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TECHNICAL MEMORANDUM

Date: November 5, 2021
To: Ms. Jennifer Carter, MRM, RPBio.
From: Chris Perrin, MSc. RPBio.
Re: Assessment of reservoir operational changes to invertebrate biomass in littoral and pelagic habitat of Nechako Reservoir.

INTRODUCTION

At your request, calculations were run to show change in littoral (near shore) and pelagic (open water) habitat area and potential change in areal biomass of fish food organisms occupying those habitats among normal water surface elevations in the Nechako Reservoir. The normal maximum and minimum water surface elevation is 853m and 849m respectively (a 4m drawdown in a normal year of operations)[1]. Results may contribute to technical criteria in support of water management decisions where biomass of fish food organisms is one of many valued ecosystem components. Variation in zooplankton biomass associated with hydraulic residence time (HRT) that can modify biomass and availability of food for fish due to fallout of insects from the riparian zone were two modifiers of food availability that were out of scope for this memo. This memo focusses on areas of littoral and pelagic habitat and biomass of fish food organisms that may be supported in those areas at different water surface elevations during routine operations of the reservoir.

METHODS

In a reservoir, the spatial extent of aquatic macrophytes, that commonly defines the area and depth of a littoral zone (Wetzel 2001)[2], is small or non-existent. This absence is caused by desiccation during drawdown, which prevents most aquatic macrophytes from becoming established in a permanent subaqueous habitat having a continuous and adequate amount of irradiance. In the absence of macrophytes, a reservoir littoral zone can refer to shallow water habitat influenced by non-macrophyte primary production determined at least in part by the vertical extent of irradiance associated with change in water surface elevation. Pelagic habitat is

[1] Rio Tinto Ltd. Water management hydrograph and objectives. October 2019. Powerpoint file supplied by Ecofish Research Ltd. June 15, 2021.

[2] Wetzel, R.G. 2001. Limnology: Lake and river ecosystems. Academic Press. New York.

the zone of open water where production of non-piscivorous fish food is dominated by zooplankton. Biological production in pelagic habitat is vertically bounded by depth of the euphotic zone and by light, temperature, and nutrient supply in that open water (Wetzel 2001). These definitions were applied to calculations of areas of littoral and pelagic habitat in Nechako Reservoir.

Light can penetrate to the substratum in a reservoir littoral zone. This attribute means that the complete littoral profile is contained within a euphotic zone where the ratio of photosynthesis to respiration (P/R) is greater than 1 and that the bottom of the littoral zone is close to the compensation depth where P=R. Because the water surface elevation moves up and down in a reservoir, the littoral zone is spatially dynamic, moving up and down over substrata of the drawdown zone over the course of a year. For this reason, potential effects of change in reservoir operation on littoral processes must be considered in terms of change relative to the entire area of benthic production where P/R >1.

Net positive photosynthetic production (P>R) occurs where photosynthetically active radiation (PAR: 400 – 700 nm) in a water column is >1% of that at the water surface (Banse 2004[3], Wetzel 2001). This depth is commonly twice the Secchi depth in water reservoirs. During water quality sampling of Nechako Reservoir in August and September 1996, Perrin et al. (1997)[4] reported a mean Secchi depth of 6.2m among 22 readings at 11 stations in all basins. Doubling this value shows that the estimated depth of the euphotic zone (also the compensation depth where P=R based on available PAR) was 12.4m. We are not aware of more recent Secchi depth or direct irradiance measurements that can be used to update this value.

