Alouette Project Water Use Plan

Alouette Water Temperature

Implementation Year 6

Reference: ALUMON-5

Alouette Water Temperature – 2013

Study Period: 2013

Greenbank Environmental Inc.

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Alouette Water Temperature Monitoring: Program No. ALUMON #5

A Data Summary of Water Temperature Conditions in the Alouette Lake Watershed for the Year 2013

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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 6 report summarizes the 2013 temperature data and provides comparisons to earlier years.

Analysis of historical temperature depth profiles obtained from MOE found that strong temperature gradients that mark the separation of the epilimnion from the metalimnion only occurred consistently in the months of July to September. In July, the depth of the thermocline was generally well above the LLO intake, so that it drew water from layers deep into the metalimnion. In August, the thermocline dropped in depth just above the LLO intake. Water withdrawal by the intake occurred in the upper layers of the metalimnion so that the LLO outflow temperatures were still considerably cooler than surface layers, but tended to be much warmer in July (17.1 vs 14.9 °C respectively). In September, the thermocline dropped below the LLO intake elevation and therefore drew water from the lower layers of the epilimnion. Water temperatures therefore remained relatively high (17.3 °C), despite a cooling of surface temperatures. These predicted temperatures correlated well with LLO outflow temperatures that were measured at the same time. Variance in LLO outflow temperatures was much lower than predicted, indicating that there may be localized mixing of thermal layers. Seiching is proposed as a possible mechanism for this mixing, though the withdrawal of water by the LLO itself may be an alternative mechanism.

River temperatures where generally within the range of historical values, with the exception of mid-August to mid-September where temperatures reached record high levels. Plunge pool temperatures during the high temperature event averaged 20°C, but reached values as high as 21.4°C. These temperatures cooled as water traveled downstream towards the 224th St. Bridge, dropping to an average of 18.7°C. The warm temperatures were considered to be at the edge of thermal tolerance for juvenile salmonids, but never the less survivable and still allowed for significant growth. This could not be verified however in the 2014 smolt release data as it was unavailable at the time of this report. Significant harm however, was suspected among the returning adult sockeye, which were caught in their lowest numbers ever, with several showing symptoms of disease (an outcome of exposure to warm temperatures).

Recommendations for additional data collection to further explore the effects of seiching at the LLO intake are made. This included installation of wind speed and direction meters, as well as pressure transduces to monitor localised changes in reservoir elevations. This may help address Management Question No.5 dealing with possible mitigation activities, particularly in light of the high temperature impact that may have occurred on returning adult sockeye salmon.

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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. Initial concerns dealt with elevated temperatures that not only impacted in stream rearing fish, but operations of the Allco Fish Hatchery as well. These were addressed in 1996 as a result of a Water Use Planning exercise where it was decided that the minimum flow release from Alouette Dam should be increased to its maximum by fully opening the facility's Low Level Outlet (LLO) structure (BC Hydro 1996). Unfortunately, no formal monitoring was carried out to determine if this change in operation was sufficient to address 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 improved. However, uncertainties remained about the possibility of high water temperature impacts during late summer that could 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 potential 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 made to mitigate potential impacts. This document reports on Year 6 of the monitoring program which summarizes the water temperature data collected in 2013 and provides some preliminary comparison to earlier years. A more complete analysis and assessment of the temperature data will be carried out at the end of the data collection phase in 2014-15.

In addition to the monitor summary, part of the report presents an analysis of reservoir water temperature profile data collected as part of a long term reservoir fertilization program since 1998. This analysis is a continuation of the work of Bruce and Greenbank (2013) that explored the relationship between reservoir temperature conditions near the LLO intake structure and plunge pool temperatures downstream of Alouette Dam. It attempts to expand the timescale of observations and hence improve our general understanding of the relationship. The consequences further downstream of the dam are also further explored.

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 event 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)?

Table 3. Site description of water temperature sampling location.

Sample Site	Description
LLO	*Directly adjacent to the LLO outlet for a direct measure of water temperature leaving the Dam.*
Plunge Pool	*Immediately downstream, of the Alouette Dam plunge 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 Mud Creek confluence.*
ARMS	*On the left bank of the river approximately 50 m downstream of the Alco Park hatchery.*
224th St	*On the right bank of the river approximately 100 m upstream of the 224th Street bridge.*

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?

This report summarizes the results of water temperature monitoring completed in 2013 and begins the meta-analysis of all data since the state of the monitor. Key issues being investigated in this report include the relationship between reservoir thermocline temperatures and that observed at the LLO outlet in the plunge pool immediately downstream of the dam, as well as characterising the thermal dynamics of water as it travels downstream to 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 so that inflows to the structure are perpendicular to the water surface above. 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-001) 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, maximum or minimum 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.

