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MEMORANDUM

TO: **Nechako Water Engagement Initiative Technical Working Group**
FROM: **Susan Johnson, Ph.D., Jonathan Abell, Ph.D., E.P., and Adam Lewis, M.Sc., R.P.Bio., Ecofish Research Ltd.**
DATE: **December 7, 2022**
FILE: **1316-09**

RE: **Issue #9 – Nechako River Productivity**

1. INTRODUCTION

During Main Table and Technical Working Group meetings of the Nechako Water Engagement Initiative (WEI), concerns were raised about potential effects of Rio Tinto Alcan (RTA) operations on primary and secondary aquatic productivity. One priority is to better understand the potential impacts of changes in flow on productivity in the Nechako River. The Technical Working Group asked Ecofish Research Ltd. (Ecofish) to prepare a technical memo to review this topic and develop recommendations to help the WEI evaluate potential effects of operational scenarios on Nechako River productivity during water use planning. Specifically, the following issue was identified as a priority for evaluation:

- Issue #9: potential effects of changes in flow on primary and secondary productivity by periphyton, macrophytes, and macroinvertebrates in the Nechako River.

Accordingly, this memo provides a review of the potential impacts of changes in flow on aquatic productivity in the Nechako River, extending downstream from Cheslatta Falls to the confluence with the Fraser River at Prince George[1]. Recommendations are provided regarding potential performance measures to evaluate the effects of alternate flow management scenarios.

2. BACKGROUND

2.1. Hydrology of the Nechako River

The Nechako Reservoir is located approximately 200 km west of Prince George, BC (Map 1) and was created to provide water for RTA'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 (now at the east end of the reservoir), which inundated a chain of six major lake and river systems (Ootsa, Whitesail, Knewstubb, Tetachuck,

