Alouette Project Water Use Plan

Alouette Water Temperature

Implementation Year 5

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Alouette Water Temperature – 2012

Study Period: 2012

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 2012

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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 5 report summarizes the 2012 temperature data and provides comparisons to earlier years.

Water temperatures in the plunge pool immediately downstream of the Alouette Dam ranged from a low of about 4°C in December through to January, rising temperature conditions from February onwards with peak temperatures occurring in late August and early September, and declining temperatures for the remainder of the year. At no time did daily average water temperature reach lethal levels for salmonids. Water temperatures typically reached summer highs of 19°C to 22°C during the 2000 - 2010 monitoring period, while temperatures in 2012 did not surpass 18°C. Daily mean water temperature reached its seasonal maximum at the beginning of September where it approached 17°C at the Plunge Pool site. Plunge pool temperatures were found to be similar to that measured in the vicinity of the LLO intake in the reservoir, suggesting that inflows to the intake were selective to a narrow layer of water just above the intake structure. The only exception was during the spring surface release operation starting in April and ending in June, where plunge pool temperatures were more similar to reservoir surface water temperature.

Plunge pool temperatures remained largely unchanged while traveling to the Mud Creek site downstream. Some evidence of cooling was found, but it was believed to be due to a miss-calibrated temperature logger rather that a geomorphological event. As water travelled further downstream, there was a tendency for it warm slightly during spring, cool when mud Creek temperatures began to exceed 15 °C in mid to late summer, and cool more quickly later in the fall. The general tendency was for peak temperatures seen at the plunge pool to attenuate as it traveled downstream, becoming roughly 1°C cooler at 224th Street Bridge, and with a seasonal peak temperature arriving two weeks earlier.

Overall, preliminary indications suggest that the WUP operations at Alouette Dam has had a positive effect on river temperatures, warming sooner in spring and early summer (due in part to surface releases) and cooling sooner in mid to late summer when compared to LLO releases alone. This was seen as a positive effect on salmonid ecology and production.

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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 5 of the monitoring program which summarizes the water temperature data collected in 2012 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.

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)?
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 2012 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 was 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).

Table 1. 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.*

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 3 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.

Data Analysis

All data analysis in this report was carried out on daily average, maximum and 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.

Results and Discussion

Alouette Lake

Unfortunately, reservoir temperature data for 2012 was incomplete due to logger loss on two separate occasions. The cause for this loss was uncertain though animal activity or vandalism were likely candidates. As a result, temperature data were available only for the Jan 1 to Jun 8 time period, thus missing the high summer and late fall high temperature period that was of interest for this monitor (Figure 1). For this reason, no further analysis beyond a simple plotting exercise was carried out with this data.

Of interest this year was to use the historical reservoir temperature data collected since 2009 to determine the extent with which the draw of water through the LLO intake penetrates the thermocline that develops above it in summer. If penetration was shallow, most of the water that entered the vertically oriented LLO intake would be from a shallow layer of water just above it. Because intake elevation was 113m, this layer would in theory have a water temperature similar to that recorded by the 114m El temperature logger. Thus if one were to compare LLO outflow temperatures with the 114m logger data, one would expect little difference. In contrast, if penetration was much higher into the thermocline, a thicker layer of water would be involved in LLO outflows, and would in turn encompass a greater range of thermocline temperatures. In this case, comparison of LLO outflow temperatures with the 114m El logger data would show a considerable difference, setting up a simple but effective test of the following null hypothesis:

H_o: There is no difference in water temperature between LLO outflow and 114 El logger data sets.

Acceptance of this H_o, would suggest a shallow intake penetration into the thermocline, while a rejection would suggest that LLO intake penetration can reach some of the warmer near-surface layers of the thermocline.

The magnitude of difference would be depend on the extent of thermocline development above the LLO intake, as well as the height of inflow penetration into that thermocline. Thus to test this hypothesis, one had to first establish that a thermocline existed above the LLO intake. For this report, this was done by comparing water temperatures collected by each of the reservoir data loggers to the deepest one at 114m. A comparison of water temperatures collected at 120m El vs 114m El showed that a thermocline did indeed develop above the LLO intake (at 113m El) in all three years of data collection (Figure 2). It typically started to form mid-March to Early April, gradually increasing in magnitude to reach a maximum temperature difference in excess of 5 °C by early June. Though highly variable from day to day, this thermocline tended to persist well into late October. The work of (West 2013) suggested that the observed day-to-day fluctuation in thermocline may be the result of wind driven currents that periodically pushed warmer surface waters away from the southern shores of the reservoir, allowing cooler hypo-limnetic waters to enter the area and take its place.

