Alouette Project Water Use Plan

Alouette Water Temperature

Implementation Year 7

Reference: ALUMON-5

Alouette Water Temperature – 2014

Study Period: 2014

Greenbank Environmental Inc. &
Creekside Aquatic Sciences

June 30, 2015

Alouette Water Temperature Monitoring: Program No. ALUMON #5

A Summary of Water Temperature Conditions in the Alouette Lake Watershed for the Year 2014 and a Review of Management Questions

Technical Report: CAQ-011

June 30, 2015

Prepared for

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Executive Summary

Water temperature in the Alouette River downstream of the Alouette Dam continues to be a concern for BC Hydro, environmental agencies and stakeholders. To address these uncertainties, BC Hydro has commissioned a monitoring program to measure water temperatures at various locations in the watershed to assess the risk of a high temperature event capable of impacting fish populations, as well as explore feasible operational changes that can be taken to mitigate such impacts. This Year 7 report summarizes the 2014 temperature data and provides comparisons to earlier years. This considered the last year of data collection for the monitoring program and therefore includes a comprehensive discussion regarding the programs management questions.

River and reservoir temperatures where generally within the range of historical values, with the exception of the mid-September to mid-November period when daily average temperatures often exceeded historical maximum values. Plunge pool temperatures during these high temperature events were on average 0.4°C higher than historical maxima. This increased to 0.6°C at the Allco Hatchery site. Unfortunately there were no data for this time period for the 224th St Bridge site due to logger failure. Five warm water events (defined here as temperatures > 21°C) occurred in 2014. All occurred in late August and none last more than a few hours on a given day. Maximum instantaneous temperature was 21.27°C recorded at the plunge pool site on August 29.

Meta-analysis of the 1999 to 2014 monitoring data led to the following conclusions as they relate to the management questions posed by the WUP consultative committee (BC Hydro 1996, 2006):

1. Water temperatures in Alouette River do not approach or exceed 25°C, the upper incipient lethal limit for most salmonids. In fact, water temperatures rarely exceed 21°C, the upper sustained temperature limit. The highest ever recorded instantaneous temperature was 22.88°C.

2. In those cases when temperature was > 21°C, it was usually only for a short period of time during the day. On two occasions the warm water event lasted an entire day. One event lasted two days, the longest duration for the period of record.

3. Warm water events were not always present in the entire river. Only 9 of the 35 warm water events that appeared at the Plunge Pool site was observed at all sampling sites on the same day. In most cases, the warm waters at the plunge pool tended to cool when traveling downstream. At other sites, local conditions could trigger a warm water event that may or may not persist at downstream locations.

4. Overall, water temperatures were highest at the Alouette Dam's plunge pool. Temperatures at the site were largely governed by reservoir conditions, including the development of summer thermoclines, the effect of seiching, water source to the plunge pool, and reservoir elevation. When these waters traveled downstream there was generally no change in temperature during the late fall and winter, a warming trend during spring to early summer, and a cooling trend during summer to late fall. The magnitude of these warming and cooling trends varied considerably, but on average was less than 2°C

5. Temporal plots of annual mean summer temperatures (July to September when temperatures are at their highest) found no evidence of a thermal regime shift over the course of the

monitoring period. As a result, a shift in fish community structure from a hypothesized persistent warming was considered unlikely in the near term. This conclusion however, could not be directly tested as the abundance data for summer rearing salmonids was confounded by changes in methodology over time. Temperature related changes in fish community structure continue to be a possibility longer term.

6. There are operational changes that can be made to mitigate the occurrence of warm water events; principally increasing the reservoir water level so that the LLO intake can extract cooler waters deeper in the thermocline. To achieve this however, there may be increased flooding risks later in the year. Given that water temperatures are generally within the tolerance limits for all salmonid species for most of the summer time period, and that warm water events > 21°C are generally rare and have durations less than a day, implementation of such operational changes were unnecessary at this time.

Though the water temperature monitoring program was able to address all management questions and made significant contribution to the understanding of Alouette River's annual temperature cycle, there remained a number of uncertainties. Five topics of future study are recommended moving forward.

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Introduction

Background

Water temperature in the Alouette River downstream of Alouette Dam continues to be a concern for BC Hydro, environmental agencies and stakeholders. Initially, these concerns dealt primarily with elevated in stream temperatures that not only impacted summer rearing fish, but also operations at the Allco Fish Hatchery. These issues were addressed in 1996 during a Water Use Planning (WUP) exercise where it was decided to fully open the Alouette Dam's Low Level Outlet (LLO) structure, thus increasing the facility's water release to its maximum of about 3 m^3/s (BC Hydro 1996). Unfortunately, no formal monitoring was carried out to determine if this change in operation was sufficient to fully resolve the high temperature issue. In 2004, a review of the operational change and its effects downstream was carried out where all review participants generally agreed that temperature conditions appeared to have noticeably improved. This however, was based on largely on anecdotal observations. Some uncertainty still remained about the possibility of high water temperature impacts during late summer that could negatively impact salmonid productivity in the system, as well as potentially allowing warm water fish species to invade the watershed (BC Hydro 2006)

To address these uncertainties, BC Hydro commissioned a water temperature monitoring program to track changes in water temperature over time at various locations in the watershed (including the reservoir). The objective was to better quantify the frequency, duration and magnitude of high water temperature events, as well as explore the range of feasible operational changes that could be implemented to help mitigate potential impacts. This document reports on Year 7 of the monitoring program, which summarizes the water temperature data collected in 2014. This report also summarises a more complete analysis and assessment of the temperature data collected to date, as well as review the findings of past reports. This information was then used to address the management questions identified in the initial terms of reference for this monitoring work.

Management Questions

The Water Use Plan Consultative Committee (WUP CC) identified the following management questions that will be addressed by this temperature monitoring program.

1. How often are water temperature ≥25°C, the incipient lethal water temperature of most stream rearing salmonid species, including the duration of each event and the frequency of occurrence?
2. Is the duration of observed warm water events less than 1 day, thus limiting exposure to warm waters and thermal stress impacts?
3. Are warm temperature events restricted to certain sections of the river, indicating the inflow of cooler waters into the system (most likely ground water)?
4. Is the frequency and duration of warm water events such that it would promote a shift in community structure and/or reduce survival and growth of rearing juvenile salmonids, as indicated by a change in smolt numbers?
5. Given the extent of thermal stratification in the reservoir and the location of the LLO, is there an operational change that can be implemented to mitigate the occurrence of warm water events?

Table 1. Site description of water temperature sampling locations.