Historical Temperature Profile Data

Historical water temperature profile data were obtained from S. Harris of MOE. Data collection started in 1998 and generally occurred monthly between the months of April and October, though some observations occurred as early as mid-February or late into November. For the purposes of the present analysis, these latter profile data were ignored as they occurred too infrequently and fell outside the time period of concern when warm temperatures may be an issue. Though data for both the North and South basins of reservoir were provided, only that South basin were used in the analysis as they were considered to be more directly related to conditions at the LLO intake. When the two profile data sets were compared, North Basin surface temperatures were found to be consistently warmer by 0.8 to 1.3°C and hence deemed not to be representative of conditions at the southernmost end of the reservoir.

Key to analysing the profile data was to develop a consistent definition of the water depth that marked the bottom extent of the epilimnion and the start of the metalimnion where water temperatures began to cool rapidly as a function of water depth. For most profile data sets, water temperature was recorded at 1 m intervals to a depth of 20 m, allowing calculation of the temperature change (δt) between intervals (δz), i.e., $\delta t/\delta z$. A comparison of $\delta t/\delta z$ values at all depths across all profiles found that the start of the metalimnion was generally marked by a sudden temperature change greater than 1 °C. In some instances this was followed by a greater temperature change 1 m deeper, which was interpreted as being an artifact of the interval sampling paradigm (i.e., a bigger proportion of the δt marking the metalimnion was captured in the deeper depth interval (δz) than the previous one). As a result of these two observations, the start of the metalimnion was defined as depth where $\delta t/\delta z$ first exceeds 1°C as one descends the water column from the surface, except where $\delta t/\delta z$ at the next depth interval was greater than the first. Data analysis consisted of simple descriptive statistics and comparative plots.

Results and Discussion

Alouette Lake

2013 Data

Collection of reservoir temperature data for 2013 was largely unsuccessful due to logger loss and difficulty in finding replacements. As a result, temperature data were available only for the Nov 16 to Dec 31 time period, thus missing the summer and late fall high temperature period that was of interest to this monitor. During this short period of usable data, daily average temperatures at the water surface (at 120 m El) ranged from 4.6 to 8.7 °C and showed a general cooling trend over time. Overall, water temperatures averaged 6.2 °C and was found to be largely uniform throughout the water column from elevation 114 m to the surface. Reservoir elevations during this period ranged from 120.41 to 201.95 m, thus the temperature loggers at the 122 m and 124 m locations were out of the water column and only recorded air temperature.

Analysis of Historical Temperature Profile Data

Analysis of the 2009 to 2011 reservoir temperature data by Bruce and Greenbank (2013) was able to show that the inflow of water to the LLO for release to the Alouette River was limited to a relatively shallow layer (< 2m) just above the intake structure. Because of this selective withdrawal, along with high reservoir elevations that brought the depth of the metalimnion closer to the LLO intake elevation, intake water temperatures were found to be 4 - 5 °C cooler than what would be measured at the reservoir surface. This however, was only based on three years of data and the question arose whether this was unique to the 2009 – 2011 dataset, or reflected a more general trend applicable to all years. Since 1998, MOE have been collecting water temperature profile data on a monthly basis from April to October as part of a long term reservoir fertilization program. This coincides roughly with the duration of the present monitoring data set and hence provided an opportunity to address the concern raised above, as well as explore other potential relationships between open water thermocline development and that found near shore in the vicinity of the LLO. Thermocline data were collected both in the north and south basins of the reservoir, but for the purposes of the present analysis, only the south basin data were considered.

Surface water temperatures (recorded at 1 m depth) in the south basin were found to follow a distinct seasonal trend, rising in a relatively linear fashion staring in early April to reach a maximum sometime in mid-August (Figure 2). Average temperature during the month of August was 21.3 °C, but was found to range from 18.8 to 25.1 °C across all years. Maximum recorded temperature was 25.7°C, which was observed July 21, 2009. This was more than 5 °C warmer than the maximum surface temperatures recorded at the LLO intake on the same day. In fact, a plot of surface water temperatures between sites recorded on the same day found that this difference was persistent for all temperatures greater than 15 °C (Figure 3). On average, LLO surface temperatures were generally 4 °C cooler than that recorded by MOE mid-reservoir. The reason for this is uncertain. One possible explanation may be that outflows through the Alouette diversion tunnel created northerly current of epilimnetic waters, causing a slow upwelling of cooler hypolimnion waters at the southern end of the reservoir where the LLO is located. In all three years of data collection, the power tunnel was in use for at least part of the summer period. Of note however, was the fact that there were often long periods of time when the tunnel was not in use, especially in the month of August, yet the temperature differences still persisted.

Table 4. 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

The release of epilimnetic waters through the LLO may also be a factor, though it is uncertain whether the volume of water is sufficient to cause such an effect. At a reservoir elevation of 123m, the LLO is capable of releasing roughly 2.7 m^3/s. This translates to a volume of just under 3900 m^3 in one day of operation. Alone, this volume may be insufficient to create a slow upwelling current. It may however, help accentuate or sustain currents developed by diversion tunnel use. Use of hydraulic modelling techniques should be explored to determine the role of LLO operations in impacting local temperature conditions, supported by a network or spot measurements in the area.

