A report on the

Hydrothermal Characteristics of the Nechako Reservoir

prepared for

The Nechako Enhancement Society

by

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Executive Summary

The proposed Cold Water Release Facility (CWRF) at Kenney Dam will undoubtedly be a powerful tool to control water temperatures in the Nechako River. This report provides an assessment of the potential need for further data collection, analysis and hydrothermal modelling to determine just how powerful a tool it will be. The focus is on the ability of the CWRF to deliver up to 170 m^3/s of 10 C water between July 20 and August 20.

Even though considerable effort has been expended in modelling the hydrothermal behaviour of the Nechako Reservoir there are still at least five significant sources of uncertainty:

1. Internal waves in the reservoir will transport warm water deeper than it otherwise would be, resulting in the possibility of warm water being drawn into the cold-water intake. The maximum possible amplitude of internal waves is unknown.
2. The cold-water intake will extract water from a withdrawal layer that extends above and below the level of the intake. However, since the intake is on the bottom of the reservoir more water will be drawn from above than below. Furthermore, the temperature gradient above the intake is much greater than below so the average withdrawal temperature is increased. The dynamics of the selective withdrawal needs further investigation.
3. The Nechako Reservoir is very large and topographically complex and as such is not easy to model. The accuracy of the model was questioned during review of the Kemano Completion Project (KCP).
4. An important aspect of any modelling effort is the quality of the input data. In this case data from the Prince George Airport have been used. These data are unlikely to be representative of conditions over the Nechako Reservoir. Also, the potential impacts of climate change have not been considered.
5. Finally, the exact details of when and how much water needs to be withdrawn through the cold-water intake to satisfy the regulatory criterion have not been specified.

The differences between the Kenney Dam Release Facility (KDRF) proposed under the Kemano Completion Project (KCP) and the newly proposed CWRF are minor and, in and of themselves, do not warrant further modelling effort. Furthermore, we do not believe that additional modelling will be of value at this time. A more thorough analysis of existing data, and the collection of new data is warranted. Ongoing data collection should be initiated to provide needed information that numerical modelling will not be able to provide with certainty.

Background

The Nechako Watershed Council (NWC) has proposed a work plan for the Cold Water Release Facility (CWRF) at Kenney Dam (NWC, 2002). Appendix 5 of the work plan specifies that additional data collection and further modelling is needed to assess the ability of the Nechako Reservoir to provide water to meet the appropriate cooling water criterion through a CWRF at the Kenney Dam, which is located at the end of Knewstubb Arm.

Triton Environmental Consultants performed extensive hydrothermal modelling of the Nechako Reservoir using the two-dimensional, Generalized, Longitudinal-Vertical Hydrodynamics and Transport (GLVHT) numerical model, originally developed by Dr. J. E. Edinger (Triton, 1991, 1992). During the Kemano Completion Project (KCP) Review questions were raised as to whether the modelling adequately addressed the issue of internal waves. Further internal wave data were collected in 1994 and presented in Triton (1995).

The purpose of this report is to investigate whether the hydrothermal modelling undertaken in 1991 and 1992 and the additional data collected in 1994 is sufficient to determine if the reservoir could provide water through the newly designed CWRF to meet the regulatory criterion, or whether additional analysis, data collection and further modelling is warranted.

Regulatory Criterion

The principal performance criterion for the KCP version of the KDRF was that cooling water releases are to control temperatures in the Nechako River above the Stuart River confluence between July 20 and August 20 to limit the occurrence of mean daily temperatures above 21.7 C to less than once in 200-years on average and to reduce the occurrence of mean daily water temperature above 20 C to no more than 3.88 days per year on average. This criterion is very specific - but what does it mean for a release facility at the Kenney Dam? The KDRF Working Group (1996) notes that this criterion dictated a facility that could release specific quantities of water at a controlled 10 C with a maximum capacity of 170 m^3/s. A question that arises is exactly what are the specific quantities of water that need to be released at the dam to satisfy the basic cooling water release criterion. The importance of this question will be illustrated below.

Initially, a number of cases were modelled with a maximum release of 200 m^3/s (Triton, 1991). Subsequently, cases were run with a maximum cold-water release of 170 m^3/s (Triton, 1992). These latter cases will be examined in the present report. For the purposes of this report the design of the proposed CWRF can be regarded as the same as earlier KDRF.