Sample Site	Description
LLO	*Directly adjacent to the LLO outlet for a direct measu re of water temperature leaving the Dam.*
Plunge Pool	*Immediately downstream, of the Alouette Dam plun ge pool approximately 50 m downstream of the LLO on the left bank of the river. The location will measure the effect of the plunge pool residence time on outflow water temperatures.*
Mud Creek	*On the left bank of the river just upstream of the Mu d Creek confluence.*
ARMS	*On the left bank of the river approximately 50 m dow nstream of the Alco Park hatchery.*
224^{th} St	*On the right bank of the river approximately 100 m u pstream of the 224th Street bridge.*

Methods

Field methods

Temperature data were collected from both the Alouette Lake reservoir and in the Alouette River between the Alouette Dam and 224th Street in Maple Ridge, BC (Figure 1). Temperature monitoring in the reservoir was done using a string of 5 temperature data loggers hanging off of the LLO gate tower. The string of loggers was orientated vertically with a 2 m spacing between units starting at an elevation of 124 m. The lowest logger unit was located at 114m El, roughly 1 m above the LLO intake gate, which is vertically oriented with a sill elevation of El 112.9 m and a trash rack elevation of El 113.5m. Temperature data loggers were also installed at five locations on the South Alouette River between the Alouette Dam and the 224th Street bridge-crossing (Table 1).

The temperature data loggers used in this monitor were TidbiT V2 Temp Logger (Part # UTBI-1) manufactured by the Onset Computer Corporation. The operational temperature range of these loggers was from -20°C to 70°C in air and have a maximum sustained temperature of 30°C in water. The accuracy of the loggers was 0.2°C over a range of 0 to 50°C. Throughout the monitoring program, the loggers were set to log temperature at hourly intervals at all locations. The loggers were downloaded in the field at regular 4 month intervals. At this time, unit functionality was verified along with temperature accuracy. When necessary, the units were either replaced and/or recalibrated to a standard thermometer. All temperature data were stored as a comma delimited file (.csv) and later converted and stored in the form of an excel spreadsheet.

Analysis of Monitoring Data

All data analysis in this report was carried out on daily average (T_{Avg}), maximum (T_{Max}) or minimum (T_{Min}) values calculated from the logged hourly data. Hourly data were only available from 2008 onward. Data in earlier years was provided by BC Hydro in daily mean, maximum and minimum format only. All data were stored in Excel spreadsheets for analysis, which consisted mainly of between-site or between year/season comparisons using summary statistics. To facilitate these comparisons, plots were used that compared the relationship of temperature data set to a line of equality (i.e., a regression line with a slope of 1 and an intercept of 0). Because data sets were so large, data markers were set to be 90% transparent so when stacked on top of each other, the markers became darker providing an indication of local data density. Thus areas in the plot with very dark shading indicated a high frequency of similar observations while areas with low shading tended to identify infrequent observations. Each of these plots were analysed by looking for data patterns that deviate from the line of equality. In addition to these bivariate density plots, data sets were also plotted as time series. These were used to explore seasonal trends that may have differed between years.

Warm water temperature events were defined in the terms of reference for this monitor (BC Hydro 2006) as periods of time when water temperatures are > 25°C, the upper incipient lethal temperature of most Pacific Northwest salmonids (Jobling 1981, Sullivan et al. 2000). Such warm temperatures however, were not encountered over the duration of the monitoring period, requiring an alternative definition. In this case, we lowered the threshold temperature to 21°C, the upper sustained temperature limit of most salmonids (Brett 1952, Greenbank 2009), which is also similar to the upper limits of the thermal preferendum envelope defined in Sullivan et al. (2000). An event was considered short term if T_{Max} > 21 °C, but T_{Avg} < 21 °C, indicating that the 21°C threshold was only exceeded for a short period (e.g., a few hours) in a given day. Days when T_{Avg} > 21°C was considered a longer term event and could have a duration of one or more consecutive days.

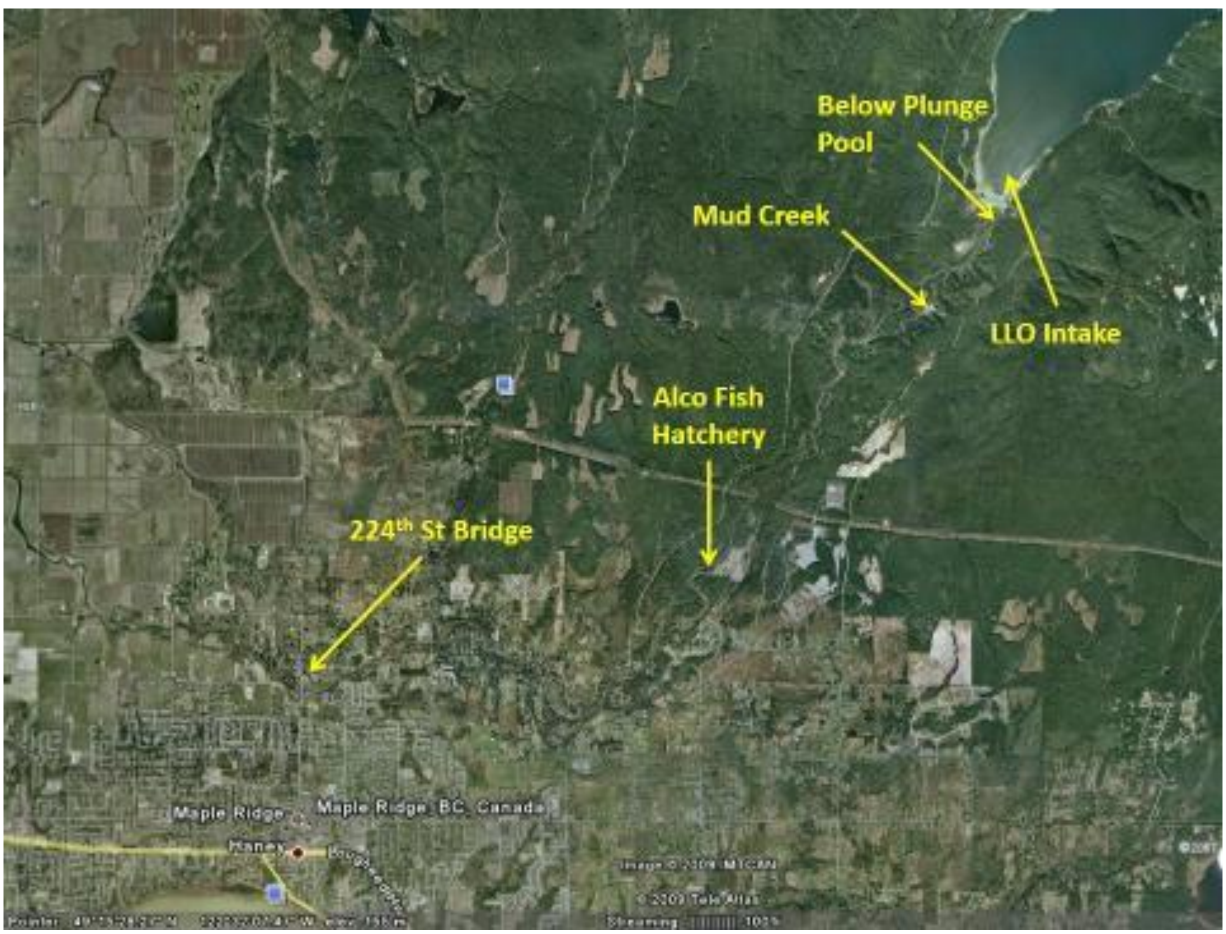

Figure 1. Air photo of Alouette River showing the water temperature sampling locations as described in Table 1.