Another possibility is that winds from the south create a current through seiching (where winds push water to one side of a lake or reservoir causing a 'sloshing' action). Indeed, seiching was proposed by West (2013) as a possible mechanism explaining diurnal fluctuations in LLO outflow temperatures. He did not however explore whether such seiching could result in slow upwelling currents at the southern end of the reservoir. Weigand and Chamberline (1987) found that such currents were indeed possible if winds speeds were of sufficient magnitude and duration relative to the length of the reservoir. Expanding on the work of West (2013) by collecting localized wind data and incorporating it into his analysis could help determine whether this is indeed the case. Regardless of the mechanism, the cooler temperatures found at the southern end of the reservoir has major implications regarding release temperatures at the LLO, especially mid-summer when epilimnion temperatures are at their warmest.

Also following a seasonal trend was the depth of the epilimnion as marked by the sudden change in water temperature (Table 2). Strong thermoclines were generally not observed in April, and in only ⅓ of the profiles collected in May. This increased to ½ the profiles in June, after which consistent thermoclines were noted in all profiles (95%) collected in July through to September. These appeared to rapidly breakdown in October where only ⅓ of the profiles were found to still have strong temperature gradients. From May through October, the depth of the metalimnion, when present, tended to increase in a quadratic fashion, nearly doubling in depth by October ($r^2 = 0.999$, $P < 0.001$). Average temperature of the epilimnion however, did not follow the same trajectory. It increased steadily from May onward, reaching a peak value in August, and then began declining in the months of September and October. As would be expected, the temperature gradients that defined the lower limits of the epilimnion were highly correlated with average epilimnion temperature (i.e., the warmer the epilimnion, the deeper it's lower boundary; $r = 0.96$, $P < 0.001$). These trends in the temperature profile data are considered typical of warm monomictic lakes (Wetzel 2001), though the timing, depth, and peak temperatures of the thermoclines varied considerably from year to year. Of particular interest was the timing of peak epilimnion temperature, which occurred in mid-August. This was in line with the peak temperatures observed at the LLO outflow (see below). As well, the depth of the epilimnion at the time was on average 8.5 m deep and relatively consistent from year to year compared to the other months. The temperature profiles of July and September were also of interest as there was clear thermal stratification in the reservoir in most years and in some instances where surface temperatures approached or rivaled that found in August (Figures 4a to c). The remainder of the discussion will focus only on these three months.

From the reservoir elevations data provided by BC Hydro, average depth to 114m (the depth 1m above the LLO) in August coincident with the profile data was found to be 8.8 m, indicating that the LLO was typically drawing water mostly from the upper layers of the metalimnion (Figure 4b). The average difference in temperature between surface conditions and that at El 114 was 4.3 °C. In July however, that difference was much larger, approaching 5.7°C, reflecting the fact that metalimnion was slightly higher in the water column (Table 2, Figure 4a), but that the LLO was drawing water from a similar depth as in August (i.e., 9.0 m). In September, average depth to El 114 m dropped to 8.0 m, but as indicated in Table 2, depth to the metalimnion increased to 9.7 m. This placed the metalimnion below the LLO intake, causing the LLO to draw water from the epilimnion (Figure 4c). As a result, the difference in water temperature between the water surface to El 114m dropped to only 1.5°C. Because of these varying withdrawal conditions, predicted LLO intake temperatures based on the south basin profile data were found to follow an increasing trend over time; where July temperatures averaged 14.9°C, August 17.1°C , and September 17.6°C. These averages were very similar to the measured LLO outflow data (taken on the same day as the profile data) where values of 15.1 °C 17.3°C and 16.9 respectively. The largest difference between data sets was found in September, where a slightly higher temperature reading was expected, but actual measurements found a 0.7°C drop. Also noticeably different were the variances about each monthly mean. In the predicted LLO data, monthly coefficient of variances were 18, 14 and 11% respectively for each month, but in the measured outflow data, it was consistently between 9 and 10% for all months. Because the monthly averages did not differ substantially between data sets, this suggested that cooler temperatures at El 114m in open waters tended to be warmer at the LLO intake, and warmer temperatures at El 114m tended to be cooler.

The reason for this attenuation in temperature differences is uncertain, though the overall cooling of surface temperatures at the southern end of the reservoir suggests that there may be some slow current driven mixing between epilimnion and metalimnion water (Weigand and Chamberline (1987). West (2013) was able to show that in the month of August, seiching may be responsible for the cooler LLO outflow temperatures. Though he limited his study to the month of August, there is no reason why this could not also be the case for the months of July and September. Whether this also explains the warming trends found at the LLO intake is uncertain. The seiching hypothesis assumed a wind direction that blew in from the south. Perhaps a reversal in wind direction may explain the warming trend, where warm surface waters are pushed against the southern shores, forcing the warm epilimnion into deeper depths. Alternatively, solar irradiation on relatively calm days may be the primary cause, or simply the draw of water from the LLO is causing a mixing of local metalimnitic waters.