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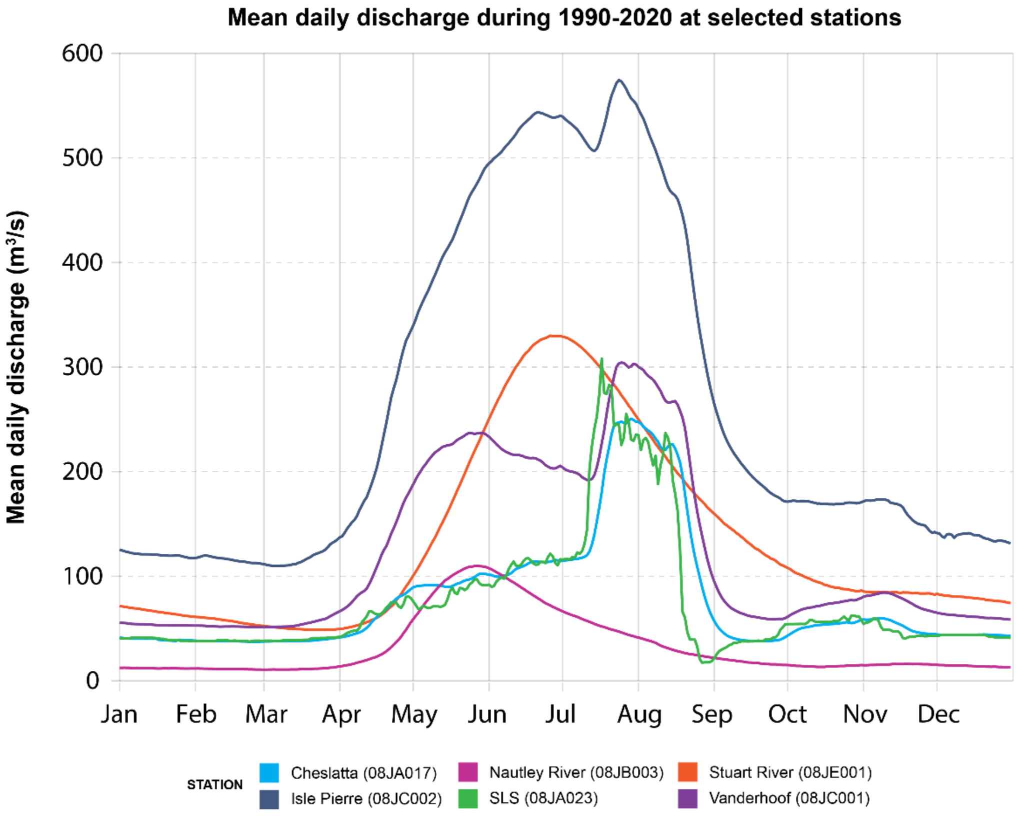
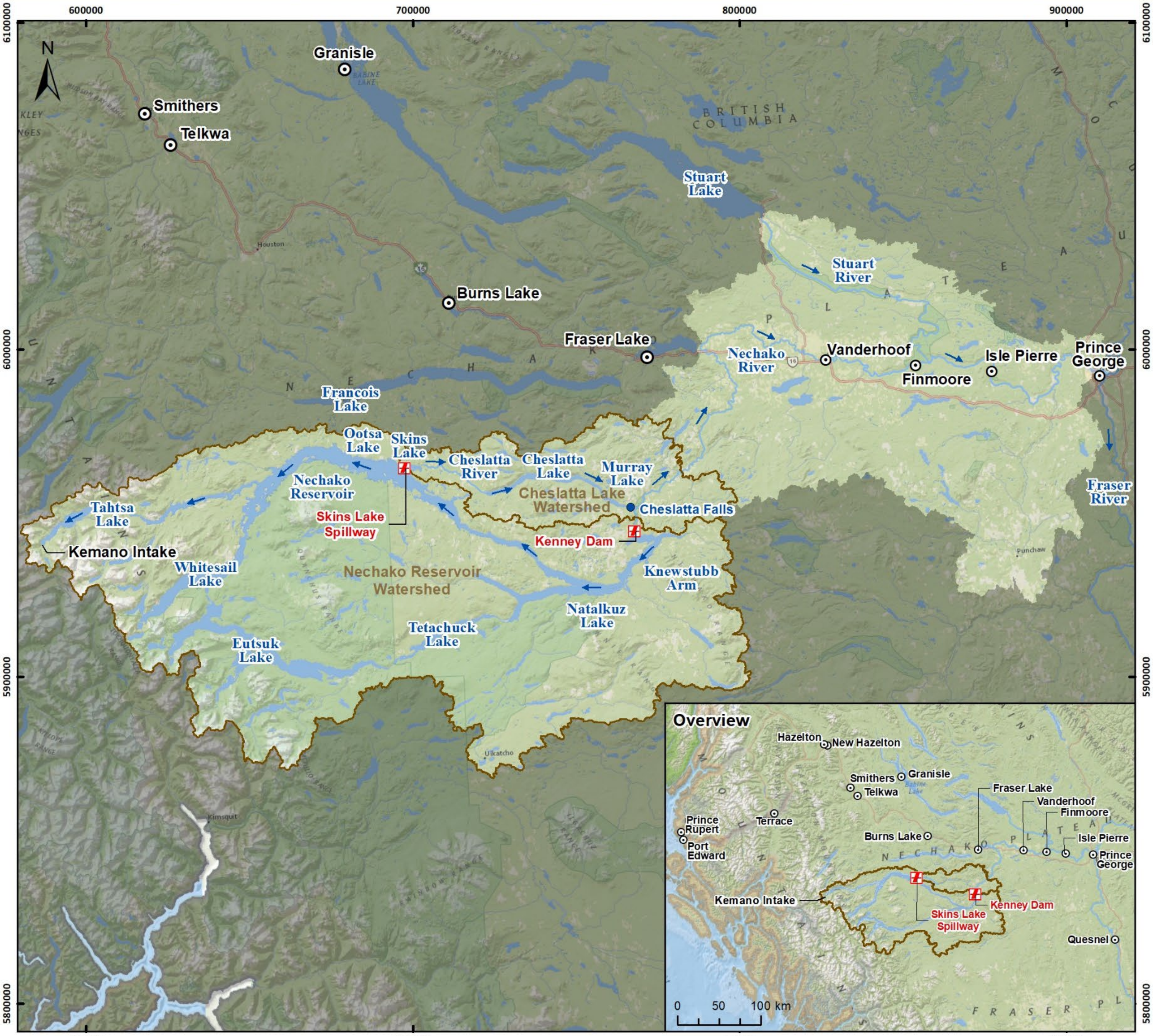
[1] The effects of flow on productivity in the Cheslatta watershed are considered in a separate Ecofish memo (Abell and Lewis 2022).

Natalkuz, and Tahtsa, ~420 km total length). Nechako Reservoir is ~910 km^2 with a normal annual drawdown of ~3 m (10'); low water is in late spring and high water occurs in late summer.

A detailed overview of the hydrology of the Nechako watershed is provided in a separate Ecofish memo (Beel *et al.* 2022). In summary, all flow from Nechako Reservoir to the Nechako River is currently via Skins Lake Spillway, which directs flow into the Cheslatta watershed, from where water flows into the Nechako River, downstream of Cheslatta Falls (Map 1). The Nechako Reservoir provides the majority of flow in the upper Nechako River (there is minimal local inflow); here, flow is reduced to ~30% of pre-dam conditions and mean annual discharge (1990–2020) is 75 m^3/s below Cheslatta Falls (Beel *et al.* 2022; Figure 1). The Nautley River (~95 km downstream of the dam) and local inflows together make moderate contributions and mean annual discharge (1990–2020) in the Nechako River at Vanderhoof (~150 km downstream of the dam) is 126 m^3/s (Beel *et al.* 2022). The Stuart River contributes significant inflow, and by Isle Pierre (~215 km downstream of the dam) mean annual discharge (1990–2020) is 268 m^3/s (Beel *et al.* 2022). The Nechako River flows into the Fraser River at Prince George ~275 km downstream of the dam. The Nechako River has a hydrograph dominated by snowmelt with a summer freshet (Figure 1).