Results and Discussion

2014 Data

Alouette Lake

Unlike the previous two years, reservoir temperature data were successfully collected in 2014 without incident (Figure 2). The temperature data logger at El 124 m however, was rarely submerged in 2014 and therefore only recorded local air temperature. The data was excluded from analysis. There were extended periods of time when the logger at El 122 m was also out of the water; most notably the first two weeks of January, the month of February, the latter half of September and most of October.

The data in Figure 2 which show a gradual rise in forebay water temperatures over the spring and early summer months. In addition to this rise, there was a gradual widening in difference between surface (El 122 m) and LLO intake (El 114 m) temperatures. The difference in temperature reached its widest point in early August, after which surface water temperatures began to cool. LLO intake waters continued to rise during this period, reaching a peak in early September. By mid-September, surface and intake waters had converged to an average of 19.5 °C throughout the water column and a temperature gradient was no longer evident.

This pattern of thermocline development was consistent with those recorded in 2009 through 2011 (Bruce and Greenbank 2013) and well as in the thermocline data collected by MOE since 1998

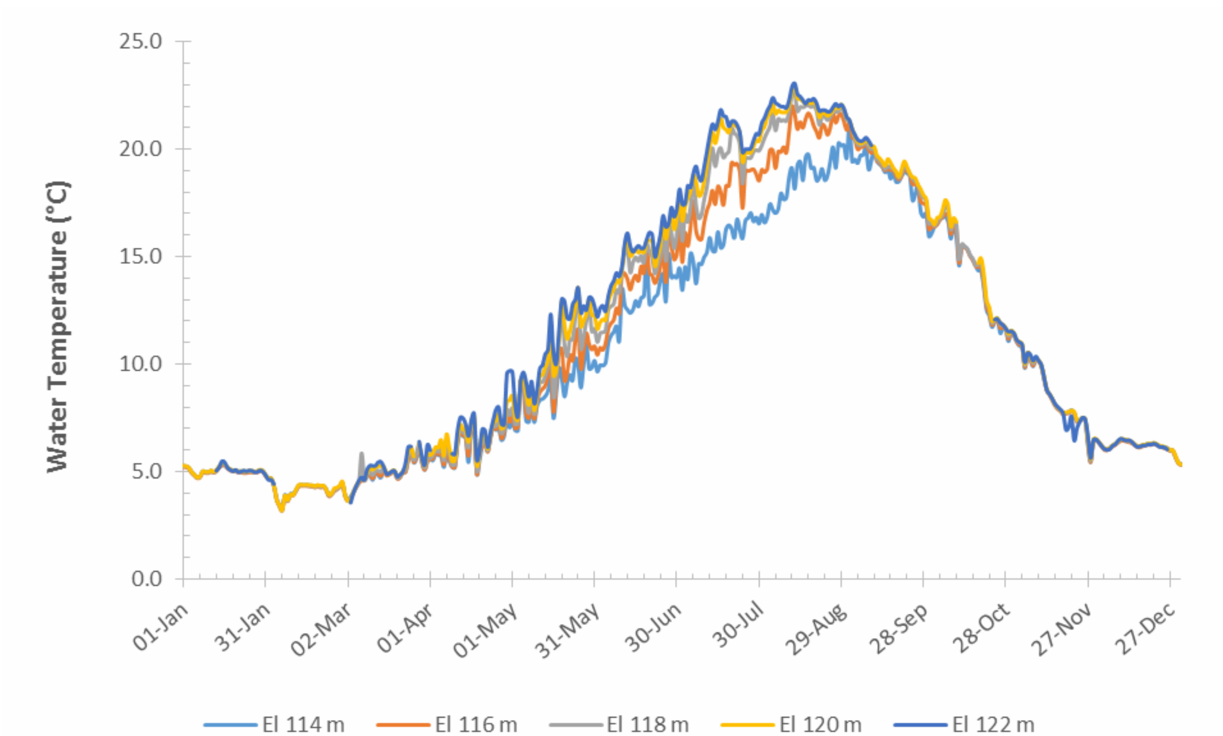

Figure 2. Plot of reservoir water temperatures recorded in 2014 at 5 different elevations in the water column. Though a data logger was placed at El 124 m, it was rarely submerged in the water column and therefore excluded from analysis. Also evident in the plot are gaps in the EL 122 m time series, reflecting time when it too was out of water.

Table 2. Summary statistics showing the frequency that thermoclines develop in Alouette Lake Reservoir, the average depth of the epilimnion, the average surface temperature, and the average temperature density marking the start of the metalimnion. The statistics are based on data collected by MOE since 1998 to present.

Month	No. of Profiles	Profiles with dt/dz > 1.0	Mean Depth (m)	SD	Mean Temp (°C)	SD	Mean dt/dz (°C/m)	SD
April	15	0	-	-	8.1	1.9	-	-
May	24	7	6.4	1.3	12.2	2.6	1.5	0.2
June	25	13	6.6	2.3	15.8	2.6	2.1	0.6
July	20	19	7.4	1.3	20.2	2.1	2.3	0.9
August	20	19	8.5	1.0	21.3	1.8	2.4	0.9
September	20	19	9.7	1.6	19.0	2.1	2.1	0.9
October	13	4	11.5	1.7	13.3	2.0	1.6	0.4

(Bruce and Greenbank 2014). In both cases, the depth and average temperature of the epilimnion increased over time starting in May (Table 2). By late-August/early-September, the depth of the epilimnion typically reaches or exceeds the LLO intake elevation of El 112.9 m (August water surface elevation is normally greater than El 122.5 m; BC Hydro 2013). Also, after the first week of September, the reservoir is drafted in preparation for higher inflows due to the upcoming seasonal fall rains. Both events have the net effect of placing the LLO intake more into the epilimnion than the cooler thermocline. The end result is that at this time of the year, the LLO no longer supplies cooler thermocline waters downstream.

