EXAMINATION of FACTORS INFLUENCING NECHAKO RIVER DISCHARGE, TEMPERATURE and AQUATIC HABITATS

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ABSTRACT

This report assesses temperature and flow management options in the upper and lower Nechako system with reference to the needs of the resident and migratory fish species. The efficacy of an existing management scheme is considered as are the possible benefits of developing cold water release capabilities at the Kenney Dam as a means to broaden water management options. If summer temperature targets can be achieved while releasing a lower volume of water, the broad interests of many stakeholder groups may be met without forgoing the current temperature benefits to salmon resulting from the current flow regime. The goals of this manuscript can be summarized as follows:

1. To assess the success of the existing water management scheme in terms of moderating high summer water temperatures in the Nechako upstream of the Stuart confluence.
2. To consider the effects of the existing management scheme on temperatures in the Nechako downstream of the Stuart confluence and to assess the overall effect on sockeye salmon that migrate through the Nechako upstream and downstream of the Stuart confluence.
3. To introduce a model that examines the downstream consequences of possible future release scenarios if a Kenney Dam release facility were constructed.

While water release facilities at Kenney Dam may have many positive environmental benefits there is a proven temperature management efficacy to maintaining the release of large volumes of water during the summer period when salmon are in the vicinity. Current temperature targets at Finmoore can be achieved with the release of smaller amounts of cooler water from Kenney Dam but may result in warmer conditions in the lower Nechako and cooler conditions in the upper Nechako compared to conditions under the current temperature management regime. Changes to the existing management protocol must be made with caution and should consider a broad range of environmental and operational factors.

INTRODUCTION

The regulation of river flow and the impoundment of water has often been in conflict with ecological values (Ward and Stanford 1987; Dynesuis and Nilsson 1994). This conflict has led to management schemes that seek mitigation strategies to allow water use development while maintaining and preserving natural values. However, after a water use plan has been adopted there have been very few case studies that have evaluated the efficacy of the plan in relation to the original objectives. Even rarer are case studies that evaluate a plan that specifies multiple objectives including water volume and temperature, and release timing. The evaluation of a water management plan in the Nechako River watershed (Fig. 1) that was designed to moderate environmental conditions during critical periods of salmon migration provides a unique opportunity to complete such an assessment.

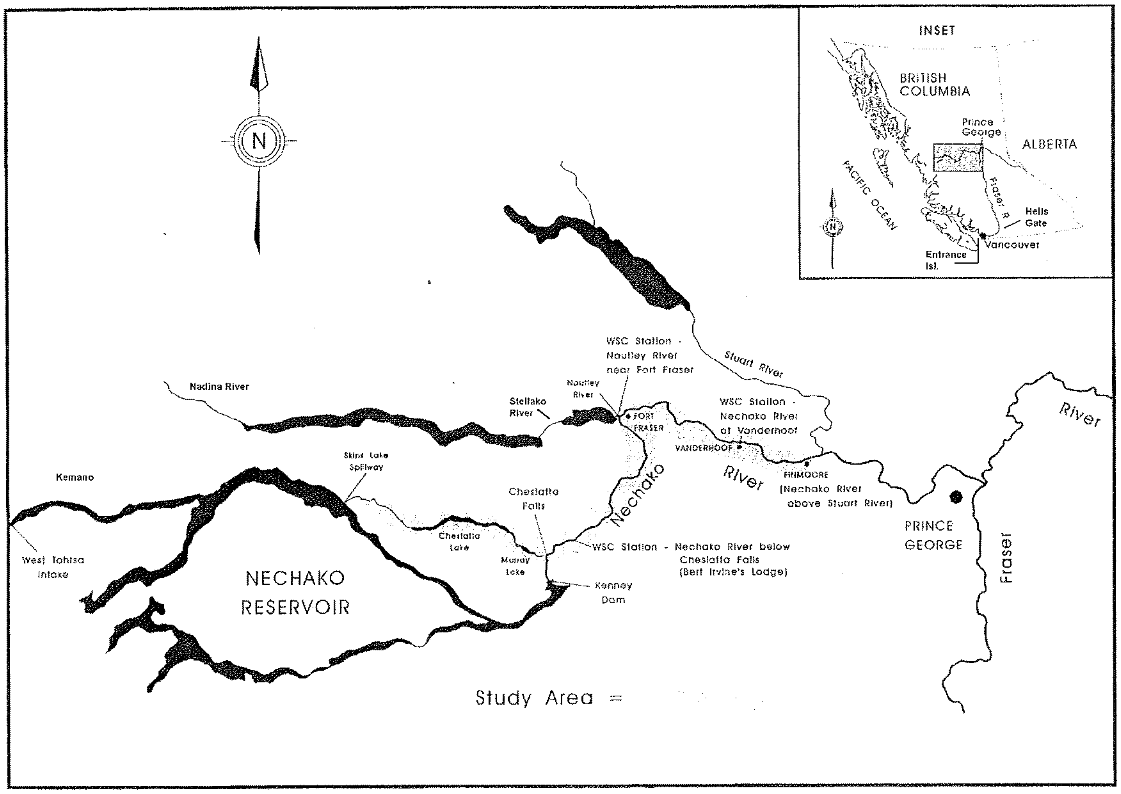

Figure 1: The Nechako watershed with locations of data collection sites, salmon spawning sites and water corridors.

In 1951, the Aluminium Company of Canada (later Alcan Inc.) began construction of the Kenney Dam in what was then known as the Grand Canyon of the Nechako River (Fig.1). The area upstream of this canyon comprised 30% of the Nechako watershed, and contained a horseshoe-shaped chain of rivers and lakes that would be flooded to form what is now known as the Nechako Reservoir. Once full, the majority of the water from this impoundment was diverted to a powerhouse at Kemano, on the other side of the Coast Mountains, via a 16 km long tunnel with an elevation drop of 792 m. During five years of construction water from the Cheslatta Lake system and other small streams provided the only flows for salmon migration, spawning and incubation in the Nechako River above the first large tributary, the Nautley River; a distance of approximately 100 km. (IPSFC 1979). In 1956, when the reservoir was filled, a spillway above Skins Lake first provided controlled flows from the reservoir to augment water from the Cheslatta system (Fig. 1). Releases from the Skins Lake Spillway (SLS) were initially highly variable but would eventually be managed to provide flows for the conservation of fisheries resources in the Nechako River (Fig. 2).

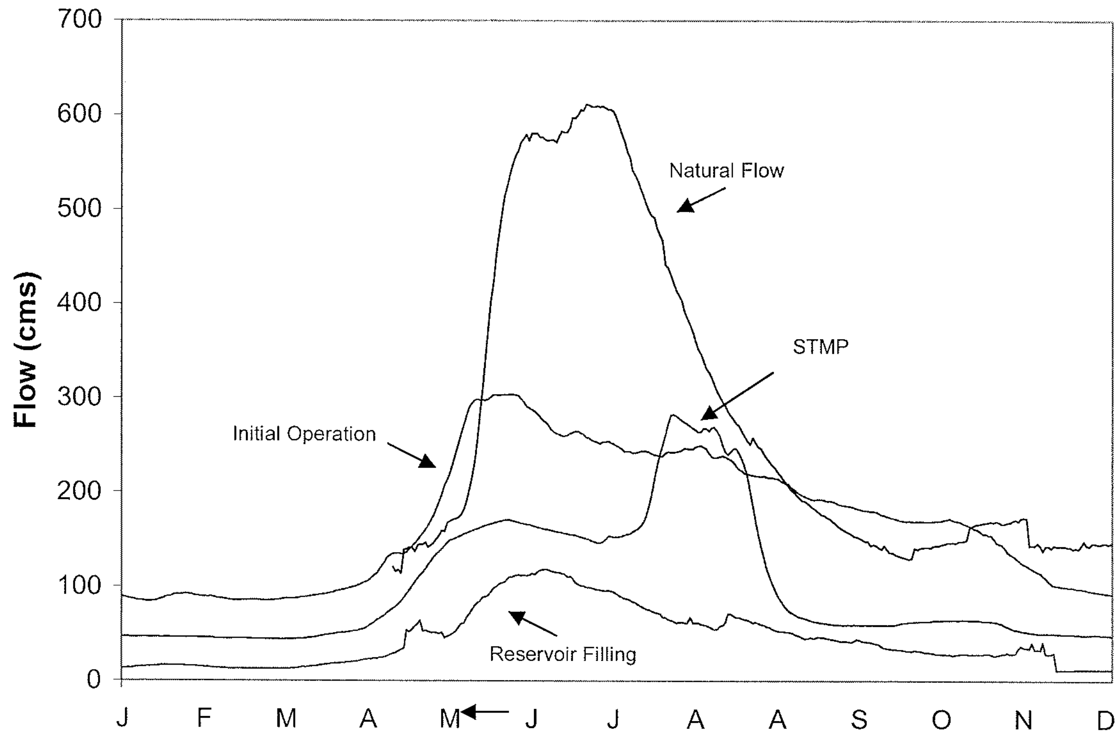

Figure 2: Mean daily discharge (cms) in the Nechako River at Vanderhoof during the entire year. Data spans the pre-dam, natural flow period (1950-52), the extreme low flows when the reservoir was filling (1953-1956), the pre-STMP period during initial operation when greater water volume was released but releases where variable (1957-1982), and the present situation typified by more uniform releases of moderate volumes for a 30 day period for STMP cooling purposes (1983-2003).

In 1980, in response to a court injunction, Alcan began releasing flows designed to protect fisheries values in the Nechako River, with a particular focus on the Nechako upstream of the confluence with the Stuart River since this area was most directly affected by flow regulation (NFCP 2005). These flows consisted of year-round minimum flow requirements for the benefit of Chinook salmon (*Oncorhynchus tshawytscha*) of approximately 30 m^3/sec and summer "cooling flows" during July 10th and August 20th for the benefit of sockeye salmon (*Oncorhynchus nerka*) of approximately 158 to 213 cms, both measured at Cheslatta Falls. The cooling flows are what is now referred to as the Summer Temperature Management Program (STMP).