Figure 1. Nechako River mean daily discharge 1990 to 2020 at select stations (see locations on Map 1). "SLS" denotes Skins Lake Spillway.





NECHAKO RIVER

Nechako WEI Overview Map

Legend

- ⊙ Community
- 🟥 Dam
- → Flow Direction
- ▬ Lakes
- ● Fish Barrier

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 5 10 20 30 40 50 60 km

Scale: 1:1,650,000

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Coordinate System: NAD 1983 UTM Zone 9N

ECOFISH RESEARCH

Map 1

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2.2. Primary and Secondary Productivity Studies in the Nechako River

2.2.1. Primary Productivity

Primary and secondary productivity in river systems is related in part to patterns of stream flow (magnitude, frequency, timing, duration). RTA operations directly influence streamflow throughout the Nechako River, and therefore operations may influence the productivity of riparian and aquatic plant communities and aquatic invertebrates in the Nechako River.

Insightful information about limitations to aquatic productivity was obtained from experimental studies in the late 1980s and early 1990s by the Nechako Fisheries Conservation Program. A fertilization study was conducted between May and July in an upper Nechako River side channel to examine the relationship between nutrient concentration and periphyton production as part of a Chinook Salmon (*Oncorhynchus tshawytscha*) conservation effort (Perrin 1993a). Bioassays showed that periphyton in the Nechako River side channel was primarily nitrogen (N) limited and when nitrate was added to the river, the periphyton community became phosphorus (P) limited (i.e., secondary P limitation; Perrin 1993a; Perrin and Richardson 1997). Similar responses were obtained for benthic invertebrate emergence (the experimental design and invertebrate results are discussed in further detail in Section 2.2.3). A second study conducted in 50 km of the mainstem Nechako River between Swanson Creek and Fort Fraser during the same season indicated there was strong co-limitation of N and P and, common with algal communities generally, ammonium was the preferred N source for periphyton in the Nechako River since biomass response was greater with ammonium addition than nitrate addition (Perrin 1993b). The periphyton community in the mainstem study location in the Nechako River prior to fertilization consisted of 90% diatoms but following nutrient addition (N concentrations > 20µg/L and P concentrations > 5 µg/L) the community shifted to an equal proportion of diatoms and chlorophytes.

Nutrient concentrations in the Nechako River are generally expected to be low, partly reflecting nutrient uptake and attenuation in upstream lentic waterbodies. For example, dissolved N and P concentrations measured in August 2020 at a mainstem site (“NR-80”) were near-to or below detection limits, whereas total N (0.152 mg/L) and total P (0.009 mg/L) concentrations were also low (Knight Piésold Consulting 2020). Nutrient concentrations were higher upstream, within or immediately downstream of the canyon (Knight Piésold Consulting 2020).

2.2.2. Aquatic Macrophytes

French and Chambers (1997) completed a modelling study of relationships between flow and the coverage and biomass of aquatic macrophytes, i.e., vascular plants such as Canadian pondweed (*Elodea canadensis*). Macrophyte coverage was assessed with an aerial survey in 1991, supported by sampling in 1992 using SCUBA. Relationships were then developed between flow and velocity (m/s) which, in turn, were used to predict macrophyte abundance (bed cover %) in the Nechako River. Mean summer channel velocity of 0.8 m/s was identified as a key threshold below which there was a negative relationship between macrophyte cover and velocity. Macrophyte abundance was modelled for four flow regime scenarios: average summer flows of 408 m^3/s (natural regime), 165 m^3/s (1952-1990 average), and hypothetical scenarios of 120 m^3/s and 60 m^3/s (French and Chambers 1997). Results suggested that flow has little influence on macrophyte abundance in fast flowing reaches of the Nechako River (~50% of the river length including the lower Nechako River and middle Nechako River between the Nautley River inflow and Vanderhoof); however, RTA operations have increased macrophyte biomass and cover on average by 66 g/m^2 or 15% respectively in a slow-flowing reach (~20% of the length of the Nechako River – middle Nechako River between Vanderhoof and the Stuart River inflow and the upper Nechako River) (French and Chambers 1997). In this reach, channel velocity was particularly sensitive to changes in flow within the range of flow studied, whereas further downstream, simulated mean summer channel velocity was generally above the threshold of 0.8 m/s. The study predicted that biomass and cover in the slow flowing reach of the Nechako River could increase by 65 g/m^2 and 9% respectively if average flows are reduced to 120 m^3/s or by 240 g/m^2 or 29% if average flows are reduced to 60 m^3/s (French and Chambers 1997).