A recent digital elevation model (DEM) of partial storage areas in the Nechako Reservoir (Ecofish Research Ltd. 2021)[5] was used to calculate littoral and pelagic areas among basins based on depth of the euphotic zone. For simplicity, a mean euphotic zone depth of 13m was assigned by rounding high the 1996 observations. The area of the littoral zone in a given basin was defined as

$$A_{lj} = A_{tj} - A_e \qquad \text{Equation 1}$$

Where:
A_l is planar area (km^2) of the littoral zone of reservoir basin j, and
A_t is total wetted planar surface area at a given water surface elevation (km^2) of reservoir basin j, and

[3] Bense, K. 2004. Should we continue to use the 1% light depth convention for estimating the compensation depth of phytoplankton for another 70 years? Limnology and Oceanography Bulletin. 13. 49-52.
[4] Perrin, C.J., C.A. McDevitt, E.A. McIsaac, and R. Kashino. 1997. Water quality impact assessment for Nechako Reservoir submerged timber salvage operations: baseline water quality. Report prepared by BC Research Inc for BC Ministry of Environment Lands and Parks. Smithers, B.C. 71pp.
[5] Ecofish Research Ltd. 2021. DEM output from analysis of data originally collected by Triton Environmental Consultants. Candace Ashcroft and Jennifer Carter, Personal communications.

A_e is wetted planar area at the depth of the euphotic zone (set at 13m) that was common to all basins.

It follows that pelagic area for a given basin (A_{pj}) is

$$A_{pj} = A_{tj} - A_{lj} \quad \text{Equation 2}$$

Total littoral area for the whole reservoir (A_{la}) is

$$A_{la} = \sum_{j=1}^{n} A_l \quad \text{Equation 3}$$

Total pelagic area for the whole reservoir (A_{pa}) is

$$A_{pa} = \sum_{j=1}^{n} A_p \quad \text{Equation 4}$$

Where data allowed, a model showing area as a function of water surface elevation was fit to the output from Equation 3 and another was fit to output from Equation 4 using standard regression techniques.

Biological communities in a littoral zone are mostly associated with benthic habitat. Planktonic communities are present but given the relatively shallow water, benthic communities are expected to drive most production. We are most interested in benthic invertebrates (also called benthos) that are potential food for fish that forage in shallow water along shorelines.

Benthos density is not particularly valuable when interest is in biomass of food for fish as is the case in the Nechako project. Fish population modeling commonly uses biomass from which production/biomass ratios can be calculated to explore interactions between trophic levels exposed to treatments or some sort of change, whether it be driven by anthropogenic or other processes[6]. For Nechako, some estimate of benthos biomass was needed to facilitate comparison with zooplankton and to examine variation over different water surface elevations. To reach that goal I reviewed benthos density and biomass from other reservoirs in British Columbia for which I have data. These data were used in combination with earlier collections from Nechako Reservoir to estimate dry weight biomass of invertebrates in the Nechako littoral zone computed as

$$B_l = A_{la} * D_l * M_b \quad \text{Equation 5}$$

Where:

B_l is dry weight benthos biomass over the whole littoral zone of Nechako reservoir

[6] Christensen, V. and C.J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modeling. 172: 109-139.

D_l is benthic invertebrate density (number/m^2) over the whole littoral zone of all basins of Nechako Reservoir, and

M_b is the average dry weight biomass of an individual in the benthic assemblage.

The same approach was used to estimate biomass of zooplankton in pelagic habitat. I reviewed zooplankton density and biomass data from other reservoirs in British Columbia for which I have data. These data were used in combination with earlier measurements of zooplankton density in Nechako Reservoir to estimate dry weight biomass of in the pelagic zone computed as:

$$B_p = A_{pa} * D_p * M_b \qquad \text{Equation 6}$$

Where:

B_p is dry weight zooplankton biomass over the whole pelagic zone of Nechako reservoir

D_p is zooplankton density (number/m^2) among all basins of Nechako Reservoir, and

M_b is the average dry weight biomass of a zooplankton individual in a community of copepods and cladocerans.

Areal zooplankton densities were calculated from original volumetric densities by dividing number/m^2 by haul depth. This change of units was needed to facilitate comparison to littoral benthos biomass reported in areal units.

RESULTS

Application of Equations 1 and 2 to DEM output in 1m depth intervals for each basin showed increasing pelagic area and little change in littoral area with increasing water surface elevation (Figure 1). In all basins, pelagic areas were greater than littoral areas at all modeled water surface elevations.