The STMP was developed between 1980 and 1982 and has been implemented in its current form each year since 1983, except those years when Alcan has released additional water due to reservoir management considerations. The STMP is intended to moderate potential high water temperatures in the Nechako River, with the specific goal of reducing the frequency of observed mean daily water temperatures >20°C at Finmoore, located just upstream of the confluence with the Stuart River (Fig. 1), between July 20th and August 20th (Triton 2004, NFCP 2005). This is achieved by releasing reservoir surface water through Skins Lake Spillway based on computer generated water temperature responses to anticipated meteorological conditions in the watershed between July 10th and August 20th. During the warmest period (late July, early Aug.), Skins Lake surface temperature can approach 20°C but summer water temperatures at Finmoore have generally been below the 20°C target and the STMP-based water releases have become an annual policy on the assumption of their efficacy (Fig. 3). Yet there has never been a formal peer reviewed examination of the effectiveness of the STMP at achieving temperature targets at Finmoore. This study addresses this shortcoming as its first goal.

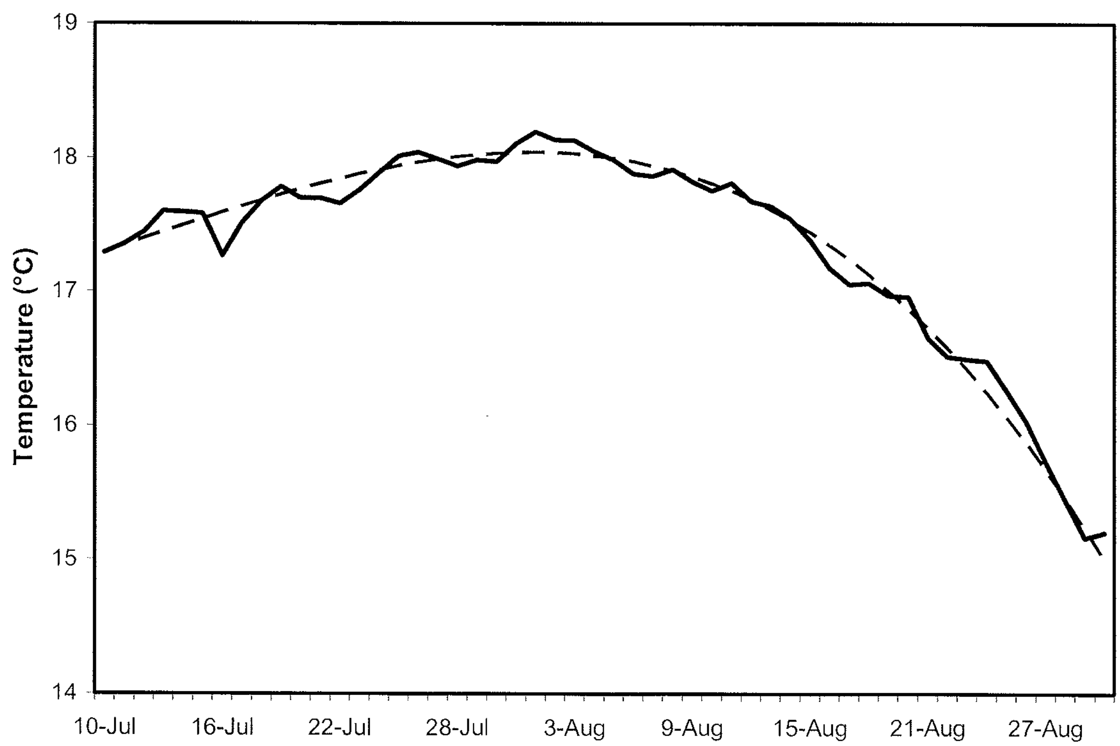

Figure 3: Mean daily Nechako water temperatures at Finmoore in July and August during the present water diversion period (1953-2000). A polynomial fit to the data has an R^2 of 0.9824.

Flow releases from the Nechako Reservoir to the Nechako River have followed the same management regime since 1983. Studies have shown that the Chinook population, which typically spawn in the Nechako mainstem between Vanderhoof and Cheslatta Falls between August 25th and October 8th, have maintained a return strength that fluctuates within the identified target range (Hill and Irvine 2001). However, of the five runs of sockeye salmon that use the Nechako River as an adult migration corridor (Table 1), the Early Nadina, Early Stuart and Late Stuart have declined in recent years (NUSEDS, Stock Assessment, DFO). Three of these runs spend 4-6 days in the Nechako River during the warmest summer months to reach spawning grounds in the Nadina, Stellako or Stuart watersheds (Fig. 1). The fish in these runs may reach the spawning grounds but fail to spawn in larger numbers than in the two 'late' runs (PSM – Table 1)(Gilhousen 1990; Macdonald et al. 2000a; Cooke et al. 2004). The susceptibility of returning sockeye salmon to high water temperatures is well documented (Macdonald et al. 2000a and b; Cooke et al. 2004; Hyatt et al. 2003; Patterson et al. 2007). and the mid-summer temperatures of the Nechako and Stuart rivers are the warmest they will experience during their 4-5 year lifecycle (Fig. 4). When the STMP temperature target was established, there was no requirement to assess its benefit to sockeye salmon in the Nechako system and its efficacy remains untested particularly in the reach below the Stuart confluence which is excluded from the STMP target. Alteration of flow above the confluence in summer may have an undesirable effect on migration temperature below the confluence depending largely on Stuart River conditions. The second goal of this study is to consider the effects of the STMP on temperatures in the Nechako below the confluence with the Stuart, and to assess the actual benefit of these flows to sockeye salmon that migrate through the Nechako system in the summer.

Nechako Location	Early Nadina	Late Nadina	Stellako	Early Stuart	Late Stuart
	Timing Range				
Fraser R. Confluence	July 16 - Aug 12	July 23 - Aug 18	Aug 11 - Sept 29	July 8 - Aug 7	July 31 - Sept 4
Stuart R. Confluence	July 20 - Aug 16	July 27 - Aug 23	Aug 15 - Oct 2	July 12 - Aug 11	Aug 3 - Sept 8
Nautley R. Confluence	July 22 - Aug 18	July 29 - Aug 25	Aug 18 - Oct 5	N/A	N/A
Spawning Success Mn.% / SD	90.78/14.36	94.12/9.05	91.65/10.08	89.44/11.92	95.60/13.15

Table 1: Timing of adult sockeye salmon that rely on the Nechako River at key location on the migration route (NFCP 2005) and mean percent spawning success/standard deviation (estimated as effective females on the spawning grounds) from 1938-present with the exception of the early Nadina where spawning data was not collected following the 1990 run. Early Nadina spawning success data does not consider fish that returned to the Nadina spawning channel (data courtesy of Ms. T. Cone, DFO Canada).

The recent listing of the Nechako population of white sturgeon (*Acipenser transmontanus*) to endangered status under the federal Species At Risk Act (SARA) (COSEWIC 2003) has increased the need for assurance that Nechako habitat management strategies effectively protect a wider list of biota. The white sturgeon tends to spawn on the descending limb of the hydrograph in gravel, at locations associated with floodplain habitat and sloughs that may be beneficial for incubation and larval survival

(Coutant 2004; McAdam et al. 2005; Nelson, et al. 2007). Similar habitat types are frequently cited for their importance to the juvenile stages of many species of salmonids (edited reviews in Groot and Margolis 1991). The timing, shape and volume of the hydrograph and consequently these habitats, have been altered in the upper Nechako River since the advent of river regulation (HYDAT 2003, Boudreau 2004) (Fig. 2). In addition, First Nations and stakeholder groups in the watershed have expressed concern for interests other than fisheries, and have put these interests forward for consideration in the potential development of a new flow regime (eg N-DAM, Bouillon 2004).

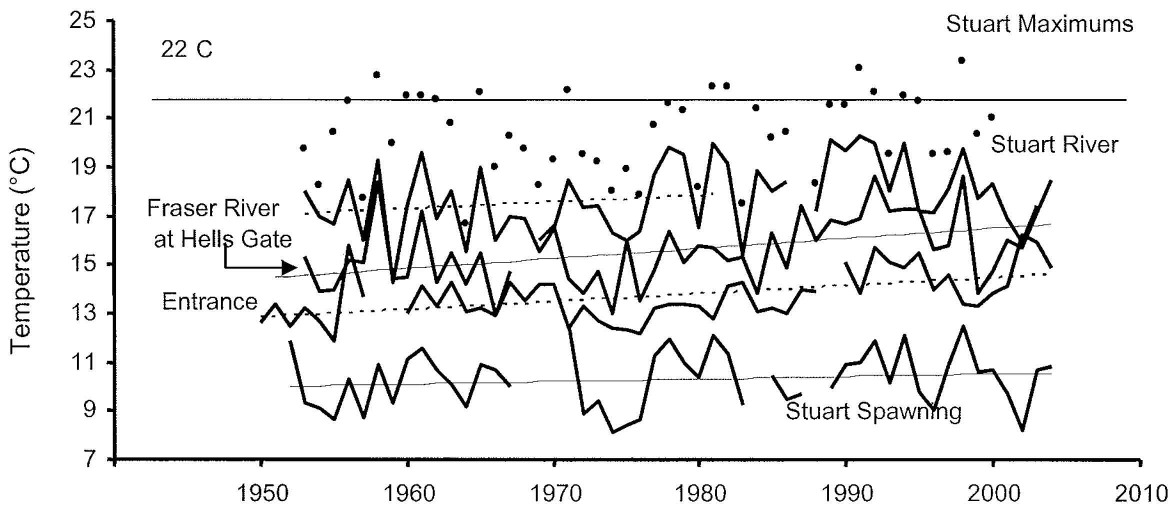

Figure 4: Annual mean temperatures (°C) experienced by the Early Stuart sockeye since the early 1950's during their return from the open Pacific Ocean to their spawning grounds north of Stuart River (Fig. 1). Entrance Island is in the Strait of Georgia 30 km. from the mouth of the Fraser River. Hells Gate is a high gradient reach of the Fraser River approximately 200 km upstream from the river mouth. Stuart River mean temperatures are graphed with annual maximum temperatures indicated by individual dots. Data sources are provided in Table 2.