2.2.3. Benthic Invertebrates

Benthic invertebrates in the Nechako River have been studied through the CABIN (Canadian Aquatic Bio-monitoring Network) national biomonitoring program. The program uses a standardized sampling protocol (kick net sampling) to collect benthic macroinvertebrate data that can be directly compared among sites sampled across Canada, including reference sites (Environment Canada 2012). A range of habitat data (e.g., water chemistry, substrate characteristics, physical channel measurements) are also collected to characterize sampling sites. Data can be analyzed using modelling to compare benthic invertebrate community characteristics at sampling sites with undisturbed reference sites to classify sites as “not stressed”, “slightly stressed”, “stressed”, or “severely stressed”.

Most sites were assessed only once, thus evaluation of change in benthic invertebrate communities over time was not possible. However, of the 43 test sites (i.e., non-reference sites) sampled in the Nechako watershed (not all in the Nechako River mainstem), 93% were assessed as “not stressed” or “slightly stressed” and 7% of the test sites were classified as “stressed” or “severely stressed” (Fraser Basin Council 2015). Two severely stressed sites were located in McMillan Creek (near Prince George) and Sweetnam Creek (near Francois Lake) but the cause(s) of severe stress at these tributary sites and the implications for the Nechako River mainstem are unclear (Fraser Basin Council 2015).

A nutrient addition study was conducted in the Nechako River as part of an effort to mitigate potential impacts of RTA operations on Chinook Salmon to determine if increasing primary and secondary production would increase food resources for salmonids and thus improve salmonid yields (Perrin and Richardson 1997). The objective of the study was to quantify the change in composition and abundance of benthic invertebrates in response to nutrient addition. A mesocosm-scale experiment was used to quantify change in periphytic algae and benthic invertebrate composition and abundance in response to additions of inorganic N and P (N alone, P alone, and N + P), and a control (no nutrient additions). The experiment was conducted in troughs at the margins of the upper Nechako River and mean flows were regulated at 60 m^3/s for the duration of the study. Nutrient solutions (DIN 10 µg/L, SRP 5 µg/L, a combination of N and P and a control) mixed with river water were introduced at the upstream end of each treatment trough. The downstream end of the trough was lined with gravel as a substrate for the colonization of benthic invertebrates and a sheet of open cell Styrofoam that provided a surface for sampling periphyton. Each of the three treatments and the control were replicated four times for a total of 16 experimental units, with treatments assigned randomly to troughs. Measurements were made of changes in periphyton accrual and species composition as well as macroinvertebrate density, drift rate, and adult emergence as a function of nutrient augmentation. Results showed that addition of inorganic N alone and in combination with P to the Nechako River mesocosms greatly increased the accrual of periphyton and abundance of macroinvertebrates. The addition of N produced a greater periphyton biomass response than the addition of P indicating that the periphyton community was primarily N limited. The study further concluded that, although N limitation was linked to high concentrations of soluble P and presence of N-fixing algae, where both N and P concentrations were low, N-fixers were not favoured, and diatoms were the most abundant group in all treatments in the Nechako River mesocosms. This finding agrees with Suttle and Harrison (1988) who found that many N-fixers are poor competitors for available P. The manipulation of N concentration (alone or in combination with P) had significant indirect effect on aquatic invertebrates and results suggest that invertebrate densities are limited by production of periphyton in the Nechako River (Perrin and Richardson 1997). These results are consistent with other studies that showed nutrient augmentation produced a functional response by grazing invertebrates and an increase in invertebrate abundance (Hart and Robinson 1990; McCormick and Stevenson 1991; Mundie *et al.* 1991; Peterson *et al.* 1993). An increase in the absolute number of invertebrate emigrants and benthic macroinvertebrates in the experimental troughs implies an increase in survival of benthic insect immigrants, which supports the results of previous studies that indicate that increased abundance of aquatic invertebrate is partly due to improved survival of larvae (Mundie *et al.* 1991; Richardson and Neill 1991).

Benthic invertebrates that consume algae or fine particulate detritus were the predominant invertebrate groups found in the Nechako River and the invertebrate species that responded most to increased nutrient additions were the species that compose the diets of young Chinook salmon in the Nechako River (e.g., chironomids and mayflies) (Perrin and Richardson 1997). These results suggested that fertilization of the Nechako River could potentially lead to increased availability of food resources for fish such as juvenile Chinook Salmon.

3. METHODS

A background review was completed to summarize potential interactions between RTA's operations (i.e., Nechako Reservoir outflows) and aquatic productivity in the Nechako River. Literature was considered regarding the potential effects of flow management operations on aquatic productivity generally, as well as specifically in the Nechako River (e.g., Perrin 1993a, 1993b; French and Chambers 1997). 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 studies of primary and secondary productivity conducted in the watershed (see Section 2.2) and the background information reports prepared by Helm *et al.* (1980), Rescan (1999), and 4Thought Solutions (2005), which summarized geomorphological, biological, and hydrological information regarding the Nechako River watershed, with a focus on interactions with water management.