Application of Equations 3 and 4 showed the combination of pelagic and littoral areas over the whole reservoir, not including Tetachuck Lake and Tahtsa Lake that did not have sufficient bathymetry in the DEM to distinguish littoral and pelagic areas. Results showed a flat line of no change in littoral area with change in water surface elevation and a linear positive change in pelagic area (Figure 2).

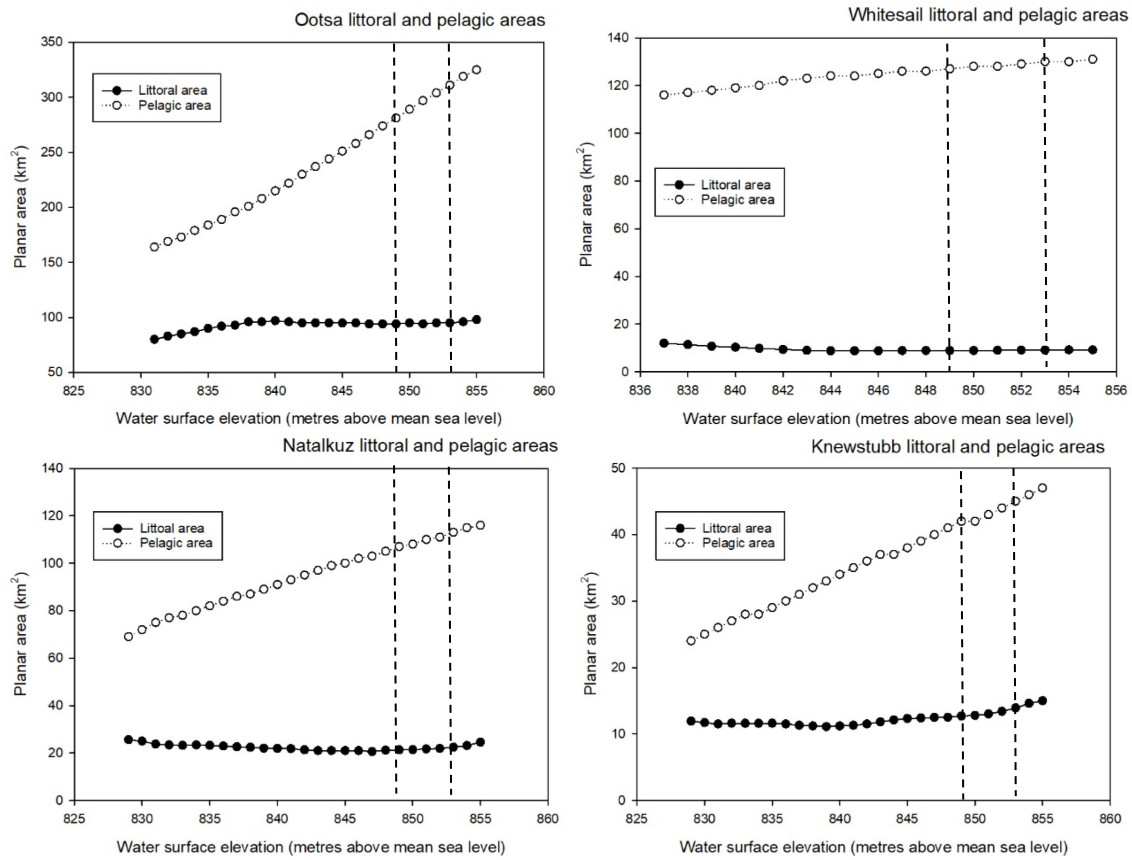

Figure 1. Change in pelagic and littoral areas over a range of water surface elevations in four basins of Nechako Reservoir (Ootsa Lake, Whitesail Lake, Natalkuz Lake, Knewstubb Lake). Values were calculated from Equations 1 and 2 using data from the Nechako DEM. Vertical dotted lines show maximum and minimum normal water surface elevations occurring in a year.