It has been postulated that the return to a more naturalized hydrograph (in terms of shape rather than volume) might address some of the outstanding concerns related to fisheries and other resource values that have been impacted by flow regulation. However, the current infrastructure limits the adjustments that can be made to the existing flow regime without compromising the ability to meet downstream temperature targets. Water release temperature from the Skins Lake Spillway is currently dependent on reservoir surface temperature, but the ability to control temperature has been proposed with the construction of a deep - cold water release facility at the Kenney Dam (Fig. 1). The third goal of this study is to introduce a model that examines the downstream consequences of several possible release temperature scenarios if the Kenney Dam release facility were constructed. Existing temperature targets may be achieved with less volume of water than currently required under the STMP.

In their pursuit of possible amendments to a watershed management plan that will continue to maintain summer water temperature for salmonids but also provide water to restore a more natural hydrograph and provide more certainty for power production, Alcan, the Province of B.C. and the Canadian Federal Government have agreed to assess the efficacy and benefits of the current water management process. This report assesses the existing temperature and flow management program in the upper and lower Nechako system and alternative strategies with reference to the needs of the resident and migratory fish species. It also considers the possible benefits of developing cold water release capabilities at the Kenney Dam as a means to broaden water management options.

METHODS

Study Area

The Nechako River is located in the northern portion of the interior plateau of British Columbia. The Nechako and it's tributaries drain an area of approximately 47,200 km^2 which accounts for approximately 20% of the Fraser basin, and is second only to the Thompson River watershed (24%) in this regard. Since the construction of the Kenny Dam in 1952, the Nechako River has been regulated by flows from the impoundment of five lakes (the "great Circle Chain of Lakes") through Cheslatta Lake, River and Falls (Fig. 1). During the 275 km passage to join the Fraser River at Prince George, the volume of the Nechako is approximately doubled by two watersheds. First the Nautley River, draining the Fraser and Francois lakes system, and then the Stuart River, draining Stuart and associated lakes in the most northerly portion of the Fraser River watershed. The watershed is situated in the subboreal spruce biogeoclimatic zone, and during the key months of July and August has a mean precipitation of $\approx$ 45 mm and a mean air temperature of $\approx$16 ^{o}C (as recorded at the Vanderhoof Airport). Winter precipitation generally falls as snow which results in snow-melt generated hydrographic peaks in the late spring in the unregulated tributaries of the Nechako (Fig. 2).

Data Collection and Sources

Examiners of the physical characteristics of the Nechako watershed have a number of data sources to choose from. The most reliable and long-term source of meteorological data (air temperature, cloud cover, solar radiation, dew point) has come from the Prince George airport. Summer water temperature and flow data have been collected from many locations throughout the watershed. Since the 1950's, water temperatures have been collected from the diversion route at the Skins Spillway and Cheslatta Lake, the Nechako River at Bert Irvine's Lodge, Vanderhoof, Finmoore, Isle Pierre and Prince George, the Nautley River and three locations on the Stuart River. Similarly, water flow data has been collected at numerous locations including at the Skins Spillway, the Nechako River at Bert Irvine's Lodge and Vanderhoof, and the Nautley and Stuart rivers. However, very few locations have been sampled continuously since the construction of the dam and almost no physical data with the exception of air temperature exists from the period before the dam was constructed. In the 1980's in coincidence with the plans to construct

Kemano II, year round coverage at existing and additional locations were added to the sampling design. Almost all earlier data were collected with paper chart recorders (e.g. Wexlers) but with the advent of electronic dataloggers (e.g. Vemco etc.) data collection and management was greatly simplified. The working database for this study was selected from the plethora of available data sources based on location, consistency of collection period, and QA/QC confirmations (and occasional extrapolations) using nearby collection sites (Table 2, Fig. 1).

Location	Lat/Long	DATA TYPE			Data Source
		Water T^0C	Discharge	Meteorological	
P. G. Airport	53^0 53' N $122^0$40'W	-	-	1953-2007	CMS (Station 1096450)
Stuart River	$54^0$25'N $124^0$16' W	1953-2003*	1929-2007	-	WSC (Station 08JE001); *WSC(53-00) and DFO(00-03)
Vanderhoof	$54^0$1' N $124^0$0' W	1969-present	1915-present	1916-present	WSC (Station 08JC001); CMS (5 stations)
Finmoore	$53^0$58' N $123^0$37' W	1953-present	-	-	Alcan (Triton)
Nautley River	$54^0$57' N $124^0$36'W	1954-present*	1950-present	-	WSC (Station 08JB003); *DFO
Bert Irvine's (below Cheslatta Falls)	$53^0$41' N $124^0$50' W	1981-present*	1980-present	-	WSC (Station 08JA017); *DFO
Spawning Grd.	$55^0$09' N $125^0$42' W	1938-present	-	-	S. Macdonald unpublished
Hells Gate	$49^0$50' N $121^0$26' W	1941-present	-	-	Patterson et al. in press
Entrance Island	$49^0$12' N $123^0$49' W	1950-2005	-	-	R. Thompson DFO, IOS, Sidney,B.C.

Table 2: Environmental databases used in this study by location, source and custodian. July and August data from 1950 to 2005 was most useful for the objectives of this MS. Most of the data were available through Water Survey of Canada (WSC), Fisheries and Oceans Canada (DFO) or Alcan Inc.

Data Analysis/Models

The current strategy of increasing flows in response to predicted warming trends assumes that the water temperature at Finmoore is a function of both meteorological conditions in the Nechako watershed and the volume of water released at the ambient temperature, from the surface of the Nechako reservoir. A regression of the daily Finmoore water temperature response to all potential and available predictors, including meteorological variables (i.e. daily mean air temperature, solar radiation and dew point) and the mean daily water released from the Skins Lake Spillway (SLS), is a test of this assumption.

However, considering that SLS water releases are frequently based on anticipated meteorological conditions, the predictor variables in this model are very likely to be correlated thus violating a statistical assumption of regression (Draper and Smith 1981); an assumption that is particularly important when judging the significance of individual variables (Green 1979). The potential for correlation among predictor variables was examined with a principle components analysis (PCA) for the years 1981-2002 during the STMP period (July 20th to August 20th). A regression using the resulting PCA scores, which are uncorrelated transformations of the original predictor variables, avoids the statistical violation (Green 1979) and provides a test of the efficacy of the current STMP policy:

$$T_{Finmoore} = a + b_1 PCI + b_2 PCII + b_3 PCIII \qquad (1)$$

Strength of the variable loadings on principle components combined with the regression results provided a measure of the relative influence of each original variable on Finmoore water temperature. For the analysis the Skins spillway flow variable was lagged by four days to account for the travel time of water between the upper Nechako and Finmoore in the summer. Subsequently, a regression model was developed to predict daily Finmoore water temperatures associated with a variety of possible Skins flow management regimes based on the original predictors that were chosen as influential in the preceding analysis.

Predictions of daily water temperature downstream of Finmoore, below the confluence of the Nechako and the Stuart rivers, were based on a simple mixing model that combined the effects of water temperature (T °C) and volume (V) of both systems:

$$T_{below\ confluence} = \left(V_{Finmoore} T_{Finmoore} + T_{Stuart} V_{Stuart}\right) / V_{below\ confluence} \qquad (2)$$

If we assume that 22°C is a critical temperature beyond which migrating sockeye salmon can not endure (Brett 1952), and avoid (Hyatt et al. 2003, Quinn et al. 1997), an estimate of the ability of a volume (V) of water at Finmoore with a temperature (T °C) to cool a warmer downstream reach is its cooling power (CPwr):

$$CPwr = V_{Finmoore}\left(22 - T_{Finmoore}\right) \qquad (3)$$

Cooling power declines with declining water volume and/or increased temperature and only provides a cooling effect to migrating salmon in the lower Nechako if the summer water temperatures tend to be warmer in the Stuart River than in the Nechako River at Finmoore; an assumption that we test for the years 1982 – 2002. The annual cooling power of the Nechako River at Finmoore during the period Early Stuart Sockeye salmon were estimated to be migrating through the lower Nechako, was examined for its efficacy as a predictor (and cause) of their pre-spawn losses on the spawning grounds (DFO Stock Assessment Kamloops unpublished data). Data for this analysis is available from the early 1950's. This approach provided a solution to two problems. First, it allowed us to use temperature data from a stretch of the river that while not used by Early Stuart fish, was the downstream extent of temperature regulation targets and most influenced by the flow regulation. Secondly, a similar analysis using Nechako temperature from below the Stuart confluence, a reach actually used by these fish, was restricted by lack of pre-1981 temperature data.

The construction of a water release facility at the Kenney Dam would create the opportunity to not only control water volume but also control water release temperature. At the outset of this analysis, a facility that controlled river temperature appeared to improve summer water management options by allowing existing downstream temperature targets to be achieved while reducing water demand. However, before considering construction, an analysis of the influence of both release water volume and release water temperature on river temperature downstream was conducted. Retrospective regression models based on empirical (historic) data are inadequate for this task, but a theoretical approach developed by Foreman et al. (1997) (Institute of Ocean Sciences River Temperature Model - IOSRTM), has proven adept at providing 10 day river temperature forecasts of the Fraser River during the salmon migration season and has been in continuous use for that purpose since 1996 (Macdonald et al. 2000a). It divides a river and its tributaries into many reaches within which hourly volumes and velocities are estimated with a routing model, for subsequent use in a model to estimate hourly temperature based on the following energy balance calculation:

$$E_{\Delta} = E_{flowin} + E_{atm} - E_{flowout} \qquad (4)$$

E_{flowin} represents the energy in the water flowing into a reach from both the mainstem and any tributaries.

$E_{flowout}$ represents the energy in the water flowing out of the reach.

E_{atm} represents the heat exchange with the atmosphere and is calculated using air temperature, dew point temperature, wind speed, cloud cover, and solar radiation.

Foreman et.al (1997) based the original model on the work of Edinger et.al (1968) and Wunderlich (1972). The version of the model used in this study was modified slightly as a result of a sensitivity analysis of model parameters (Morrison and Foreman 1998) and was set up to run from the Kenney Dam with a cold water release (CWR) to the confluence of the Stuart River near Finmoore. It consisted of 34 reaches, each being 5700m long, with two tributaries, the Cheslatta at reach 2 and the Nautley at reach 16. The validation runs that used observed flows and temperatures were run between the Cheslatta and Finmoore while other scenarios were run starting at the proposed CWR.