Based on the review, the potential for each pathway to influence aquatic productivity in the Nechako River system 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 Effects

Key pathways that were identified by which RTA operations could potentially affect aquatic productivity in the Nechako River can be summarized as follows:

- Changes to nutrient input due to flow-related effects in the Cheslatta watershed;
- Changes to hydraulically suitable habitat availability due to changes in flow;
- Scour of benthic and riparian habitats during high flows;
- Loss of connectivity with lateral habitats (e.g., side channels) at lower flows; and
- Changes to productivity due to flow-related temperature effects.

4.2. Nutrient Input from the Cheslatta Watershed

The operation of Skins Lake Spillway has greatly increased flow through the Cheslatta watershed relative to pre-reservoir conditions, which has reduced residence time in the series of lakes and flushed the system with unproductive water originating from the surface of the Nechako Reservoir, reducing nutrient concentrations and primary productivity in the system (Stockner and Slaney 2006). In turn, changes to productivity in the Cheslatta watershed affect primary and secondary productivity in the Nechako River, which is nutrient limited (Perrin 1993a, 1993b; Perrin and Richardson 1997; Section 2.2.1).

The potential impacts of changes in flow on aquatic productivity in the Cheslatta watershed are considered in a separate Ecofish memo prepared for the WEI (Abell and Lewis 2022). In brief, multiple pathways of effect were identified by which operation of Skins Lake Spillway could affect productivity in the Cheslatta watershed; however, flushing, as it pertains to nutrient retention and plankton growth in lakes, is expected to be the most biologically important, as supported by Stockner and Slaney (2006). Lower flows during the growing season are expected to be beneficial for Cheslatta watershed productivity, and 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, representing greatly reduced flows relative to current conditions, e.g., current average growing season discharge at Skins Lake Spillway of ~100 m^3/s (Figure 1).

Therefore, based primarily on the work by Stockner and Slaney (2006), there is high confidence that reduced flows through the Cheslatta watershed during the growing season will markedly increase productivity in the Cheslatta watershed; however, the magnitude of associated effects downstream in the nutrient limited Nechako River is expected to be smaller, with lower certainty regarding the direction of change. Higher productivity in lakes in the Cheslatta watershed will increase the biomass of planktonic organisms that may be entrained in lake outflows and thereby provide a source of nutrients to the Nechako River downstream. However, this positive effect to downstream productivity may be at least partially offset by greater retention of nutrients in the Cheslatta watershed that originate from tributaries to Murray, Cheslatta, and Skins lakes. Furthermore, given the large decreases in average discharge recommended by Stockner and Slaney (2006) described above, there are likely trade-offs between benefits associated with this pathway and benefits associated with other pathways, notably the availability of aquatic habitat in the Nechako River (Section 4.3). Details of such trade-offs are unknown, but trade-offs could be better understood based on analysis of performance measures for contrasting flow scenarios (Section 5.3).

4.3. Hydraulically Suitable Habitat Availability

Flow regulation can alter the availability of hydraulically suitable habitat for aquatic plants and invertebrates by changing the velocity, depth, and wetted area of a river (e.g., Jowett and Duncan 1990; Morgan *et al.* 1991; Moog 1993; Cortes *et al.* 2002). Changes to wetted area can affect the availability of habitat for benthic invertebrates and periphyton, and flow changes can alter community composition due to changes to habitat suitability (Jowett and Duncan 1990; Morgan *et al.* 1991; Cortes *et al.* 2002).

RTA operations have decreased flow in the Nechako River relative to pre-reservoir conditions. French and Chambers (1997) predicted that lower flow in the Nechako River has resulted in an increase in aquatic macrophyte production in slower flowing portions of the river (Section 2.2.2). Thus, lower maximum flows in summer are generally expected to increase the productivity of aquatic plants in the Nechako River due to improved habitat suitability (lower velocity in the margins) and reduced erosion (Section 4.3). However, increased biomass of emergent and invasive macrophyte species such as reed canary grass (*Phalaris arundinacea*) along the margins has been identified by the WEI as a concern due to impaired riparian and wetland habitat for fish and wildlife (Wright and Kurtz 2022).

An instream flow study (IFS) was conducted in the mid-1980s to determine habitat capacity in the Nechako River for salmonids, but the study did not consider non-fish aquatic species such as invertebrates. A flow regime at Cheslatta Falls of >70 m^3/s in the spring and summer, 38 m^3/s in fall and winter and a peak flow of 170 m^3/s was recommended to maximize abundance of resident Rainbow Trout (*O. mykiss*) and char populations in the Nechako River (Slaney *et al.* 1984). A more recent IFS would be beneficial that considers the amount and suitability of habitat for aquatic plants and invertebrates in the Nechako River. An IFS is recommended as part of the Kenney Dam Water Release Facility baseline study (Knight Piésold Consulting 2020).

The 9 km of the Nechako River between Kenney Dam and Cheslatta Falls (the Nechako Canyon) was essentially dewatered with construction of the dam and is not considered in this memo.