Input data

The GLVHT model was run with extreme input conditions to test the feasibility of the release facility to meet regulatory criterion. Hourly data recorded at Prince George Airport during the modelling period (1 March 1979 to 31 December 1981) served as meteorological input to the model. Inflows were recorded reservoir inflows for the modelling period reduced in volume equivalent according to the three driest years on record (1943 to 1945). The meteorological conditions and reservoir inflows were calculated to have return periods of 37 years and 12 years, respectively. It is not clear how representative the Prince George Airport data is of conditions over the Nechako Reservoir. Some data has been collected on the Nechako Reservoir, but more needs to be taken, so that comparisons can be made. The potential impacts of climate change should also be considered.

Results of hydrothermal modelling

Triton (1992) investigated three release scenarios:

Case 21: Base flows as outline in Schedule D of the Settlement Agreement, plus Cold Water Release (CWR) flows as defined in Envirocon (1984)

Case 22a: Cold water releases increased to 170 m^3/s for July 15 to July 28, 1979 and August 2 to August 15, 1981

Case 23a: Cold water releases increased to 170 m^3/s for July 20 to August 20, 1979 and 1981.

In each of the above cases it was assumed that the water drawn into the cold-water intake would have the temperature predicted at a depth of 795 m in Knewstubb Arm. During the cooling-water period this water would be mixed with the appropriate quantity of surface water to give a mixed temperature of 10 C, as illustrated in Figure 1. In general, the intake temperature rose through the spring and summer reaching a peak in November. The maximum temperature in the cooling period was at the end of the cooling period (August 20).

In the most severe case (23a) the 10 C criteria was exceeded when the intake temperature reached a maximum of 10.2 C on August 20, 1979 the last day of the 32 day cooling period, see Figure 1b. However, it would be inappropriate to regard this as “failure” of the facility. Triton (1992) put this result in perspective by noting that the only time KDRF would be required to provide 170 m^3/s at 10 C for 32 days would be when 200 year (or greater) return period conditions in the Nechako River basin persisted for 32 consecutive days.

Russell (1992) performed a return period analysis of the volume of cold water required. He estimated the 10,000-year return period volume at 5,440 m^3/s-days, which is equivalent to a release of 170 m^3/s for 32 days. So Case 23a corresponds to a release condition with a return period far in excess of 200 years and need not be considered further. The 200 year return period volume was estimated to be 2,900 m^3/s-days, equivalent to a release of 170 m^3/s for 17.1 days, which suggests that Case 22a is the most appropriate of the three cases to consider.

The results from Case 22a are presented in Figure 1a. The maximum predicted deep-water intake temperature is 9.0 C. This predicted temperature could be in error by 1 - 2 C, and the 10 C criterion would not necessarily be satisfied. Similarly, the maximum predicted deep-water intake temperature for case 21 is 8.7 C (Triton 1992), which is also within the margin of error of the model predictions. However, for the moment we will assume that the predictions of the model are accurate.

The modelled position of the 10 C isotherm in Case 22a is shown on Figure 2. The lowest predicted level during the summer cooling period is 804 m on August 20, 1979. Given that the proposed intake extends from 790 m to 796.6 m it might seem that the facility could easily deliver sufficient quantities of 10 C water. There are however two other factors to consider: selective withdrawal and internal waves.

Selective Withdrawal:

When water is withdrawn from a density stratified reservoir it is constrained to come from a withdrawal layer that generally extends above and below the withdrawal pipe. In the case of the CWRF the intake is very near the bottom of the reservoir so it is likely that more water will be drawn from above than below. Furthermore, the temperature gradient above the intake is much greater than below which will tend to increase the average temperature of the withdrawn water.

It is useful to consider a critical level above which the 10 C isotherm needs to sit, in the absence of withdrawal, to ensure that if a 170 m^3/s withdrawal is initiated the average withdrawal temperature will be less than 10 C. The hydrothermal modelling has assumed that this level is 795 m, however this must be regarded as an approximation. Laboratory experiments were performed by the LaSalle Hydraulics Laboratory, and numerical modelling conducted using the SELECT one-dimensional numerical model developed by the Waterways Experiment Station, US Army Corps of Engineers. The results of SELECT indicate that the critical level is lower than 798.3 m (Klohn Leonoff, 1992). In general the laboratory experiments suggest a critical level 1-2 m higher than SELECT.

It should be noted that SELECT assumes a steady withdrawal layer thickness. This will not be the case when the withdrawal rate is unsteady (Imberger et al, 1976). Whenever a withdrawal is initiated or modified, a series of shear waves propagate into the reservoir. It is the combination of these waves that generates the withdrawal layer. After an increase in withdrawal rate, the withdrawal layer thickness will be larger than the predicted steady thickness for a period of days in the case of the Nechako Reservoir.