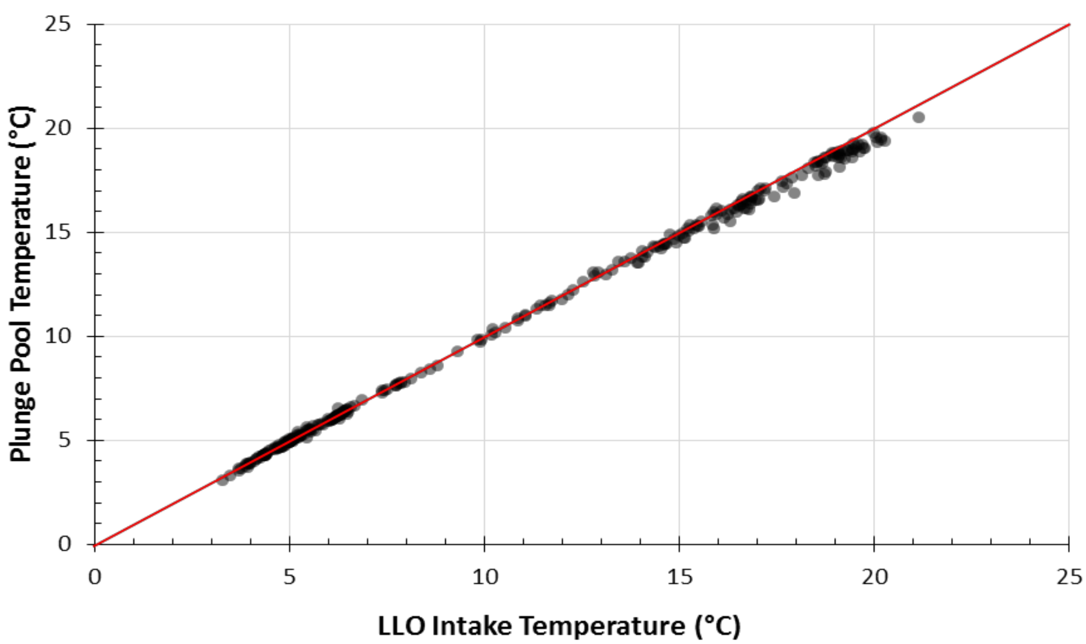

Figure 3. Plot of plunge pool and LLO intake (El 114 m) temperatures comparing the two. Solid read line indicates the line of equality.

A comparison of water temperatures recorded at El 114 m to that at the LLO outlet in the plunge pool found at very high degree of correlation when the LLO was in use (Figure 3). Plunge pool temperatures were generally within a 0.8 °C range of El 114 m temperatures year round. However there was a slight tendency for EL 114 m temperatures to be up to 0.5 °C cooler when plunge pool temperatures were > 15 °C, indicating that there may have been some localised heating at the plunge pool site, either by local inflows (e.g., dam leakage flows) or direct solar heating. During the surface release period (April 15 to June 15), plunge pool temperatures were more closely related to surface temperatures in the reservoir (R^2_{Adj} = 0.991, P< 0.0001), which tended to be slightly warmer (Figure 2). The high correlation between the LLO intake and plunge pool data sets is consistent with the patterns observed in previous years and affirms the notion that water extraction at the LLO intake is highly localised and limited to a layer of water about 1 -2 m above the intake pipe sill (Bruce and Greenbank 2013, 2014).

The epilimnion immediately above the LLO Intake structure was slightly warmer during the late summer months (July to September) than in previous years (Figure 4). The difference in temperature approached 2 °C at the water surface, which persisted to a depth of 4 m, but gradually narrowed to less than 1°C near the intake structure itself. Given the relationship between LLO intake temperatures and that of the plunge pool, warmer water temperature downstream of the dam would be expected. This was indeed was the case.

Alouette River

Plots of the 2014 water temperature data collected at each site found that river temperature conditions were generally within the range observed since the start of data collection (Figures 5a to d). This included the normally warm months of July through to mid-September, indicating that the draft of cooler thermocline waters at the LLO intake had the desired effect of providing cooler thermocline waters downstream. Average plunge pool temperatures during the period was 17.5°C (Range = 13.5 to 20.5°C), which was found to decrease slightly with distance downstream of the dam. Average water

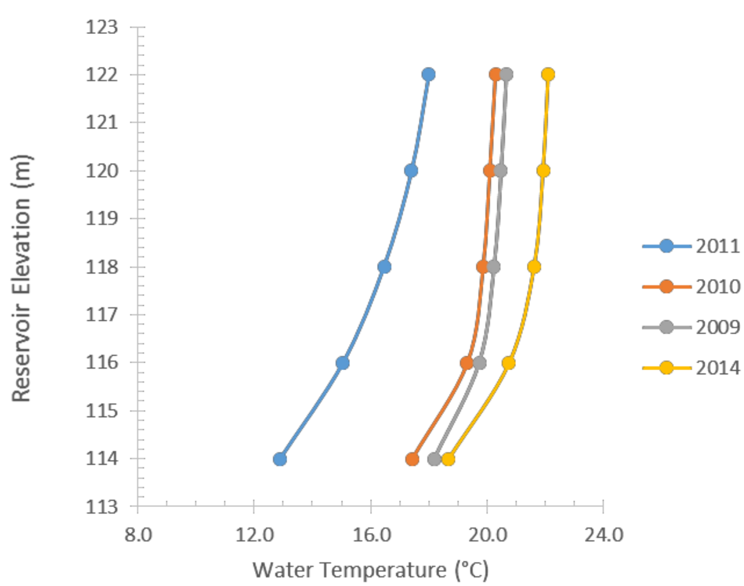

Figure 4. Average late summer water temperature of epilimnion immediately above the LLO intake at the Southern end of Alouette Lake Reservoir.

temperature at the Allco Hatchery site was 17.1°C (Range = 14.1 to 19.3°C). Unfortunately, no data was available for this time period at the 224th St. Bridge site due to logger failure. Nevertheless, the temporal and spatial pattern of water temperatures for this time of year was consistent with the data collected in previous years, falling more or less in line with historical median values (Figures 5a to d).

This typical pattern however, did not persist into the mid-September to mid-November period where daily average temperatures often exceeded historical maximum values. At the plunge pool site, roughly one third of this 60-day period (22 days) experienced record high temperatures, which on average was 0.4 °C (Range = 0.02 to 0.83°C) warmer than the corresponding pre-2014 historical maxima. At the Mud Creek site, the frequency of 'record breaking' temperatures increased to 37 out of 60 days (62%), along with the average "breakout" temperature which had increased to 0.7°C (Range = 0.03 to 2.19°C). The frequency of 'record breaking' temperatures increased further still at the Allco Hatchery site, where two thirds of the 60-day period had higher than historical maximum temperatures. In the latter case however, the average increase in maximum temperature was only 0.6°C (Range = 0.01 to 2.18°C), slightly less than at the Mud Creek site. Unfortunately, no data was available for this period at the 224th St. Bridge site due to logger failure. Regardless, the data do suggest that some instream warming did occur in the Alouette River at this time, contributing to the higher than normal values.