4.4. Scour

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 system result in low densities of fish food organisms due to physical scouring effects (Sneep *et al.* 2020). As is typical for interior BC rivers, high flows occur during part of the growing season (Figure 1) and scour presumably occurs to some extent during freshet, although applicable flow thresholds are unknown. However, in relative terms, scour of benthic organisms is expected to limit aquatic productivity to a lesser extent than in the Cheslatta River where, unlike the mainstem Nechako River, flows have greatly increased following reservoir construction (Section 4.2).

Aside from directly causing loss of periphyton and invertebrates via physical detachment, scour may affect aquatic productivity more indirectly via effects associated with erosion and changes to sediment supply. Regulation of Nechako River flows since 1952 due to RTA operations has resulted in a decrease in the magnitude of annual peak flows, causing increased sediment deposition through reduced capacity to transport sediment, decrease in channel width, and encroachment of vegetation into the channel due to lower velocity (Rood and Neill 1987). Erosion of the Cheslatta River due to increase inflows from the Skins Lake Spillway has increased the sediment supply to the Nechako River;

however, Murray and Cheslatta lakes are efficient sediment traps so only a small amount of fine sediment generally passes into the Nechako River (Rood and Neill 1987). Nonetheless, substantial additional sediment input to the upper Nechako River has occurred episodically through erosion of the Cheslatta River near Cheslatta Falls that has added hundreds of thousands of tons of sand and gravel to the upper Nechako River (Rood and Neill 1987). For instance, in 1961 the right bank of the Cheslatta River was breached just upstream of Cheslatta Falls, eroding approximately 0.9 million m^3 of sediments, half of which were deposited downstream to form the Chelsatta Fan, while the other half was transported downstream into the Nechako River (Hay 2000). Additionally, in 1972 a large erosion event again breached the Cheslatta River right bank, and more material was deposited on the Cheslatta Fan, blocking the Nechako River. A saddle dam was constructed to divert all flows over the Cheslatta Falls to prevent high flows from re-entering the area where the scour occurred during these events (Hay 2000).

Increases in summer flows to the Nechako River as part of the Summer Temperature Management Program (STMP) leads to an initial increase in total suspended solids (TSS) that decreases over subsequent weeks even if higher flows are maintained (Fedorenko 1987). Increased turbidity in the Cheslatta watershed during high summer flows is attributed to erosion in the Cheslatta River, while increased turbidity in the Nechako River in summer is attributed to the erosion and transport of sediment within the Nechako River channel. The upper Nechako River is also affected by the delayed transport of fine silt from the Cheslatta River that occurs during lower flows in the fall (Fedorenko 1987). These flow-mediated effects on water quality presumably affect aquatic productivity, although the characteristics of such effects are uncertain.

4.5. Connectivity to Lateral Habitats

Reduced flows in the Nechako River could reduce connectivity to off-channel habitats, reducing the input of nutrients and invertebrates to the river from these sources. Tributary and side channel connectivity in the Nechako River is considered in a separate memo for the Nechako WEI (Johnson *et al.* 2022).

4.6. Water Temperature

Water temperature influences aquatic productivity by directly affecting nutrient cycling and the physiology, life history traits and metabolic rates of aquatic species (Magnuson *et al.* 1979; Petts 1986; Poole and Berman 2001; Caissie 2006; Webb *et al.* 2008). To an extent, water temperature is influenced by flow and thus change to productivity due to flow-related temperature effects has been identified as a pathway of effect. However, as described below, water temperature is also greatly influenced by a range of non-flow-related factors, limiting the potential for flow management to yield positive outcomes for aquatic productivity via this pathway. Furthermore, the effects of flow on water temperature are already managed via the STMP, which focuses on minimizing adverse physiological effects to fish due to warm temperatures.

Water temperature in the Nechako River is affected by RTA operations, in addition to a variety of other influences including resource development, riparian land use, and climate change (Carter and Kurtz 2022; Carter *et al.* 2022). A recent study of climate change impacts in the Fraser River Basin showed that the frequency of temperature extremes in the Nechako River watershed has increased in recent decades and Nechako River natural water temperatures often exceed 18°C and sometimes 20°C (Islam *et al.* 2019). Additionally, reduction in riparian shading resulting from land clearing for agricultural and residential development and forestry has been linked to increased water temperatures in the Nechako River (Beschta 1997).

Lower flows in the Nechako River are associated with higher water temperatures during the growing season (Carter and Kurtz 2022), presumably due to longer water residence time and thus greater potential for solar heating. Warmer water temperatures can increase the growing season resulting in increases in primary and secondary productivity. Thus, operations that reduce growing season flows could positively affect aquatic primary production; however, any associated benefits to fisheries may be outweighed by adverse impacts to migrating and spawning salmon due to adversely high temperatures. The relationship between flow and aquatic productivity is uncertain and moderated by multiple factors that vary among years, notably weather conditions.