For the purposes of this report, the critical level is nominally set at 798 m, but this should be regarded as an approximate value. A more thorough study of the selective withdrawal phenomena should be conducted.

Internal Waves:

The British Columbia Utilities Commission (1994) noted that:

> "The NFCP also raised concerns that Alcan had not considered the possibility that winds blowing over the reservoir surface might cause internal waves (seiches) that could disrupt the supply of cold water to the lower inlet (E. 188). Alcan's initial response (E. 187, 188) to these concerns noted that internal waves were not detected in either the observed data or GLVHT modelling runs …".

Internal waves are a ubiquitous feature of lakes; particularly when the wind blows. In fact internal waves would continue to propagate in a reservoir the size of the Nechako Reservoir for weeks after the wind that causes them stops. Needless to say internal waves were subsequently observed in the Reservoir. Triton and Edinger (1992) wrote "The 1992 observations show that depressions of the 10 C isotherm by 5-6 m from its equilibrium position are possible for winds of 20 km/h for durations of 4 days." Based on data collected in 1994, Triton (1995) state "thermocline response observed during this study corresponded with results obtained in 1992 under similar conditions. During both studies a maximum fluctuation of up to 9 m was observed for the 10 C isotherm, depressing it to a depth of 29 m."

The question that still remains is how big can the internal waves be? This question is far from easy to answer with a numerical model. What is needed is more field data, and even prior to that, a more thorough analysis of the existing field data. For example, assigning a constant 'equilibrium level' throughout the summer is not appropriate given that for almost all of the record in Knewstubb Lake (Triton, 1995, Fig. 5a) the 10 C isotherm is below the assigned 'equilibrium level' of 20 m. The 'equilibrium level' varies throughout the summer. A statistical analysis of internal wave height variation needs to be performed in a manner similar to that used in the analysis of surface waves with allowance made for the slow variation in 'equilibrium level'.

The importance of answering this question is illustrated in Figure 2. A relatively small depression of the modelled 10 C isotherm (~6 m) would result in greater than 10 C water being withdrawn through the intake. Given uncertainties associated with the modelled results and the position of the critical level, internal waves are a cause for concern.

Relevant questions

The following questions need to be answered regarding the hydrothermal characteristics of the Nechako Reservoir as it pertains to the ability of the proposed CWRF to meet the cooling water criterion.

Selective Withdrawal

- Will the proposed changes in withdrawal rate result in unsteady withdrawal layers thicker than those predicted by steady state models (e.g. SELECT)?
- What is the 'critical level' for selective withdrawal? How does it vary with withdrawal rate and stratification.

Internal Waves

- What is the possible amplitude of internal waves in Knewstubb Arm?
- What are the statistics of the internal wave motions observed to date?
- Are the internal wave motions of Knewstubb Arm correlated with those of Natalkuz Lake?
- How do internal wave motions affect the transfer of cold water between Natalkuz Lake and Knewstubb Arm?
- How does the observed internal wave behaviour compare with theoretical analyses and observations in other B.C. lakes?
- How well does the wind speed and direction correlate with internal wave response?
- What is the best way to determine the equilibrium level from thermistor data?

Other

- Can the hypolimnion of Knewstubb Arm become isolated from Natalkuz Lake when the thermocline is lowered?
- How does meteorological data compare between Prince George Airport and the Nechako Reservoir.
- What impact could climate change have on water temperatures in the Reservoir?

Terms of Reference for Future Field Work

The above questions highlight the importance of collecting further data as follows.

Temperature monitoring at the dam site

In order to evaluate the variability in both thermocline depth and internal waves, long term records of temperature are needed for both Knewstubb and Natalkuz lakes. The Natalkuz site will indicate whether changes in the deep temperatures in Knewstubb Lake are the result of local effects and, once in place, from the withdrawal.

For best use of resources, semi-permanent monitoring stations should be considered for both sites. The cost of installing and removing monitoring gear each year should be balanced against the higher cost of installing a more robust buoy that would remain moored through winter. The cost of adding telemetry (radio or satellite communications) is modest in comparison to repeated site visits to check equipment and upload data.

The following should be considered for both stations:

- Water temperature every 2 m from surface to near bottom. Water temperature sensors should have an accuracy of at least 0.2 C.
- Wind speed and direction. If the mooring is held in place with a single line to depth, then a compass to determine the buoy orientation.
- Air temperature and relative humidity.
- Short wave solar radiation (using e.g. a silicon diode pyranometer such as the LICOR LI-200SA).