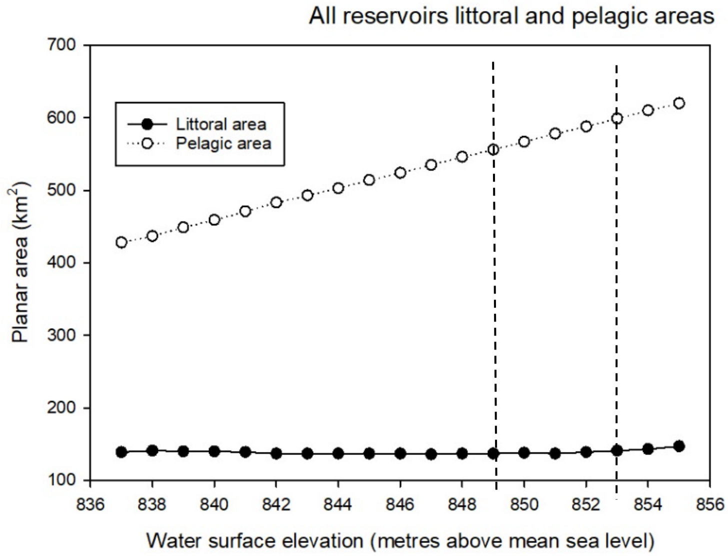

Figure 2. Change in pelagic and littoral areas over a range of water surface elevations in all basins not including Tahtsa Lake and Tetachuck Lake for which there was not enough bathymetric data in the DEM to be able to distinguish littoral and pelagic areas. Values were calculated from Equations 3 and 4 using data from the Nechako DEM. Vertical dotted lines show maximum and minimum normal water surface elevations occurring in a year.

Fitting a linear model to the pelagic data resulted in Equation 7:

$$A_{pa} = -8.5 + 10.7(W_e) \qquad \text{Equation 7}$$

Where:

W_e was water surface elevation in metres above mean sea level and

A_{pa} (pelagic area of the whole reservoir) was in units of km^2.

Statistics for Equation 6 were $p<0.001$, $R^2=1$ (e.g. a perfect fit, which is rare). Littoral area for any water surface elevation between modeled maximum (855 m) and minimum (837 m) values can be defined as the arithmetic mean over that range, which is 139 km^2.

Sampling in 1997 showed that littoral benthos of Nechako Reservoir was mainly comprised of chironomids (Orthocladiinae, Tanytarsini, Chironomini, Tanypodinae, and Diamesinea), fewer numbers of ostracods, oligochaetes and nematode worms, and trace numbers of mayflies (Ephemeroptera), caddisflies (Tricoptera), gastropods, bivalves (Pelecypoda) and water mites (Hydracarina) (Perrin and McDevitt 1997[7]). Areal densities of all invertebrates that were potentially food for fish (excluding bivalves) between sites and times of sampling were 875 – 5,528 individuals/m^2 with an overall average of 3,138 individuals/m^2. Biomass that is commonly determined from mass - length relationships (e.g. Smock 1980[8],

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[7] Perrin, C.J. and C.A. McDevitt. 1997. Water quality impact assessment of Nechako Reservoir submerged timber salvage operations. Report prepared by B.C. Research for BC Ministry of Environment and Parks. Smithers, B.C.

[8] Smock, L.A. 1980. Relationships between body size and biomass of aquatic insects. Freshwater Biology:10. 375-383.

Benke et al. 1999[9], Johnston and Cunjak 1999[10]) was not measured so we are not able to calculate standing stock or rates of production (e.g. Whiting et al. 2011[11]). I am not aware of more recent Nechako Reservoir data from which biomass and production metrics could be determined.

Using the review of benthos density and biomass from other reservoirs in British Columbia, a similarity arose between the composition of benthos from Campbell Lakes on Vancouver Island (Perrin et al. 2017)[12] with the Nechako benthos. Both reservoirs are oligotrophic and of advanced age. A rough calculation using the Campbell data showed that the mean dry weight biomass of an invertebrate in a mixture of mostly chironomids as in Nechako Reservoir was 0.07 mg dry weight. A similar value may be expected in Nechako Reservoir given the same trophic state and similar composition of benthos taxa. While rough, this value does provide a ball park estimate to apply to the Nechako benthos densities. Application of Equation 5 showed the areal biomass of benthos in the littoral zone of Nechako Reservoir was approximately 30.5 metric tonnes.