5. DISCUSSION

5.1. Limiting Factors

As summarized below, five key pathways of effect have been identified (Section 4) that relate to the potential for flow-related factors to limit or enhance aquatic productivity in the Nechako River. Each pathway is summarized separately, although interactions and trade-offs between the pathways should be considered when evaluating flow scenarios.

- ***Nutrient input from the Cheslatta watershed*** – high flows from Skins Lake Spillway relative to pre-reservoir conditions reduce productivity in the Cheslatta watershed (Stockner and Slaney 2006), as reviewed in a separate memo for the WEI (Abell and Lewis 2022). The Cheslatta watershed provides the primary source of flow to the Nechako River, where primary and secondary productivity is strongly nutrient limited (Perrin 1993a, 1993b; Perrin and Richardson 1997; Section 2.2.1). Accordingly, in isolation of other pathways, reduced flows through the Cheslatta watershed during the growing season have the potential to increase nutrient input to the Nechako River, leading to an increase in productivity. However, there is uncertainty regarding this pathway and the potential for flow reductions to increase productivity in the Nechako River via this pathway is considered minor.

- ***Habitat availability*** – changes to flow affect the amount of habitat in the Nechako River with suitable depth and velocity to support biota such as aquatic plants and benthic invertebrates. Decreased flows in the Nechako River have increased habitat for riparian and aquatic macrophytes (French and Chambers 1997), indicating that generally lower flows during the growing season increase productivity of such species. However, species that benefit from such changes can be invasive (notably Reed Canarygrass; Wright and Kurtz 2022) and cause adverse ecological changes. It is uncertain how flow affects availability of suitable habitat for algae and benthic invertebrates in the Nechako River. There may be trade-offs to consider when evaluating flow scenarios with respect to potential benefits of flow reduction through the Cheslatta system (see point above) and changes to habitat availability in the Nechako River for biota such as benthic invertebrates.
- ***Scour*** – there is potential for scour during high flows to reduce primary and secondary productivity in the Nechako River. Specific flow ranges at which scour effects potentially occur are unknown, although lower peak freshet flows are generally expected to be beneficial. A mitigating factor is that, unlike the Cheslatta watershed, flows in the Nechako River are reduced relative to pre-impoundment conditions, presumably meaning that the aquatic ecosystem in the mainstem channel evolved under a regime with higher velocities during freshet, although increases to peak flows would scour benthic habitats, reducing productivity in the short term at least.
- ***Connectivity to lateral habitats*** – input of nutrients, phytoplankton, and invertebrates from lateral habitats such as side channels and wetlands will be reduced at low flows that result in loss of lateral connectivity. The relationship between flow and associated effects on aquatic productivity is expected to be non linear, i.e., lateral habitat disconnection will occur at discrete flow conditions at low to moderate flows, with the greatest influence on aquatic productivity during the growing season. The issue of tributary and side channel connectivity with the Nechako River is addressed in another memo (Johnson *et al.* 2022).
- ***Water temperature*** – aquatic productivity is sensitive to changes in water temperature which, in turn, can be affected by factors that include flow. Lower flows have potential to increase water temperatures in the growing season, potentially enhancing aquatic productivity. However, operational flow scenarios that enhance water temperatures may cause adverse physiological effects to migrating and spawning salmon, which are currently managed via the STMP. Accordingly, there is limited scope to optimize aquatic productivity by managing flow-mediated changes to water temperature, without potentially conflicting with the objectives of the STMP.

5.2. Data Gaps

Key data gaps that have been identified are as follows:

- Information about the productivity of the Nechako River is primarily limited to the fertilization studies conducted in the early 1990s (Perrin 1993a, 1993b). Current water quality data in the Nechako River indicates that, in general, water quality is good and generally meets BC water quality guidelines with low levels of nutrients, metals, and suspended solids (Philibert and Kurtz 2022) There is no recent information on algal and benthic invertebrate productivity or habitat availability.
- Quantitative relationships between flow and habitat availability (e.g., for benthic invertebrates) in the Nechako River are lacking. Relationships exist for fish although they were developed ~40 years ago (Slaney *et al.* 1984). Such relationships could be developed as part of an updated IFS that focuses of quantifying relationships between flows and habitat in the system (Girard *et al.* 2022). An IFS has been recommended as part of the Kenney Dam water release facility baseline study that includes the Nechako River (Knight Piésold Consulting 2020). There is a lack of information about the flow ranges at which physical scour of periphyton and benthic invertebrates 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 Water Use Plan monitoring in the Lower Bridge River for context (Sneep *et al.* 2020). Such flow trials could also be used to understand the linkages between flow and primary and secondary productivity in the Nechako River more generally.
- Information is lacking regarding the relationship between flow and connectivity with lateral habitats, as described further in Johnson *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.