In total over a thousand simulations were run in four broad categories. The first and smallest group involved annual validation runs for 18 years using observed historic flows and temperatures from Cheslatta and the Nautley rivers, and corresponding daily atmospheric conditions to verify that the model could reproduce the observed average daily river temperatures at Finmoore. The next group of runs incorporated the atmospheric and tributary conditions in 1995 and 1998. The flow regime in the Cheslatta River was fixed at 15cms with the temperature set to the temperature observations from the Nautley River. Volumes from the CWR made up 50 to100% of the actual water released in these years. Release temperature was held constant while combinations of flow at selected temperatures (from 10 to 18 °C) were chosen for their ability to deliver water to Finmoore at temperatures approaching 20 °C.

A third group of runs were used to exemplify the difficulties associated with using lower release water temperature to compensate for the effects of reduced flow on downstream temperatures. For maximum effect, combined water volume from both Cheslatta and Kenney releases was held constant at 53 cms, which is the minimum seasonal flow set out in an agreement between Alcan and the governments, and release temperature was 10°C. The model used 30 year mean tributary volumes and temperatures, and atmospheric data.

A final set of model runs was designed to assist with water release decision making by estimating the number of days that STMP temperature targets would be exceeded if specific water quantities and temperatures were released immediately below the Cheslatta/Nechako confluence. A total of 28 flow and temperature scenarios were examined beginning at 56.6 cms, 75 cms and increments of 25 cms up to 200 cms. Temperatures were 12, 14, 16 and 18°C. Daily atmospheric and tributary model inputs were based, not on a single year, but on model runs with conditions observed each year between 1981 and 1999. The mean number of days temperature exceeding 19.6°C at Finmoore in this period were plotted for each of the 28 temperature/flow scenarios.

Results

Since 1981, water volume released from the Skins Lake spillway during the STMP period has been larger during warm summers, as estimated from air temperature at the Prince George airport (Fig. 5). However, this relationship is weakened as a result of several years during which above average snow pack volumes during the previous winter/spring necessitated summer forced spills for dam safety reasons, unrelated to summer temperature (e.g. 1997, Macdonald 2000b, 1985, 1992, 1996, NFCP 2005). From this relationship 1995 and 1998 were chosen as being particularly cool or warm years when relatively minor or major STMP release responses occurred respectively.

Over 90% of the variation among the predictor variables is described by the first three principle components, with the meteorological variation (PCI and II) providing the greatest amount of the information in the environmental matrix (Table 3). The correlation between daily flow from the Skins facility and the meteorological variables, albeit weak, is confirmed by the variable loadings on the first principle component (PC1) of the PCA. This suggests that the summer operation of the Skins spillway is based on functional five day meteorological forecasts that promote the release of water as conditions become warmer. The variation in PCI, largely associated with air temperature, has the greatest influence on Finmoore water temperature ($p<0.01$, Table 4). However, the variation in Skins spillway flow not associated with meteorological conditions (PCIII at 24 % of the variation), had a significant influence on Finmoore water temperature that was second only to air temperature ($p<0.01$, Table 4). This provides credence to the efficacy of the STMP protocol. High humidity during days with reduced solar radiation (PCII) has an influence on Finmoore water temperature (Table 4) through reduced evaporative energy loss.

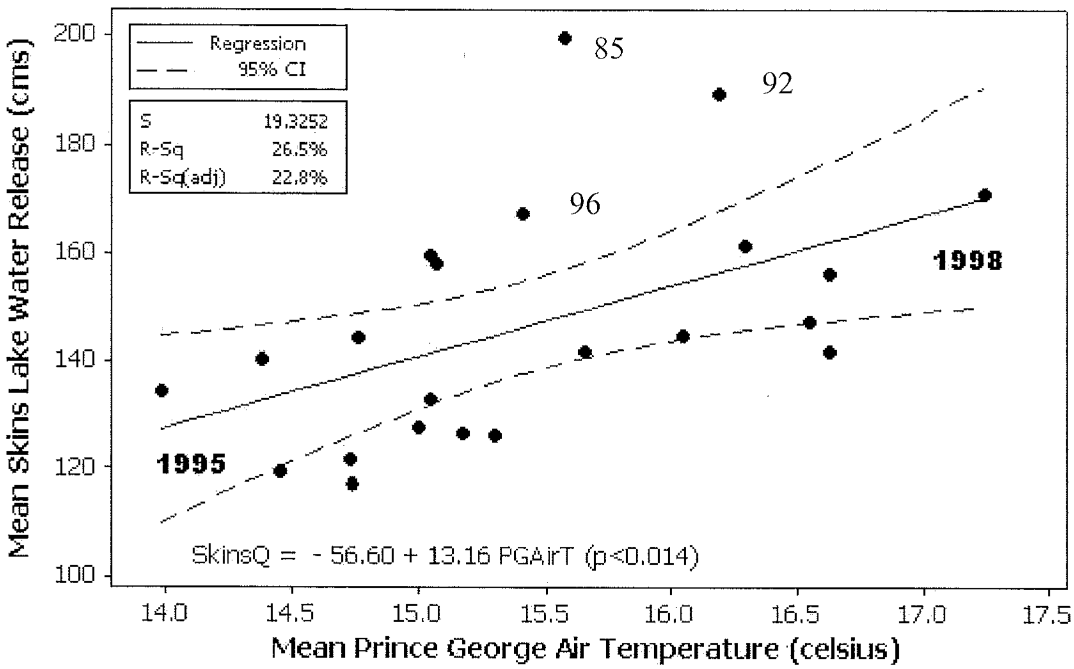

Figure 5: A comparison of mean annual Skins Lake water release volume (cms) and mean annual summer temperatures (°C) at Prince George between 1981 and 2002. Three years are indicated during which forced spills occurred beyond those needed to control summer temperature. A fourth year, 1997, is not shown (15.7°C x 284.2 cms). The regression equation, p-value and 95% confidence limits are provided. The R^2 for the relationship was 26.5% but improved to 39.6% ($p<0.004$) when years with forced spills were removed. Both 1995 and 1998 were chosen as being representative of cool and warm years respectively.

Variable	PCI	PCII	PCIII	PCIV
Skins 4.0	0.225	-0.191	**0.954**	0.051
PG Air Temp	**0.735**	-0.001	-0.138	-0.664
PG Humidity	0.401	**-0.721**	-0.265	0.500
PG Solar Radiation	0.498	0.667	-0.014	0.554
Proportion	0.402	0.294	0.240	0.064

Table 3: Results of a principle component analysis to describe the information shared among the daily mean meteorological and water release variables during a 30D period (July 20th – August 20th, 1981-2002) when STMP flows from Skins Lake were released in response to meteorological forecasts. The first three components described 93.6% of the database variation accounted for primarily by the variables indicated in bold.

Predictor	Coefficients	T-Value	Probability	R^2	N
Constant	18.0	368.78	0.000	40.5%	629
PCI (Air Temp °C)	0.792	20.19	0.000		
PCII (Humidity)	0.0923	2.11	0.035		
PCIII (Skins Lake Q)	-0.193	-3.96	0.000		

Table 4: A table describing the results of the regression of daily Finmoore water temperature response to the effects of the variation in meteorological and Skins Lake water release variables from July 20th – August 20th, 1981-2002. Predictor variables were PC scores from the PCA analysis (Table 3), which are transformations of the original variable loadings (in brackets) on each component. Humidity refers to both variation in solar radiation and dew point, variation in Skins Lake water releases as described by PCIII represents water released independent of meteorological forecasts.

Based on these results, both air temperature and water discharge were proposed as predictor variables to model Finmoore daily mean water temperatures during specific summers (Table 5). Daily Skins flow when subtracted from Finmoore flow with a four day lag, became the discharge predictor which was used with the observed daily air temperatures to estimate Finmoore water temperature to mimic scenarios where STMP flows were reduced or eliminated (Fig. 6). Humidity was omitted to simplify the model. Modification of the Finmoore water discharge predictor to reflect a water release reduction at Skins to 53 cms and 15 cms resulted in an annual mean increase in water temperature at Finmoore of 0.38 °C ($range_{81\text{-}02}$ = 0.22-0.85 °C) and 0.51 °C ($range_{81\text{-}02}$ = 0.34-0.97 °C) respectively. With these reduced water volumes, annual mean summer temperature predictions remained below 20°C in the Nechako above the confluence with the Stuart River. However, below the confluence, temperature increased with the imposed water reductions since Stuart temperature was higher than the Nechako during most summers (Fig. 7). Increases in the lower Nechako River of 0.5–1.0 °C were predicted, particularly during the three week period centred on annual peak migration of Early Stuart Sockeye through this portion of the Fraser watershed.

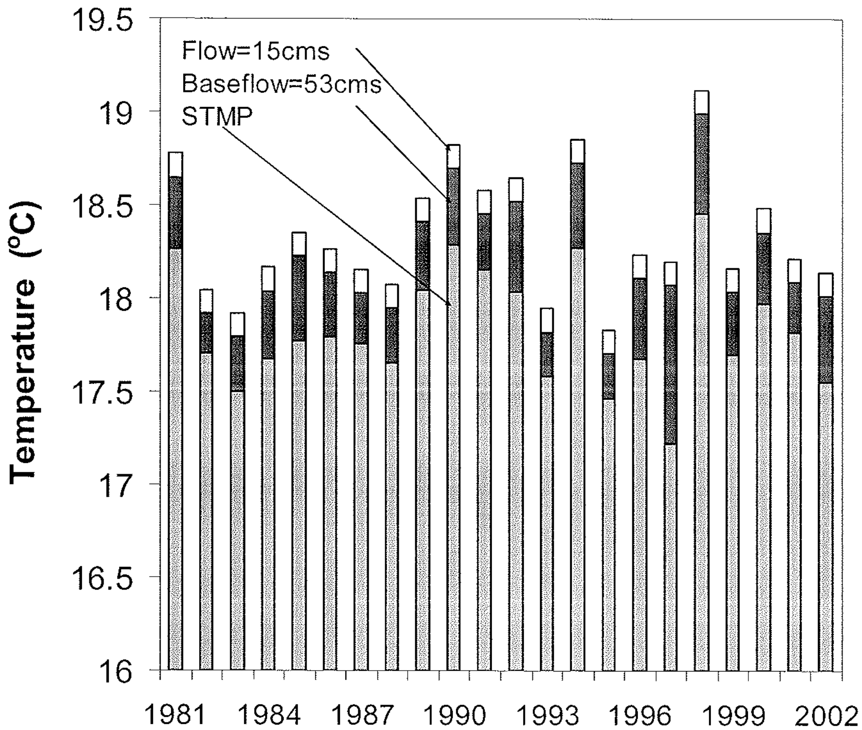

Figure 6: Predictions of mean annual water temperature (°C) at Finmoore in July and August from 1981 to 2002 using the regression model described in Table 5. Three Finmoore flows scenarios were considered; actual (STMP), the actual baseflow without the STMP (53 cms) and a simulated baseflow without the STMP (15 cms). Flow calculations at Finmoore were modified based on a 4D lag in water release from Skins spillway.