Each year in July, water surface elevation in Alouette Reservoir exceeded 122m El, but rarely rose above 124m El (Figure 3). Typically, reservoir elevation at the time centered about 123m El. A plot of average temperature at each of the logger elevations showed that a thermocline was well established above the LLO intake in all three years of measurement. The depth of water above the intake gate was in the order of 10 m, and temperatures in the thermocline typically ranged between 4 and 5°C from top to bottom (Figure 4). There was however, a significant difference in depth-integrated mean temperatures between years. In 2009, mean temperature above the LLO intake was 18°C, while in 2010 and 2011, it dropped to 15.8 and 13.1 °C respectively. The reason for the change was unclear and worthy of further investigation.

A plot of LLO intake temperatures as a function of LLO outlet temperatures observed at the plunge pool found that for very cold or very warm temperatures, there was no difference between the two data sets. This trend however, did not appear to apply for moderate temperatures ranging between 5 to 12°C (Figure 5). A comparison of time series plots between the two datasets found that the discrepancy was limited to the spring period, starting in mid-April and ending in mid-June. This was coincident with the annual spring release operation at Alouette Dam where LLO operation was shut down and flows released to the Alouette River were provided through the spillway. As would be expected, plunge pool temperatures during this spring release period was more closely correlated to reservoir surface temperatures measured at 122m El (R^2_{Adj} = 0.927, slope = 0.98, intercept = 0.37°C) than at the LLO intake (R^2_{Adj} = 0.759, slope = 1.39, intercept = -1.08°C). When excluding the spring release temperature data, the correlation between 114m El and LLO outflow temperatures increased substantially (R^2_{Adj} = 0.996, P <<0.0001), where the slope of the relationship is not significantly different from unity (slope = 1.02, P <<0.0001), and the intercept was not significantly different from 0 °C (intercept = 0.00, P <<0.0001). This outcome lead to the null hypothesis H_o being accepted, implying that intake flows were drawn more from a horizontal plane in the water column than along a vertical line from the LLO to the surface.

Several inferences were drawn from this conclusion. Firstly, it appeared that the LLO tends to release the coolest water available to it due to the horizontal withdrawal of water at the intake structure. During much of the year, this has little impact on downstream releases. However it can lead to the selective withdrawal of cooler water layers in the summer when a thermocline develops and reservoir elevations are high. Indeed, LLO releases were typically cooler than reservoir surface temperatures by 4 to 5°C during the summer monitoring periods of the study. However, as shown in Figure 4, the intake temperature can vary considerably from year to year depending on reservoir surface temperatures during the mid to late summer period. The second inference of note was that the selective nature of intake flows, along with the presence of a thermocline during summer, could provide a limited means of temperature regulation downstream of the dam by varying reservoir elevation. Raising reservoir elevation would have the effect of lowering the LLO intake and hence allow withdrawal of deeper cooler waters. The feasibility of such regulation however would require further study which is beyond the scope of the present document. It should be noted that the LLO intake is not located deep enough to access mid-summer hypolimnion waters; which tend to remain stable at 4 - 6 °C for much of the year.

Alouette River

A plot of water temperature data collected at each site during 2012 compared to all other historical data showed that these data were well within the range observed in the past, and many instances was close to median values (See Figures 6 A to D). Only partial data records were available for the Mud Creek and Allco Park sites due to logger loss. At no time during the year did daily average water temperature exceed 18°C at any of the sites, nor were there significant periods when hourly water temperature exceeded 20°C. The observed temperatures were all within the tolerance limits of salmonid fishes (Greenbank 2009) and the potential for negative high water temperature impacts was considered unlikely. In fact, as the analyses below would suggest, the temperature regime in general may be considered highly favourable for salmonid fishes.

As noted above, plunge pool water temperature 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 temperature was highly correlated to reservoir surface temperature. This 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. This could have a significant positive impact on the downstream ecology of the river, allowing the summer growth period to start earlier in the year. The extent of this potential impact however is uncertain and requires further study which is beyond the scope of the present document.