Nutrient input from the Cheslatta watershed – scenarios that result in lower average discharge at Skins Lake Spillway during the growing season are expected to increase aquatic productivity in the Cheslatta system, potentially increasing nutrient input to the Nechako River downstream of Cheslatta Falls, potentially leading to minor increases to productivity in the Nechako River. PMs developed for evaluating aquatic productivity in the Cheslatta watershed are applicable to evaluating this issue (see Abell and Lewis 2022). Accordingly, we propose PM1 below, which is consistent with the "flushing" performance measure developed for the Cheslatta watershed, recognizing that this performance measure relates to the key pathway identified in that watershed in relation to the effects of flow on aquatic productivity:

- PM1: *refer to the "flushing" performance measure developed for the Cheslatta watershed.*

Habitat availability and suitability – changes to flow in the Nechako River will change the availability and suitability of habitat for aquatic plants and invertebrates. Quantitative relationships between flow and aquatic biota aside from fish are lacking. In lieu of such relationships, we expect it is reasonable to defer to the performance measure that is currently being finalized to evaluate the effects of flow on rearing habitat for resident fish. The rationale for this assumption is that optimum hydraulic habitat conditions for species such as Rainbow Trout broadly align with suitable habitat for aquatic biota such as mayfly and caddisfly larvae that provide an important food source in aquatic food webs (Jowett and Davey 2007). Accordingly, we propose PM2 below:

- PM2: *refer to the "resident fish rearing habitat" performance measure developed for the Nechako River.*

For context, an IFS of salmonid habitats in the Nechako River suggested a flow regime at Cheslatta Falls of >70 m^3/s for spring/summer, 38 m^3/s for fall/winter and 170 m^3/s peaking flow is optimal from the perspective of maximizing the area of suitable habitat for adult Rainbow Trout and char populations (Slaney *et al.* 1984). Optimal flow for juvenile trout was described as 40 m^3/s for the Nechako River in that study.

Scour – peak flows during the growing season in the Nechako River have potential to reduce aquatic productivity via direct physical scour effects, although flows been reduced following construction and operation of the Skins Lake Spillway and information is unavailable regarding flow thresholds at which scour is potentially a concern. PM3 below is proposed for initial consideration by the WEI:

- PM3: *refer to the "scour" performance measure developed for the Cheslatta watershed.*

PM3 is based on mean peak growing season discharge at Skins Lake Spillway (the main source of flow to the Nechako River), with the assumption that lower values will correspond to preferable conditions. PM3 is intended to provide a measure of the differences in relative risk (only) among scenarios of adverse scour effects and does not account for the expectation that the relationship between flow and physical scour is non-linear. 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 Nechako River watershed (e.g., Sneep *et al.* 2020).

Connectivity to lateral habitats – no PM is currently proposed in relation to this pathway. This issue is considered in a separate memo (Johnson *et al.* 2022), which discusses the uncertainty regarding how flow affects connectivity to lateral habitats such as side channels, including how field studies could be undertaken to reduce uncertainty.

Water temperature – no PM is currently proposed in relation to this pathway because, as described in Section 4.6, the links between flow, water temperature, and aquatic productivity are indirect. Furthermore, the effects of flow on water temperature are already managed via the STMP, which focuses on minimizing adverse physiological effects to fish due to warm temperatures. From an ecological perspective, such effects are arguably higher priority to manage than less-direct effects on aquatic productivity.

5.4. Operational Considerations

In general, reductions to flow, primarily during the growing season, are expected to improve aquatic productivity in the Cheslatta system that provides input to the Nechako River. Stockner and Slaney (2006) provided recommendations for target flows (10–20 m^3/s) in the Cheslatta system to increase fish production. Additionally, flow scenarios for the Nechako River downstream of Kenney Dam were explored in an assessment of flow regimes designed to balance various interests, e.g., hydroelectric power generation, suitable water temperature and habitat for salmon, and economic development (4Thought Solutions 2005).

5.5. Other Management Options

Insights regarding options to enhance productivity have been provided by the Nechako Fisheries Conservation Program. Placement of woody debris has been shown to provide cover for juvenile fish and improve habitat complexity in the Nechako River (Slaney *et al.* 1994), thereby potentially enhancing productivity. Additionally, fertilization studies in the Nechako River showed that the system is nutrient limited, and fertilization was therefore recommended to increase primary and benthic invertebrate production to benefit Chinook Salmon (Perrin 1993a, 1993b). Specifically, Perrin (1993b) proposed a fertilization strategy involving continuous low level nutrient addition to the Nechako River. Any renewed proposals to undertake fertilization should consider more recent research relevant to this restoration method generally (e.g., Wilson *et al.* 2021) and carefully consider the substantial logistical challenges associated with fertilizing a large river ecosystem.

6. CLOSURE

This memo has reviewed the potential for changes in flow to affect aquatic productivity in the Nechako River downstream of the Cheslatta Falls. Outcomes of the review have been used to develop recommended preliminary performance measures for the WEI to consider, and data gaps have been identified that could be addressed with further study.

Yours truly,

Ecofish Research Ltd.

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