Unfortunately, there is little local wind or solar data available to test these hypotheses. Collecting such data by installing a pressure transducer to monitor local water surface elevations and an anemometer to record prevailing wind conditions may help resolve this uncertainty. In addition to providing a possible explanation for the observed patterns in LLO outflow temperatures, this information in conjunction with the reservoir temperature data may be used to help determine whether any mitigation measures are possible, particularly in the months August when LLO temperatures are at their warmest, and if so, what the relative effectiveness of each option would be. As well, incorporating the MOE water temperature profile data should be continued as part of the present monitor as it has proven to provide additional insight on the temperature dynamics at the LLO intake site.

Alouette River

Plots of the 2013 water temperature data collected at each site found that river temperature conditions were generally within the range observed since the start of data collection in year 2000. A key exception was a period between mid-August and late September when recorded mean daily average temperatures reached record high levels (Figures 5a to d). The highest daily average temperature during this period was 21.2°C observed on Aug 28 at the Plunge Pool site. Peak daily average temperature at the Mud Creek site was 20.8 °C, while at the Allco Park and 224th St Bridge sites, it was 20.2 and 19.7 °C respectively. Starting from the plunge pool site and moving downstream, the site averages during this high temperature event were 20.0, 19.7, 19.1 and 18.7 °C respectively, showing a cooling trend as water travelled from the plunge pool to the 224th St. Bridge site that was consistent with the historical data analyzed by Bruce and Greenbank (2013). Daily maximum temperatures averaged 20.79, 20.60, 20.29 and 19.83 °C and peak hourly temperatures were 21.46, 21.58, 21.37, and 20.77 °C respectively.

Water temperatures in this mid-August to mid-September period, though high, were still below the upper incipient lethal limits of juvenile coho salmon or steelhead trout (about 25°C, Jobling 1981, Brett 1952) and hence within the zone of indefinite tolerance. These temperatures however, were generally warmer than what is considered optimal for growth (typically between 10 and 15 °C for salmonids) and may have had an impact on some aspects of physiological function and mobility (Greenbank 2009). Though less efficient, these fish would nevertheless have continued to grow and survive these conditions (to be confirmed by examining the annual steelhead and coho smolt capture numbers of 2014, but this data was not available at the time of the report). This could not be said of the adult sockeye that migrate into the river at this time of the year (Borick-Cunningham, 2013), in particular the latter half of their migration period. Temperatures greater than 21 °C have been found to inhibit migration and in the case of stocks in the lower Fraser River such as the Weaver Creek stock, temperatures greater than 19 °C have been linked to high mortality when exposure exceeds more than a few days (Mathes et al. 2010). Also, exposure to temperatures greater than 18°C for extended periods of time have been linked to increases in parasitic infections as well as other diseases (Rand et al. 2006, Crossing et al. 2008, Mathes et al. 2010, and Eliason et al. 2011).

River temperatures in August and September 2013 certainly approached or exceeded these limits and may have been a contributing factor to the year's lowest adult catch ever (10). One of the fish caught had numerous lesions indicative of a severe disease infection (Columnaris dissease?), while another was found to have a either the same disease or a saprophytic mold infection (Figure 6) respectively). Both are indicative of severe thermal stress, suggesting that the high temperature event may indeed have had a serious impact on these fish. It should be stressed that that these are the fish that were caught in the traps. There may have been many more that had succumbed to high temperature effects that did not make to the trap and went undocumented. It is recommended that snorkel surveys be carried out during future high temperature events to better document potential impacts to return adult sockeye, as well as to document the location of potential thermal refugia, if any. The survey crews should be made aware of external disease symptoms in order to better document the incidence of disease.

In 2013, analysis of the plunge pool water temperature found that it was directly related to LLO intake temperature for much of the year, the only exception was during the spring surface release operation when the LLO was closed and flow delivery downstream was provided through spillway (April 15 to June 15). During this short period of time, plunge pool temperatures were highly correlated to reservoir surface temperature and the switch in water source was found to have a warming effect compared to what would be expected with LLO releases. The temperature increase tended to be highly variable, but in general was roughly 20% warmer than LLO temperatures. This translated to an average 2.8°C warmer plunge pool temperature over the course of the spring surface release period (typically April 15 to June 15), across all years (2009 to 2011) and was hypothesized to provide a positive impact on the downstream ecology of the river, allowing the summer growth period to start earlier in the year.