Given that A_{la} is fixed at 139 km^2 over the modeled range of water surface elevations, and that D_l and M_b are fixed values in Equation 5, the estimate of 30.5 metric tonnes of dry weight benthos biomass in the whole littoral zone is the amount of potentially available littoral food for fish distributed over the whole reservoir at any water surface elevation.

Variation in this estimate may occur in relation to time delays for community development among substrata at the deeper end of the littoral zone (furthest away from shore) as water surface elevation declines and among newly wetted substrata near the surface of the littoral zone (closest to shore) as water surface elevation rises. It is unknown what are those time delays in the Nechako Reservoir, but they may be on the order of a month or more. If we assume those rates are similar in surface and bottom strata, gain of animals at the surface and loss at the bottom when water is rising will cancel each other out, resulting in no net change. The same may occur as water surface elevation declines. Whether or not this balancing act occurs cannot be resolved with available data.

Different areas of the littoral habitat may not support the same rates of biological production. In an assessment of the role of littoral habitat in contributing to fish production in the Campbell Lakes on Vancouver Island the concept of “effective littoral zone” (ELZ) was applied (Perrin et al. 2017). An ELZ was the sum of products of littoral area and biomass of accrued periphyton (no macrophytes were included because of their paucity in the Campbell Lake system) that grows as a function of photosynthetically active radiation (PAR), the concentration

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[9] Benke, A.C., A.D. Huryn, L.A. Smock, and J.B. Wallace. 1999. Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. Journal of the North American Benthological Society. 18. 308-343.

[10] Johnston, T.A. and R.A. Cunjak. 1999. Dry mass-length relationships for benthic insects: a review with new data for Catamaran Brook, New Brunswick, Canada. Freshwater Biology. 41. 653-674.

[11] Whiting, D.P, M.R. Whiles, and M.L. Stone. 2011. Patterns of macroinvertebrate production, trophic structure, and energy flow along a tallgrass prairie stream continuum. Limnology and Oceanography. 56: 887-898.

[12] Perrin, C.J., J. Harding, M. Hocking, N. Swain, J. Abell, A. Marriner and T. Hatfield. 2017. JHTMON4: Upper and Lower Campbell Reservoirs Littoral Productivity Assessment Year 2 Annual Monitoring Report. Report prepared for BC Hydro by Laich-Kwil-Tach Environmental Assessment Ltd. Partnership, Limnotek Research and Development Inc. and Ecofish Research Ltd., October 23, 2017.

of growth – limiting nutrients, and water temperature, among many strata within a littoral zone. Given that PAR will vary with water depth, biological production is expected to be greater near the top of a littoral zone compared to closer to the bottom regardless of water temperature and nutrient concentrations that in turn can vary and affect biological production over large spatial scales of a littoral zone. Application of the ELZ concept to Nechako Reservoir shows there is little question that effective biologial production will vary among and within littoral strata of the different basins. This variability means the fixed littoral area of 139 km^2 is expected to host a wide range of habitats, some more effective than others in producing biota and food for fish. Without data describing the key drivers of production over those littoral strata, as is the case for Nechako Reservoir, the actual amount of biomass produced in littoral habitat may be different than the modeled estimate.