Equally important were the record warm water temperatures observed at the Plunge Pool site itself, indicating that reservoir condition had also played a role. After the Labour Day long week end (September 9), the process of drawing down the Alouette Lake Reservoir had begun in anticipation of increased local inflows typical of the fall season. As water levels dropped, so did the lower depth limit of the epilimnion, which also continued to increase in total depth (Table 2). As noted earlier, this in turn had the effect of placing the LLO intake structure more into the epilimnion than in the thermocline zone where it had been for much of the summer period. With the warmest epilimnion temperatures recorded to date for this time of the year (19.5°C in mid-September), it lead to some of the warmest September to November Plunge Pool water temperatures since year 2000. The effect of these slightly warmer temperatures on downstream fish ecology however, are uncertain as the difference in temperature for the most part were less than 1°C.

General Discussion

Given all of the reservoir and river temperature data collected as a result of this monitoring program, as well as the reservoir data provided by MOE, its meta-analysis has led to a reasonably good understanding of the Alouette River's temperature dynamics and the role of thermocline development in the reservoir has in shaping it. Starting in winter when Alouette Lake reservoir is fully mixed and uniformly cold at an average temperature of 5°C, the LLO delivers water to the Alouette River that is similar in temperature. As this water travels downstream, there can be a slight warming or cooling depending on the prevailing weather such that variance in temperature increases with distance. This increasing variance with downstream distance is a persistent feature throughout the year.

In March, as ambient air temperatures and total solar irradiance levels begin to rise, outflows to the Alouette River begin to warm as they travel downstream. After several weeks, outflow temperatures themselves begin to warm as reservoir waters also respond to this ambient warming trend. By mid-April, near-surface water temperatures will have increased to about 8°C with the beginnings of a thermocline forming roughly 6 m below the surface. Outflow temperatures will have increased slightly as a result of this forming thermocline, typically by about 1°C. As these outflows travel

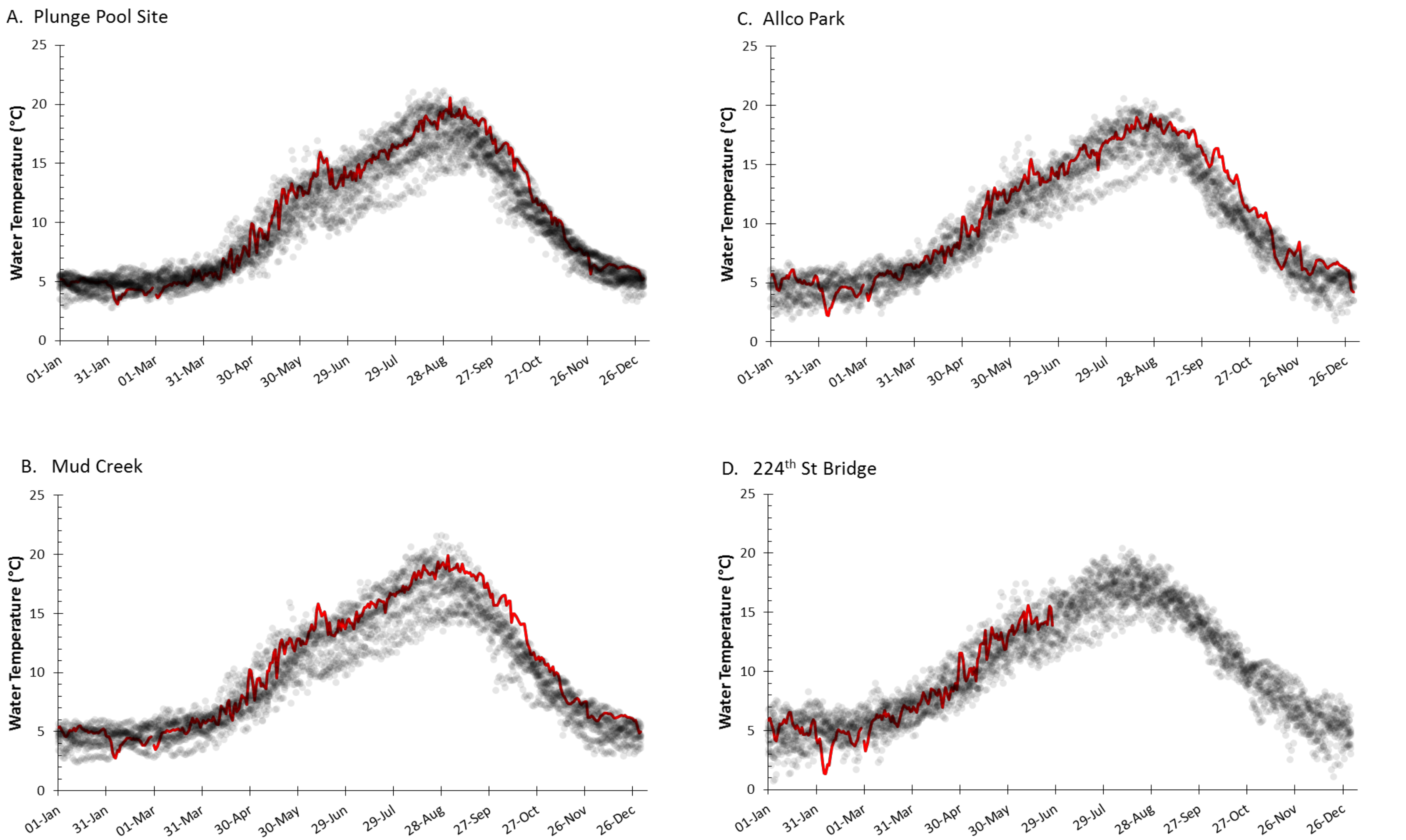

Figure 5. Plot of 2014 Alouette River water temperatures (red line) at four locations in the watershed downstream of Alouette Dam. These are plotted against a backdrop of all data collected at each site since year 2000. For the latter data, the darker the symbol, the greater the local density of observations.

downstream, there is considerable warming that can occur, such that on average, water temperatures at the 224th St Bridge are generally 2°C warmer than at the plunge pool. It is at this time of the year when the largest in-river temperature increases typically occur. On April 15, the LLO is shut down and the spillway is opened to allow for a surface release from the reservoir. Up to this point, plunge pool and the immediate upper layers of the LLO intake pipe were highly correlated. With the surface release, this correlation breaks down to be replaced by a correlation with surface water temperatures in the reservoir. This introduces a lot of variability in downstream water temperatures, largely because the reservoir's water surface tends to be much more responsive to changing ambient conditions. Overall, there is a tendency for plunge pool temperatures to become slightly warmer as a result. This warming trend becomes more pronounced towards the end of the spring surface release operation, which ends June 15. This warming trend corresponds to an increasing development of a warming epilimnion and a more pronounced thermocline. As well, during this period, water temperatures continue to warm with distance downstream, but the extent of this in-river warming begins to wane (presumably due to shading as trees become fully leafed).