Predictor	Coefficient	T-Value	Probability	N
Constant	13.2	59.57	0.000	1097
Finmoore Q	-0.00331	-7.15	0.000	
Air Temp °C	0.346	25.36	0.000	

Table 5: Description of a model (Finmoore T°C = 13.2 – 0.00331 Finmoore Q + 0.346 PG Air T°C), to predict daily Finmoore water temperature response to both Prince George air temperature and Finmoore water flow from July 7th to August 30th, 1981-2002. Predictor variables were chosen based on variable selection results described in Tables 3 and 4.

When the theoretical model was run initially using observed conditions for validation purposes the mean and RMS error were estimated to be -0.20 and 1.05 respectively (n=18). The negative mean error indicated a tendency of the model to produce temperature estimates at Finmoore that were cooler than those actually observed.

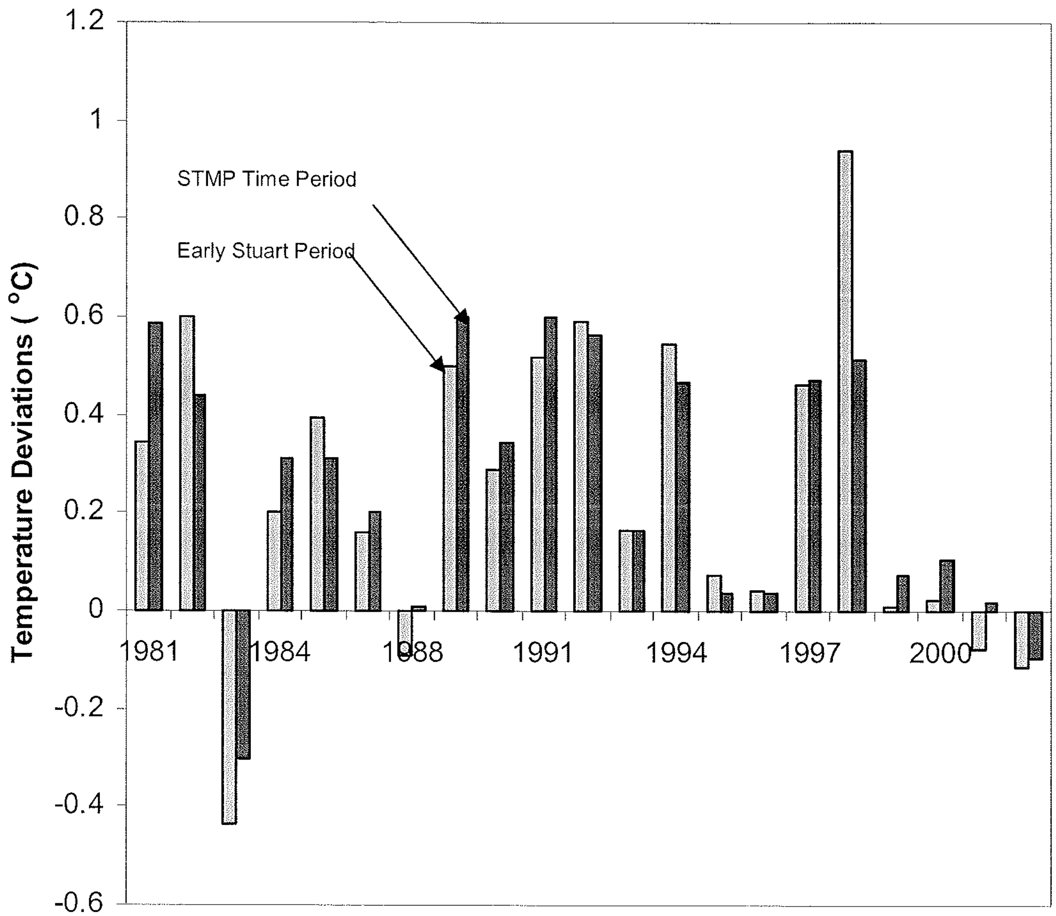

Figure 7: The effect of reduced flows from the Skins spillway on deviations in annual mean Nechako water temperature below the confluence of the Stuart. Reductions were based on the elimination of the STMP flows and the adoption of a baseflow release strategy of 53 cms. Deviations are calculated for the period the STMP was in effect (July 10^{th} – August 20^{th}) and for the briefer period, calculated annually, when Early Stuart sockeye were migrating through the Nechako system in July and early August (Table 1).

The actual atmospheric and tributary conditions ranged from cool (e.g. 1995) to warm (e.g. 1998) with minor to major STMP responses respectively (Fig. 5). Release scenarios run with the conditions experienced these years, while simulating temperatures and volumes from a re-engineered outlet at Kenney Dam that ranged from 10 - 18°C and 50 – 100% of the actual 1995 and 1998 water releases, were able to deliver water to Finmoore at temperatures that approached but rarely exceeded the 20°C target (Fig. 8). When the model was run to mimic actual release conditions (100% flow @ 18°C) and meteorology in 1998, temperature at Finmoore exceeded 20°C on one day in August. Reducing release temperature by 3°C, to 15°C had the greatest influence in the upper Nechako (above the confluence with the Nautley River), but also caused modest cooling at Finmoore. At 15°C, the amount of water released could be reduced by 20% without exceeding the 20°C target at Finmoore, but after mixing with the warmer Stuart River water, temperature in the lower Nechako River exceeded 20°C on 3 occasions, as it did when 100% was released at 18°C. Further reduction of both flow and temperature (50% flow @ 10°C) created yet cooler flows in the upper Nechako River, but provided only modest reductions above and below the Stuart confluence and caused the temperature to exceed 20°C at both locations on one occasion. A similar pattern was predicted from flow and temperature manipulations of the cooler conditions experienced in 1995; a reduction in release temperature when accompanied with a reduction in flow failed to provide large temperature benefits in the Nechako River above and below the confluence of the Stuart River. In fact, temperatures increased in all of the 1995 scenarios.

If modelled using 30 year mean tributary inflow volumes and temperatures, and atmospheric data, a minimum base flow (53 cms) released at an extreme low temperature (10°C) will create much lower temperatures in the upper Nechako, ensure achievement of the 20°C target above the Stuart confluence, but will not be of an adequate volume to moderate Stuart River temperatures and promote conditions more conducive to salmon migration in the lower Nechako River (Fig. 9). In fact, in comparison to the temporal patterns of thermographs in other model runs (e.g. Fig. 8), the lower Nechako River thermograph was less responsive to the effects of the upper and mid-Nechako reaches during base flow, and more responsive to conditions in the Stuart River. This uncoupling of the lower river from upstream events as water volume declines, is caused by the tendency for small water volumes to be more greatly affected by the atmospheric inputs listed in the model (e.g. solar radiation and air temperature) than large volumes. The influence of atmospheric inputs becomes relatively larger as river volume declines. Consequentially, regardless of the temperature of water released in the upper reaches of the Nechako River, near equilibrium conditions will occur several days later when the water reaches the confluence with the Stuart River (Fig. 10) unless considerably more than base flow levels are released.