Sampling in 1997 showed that zooplankton of Nechako Reservoir was mostly comprised of calanoid and cyclopoid copepods with fewer numbers of Cladocera (Perrin et al. 1997). *Cyclops bicuspidatus thomasi* and *Cyclops scutifer* were the common Cyclopoids, the former being a raptorial omnivore feeding on microphytoplankton (>20 μm), other zooplankton, and copepod nauplii. *Cyclops scutifer* is a raptorial predator mainly feeding on other zooplankton. *Diaptomus ashlandi* was the only abundant Calanoid copepod and it is predominantly a herbivore ingesting a wide range of particle sizes from about 5 μm up to 40 μm. All of the crustacean zooplankton that were found are relatively large-bodied species that are common to oligotrophic B.C. lakes and reservoirs that lack large numbers of planktivorous fish. Cladocerans were represented by roughly equal numbers of *Daphnia galeata mendotae*, *Eubosmina longispina*, and *Holopedium gibberum*. *Daphnia* is a large and general herbivore that can filter a wide range of phytoplankton particle sizes (0.2-40 μm maximum length). *Eubosmina* and *Holopedium* are smaller, more specific grazers with an affinity for selective grazing on nanoplankton (2-20 μm), particularly the flagellates.

Biomass data were again not available, this time for Nechako zooplankton, so I reviewed zooplankton benthos density and biomass from other reservoirs in British Columbia for which I have data. Similarities were found between zooplankton from Coquitlam Reservoir in 2020 and Nechako zooplankton from 1996. Again, a rough calculation to derive biomass was run, this time using the Coquitlam data as a surrogate for Nechako. It showed that the mean dry weight biomass of a zooplankton individual within a mixture of copepods and cladocerans was 8.32 µg dry weight. The mean of the products of areal density (number/m^2) and this estimated dry weight biomass among all samples collected in 1996 from the Nechako Reservoir was 1.95 g of dry weight zooplankton/m^2.

Application of Equation 6 showed the change in zooplankton biomass with water surface elevation results in estimated zooplankton standing crop varying from 834 metric tonnes to 1,189 metric tonnes over the range of modelled elevations (Figure 3). The response is linear because it is driven by the linear change in pelagic area over the modeled water surface elevations (Figure 2, Equation 7) and estimated constant areal biomass in pelagic habitat over those elevations.

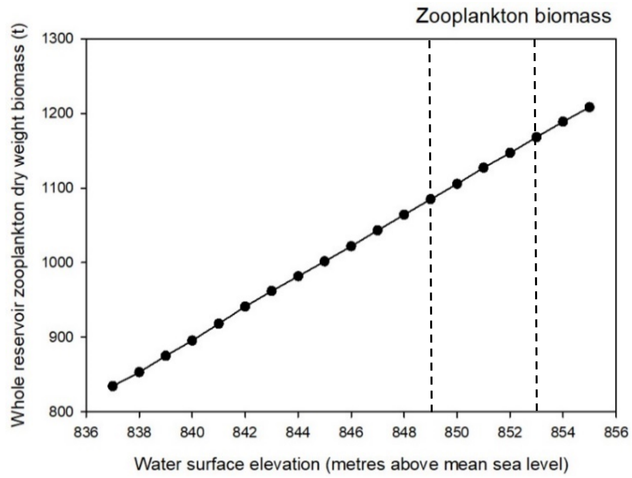

Figure 3. Estimated whole reservoir zooplankton dry weight biomass in pelagic habitat among modeled water surface elevations. Vertical dotted lines show maximum and minimum normal water surface elevations occurring in a year.

The estimates of pelagic zooplankton biomass are 27 to 40 times the amount of littoral biomass shown above to be approximately 30.5 metric tonnes and constant over the modeled range of water surface elevations. Change in water surface elevation has a large positive and linear effect on availability of food for planktivorous fishes but essentially no effect on availability of food derived from benthic production for fish in littoral zones. This difference is due to a strong effect of water surface elevation on pelagic area and no effect of water surface elevation on littoral area. Any variation in actual rates of biological production within the littoral strata or among pelagic habtiats of the different basins, which is presently unknown, would add to these habitat – specific differences in standing biomass.

DISCUSSION

Most water management objectives and scenarios that have been discussed by a group known as the Nechako Technical Working Group (TWG) have been associated with downstream flow (Main Table Meeting #18)[13]. Discussions include maximizing trout and salmon production, flood control, needs for terrestrial wildlife and bird populations, among others. An objective of the TWG for reservoir fish populations is to maximize fish production while minimizing fish mortality due to entrainment. For this memo, we are interested in what reservoir management scenario might optimize availability of food for fish, thus supporting the objective to maximize fish production in the reservoir.