With the end of the spring surface release and resumption of LLO outflows, there tends to be an immediate cooling effect in the plunge pool as cooler thermocline waters are now being released. The drop in temperature is typically in the order of 1.5°C, but can vary considerably from year to year depending on the extent of thermocline development at the time of spillway closure. LLO intake and plunge pool temperatures again become highly correlated, and resume the warming trend as the epilimnion deepens and warms up further. It is important to note that the depth of the thermocline above the LLO is generally not as deep as in the reservoir center. Seiching as a result of daily thermal winds appears to push some of the warmer epilimnion waters to the north of the LLO causing an upwelling of cooler waters near the LLO. As a result LLO intake temperatures tend to be on average 4°C cooler than would be expected if the seiching action did not occur (Bruce and Greenbank 2014).

A critical point is reached in mid-August when LLO waters are no longer heated while traveling downstream and marks the start of a seasonal cooling trend. The reason for this is uncertain but is likely related to the shortening day length and cooler evenings. This point also coincides with peak summer temperatures at the 224th St Bridge, which have averaged 17.4°C since the start of monitoring in year 2000. Maximum daily average temperature recorded for this time of year was 20.4 °C, and the highest instantaneous water temperature ever recorded was 21.8°C for this site. After this point, downstream temperatures begin a general cooling trend that lasts till winter. Epilimnion temperatures in the reservoir however, continue to increase at this time and does not typically reach its peak for another two weeks. This is reflected in the LLO outflow temperatures at the plunge pool, where peak daily average temperature have averaged 18.0°C for the period of record. Maximum daily average temperature recorded at the plunge pool site for this time of year was 20.8 °C, while the highest instantaneous water temperature ever recorded was 22.9°C. At no point throughout the reservoir has water temperature ever approached or exceeded the incipient lethal temperature of 25°C for salmonids.

For much of the summer period, reservoir elevation is held relatively constant at El 122.5 m to meet the recreational requirements of Golden Ears Park. Following the Labour Day weekend in September, however, the Alouette Lake Reservoir is drawn down over a period of several weeks in preparation to accept the seasonal increases in local inflow due to the fall rains. During this drawdown period, the depth of the epilimnion continues to grow, but now starts to cool due to lower solar inputs. As the reservoir is drawn down, both processes place the LLO intake more into the epilimnion, forcing it to draw more from its warmer waters than the cooler thermocline. The cooling trend that occurs at this time however, tends to limit the warming effect on LLO releases, which is cooled further as it travels downstream.

By the beginning of November, average water temperature become more or less uniform throughout the river system, and continues to cool to the winter low of roughly 5°C by the end of December. This marks the end of the annual temperature cycle of Alouette Lake Reservoir and its outflows to the Alouette River. This cycle forms the back drop from which the management questions listed in the Introduction are discussed below.

Management Questions

The terms of reference for the water temperature monitoring program listed five management questions to be addressed. Included with these management questions were five testable impact hypotheses that helped frame the management questions in a statistical context. The following section discusses each management question separately, including any associate impact hypotheses.

Question 1

How often are water temperature ≥25°C, the incipient lethal water temperature of most stream rearing salmonid species, including the duration of each event and the frequency of occurrence?

At no time since monitoring started in 1999 has water temperature approached or exceed the 25°C upper incipient lethal limit, regardless of study location. Maximum daily average water temperature for the period of record was 21.58°C measured at the Mud Creek site on August 28, 2013. Maximum instantaneous water temperature was 22.88°C measured at the Plunge Pool site on August 8, 2004

Question 2

Is the duration of observed warm water event less than 1 day, thus limiting exposure to warm waters and thermal stress impacts?

Because maximum instantaneous water temperature never exceeded 25°C, the temperature threshold that originally defined the onset of a warm water event, the literal answer to this question mirrors that of Question 1. However, changing the threshold that defines a warm water event to 21°C, the upper temperature limit that most salmonids can tolerate indefinitely (most notably the upper sustained temperature limit for juvenile steelhead and thermal avoidance limit for adult sockeye, (Greenbank 2009), additional insight on potential thermal impacts can be gained. Since 1999, there were a total of 35 warm temperature events when maximum instantaneous water temperatures exceeded the 21°C threshold for one or more days. Of these, 32 events (91%) had an average daily mean water temperature that was < 21°C, indicating that the duration of theses "warm water events" was less than 1 day. Two of the three remaining events had an average daily mean temperature > 21°C and each lasted only a single day. The last event had a duration of two consecutive days. It should be noted that these statistics pertain to water temperatures measured at the Plunge Pool site and that downstream values tended to be cooler. Thus over the last 15 years, the occurrence of water temperatures outside the upper limits of indefinite tolerance was relatively infrequent and when such incidents did occur, lasted less than one day 9 out every 10 events. At no time was water temperature sufficiently warm to cause irreversible harm (i.e., > 25°C). Given this information, the impact hypothesis associated with this management question:

$H_0$1: The duration of warm water events are greater than the tolerance threshold (maximum temperatures that can be tolerated for periods less than 1 day) for rearing salmonids

can be rejected as the upper incipient lethal limit (the temperature at which 50% mortality occurs over a minimum 7 day period, accounting for the effects of acclimation) was never encountered during the monitoring period. Furthermore, the upper lethal limit, the temperature at which mortality can occur within minutes is in the range of 27 to 30°C for salmonids (Jobling 1981), which also was never encountered during the monitoring period.

Question 3

Are warm temperature events restricted to certain sections of the river, indicating the inflow of cooler waters into the system (most likely ground water)?

A plot of average daily water temperatures at each of the sampling sites (Figure 5 a to d) suggest a progressive warming trend as water travels downstream from the LLO during the spring and early summer periods, and a cooling trend during the summer and fall periods. The net effect of these warming and cooling trends is illustrated in Figure 6. In all years the highest water temperatures occurred in the plunge pool area and was largely a direct result of LLO releases from the reservoir environment (e.g., Figure 3).

As noted above, 35 warm water events (>21°C) were identified at the plunge pool site. This frequency drops to 23 events at the Mud Creek site, all of which were less than 1 day in duration. Furthermore, only 17 of these events occur on the same days as the Plunge pool site, suggesting localised effects may play a small role, either heating or cooling discharges from the LLO. At the Allco Hatchery site, the frequency of warm water events increases to 30, all of which are also less than 1 day in duration. Only 21 of these correspond to the timing of events at the Mud creek site, and only 15 have common dates with both upstream sites. A similar pattern emerges at the 224th St Bridge site where