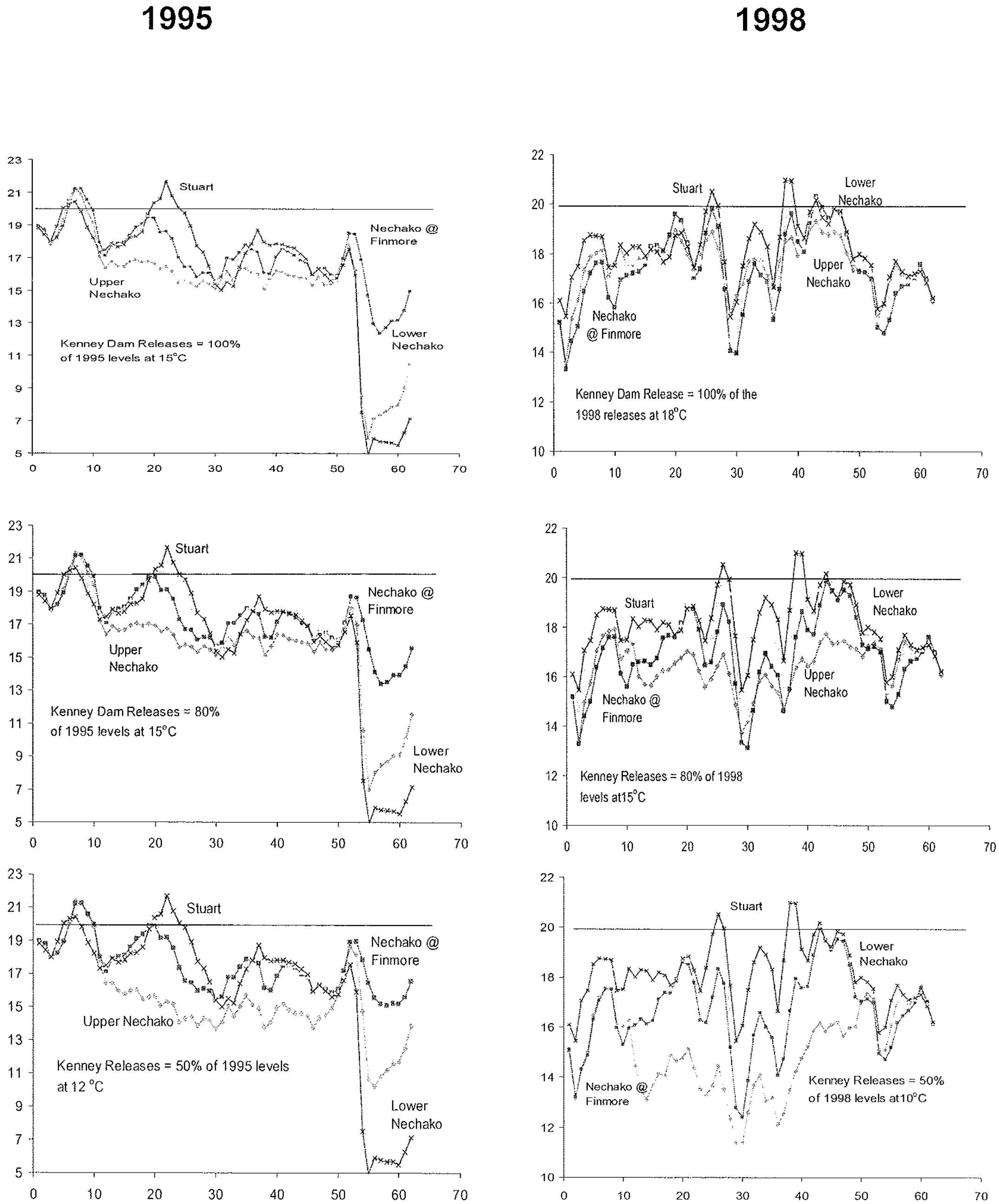

Figure 8: Daily summer water temperature predictions resulting from the modelling of various indicated Kenney Dam release volume and release temperature scenarios, at four locations in the Nechako/Stuart watershed. Release volume was based on a percentage of the actual volumes released from the Skins spillway during warm (1998) and cool (1995) years. A horizontal 20°C line identifies the STMP target temperature at Finmoore and a value that approaches the biological limit for migrating salmon. The top left and right graphs are approximately represent the actual conditions in 1995 and 1998 respectively.

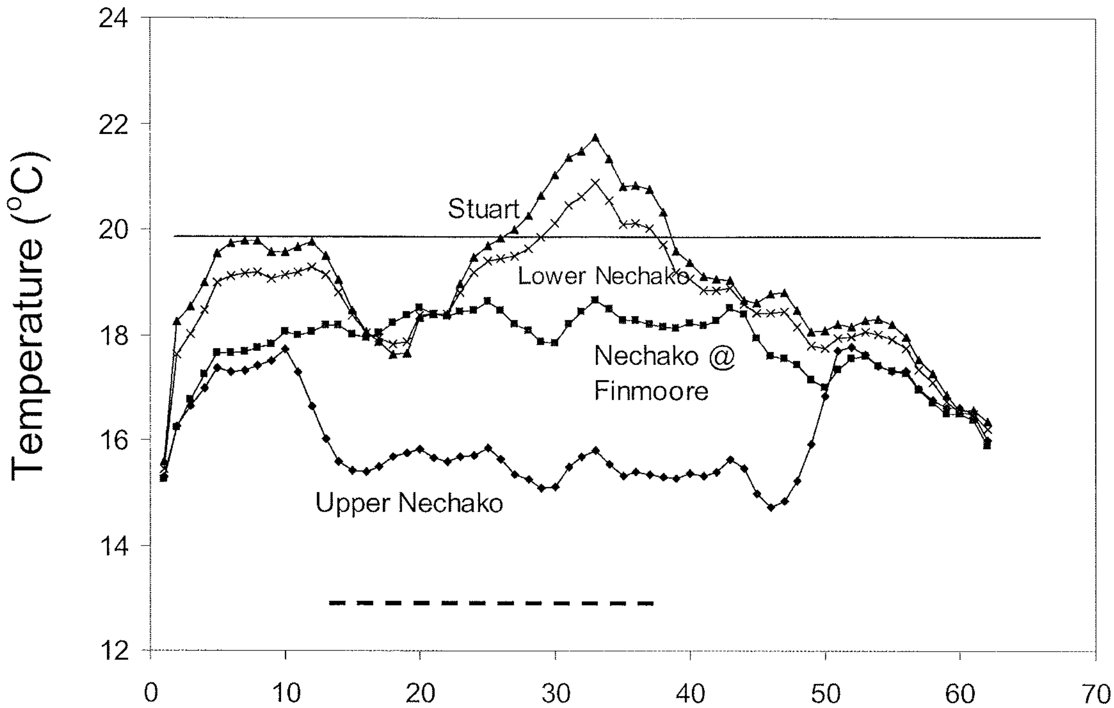

Figure 9: Daily summer water temperature predictions resulting when a baseflow of 53 cms of water is released from Kenney Dam at 10°C. The model uses mean meteorological and tributary conditions during the past 30 years as input. The 20 °C temperature target at Finmoore is indicated with a horizontal line. Historically Early Stuart sockeye can enter the Nechako during a period spanning several weeks as described by a dashed horizontal line above the x-axis (Table 1).

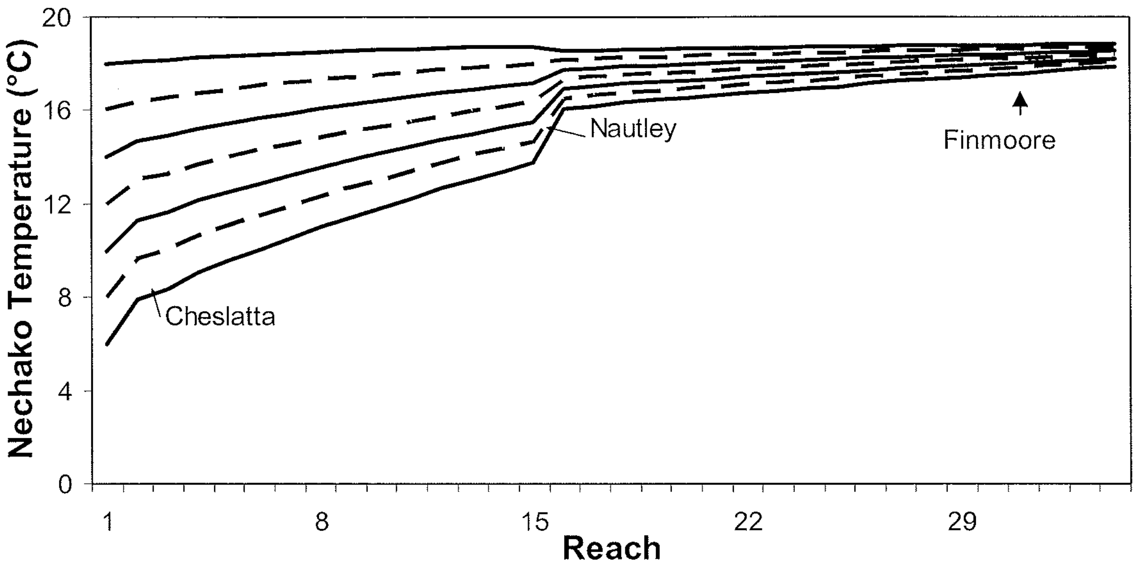

Figure 10: A model rendition of downstream temperature convergence of small quantities of water (25 cms) released at seven different temperatures from the Kenney Dam (Reach 1) and tracked by reach to the Stuart confluence (Reach 34). Input from 2 major tributaries and the temperature target site at Finmoore are indicated. Coined the "rake effect", it is most apparent at low flows but demonstrates the tendency for cool water to warm at a greater rate than water with a temperature near thermal equilibrium regardless of volume.

If we expect water release operation decisions to achieve the Finmoore temperature target 95% of the time during the STMP period (28.5 days out of 30), 100 cms of water released at the Cheslatta/Nechako confluence at 12°C will achieve the Finmoore temperature target (Fig. 11). A release of 150cms at a release temperature of 14 °C will also succeed. However, if 16°C water is released at 200 cms, temperature requirements are not always met and at 18°C the requirement will be met less than half the time. This analysis did not consider temperature elevation in the Nechako below the confluence with the Stuart that is likely to occur as water flow at Finmoore is reduced (Fig. 7).

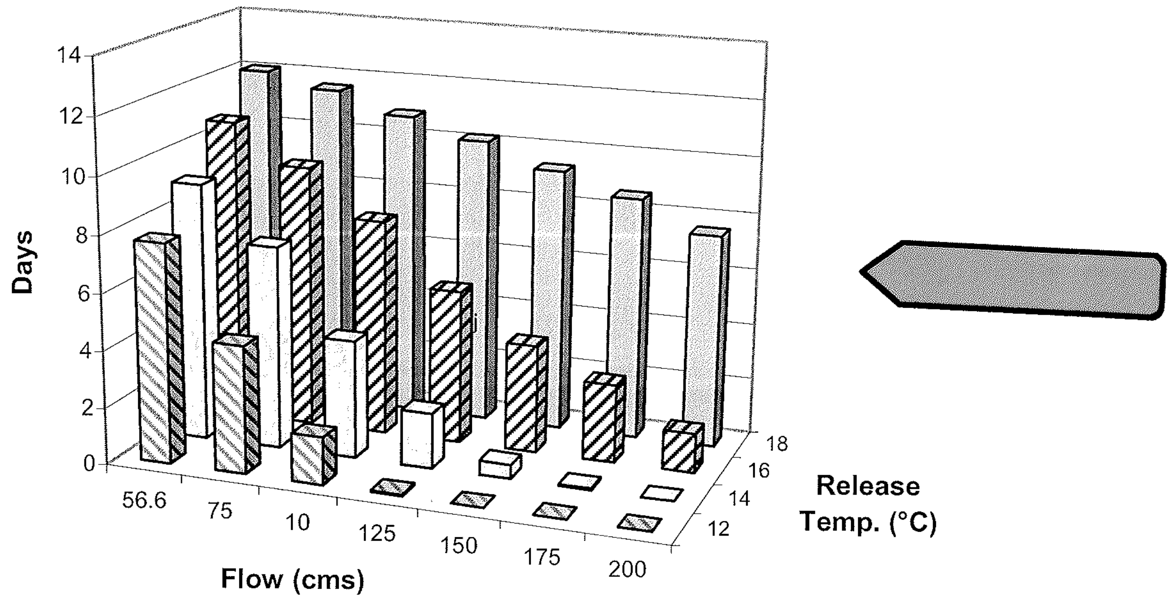

Figure 11: Number of days when modelled Finmoore water temperatures will exceed the STMP target of 19.6°C as a consequence of 28 scenarios with differing water volumes (cms) and temperatures (°C). Temperature and volume were modelled below the Cheslatta/Nechako confluence.