A possible test of this hypothesis was to examine the size at age data for both coho and steelhead smolts collected by Cope 2013 since 1999 and to compare the years prior to the spring release operations (years 1999 to 2004) with that afterwards (years 2005 to present). A review of past reports however found that size at age data were confounded by a change in the lower RST trapping location (from 216th St. Bridge to 224th St. Bridge) that occurred the same year that the spring release operations started. The change extended the duration of smolt trapping operations further in to the month of June, and given that smolts grow throughout the outmigration period, this allowed larger fish to be included in the size distribution of smolts. The size data was also found to be density dependent, with a general trend of decreasing as smolt abundance increased (Cope 2013). This further confounded the data set as smolt abundance tends to be a function adult recruitment that is believed to be independent of spring release operations. Finally, a review of the plunge pool temperature data across all years since 2000 found little difference in average temperatures between pre and post spring release treatment groups (9.2 and 9.0 respectively). It would appear that between-year differences in solar heating had a greater impact on LLO temperatures than the source of Alouette River water release. As a result, there were too many confounding factors and insufficient treatment effect sizes to test the hypothesised benefits of warm water spring releases using existing data sets. Test of this hypothesis will have to be carried out as an independent study.

Conclusions and Recommendations

Several conclusions were derived from the present study:

1. Analysis of historical temperature profile data has shown that thermoclines consistently form in the months of July through August. The depth of the epilimnion increase with each month, as does its average temperature.
2. The LLO intake typically draws water from deeper lays of the metalimnion in July, the top layers of the metalimnion in August, and into the lower layers of the epilimnion in September.

3. Water temperature measured at the at the LLO outlet was found to be similar to that predicted by the historical temperature profile data, but with much less variability, suggesting that there may be localized mixing of thermal layers.
4. Large differences in surface water temperatures were observed between that recorded in the historical temperature profile data and that recorded near the water surface at the LLO. A mixing of thermal layers due to wind-driven (seiching), slow moving currents, is proposed as a possible explanation.
5. Based on plunge pool data that reflect LLO intake conditions, reservoir water temperature was warmer in 2013 than in previous years, in particular the period between August 15 and September 15.
6. Daily average water temperature during the August 15 and September 15 period at the plunge pool area peaked at 21.2 °C and averaged 20°C. Maximum hourly temperature was 21.5°C.
7. There was a general cooling of temperatures as water travelled downstream. At 224th St. Bridge, daily average water temperature dropped to a peak value of 19.7°C and average 18.7°C for the duration of the high temperature event.
8. Though it could not be confirmed in the 2014 smolt output data, the warm temperatures were not believed to be high enough to cause serious impairment to coho or steelhead smolt growth and survival.
9. The high temperature event was believed to be of sufficient magnitude to cause harm to in migrating adult sockeye salmon. Historically low return numbers and evidence of disease in the 2013 catch appear to support this conclusion. This would be the first reported incidence of possible temperature-related harm in the river.
10. The hypothesis that the slight warmer waters during the spring release operation could be beneficial to salmonid growth in spring could not be tested with the data on hand.

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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Figures