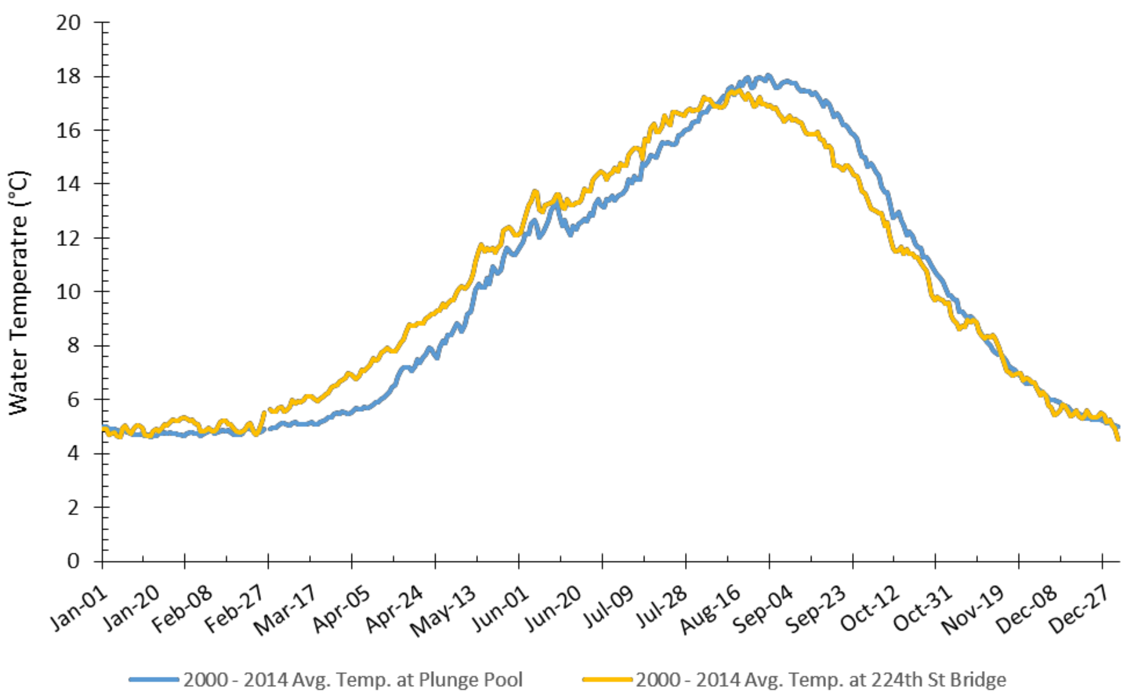

Figure 6. A comparison of 14-year daily average water temperatures collected immediately below the Alouette dam in the Plunge Pool and at the 224th St Bridge site showing the attenuating effects of heat transfer as water travels downstream from the Dam.

there were a total of 29 warm water events, all less than 1 day in duration. In this case, only 9 events occurred on the same days as all other sites, and 14 were unique to that site. Collectively, the data suggest that warm water events that originate at the plunge pool site tend to cool as these waters travel downstream, but not all. Furthermore, thermal conditions unique to each site can create short term, localised warm water events that may or may not cool as it travels downstream. Thus there can be considerable variation in water temperature from site to site despite the general warming or cooling trends that may occur on a river-wide scale.

Five impact hypotheses were identified as part of this management question:

$H_0$2: Average daily water temperatures are similar between sections.

The data collected to date showed that there were indeed small differences in water temperature between river sections. There was a tendency for a slight warming trend in the spring and early summer that may increase temperatures by up to 2°C on average as water travels from the Alouette Dam to the 224th St Bridge. Later in summer and in the fall, there was a tendency for a slight cooling trend that may reduce temperatures by up to 1.5°C on average. This null hypothesis is accepted.

$H_0$3: Average daily peak water temperatures are similar between sections.

The temporal trends observed for peak daily temperatures are similar to that described for average daily temperature. This null hypothesis is also accepted.

$H_0$4: Average duration of warm water events is similar between sections.

Regardless of how a warm water event was defined, there was little difference in duration between sampling sites. All events at the Mud Creek, Allco Hatchery and 224th St Bride site were less than 1 day in duration (i.e., average daily temperature was less than the peak daily temperature). This was also the case at the plunge pool site for 9 out of every 10 events. Two events at the plunge pool site lasted a single day, while the longest event lasted 2 consecutive days. Though duration was not identical between all sites, it was sufficiently similar to accept the null hypothesis.

$H_0$5: The frequency of warm water events is similar between sections.

The frequency of warm water events ranged from 23 to 35 events between sites over the course of the monitoring period. A simple Chi Square test showed these frequencies were not significantly different from one another (X^2 = 2.487, P = 0.478), thus the null hypothesis is accepted. It should be noted again that although the frequency of events were similar between sites, the dates of these events did not always coincide, suggesting that local thermal conditions, along with larger scaled warming and cooling trends, jointly play a role in developing site specific warm water events (here again defined as periods with water temperatures > 21°C)

Question 4

Is the frequency and duration of warm water events such that it would promote a shift in community structure and/or reduce survival and growth of rearing juvenile salmonids, as indicated by a change in smolt numbers?

Unfortunately the juvenile salmonid abundance data collected by Cope (2015) has been confounded by several changes in sampling methodology over the course of the monitor, thus a test of hypothesis $H_0$6 below was not possible.

$H_0$6: Variability in smolt output, as measured in Monitor 1, is correlated with the occurrence of warm water events.

However, a plot of mean summer temperature (from the start of July to the end of September) at the Plunge Pool site over time found no detectable increasing or decreasing trend over the course of the monitoring period (Figure 7). The warmest summer occurred in 2006 (T_{Avg} = 18.2°C), followed by 2004 (T_{Avg} = 18.1°C) and 2013(T_{Avg} = 17.6°C). The coolest summers occurred in 2011 (T_{Avg} = 13.5°C), followed by 2008 (T_{Avg} = 15.9°C) and 2000 (T_{Avg} = 15.2°C). The grand mean summer time temperature across all years was 16.5°C.

The most frequent occurrence of warm water events where 21°C was the threshold temperature was in year 2004 when 15 such events occurred. All but two of these events were less than 1 day in duration. The latter two events lasted only a single day. The next most frequent year was 2013 when nine warm water events were recorded. Eight of these lasted less than a single day, while the remaining event lasted two consecutive days. Five warm water events occurred in years 2003 and 2014, while only a single event occurred in 2012. There were no warm water events recorded in any of the remaining years. This distribution of warm water events over time do not appear to follow any kind of increasing or decreasing trend over time and aligns with the average temperature data to confirm that thermal conditions in Alouette River have remained relatively stable over time, though there may be considerable variability from year to year.

Overall, the temperature data suggest that there hasn't been a warming trend in waters of Alouette River and as a result, a shift in fish community structure driven by changes in thermal regime is considered unlikely. It should be stressed however, that the time scale of this monitor is relatively short (15 years) and that one cannot rule out the possibly of changes in the future.