Cooling power as calculated at Finmoore, can be used to predict annual Early Stuart sockeye pre-spawn losses (lnPSM +0.1, $p<0.05$) (Fig. 12). Years with cooler summer temperature (e.g. 1995, Fig. 5) had greater cooling power and subsequent lower PSM than warmer years (e.g. 1998). This relationship provides a mechanism to equate the influence of water temperature management schemes to migration habitat quality and sockeye fitness further downstream, despite only a portion of the river being used for migration. It does not necessarily imply a causal relationship as cooling power may be a surrogate for temperatures in proximate rivers and/or other habitat qualities (e.g. Stuart and lower Nechako rivers), to which the fish are directly exposed ($p<0.05$, Table 6).

	Cooling Pwr.	Stuart Temperature	Spawning Grd. Temp.	Entrance Isl. Temp.	Nechako @ Isle Pierre
Stuart Temperature	**-0.472** ***0.048***				
Spawning Grd. Temp.	-0.345 *0.175*	**0.732** ***0.001***			
Entrance Isl.Temp.	0.156 *0.537*	0.053 *0.840*	0.005 *0.986*		
Nechako @ Isle Pierre	**-0.706** ***0.001***	**0.893** ***0.000***	**0.759** ***0.001***	-0.036 *0.891*	
Hells Gate Temperature	-0.160 *0.512*	**0.493** ***0.038***	0.397 *0.114*	**0.560** ***0.016***	0.426 *0.078*

Table 6: An examination of the correlation between annual Nechako cooling power calculations at Finmoore (equation 3), and water temperature at several locations during the period they are used by the Early Stuart sockeye. Both Pearson correlation coefficients and probability values (*in italics*) are provided with significant correlations in bold ($p<0.05$). Availability of empirical data from some locations restricted the analysis to the years from 1981 to 1999 (Table 2). Very little temperature data were available from the Nechako below the confluence with the Stuart, therefore Isle Pierre data was generated using the model with annual meteorological and tributary flow inputs.

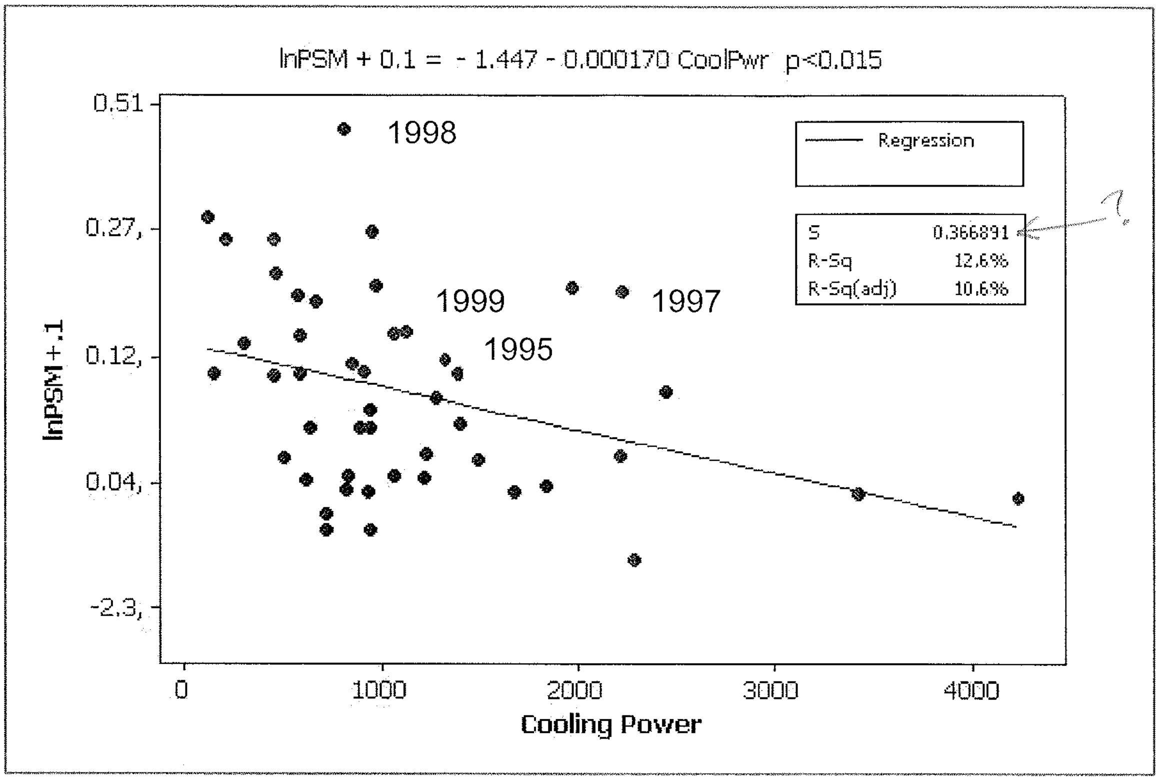

Figure 12: Annual cooling power of the Nechako at Finmoore (equation 3) as a predictor of pre-spawn mortality (PSM) among Early Stuart sockeye between 1952 and 2003. Data points are identified for select years. PSM values are ln+0.1 transformed to remove the tendency for PSM to vary with the mean and to provide a linear rendition of the data. The regression equation, p-value and R^2 are provided.

Discussion

The Summer Temperature Management Program (STMP) is the only component of the annual activity of the Nechako Fisheries Conservation Program directed at the protection and conservation of sockeye salmon (NFCP 2005). When the STMP temperature target was established, there was no requirement to assess its efficacy in terms of temperatures realized or benefits to sockeye salmon. In addition to the obvious interest in conducting such an assessment, recent interest in altering water release timing to enhance other species (e.g. sturgeon – Korman and Walters 2001) provides additional incentive (NFCP 2005). Water temperature in the Nechako River above the confluence of the Stuart has rarely exceeded the 1987 Settlement Agreement target of 20°C despite a warming summer temperature trend during the last three decades (Fig. 4) (Morrison et al. 2002). However, proof that the expenditure of considerable volumes of water (approximately 15.8 m^3/s annualized average since 1987) actually supports STMP objectives is based on theoretical approaches with mathematical energy balance models (Triton 2004). Our study, using empirical data, provided independent support for the conclusions reached with these models; increased water volume retards the rate at which water temperature increases as it proceeds downstream. Minimum flow regimes have been used to mitigate against high summer temperatures in other locations (Gu et al. 1998; Sinokrot and Gulliver 2000). The rate at which water in a river will respond to atmospheric conditions depends, in part, on the ratio of its surface area to its volume. In most rivers there is a non-linear relationship between width and flow in the form of $w = aQ^b$ with b less than 1. Thus an increase in river discharge is accompanied with a slower increase in surface area exposed to the atmosphere (Foreman et al. 1997) and is therefore less responsive to the warming effects from atmospheric (Ward 1982) or groundwater input (Webb 1995). As stated by Hockey et al. (1982), and Poole and Bergman (2001), water temperature is a function of heat load divided by discharge; a relationship that is largely responsible for the success of the STMP in meeting temperature targets at Finmoore.

Numerous studies have shown hypolimnetic reservoir drawdown to reduce down-stream temperatures in the summer (Paller and Saul 1996; Flodmark et al. 2004). However, in the Nechako, if the existing temperature targets can be met using lower release volumes of cooler water from Kenney Dam, failure to consider the volume of the Nechako at the confluence of the Stuart and the subsequent cooling effect that results most summers to the warmest portion of the migration path, could result in warmer migration conditions for the Early Stuart sockeye in the Nechako downstream of the confluence (IPSFC 1979). During the three or four days that sockeye salmon spend in the lower Nechako River, they are frequently exposed to temperature in excess of 20°C. These temperatures, have been cited as lethal thresholds for salmon (Brett 1952; Bouck et al. 1975), creating impediments to migration (Cooper and Henry 1962; Major and Migell 1966; Keefer et al. 2004; Salinger and Anderson 2006), reducing swimming performance by depleting energy and promoting exhaustion (Gilhousen 1980, Rand and Hinch 1998), and can elicit immunosuppression and disease development (Anderson 1990; Schreck et al. 2001). The incidence, development rate and virulence of bacterial and parasitic infection in salmon are positively associated with temperature (Williams 1973; Williams et al. 1977). Infection severity by the myxosporean parasite *Parvicapsula minibicornus*, which has been identified as a contributing factor in the freshwater en route loss of Fraser sockeye (St-Hilaire et al. 2001), increases with freshwater exposure and temperature. A positive feedback mechanism exists where factors that adversely affect critical sockeye swimming performance (Jain et al. 1998, Wagner et al. 2005), extend freshwater residency creating further stress. This feedback exacerbates the problem and ultimately can compromise the fitness of the entire stock (Wedemeyer 1970). And nor are temperature effects limited to fish biota. Increased stream temperatures can reduce the abundance of mayfly larvae (Brittain and Saltveit 1989) and shift invertebrate communities and emergence times, and alter abundance and diversity (Fraley 1979).

High migration temperature and infection severity has been cited as a cause for pre-spawn mortality (PSM) in many stocks of Fraser sockeye (Gilhousen 1990, Macdonald et al. 2000a). In Gilhousen's analysis, fish infected with pathogens from resident species in the lower portion of the river and/or adjacent marine coastal zones (Colgrove and Wood

1966, Williams et al. 1977), suffer elevated PSM when exposed to warm water temperatures during their subsequent migration. Warm water temperatures have also been associated with high rates of PSM by Becker and Fujihara, (1978), Traxler et al. (1998) and Quinn et al. (2007). Positive correlations among PSM in Early Stuart sockeye, the cooling power of the Nechako at Finmoore and the temperatures in the downstream migration corridor are consistent with the preceding evidence. We speculate that the warmest temperatures encountered during migration (Stuart/Nechako corridor) are the most critical for successful spawning and most deserving of temperature management. However, Nechako cooling power estimates did not correlate well with temperatures in other reaches of the Fraser River (i.e. Hells Gate, their spawning grounds) where temperature during Early Stuart migration has also been correlated to PSM (Gilhousen 1990, Macdonald et al. 2000a). This apparent contradiction, and the degree of uncertainty in the influence of cooling power on PSM (Fig. 11), limits the use of the cooling power equation in combination with cooling control releases from Skins Spillway as a fishery management tool to compensate for losses to production. We conclude, as did Gilhousen (1990), that PSM cannot be attributed to a single environmental factor and require databases of greater duration and complexity for a more complete analysis.