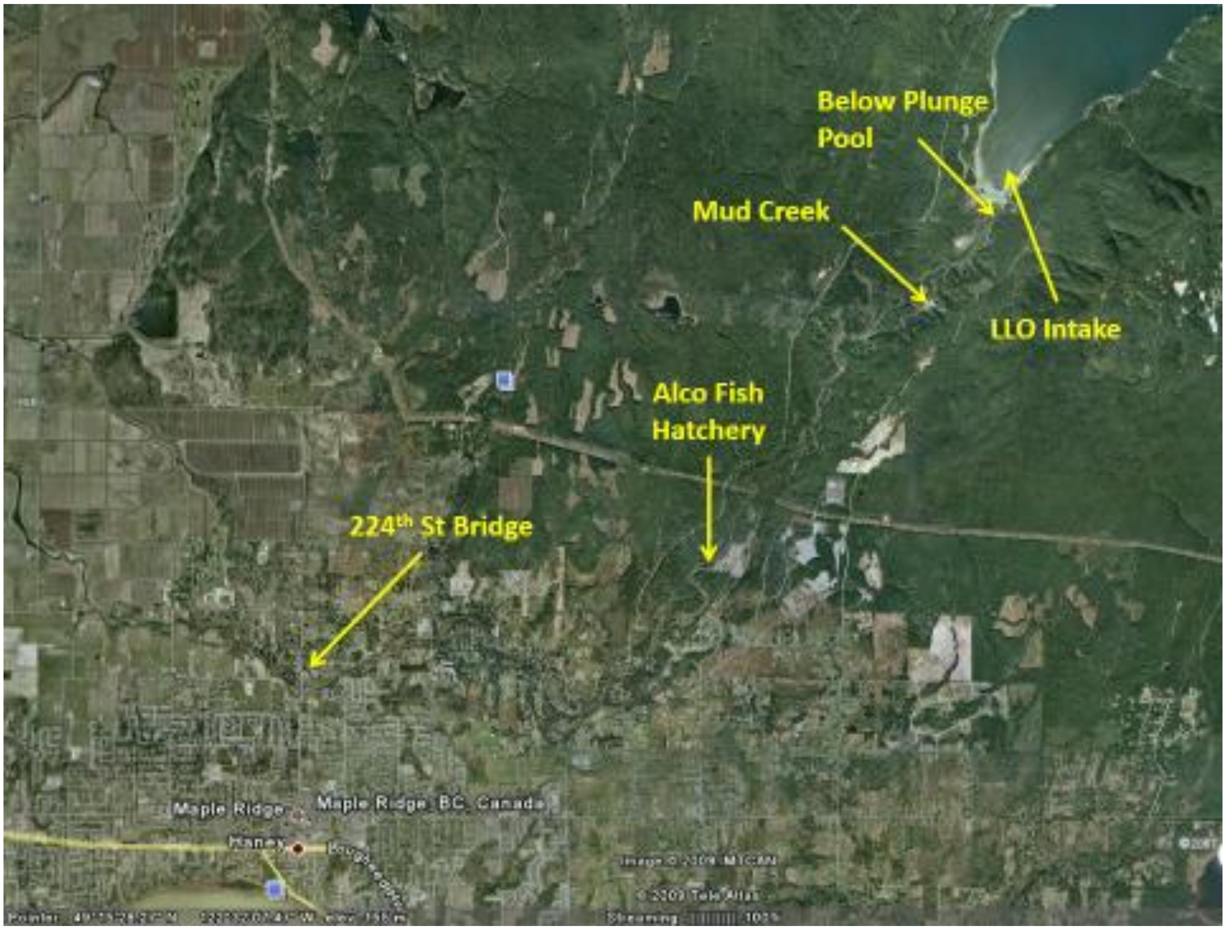

Figure 1. Location of temperature logger sites on the Alouette River watershed.

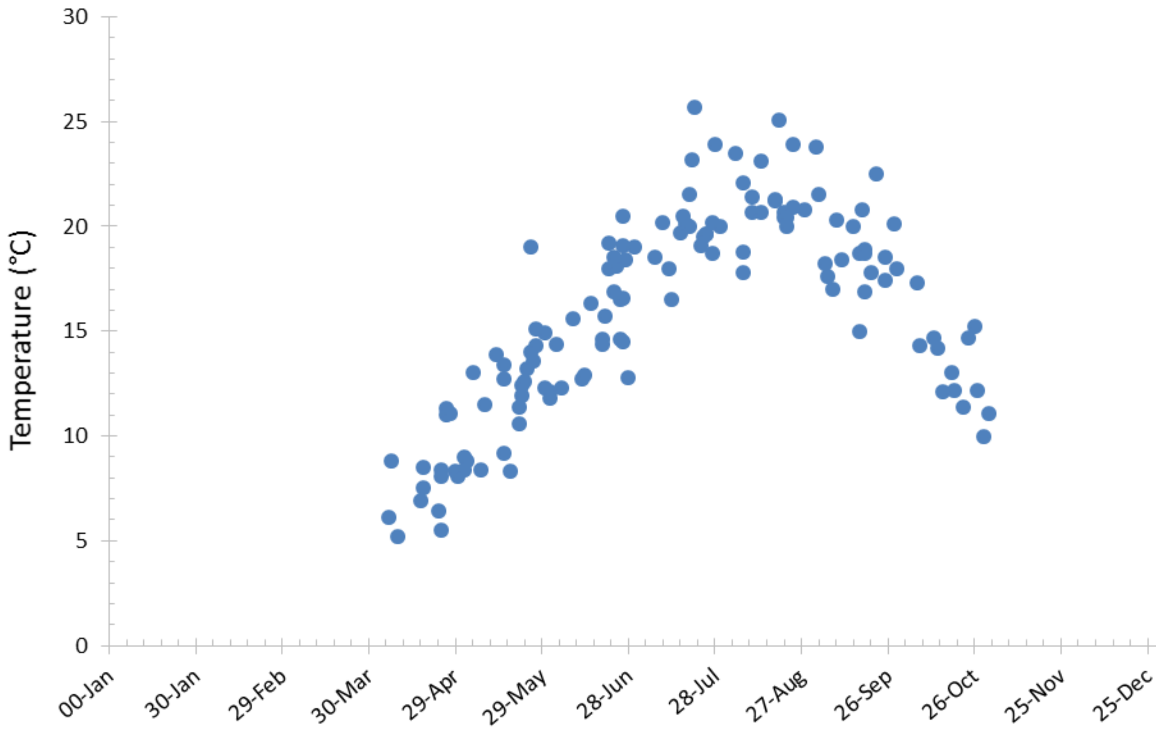

Figure 2. Surface water temperature in the south basin of the Alouette Lake Reservoir based on water temperature prolife data collected by MOE since 1998 as part of a long term reservoir fertilization program.