The water surface elevation in Nechako Reservoir and thus area of pelagic habitat (Figure 2) changes according to a seasonal cycle of declining elevation in winter, reaching a minimum operating level in the spring, rising rapidly due to inflows from snowmelt in late spring

[13] Main Table Meeting #18. 2021. Draft objectives recommended by the Nechako Technical Working Group. Powerpoint presentation dated April 7, 2021 provided by Ecofish Research Ltd. June 8. 2021. 27pp.

and early summer, followed by declining but highly variable elevations in the fall (Figure 4). While variable across years, this seasonal cycle is fixed according to snowmelt, power demand at Kemano, and required releases. Small shifts can occur, but the seasonal pattern is fixed.

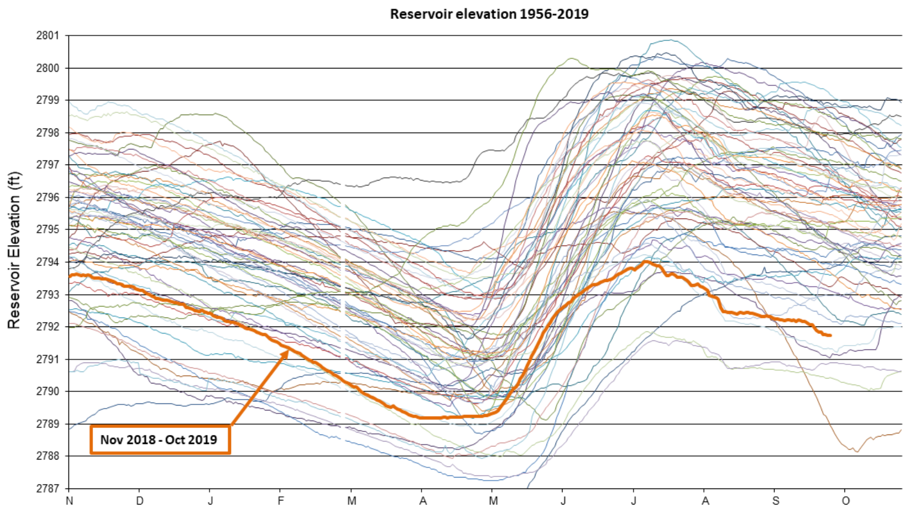

Figure 4. Variation in mean daily Nechako Reservoir water surface elevations among years, 1956 – 2019. Reprinted from Rio Tinto Ltd. Water management hydrograph and objectives. October 2019. Powerpoint file supplied by Ecofish Research Ltd. June 15, 2021.

Without substantial flexibility in modifying the seasonal pattern in water surface elevation, there are limited options for changing amounts of habitat and availability of food for fish over a year or among years. The following observations from the present modeling can be considered when making decisions:

1. Biomass of benthic invertebrates that are produced in the littoral zone is not expected to change among different scenarios of water level management. This finding is due to little change in littoral area among normal operating elevations. An assumption in this observation is that the area of effective littoral habitat that is added to the bottom of the littoral zone and lost from the top as water surface elevation declines is the same. The inverse is assumed as water surface elevation rises. We also assume that rates of production within littoral habitat areas that are coincidentally gained and lost with change in water surface elevation are the same. New data are required to test these assumptions.
2. New biological production that is added at the bottom of the littoral zone as water surface elevation declines takes time to actually be realized as contributing to the littoral food web. Since the actual amount of time in Nechako Reservoir is not known, a favoured water management scenario is to make changes to water surface elevations

slowly in small daily increments and to minimize fluctuations in water surface elevation. These actions would favour long term development of biological production in littoral habitat with limited disturbance.

3. Availability of food for planktivorous fishes increases positively with water surface elevation. This finding means that options that minimize drawdown in spring will favour the pelagic food supply at that time and in the following growing season. The water level/food relationship is driven by amount of pelagic habitat that increases with rising water surface elevation and declines with lowering water surface elevation.