A cold water release facility may open up new management options to manage flow and temperature for sockeye, sturgeon and other biota while giving greater flexibility to address the multiple interests including the production of hydro-electric energy. For example, water quantity savings during the summer could be redirected to create a more natural spring freshet for sturgeon recovery efforts (McAdam et al. 2005) or augment flows for other purposes at other times of year. Recently, a water-use needs exercise was initiated in the Nechako watershed to seek a compromise among the many public and commercial stakeholders. A model was used to collate and integrate each users requirement to seek an annual water release solution(s). (N-DAM, Bouillon 2004). For the purposes of protecting sockeye stocks, our analysis suggests that over 100cms of 12°C or 125cms of 14°C water is needed during the current temperature control period, which is considerably less than the range of STMP release rates of 158 to 213 cms since 1981. However, these estimates do not consider the importance of large water volumes for the purposes of cooling the Stuart/Nechako confluence and resisting water heating as it continues through the lower Nechako during the sockeye migration. Future temperature target models should perhaps consider the influence of the Stuart River during the period that the Early Stuart run is in the Stuart/Nechako corridor. However, the inclusion of unregulated tributaries (e.g. the Stuart) into the modelling and summer temperature management exercises could increase model complexity and the degree of management uncertainty.

Paradoxically, the use of a cold water release facility at Kenney Dam to avoid lethally high temperature thresholds at Finmoore and sites further downstream, could potentially lower temperature in the upper Nechako to suboptimum or even lethal levels. Populations of rainbow trout (*Oncorhynchus mykiss*), bull trout (*Salvelinus confluentus),* mountain whitefish (*Prosopium williamsoni)*, northern pikeminnows (*Ptychocheilus oregonensis)* and other fish species resident to the upper Nechako watershed (Brown

1995) are likely able to cope with gradual temperature change within their thermal histories and tolerances. However, the term cold shock stress has been used to describe the response to large, rapid reductions in temperature relative to thermal tolerance limits as might be expected should cold water releases be used as a component of a future Nechako River flow regime (Crawshaw 1977; Van Den Burg et al. 2005). Cold shock stress has been associated with a variety of lethal and sublethal effects in a variety of fish species. Rapid temperature reduction has elicited primary stress response as indicated by elevated plasma cortisol, in both rainbow trout (*O. mykiss*) (Barton and Peter 1982) and brown trout (*Salmo trutta*) (Hyvarinen et al. 2004), secondary stress response as indicated by blood lactate, glucose and osmoregulatory changes in Atlantic salmon (*Salmon salar*) (Galloway and Kieffer 2003) and rainbow trout (Reaves et al. 1968), and tertiary stress response such as reduced development rate (Hubert and Gern 1995), susceptibility to pathogens (Tierney et al. 2004), loss of equilibrium in juveniles (Clarkson and Childs 2000) and greater susceptibility to predation (Fuiman 1991). Rapidly fluctuating temperatures are considered stressful to much of the zoobenthos and fish below a dam on the Flathead River (Stanford and Hauer 1992). Much of the cold shock field research has focussed on thermal power plant effluent where the cold shock occurs during plant shutdown causing temperatures to return, often unpredictably, to ambient conditions. A cold water release structure at the Kenney Dam may operate more predictably and provide an opportunity to mitigate the rates and the degree of temperature alteration. However, literature related to the operation of cold water release facilities, their impact downstream as well as to the reservoir itself, is sparse. More investigation is required to understand their influence on biota particularly at the ecosystem and population level (Donaldson et al. in press).

Construction of a cold water release facility at the Kenney Dam may have many benefits beyond the ability to control outlet water temperature. In particular, during the STMP period, short-term spills can range from 14.2 - 538cms causing severe habitat alteration. Channels have widened and fine substrates have been lost, lakes have silted and water quality has declined (BCUC 1994). Therefore, diversion of water from Skins Spillway through the historic Nechako River reach below the Kenney Dam may provide restoration opportunities in the Murray-Cheslatta watershed (BCUC 1994). In addition, releasing water through the Kenney Dam facility directly to the Nechako avoids the capacitance effect experienced when water released from the Skins spillway must first pass through the Cheslatta system. Consequently, release response efficiency to meteorological forecasts is likely to increase and water savings will likely accrue. For instance, water normally dedicated to surcharging the Cheslatta system during start-up of the STMP operations (usually between July10th -19th), often creates unnecessarily large flows for early summer cooling (e.g. 1992, Triton 1995).

While water release facilities at Kenney Dam may have many positive environmental benefits, the release of large volumes of water to maintain temperatures during the salmon migration period is a proven management principle. Current temperature targets above the confluence of the Stuart River can be achieved with a reduction of water released at below ambient temperatures. However, because of the tendency of reduced volumes of water to warm more quickly when exposed to solar radiation and other atmospheric conditions, the water savings will be modest. Furthermore, when considering of the influence of Stuart River conditions on the lower Nechako River, reduced flows at Finmoore may result in warming of the salmon migration corridor, while temperatures in the upper reaches river are cooled to suboptimal levels. Temperature control has many positive benefits but should be evaluated in context with broader interests and in conjunction with reconsideration of the entire Nechako summer temperature management plan.

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Figure Captions:

Figure 1: The Nechako watershed with locations of data collection sites, salmon spawning sites and water corridors.

Figure 2: Mean daily discharge (cms) in the Nechako River at Vanderhoof during the entire year. Data spans the pre-dam, natural flow period (1950-52), the extreme

low flows when the reservoir was filling (1953-1956), the pre-STMP period during initial operation when greater water volume was released but releases where variable (1957-1982), and the present situation typified by more uniform releases of moderate volumes for a 30 day period for STMP cooling purposes (1983-2003).

Figure 3: Mean daily Nechako water temperatures at Finmoore in July and August during the present water diversion period (1953-2000). A polynomial fit to the data has an R^2 of 0.9824.

Figure 4: Annual mean temperatures (°C) experienced by the Early Stuart sockeye since the early 1950's during their return from the open Pacific Ocean to their spawning grounds north of Stuart River (Fig. 1). Entrance Island is in the Strait of Georgia 30 km. from the mouth of the Fraser River. Hells Gate is a high gradient reach of the Fraser River approximately 200 km upstream from the river mouth. Stuart River mean temperatures are graphed with annual maximum temperatures indicated by individual dots. Data sources are provided in Table 2.

Figure 5: A comparison of mean annual Skins Lake water release volume (cms) and mean annual summer temperatures (°C) at Prince George between 1981 and 2002. Three years are indicated during which forced spills occurred beyond those needed to control summer temperature. A fourth year, 1997, is not shown (15.7°C x 284.2 cms). The regression equation, p-value and 95% confidence limits are provided. The R^2 for the relationship was 26.5% but improved to 39.6% ($p<0.004$) when years with forced spills were removed. Both 1995 and 1998 were chosen as being representative of cool and warm years respectively.

Figure 6: Predictions of mean annual water temperature (°C) at Finmoore in July and August from 1981 to 2002 using the regression model described in Table 5. Three Finmoore flows scenarios were considered; actual (STMP), the actual baseflow without the STMP (53 cms) and a simulated baseflow without the STMP (15 cms). Flow calculations at Finmoore were modified based on a 4D lag in water release from Skins spillway.

Figure 7: The effect of reduced flows from the Skins spillway on deviations in annual mean Nechako water temperature below the confluence of the Stuart. Reductions were based on the elimination of the STMP flows and the adoption of a baseflow release strategy of 53 cms. Deviations are calculated for the period the STMP was in effect (July 10th – August 20th) and for the briefer period, calculated annually, when Early Stuart sockeye were migrating through the Nechako system in July and early August (Table 1).

Figure 8: Daily summer water temperature predictions resulting from the modelling of various indicated Kenney Dam release volume and release temperature scenarios, at four locations in the Nechako/Stuart watershed. Release volume was based on a percentage of the actual volumes released from the Skins spillway during warm

(1998) and cool (1995) years. A horizontal 20°C line identifies the STMP target temperature at Finmoore and a value that approaches the biological limit for migrating salmon. The top left and right graphs are approximately represent the actual conditions in 1995 and 1998 respectively.

Figure 9: Daily summer water temperature predictions resulting when a baseflow of 53 cms of water is released from Kenney Dam at 10°C. The model uses mean meteorological and tributary conditions during the past 30 years as input. The 20 °C temperature target at Finmoore is indicated with a horizontal line. Historically Early Stuart sockeye can enter the Nechako during a period spanning several weeks as described by a dashed horizontal line above the x-axis (Table 1).

Figure 10: A model rendition of downstream temperature convergence of small quantities of water (25 cms) released at seven different temperatures from the Kenney Dam (Reach 1) and tracked by reach to the Stuart confluence (Reach 34). Input from 2 major tributaries and the temperature target site at Finmoore are indicated. Coined the "rake effect", it is most apparent at low flows but demonstrates the tendency for cool water to warm at a greater rate than water with a temperature near thermal equilibrium regardless of volume.

Figure 11: Number of days when modelled Finmoore water temperatures will exceed the STMP target of 19.6°C as a consequence of 28 scenarios with differing water volumes (cms) and temperatures (°C). Temperature and volume were modelled below the Cheslatta/Nechako confluence.

Figure 12: Annual cooling power of the Nechako at Finmoore (equation 3) as a predictor of pre-spawn mortality (PSM) among Early Stuart sockeye between 1952 and 2003. Data points are identified for select years. PSM values are ln+0.1 transformed to remove the tendency for PSM to vary with the mean and to provide a linear rendition of the data. The regression equation, p-value and R^2 are provided.