CTD surveys

CTD (Conductivity-Temperature-Depth) surveys, using a Seabird SBE-19 profiler (or equivalent), should be undertaken once between July 20 and August 20 each year. Profiles provide an important check of the moored temperatures and provide conductivity data that complements the temperature. Casts should be taken at the mooring sites. While the cost of sampling the entire reservoir is likely prohibitive, a minimum of a half dozen casts should be taken through Knewstubb Lake, and another half dozen in Natalkuz Lake including the eastern parts of Intata and Euchu reach.

- A diagram showing the maximum depth of the reservoir along the thalweg would aid in appropriate design of the survey stations and interpretation of results.
- The Seabird SBE-19 profiler should be factory calibrated each year.
- Casts should extend to 5 m from the bottom at each site including in Natalkuz lake.
- Secchi depths should also be recorded at each station; Secchi depth estimates water clarity and sunlight penetration.

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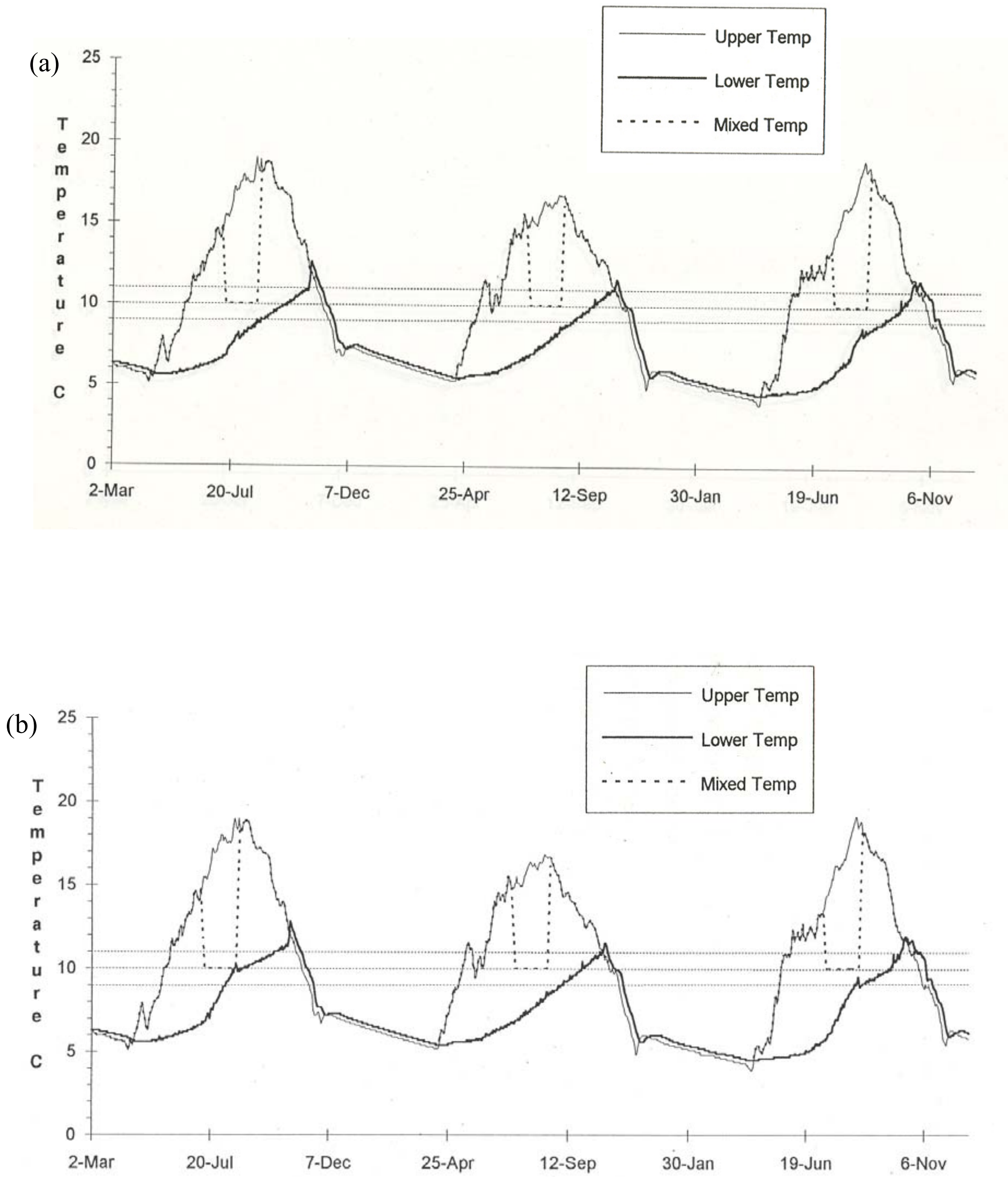