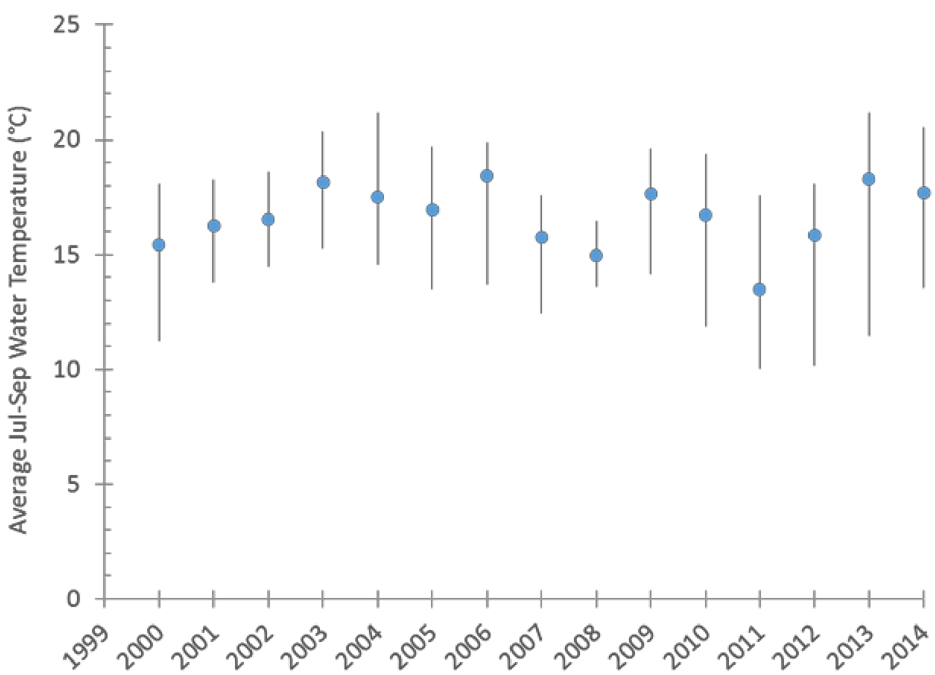

Figure 7. Mean summer temperature (July to end of September) over time for the duration of the monitoring program. Vertical lines denote the range of average daily temperatures for the period.

Question 5

Given the extent of thermal stratification in the reservoir and the location of the LLO, is there an operational change that can be implemented to mitigate the occurrence of warm water events?

The water temperature data collected during this monitoring program and reservoir temperature data provided by MOE have clearly shown that water extraction at the LLO occurs on a horizontal plane despite the intake's vertical orientation. The depth of this horizontal plane appears to be about 1 m in depth and can therefore be highly selective in a thermocline environment. At present summer time reservoir elevations, the LLO intake is generally below the epilimnion, and is drawing water from the thermocline zone. Wind driven seiching has been shown to be a significant contributing factor in bringing cooler thermocline waters into the vicinity of the LLO.

By raising the reservoir water surface elevation, access to even deeper cooler waters can occur. However, during the summer, water levels in the reservoir are already high (Min elevation of 122.5 m from June 15 to September 5) to satisfy the recreational interests of Golden Ears Park users. Thus the capacity to raise reservoir elevations is limited (overflow weir crest is at EL 125.5m), and as simulations studies have shown, may compromise the ability to control downstream flooding risks later in the year (BC Hydro 2006). Alternatively, lowering the elevation or the LLO's intake would achieve a similar result. Lowering the intake elevation however would bring it closer to the reservoir bottom, increasing the risk of recruiting fine sediments and introducing turbid waters downstream.

Though operational changes to mitigate warm water conditions downstream are possible, the benefits are likely to be limited and not without risks. Given that water temperatures are generally within tolerance limits of salmonids for much of the summer time period and that warm water events > 21°C are generally rare and have durations less than a day, consideration of such operational (or physical) changes are considered unnecessary at this time.

Conclusions

Results of the water temperature monitoring program conducted from 1999 to the end of 2014 suggest the following conclusions as they relate to the management questions posed by the WUP consultative committee (BC Hydro 1996, 2006):

1. Water temperatures in Alouette River do not approach or exceed 25°C, the upper incipient lethal temperature for most salmonids. In fact, water temperatures rarely exceed 21°C, the upper sustained temperature limit. The highest ever recorded instantaneous temperature was 22.88°C.

2. In those cases when temperature was > 21°C, it was usually only for a short period of time during the day. On two occasions the warm water event lasted an entire day. One event lasted two days, the longest duration for the period of record.

3. Warm water events were not always present in the entire river. Only 9 of the 35 warm water events that appeared at the Plunge Pool site were observed at all sampling sites on the same day. In most cases, the warm waters at the plunge pool tended to cool when traveling downstream. At other sites, local conditions could trigger a warm water event that may or may not persist at downstream locations.

4. Overall, water temperatures were highest at the Alouette Dam's plunge pool. Temperatures at the site were largely governed by reservoir conditions, including the development of summer thermoclines, the effect of seiching, water source to the plunge pool, and reservoir elevation. When these waters traveled downstream there was generally no change in temperature during the late fall and winter, a warming trend during spring to early summer, and a cooling trend during summer to late fall. The magnitude of these warming and cooling trends varied considerably, but on average was less than 2°C

5. Temporal plots of annual mean summer temperatures (July to September when temperatures are at their highest) found no evidence of a thermal regime shift over the course of the monitoring period. As a result, a shift in fish community structure as a result of persistent warming was considered unlikely in the near term. The conclusion however could not be tested as the abundance data for summer rearing salmonids was confounded by changes in methodology over time. Temperature related changes in fish community structure continue to be a possibility longer term.

6. There are operational changes that can be made to mitigate the occurrence of warm water events, principally increasing the reservoir water level so that the LLO intake can extract waters deeper in the thermocline. There may be increased flooding risks later in the year associated with this operation. Given that water temperatures are generally within tolerance limits of salmonids for much of the summer time period and that warm water events > 21°C are generally rare and have durations less than a day, consideration of such operational changes are unnecessary at this time.

Though the water temperature monitoring program was able to address all management questions and made significant contribution to the understanding of Alouette River's annual temperature cycle, there remains a number of uncertainties. The following five recommendations should be considered moving forward:

1. A series of spot measurements should be collected in the vicinity of the LLO intake structure to better define localized temperature gradients and potentially determine the source or cause of the observed cooling effect at the LLO relative to open water conditions. This may be an important consideration when addressing Management Question 5 listed in the Introduction.

2. Wind direction and speed meters should be installed on the LLO intake tower to collected local weather data that may be used to determine extent, direction and timing of seiching events. This may help explain the cooler water observed at the LLO compared to more open waters, and may be an important consideration when addressing Management Question 5 listed in the Introduction.

3. Install a pressure transducer at the LLO intake to monitor local changes in water surface elevation and hence directly measure seiching potential and relate it to the wind event data recorded above.

4. Carry out a simple modeling exercise to determine if the draw of water through the LLO is sufficient to cause local mixing of thermal layers and hence provide and alternative explanation of localized cooling of LLO waters. As above, this may be an important consideration when addressing Management Question 5 listed in the Introduction.

5. In the event of another warm water event, carry out a snorkel survey to determine if there are holding locations for adult sockeye returns that may serve as thermal refuge, and document other mortalities that may have occurred in the river.

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