Further assumptions supporting these findings are as follows:

1. The DEM and bathymetry supporting the DEM is accurate. The error free model showing change in pelagic area with change in water surface elevation is suspicious. I have never seen a perfect fit such as this. The DEM may have to be revisted to confirm it is correct.
2. Amount and rate of gain of wetted littoral habitat at the top of the littoral zone is the same as the amount and rate of loss of littoral habitat at the bottom of the littoral zone when water surface elevation is rising. Equal amount and rate of gain at the bottom of the littoral zone and loss at the top is also assumed when water surface elevation is declining. Furthermore, water surface elevation changes sufficiently slowly to allow benthic community development among newly wetted substrata as water surface elevation is rising before it is again lowered. Another assumption is that elevation changes sufficiently slowly to allow benthic community development among substrata newly exposed to PAR as water surface elevation is declining before it is again raised. Data are presently not available to determine what those rates should be within the constraints of fixed seasonal change in water surface elevation.
3. Profundal production of benthos is negligible compared to production of benthos and fish food organisms in the shallow littoral habitat.
4. There are no benthos and zooplankton density data from Nechako Reservoir other than the 1996 and 1997 data reported in this memo.
5. Extrapolation of an invertebrate density/dry weight biomass relationship from observations in Campbell Lakes to calculate areal biomass from Nechako Reservoir count data is acceptable for exploratory purposes of this memo. We don’t know if this assumption is valid until measurements are completed over a growing season in Nechako Reservoir, including measurement of benthos biomass from length mass regressions.
6. Extrapolation of a zooplankton density/dry weight biomass relationship from observations in Coquitlam Reservoir to calculate areal zooplankton biomass from Nechako Reservoir count data is acceptable for exploratory purposes of this memo. We don’t know if this assumption is valid until measurements are completed over a growing season in Nechako Reservoir, including measurement of zooplankton biomass from length mass regressions.

7. Benthos and zooplankton counts were average values from sampling only during August and September in Nechako Reservoir (zooplankton in 1996, benthos in 1997). It is assumed that animal densities during this late growing season period were representative of densities during a complete growing season. This assumption is probably false. Densities of both benthos and zooplankton can change markedly during a growing season, which means the estimates of mean density likely have errors. Amount of error is not known until measurements over a complete growing season are conducted.

8. Trophic state does not change between different scenarios of managing water surface elevation. This assumption is probably true. There is no known event or source of nutrients that could alter trophic state driven by nutrient concentrations. Anomalous addition of nutrients would increase rates of biological production regardless of water surface elevation and potentially shift trophic state.

There are uncertainties with the present analysis, largely due to lack of recent and relevant data from Nechako Reservoir. Questions that might be considered to direct data collection and further explore the influence of operating alternatives on valued fish populations more quantitatively are as follows:

- What fish species of direct and indirect interest rely on use of littoral relative to pelagic habitat and food in those habitats? This question essentially asks what are the valued fish species to be protected or sustained in Nechako Reservoir as defined by stakeholders?
- Do those valued fish eat food organisms that are produced in littoral versus pelagic habitat?
- Do fish obtain a portion of their food intake from the surrounding forest? If so, how reliant are fish in Nechako Reservoir on food produced in littoral and pelagic habitat?
- What are annual rates of production of fish food where fish food is zooplankton in pelagic habitat and benthic invertebrates in littoral habitat?
- Is there sufficient food in Nechako Reservoir to support the energetic requirements of valued fish populations in the reservoir?
- What is the trophic state of Nechako Reservoir wherein trophic state is the main driver of biological production in the reservoir?

If these questions are answered, a clearer and more quantitative assessment can be provided to explore the effects of operating alternatives on littoral and pelagic habitat and its direct and indirect use by fish species of interest. The present work is a reasonable first guess with which to stimulate discussion.

Yours truly;
Limnotek Research and Development Inc.

C.J. Perrin, MSc, RPBio.
Principal