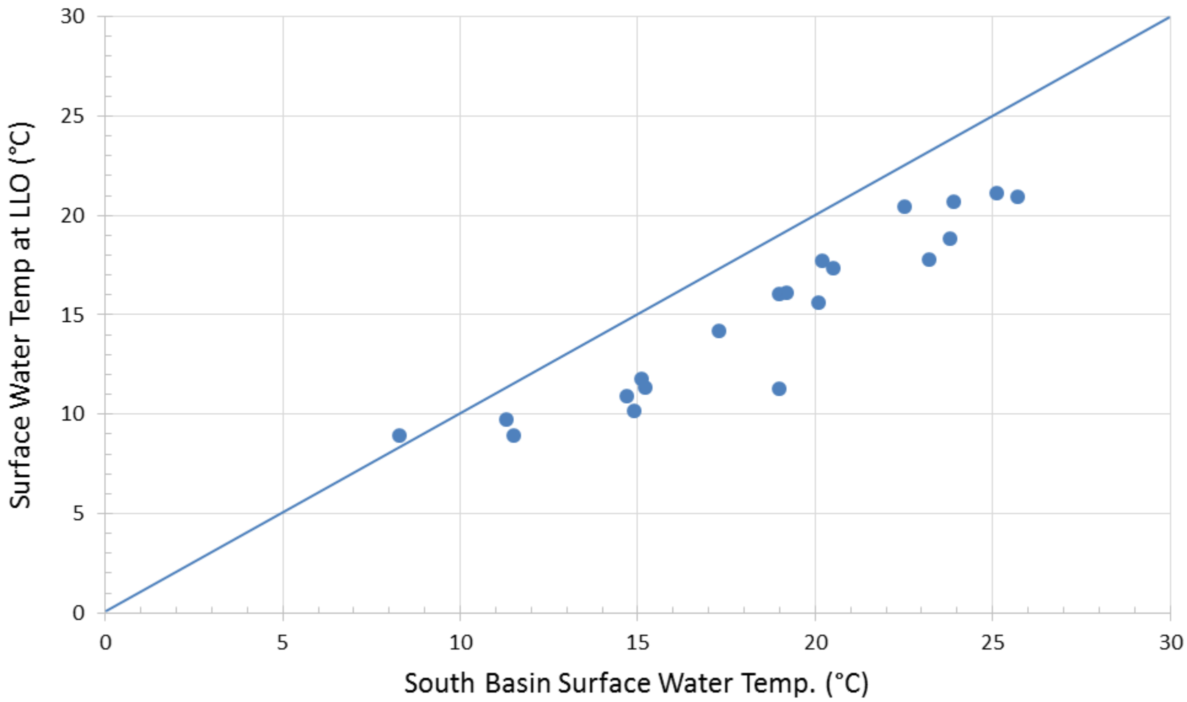

Figure 3. Plot of Alouette Lake Reservoir surface water temperatures (at roughly 1 m depth) comparing observations collected by MOE at the South Basin site with that recorded at the LLO intake structure. The diagonal line represents the line of equality.

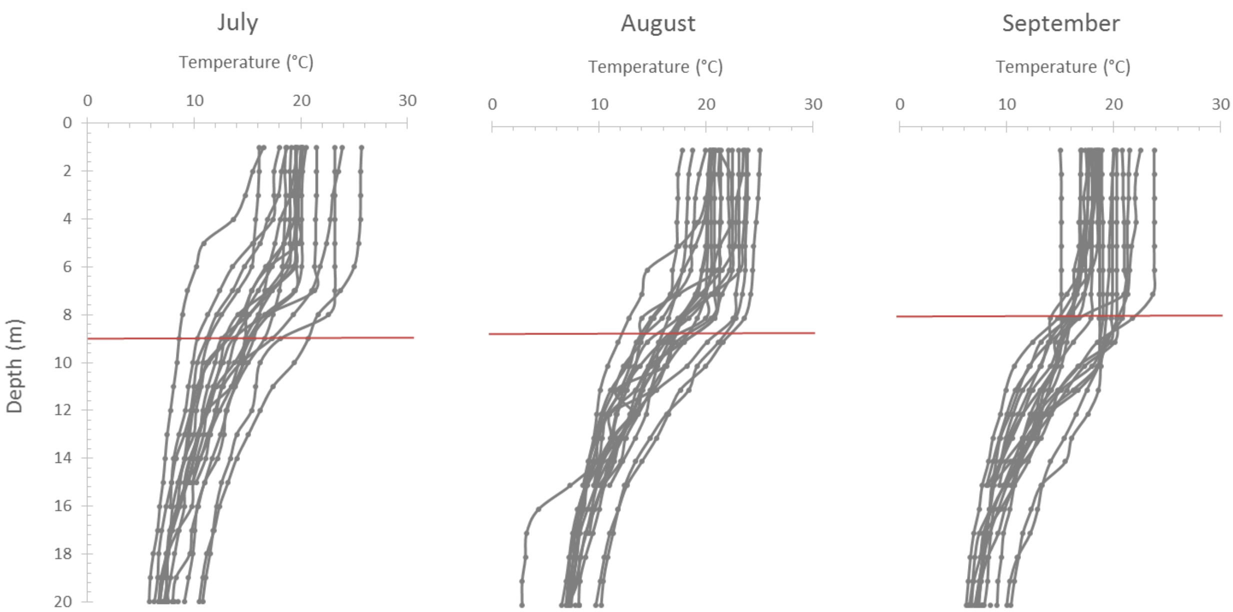

Figure 4. Plot of water temperature depth profiles in the south basin of Alouette Lake Reservoir for the months of July to September (the period when water temperatures are at their warmest). The data time series, started in 1998 and was collected monthly (in some years twice monthly) till the end of 2013. The red line through each profiles marks the average depth to reservoir elevation 114m, a location 1 meter above the LLO intake. In July it was 9.03 m, in August 8.73m and in September 7.95 m.