Figure 1. Computed Time Varying Water Temperatures at the Kenny Dam Release Facility for Supplementary Extreme Conditions Hydrothermal Modelling, March, 1979 to December, 1981 **(a)** Case 22a and **(b)** Case 23. (From Triton, 1992)

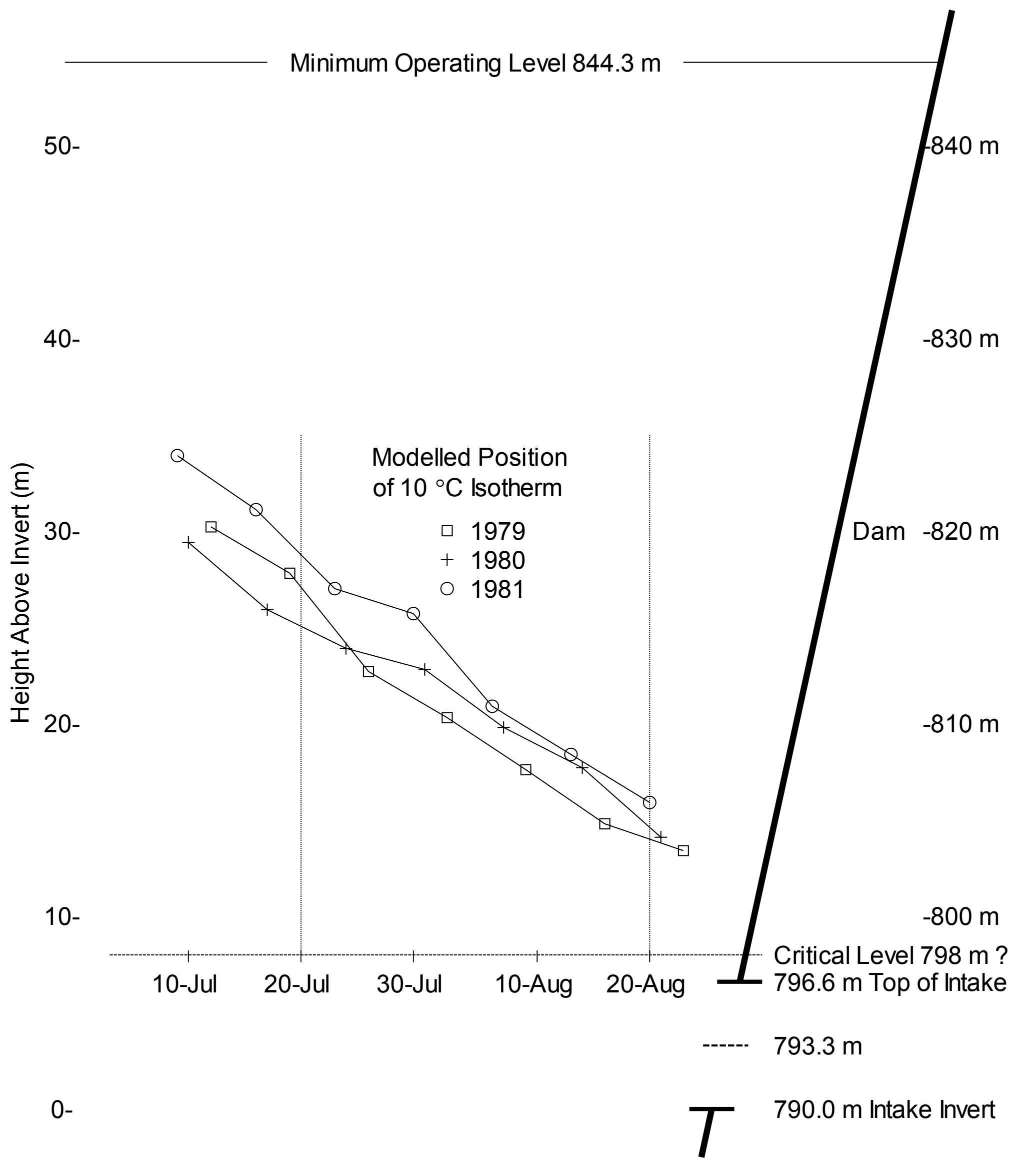

Figure 2. Modelled position of the 10 C isotherms for Case 22a in the context of CWRF.