations provided by Stockner and Slaney (2006; Section 2.3.4). Scenarios that correspond to intermediate values of mean growing season discharge could be assigned values between 0 and 1 based on linear interpolation or, preferably, interpretation based on a curve that assigns relatively higher scores to relatively lower values of mean growing season discharge, reflecting our conceptual understanding of the pathway of effect (Section 4.2).

Scour: peak flows during the growing season in the Cheslatta River have greatly increased following construction of Skins Lake Spillway. It is expected that such high flows have adversely affected aquatic

[4] The precise value will depend on the specific baseline data used for scenario analysis.

productivity due to physical scouring of benthic habitats, as has been observed in other systems. However, information is currently unavailable to confirm this expectation, or to identify flow thresholds at which scour is potentially a concern. PM2 below is proposed for initial consideration by the WEI:

- PM2: mean peak growing season discharge at Skins Lake Spillway.

PM2 will be calculated by calculating the mean peak growing season discharge for each scenario, i.e., the overall mean of peak values for individual years in the timeseries simulated. Lower values will correspond to preferable conditions. The growing season is assumed to be May through October (Stockner and Slaney 2006).

As for PM1, PM2 could be standardized to a scale from 0 (no benefit) to 1 (highest benefit). Scenarios with mean peak growing season discharge equal to or greater than that of existing conditions could be assigned a value of 0. The scenario with the greatest predicted decrease to peak growing season discharge could be assigned a value of 1, with intermediate scenario assigned intermediate values based on linear interpolation to provide scores to compare scenarios in relative terms.

Thus, PM2 is intended to provide a measure of the differences in relative risk (only) among scenarios of adverse scour effects. This approach reflects that the relationship is unknown between peak discharge (m^3/s) and aquatic productivity, e.g., expressed as benthic invertebrate biomass (g/m^2) or primary production ($g\,C/m^2/year$) of aquatic plant communities in the Cheslatta River. Such relationships are expected to be non-linear, which has not been accounted for in PM2. An experimental approach as part of an adaptive management framework could be adopted to better understand the potential for scour to adversely affect aquatic productivity in the Cheslatta watershed (e.g., Sneep *et al.* 2020).

Changes to wetted area: no PM is currently proposed in relation to this pathway because existing information (e.g., Stockner and Slaney 2006) indicates that other pathways are of greater biological significance with respect to aquatic productivity, and such pathways (primarily flushing) have contrasting relationships with discharge. Additionally, we expect there will be high alignment with performance measures considered separately for resident fish rearing habitat (Girard *et al.* 2022), i.e., any PM that is developed in relation to rearing habitat for resident fish species such as Rainbow Trout would likely provide a reasonable surrogate for aquatic productivity more generally (although, in theory, weighted usable area for organisms such as invertebrates could be explicitly modelled using habitat suitability curves developed elsewhere).

Inundation and dewatering: operation of Skins Lake Spillway has increased the maximum annual range of water levels in the Cheslatta watershed lakes; this change is likely to have had adverse effects to littoral and riparian productivity (Section 4.5). Information is limited regarding this issue although, in general, lower lake level fluctuations are considered preferable. Accordingly, PM3 below is proposed for initial consideration by the WEI:

- PM3: Mean annual range of Cheslatta Lake water level during the growing season.

PM3 will be calculated for each scenario by calculating the mean annual range in water level in Cheslatta Lake during the growing season, assumed to be May through October. A rating curve may need to be developed to relate discharge (e.g., at Skins Lake spillway) to lake elevation, if such a rating curve does not already exist. The mean annual range in water level at Cheslatta Lake is assumed to be a suitable proxy for conditions in Murray and Skins lakes, given the proximity of the lakes in the chain (Map 1). Lower values will indicate preferable conditions. Values for PM3 are expected to be highly correlated with values for PM2 because freshet flows are expected to primarily drive seasonal variability in lake elevations; such potential redundancy could be considered as part of a PM winnowing process.

If the WEI seeks a more-detailed approach, modelling that considers an "effective littoral zone" could be considered (e.g., Lewis 2001). An advantage of such an approach is that it accounts for loss of littoral productivity associated with the frequency of water level fluctuations (i.e., repeated wetting and drying events during the growing season), not only the magnitude of water level fluctuations. Such modelling would be most valuable if the WEI chooses to evaluate scenarios that encompass variability in the frequency of water level fluctuations, e.g., by comparing scenarios that correspond to a hydrograph with a single peak during the growing season(e.g., a hydrograph shaped like the average Skins Lake Spillway discharge show in Figure 1), with scenarios that correspond to multiple peaks throughout the growing season (e.g., hydrographs shaped like the timeseries shown in Figure 2).

5.4. Operational Considerations

In general, reductions to flow, primarily during the growing season, are expected to improve aquatic productivity in the Cheslatta watershed. Stockner and Slaney (2006) recommended that average discharge of 10–20 m^3/s should be targeted to achieve moderately high fish production in the Cheslatta watershed lakes, with a maximum of 10–15 m^3/s preferable for the upper Cheslatta River (Section 2.3.4). Additional discharge capacity at Kenney Dam could support an objective of reducing outflow from Nechako Reservoir at Skins Lake Spillway, while still being able to meet flow objectives in the Nechako River, e.g., in relation to Summer Temperature Management Program flows.

It is important to consider interactions with other environmental issues when evaluating flow scenarios that involve substantial reductions to flow in the Cheslatta watershed. For example, geomorphological changes (incision and downcutting) that have occurred in the upper Cheslatta River mean that substantial reductions to flow could lead to tributaries to the river flowing sub-surface (Hamilton and Schmidt 2005). Also, the general rule suggested here that lower growing season flows are preferable to restore aquatic productivity should be carefully considered in the context of resident fish habitat availability (Girard *et al.* 2022).

5.5. Other Management Options

Managing flows has been identified as critical to restoring aquatic productivity in the Cheslatta watershed (Hamilton and Schmidt 2005; Stockner and Slaney 2006). However, Hamilton and Schmidt (2005) also identified the following options that are particularly relevant to aquatic productivity in their review of restoration, rehabilitation, and redevelopment opportunities for the watershed:

- Works to the narrow channel and cut through delta at Cheslatta Lake to reduce channel erosion; and
- Revegetation of the river and lakeshores.

Additionally, Stockner and Slaney (2006) proposed the following options for further consideration:

- Add large woody debris to the Cheslatta River to trap organic matter (increase nutrient retention) and enhance fish habitat; and
- Fertilize lake shoals and the Cheslatta River after freshet.

6. CLOSURE

This memo provides a review of the potential for changes in flow to affect aquatic productivity in the Cheslatta watershed between Skins Lake Spillway and Cheslatta Falls. Outcomes of the review have been used to develop preliminary performance measures for the WEI to consider, and data gaps have been identified that could be addressed with further study.

Yours truly,

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