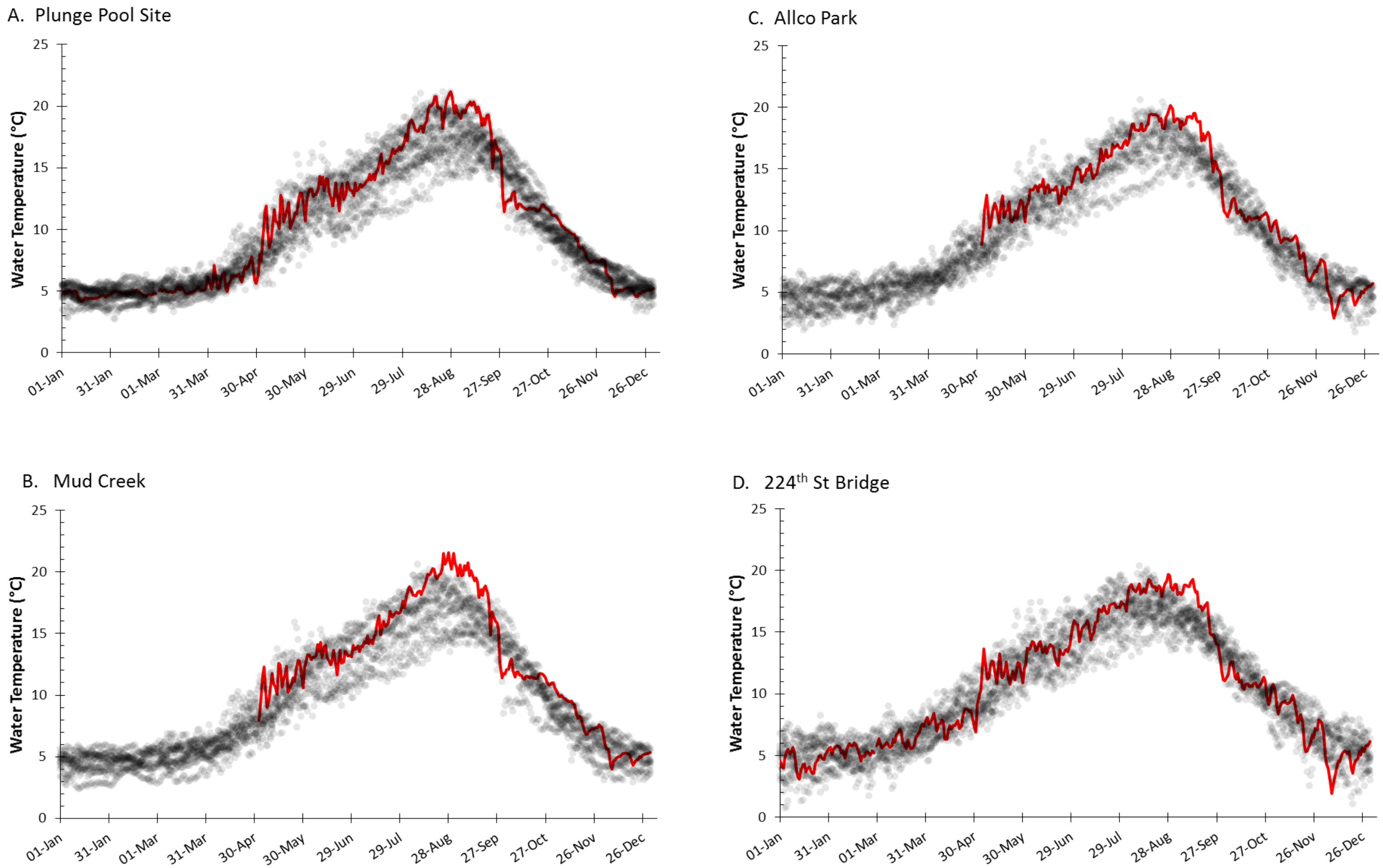

Figure 5. Plot of 2013 Alouette River water temperatures (red line) at four locations in the watershed downstream of Alouette Dam. These are plotted against a backdrop of all data collected at each site since year 2000. For the latter data, the darker the symbol, the greater the local density of observations

Figure 6. Photos of returning adult sockeye salmon caught in the Alouette River in 2013 showing symptoms of disease and/or mold infections, both believed to be the consequence of exposure to high water temperatures.