As water traveled from the plunge pool to the first of the downstream measurement site at Mud Creek, a between site comparison of temperature data revealed that for the majority of time, there was little change. There were times however, across the spectrum of observed temperatures, when some cooling was apparent (Figure 7). However, closer examination of the data found that this apparent cooling was largely limited to 1.5 year period starting in early July 2006 and ending mid-December 2007. At no other time in the time series was there a persistent 1-2°C cooling effect as seen during this period. It would appear, therefore that this may have been more a function of a miss calibrated temperature logger than a geomorphological effect, particularly given the fact that the onset and ending of this cooling period occurred suddenly. Excluding these data from the overall time series showed that in general there was little difference between plunge pool and river temperatures just upstream of Mud Creek (R^2 = 0.99). For most of the observed range, water temperature at the Mud Creek site was generally within ± 1°C of plunge pool measurements. There was however, some evidence of cooling during periods of high plunge pool temperatures, particularly when temperatures started to exceeded 15°C. This cooling effect was subtle, increasing gradually to just under 1°C as plunge pool temperatures approached 20°C.

A comparison of plunge pool temperatures and that recorded at the Allco Hatchery site found a similar pattern, but with a greater degree of variance (Figure 8, R^2 = 0.97). For plunge pool temperatures between 6 and 15°C, observations at the Allco Hatchery tended to be within ± 2°C, showing little evidence of cooling or warming. In fact, either could occur with equal probability. However, below 6°C, water temperatures tended to be colder at the Allco site, indicating a persistent cooling trend as water traveled from one site to the other. This was not unexpected as these cold temperatures typically occur during winter when there is ample opportunity for heat loss.

There was also evidence of a cooling effect during periods of very high plunge pool temperature, particularly when it exceeded 15°C (Figure 8). As in Mud creek, the effect was subtle. In this case however, the magnitude of cooling was a little greater, ranging between 1-2°C as plunge pool temperatures approached 20°C.

Water temperature at the 224th Street bridge site, varied further still from plunge pool measurements (Figure 9). However, a different pattern of change emerged compared to the other sites. Cold water cooling was still evident, but appeared to only occur at plunge pool temperatures below 5°C. From about 5 to 13°C, there was a tendency towards warming that averaged 1°C. Equal likelihood of warming or cooling was evident when plunge pool temperatures ranged between 13 and 16°C, while above 16°C there was an increasing trend towards cooling as plunge pool temperature rose to 20°C.

The net effect of these temperature changes is reflected in Figure 10 which plots the average temperature over the course of a year between the plunge pool and 224th Street bridge sites for all years of data collection. In general, there was little difference between sites during the winter except in very cold circumstances. During spring, as plunge pool temperatures rose, there was a tendency towards warming as water traveled to the 224th Street bridge site. However, as temperatures increased to 15°C, the warming trend switched to one of cooling. This had the effect of lowering peak summer temperatures slightly (by about 1°C) and shifting the peak at the downstream site roughly 2 weeks earlier. The changes were subtle, but could be sufficient to potentially benefit fish production in the system. Exploration of these potential benefits will require further study, including integration of fish production data from other monitors, and was considered beyond the scope of the present study.

Conclusions and Recommendations

Several conclusions were derived from the present study:

1. Reservoir water temperature in general was cooler in 2012 than in previous years
2. Thermoclines can form above the LLO intake, with temperatures typically spanning 4 to 5°C in the water column above the intake structure.
3. Inflows to the LLO did not penetrate the water temperatures of the thermocline. Inflows appeared to be drawn laterally from a shallow layer of water just above the intake structure.
4. Water temperatures in the plunge pool were the same as that found near the intake structure, except during the spring surface release operation when the LLO was shut and flow releases were provided by the spillway. During spring release, plunge pool temperatures were correlated with that of the reservoir surface.
5. Plunge pool waters travelled to the Mud Creek site with little change. What appeared to be evidence of a cooling trend in one of the years may have been the result of a miss calibrated data logger.
6. Water at the Allco Park site was typically cooler during winter than at the plunge pool site, largely unchanged during temperatures between 6 and 15°C, and slightly cooler during high temperature periods (> 15°C).
7. Water at the 224 St bridge site was typically cooler during winter than at the plunge pool site, slightly warmer when plunge pool temperatures were between 5 and 13°C, unchanged when

temperature was between 13 and 16°C, and slightly cooler during high temperature periods (> 16°C).

8. The net effect of these temperature dynamics was that peak temperatures at the 244th St. bridge site occurred on average two weeks earlier than at the plunge pool, and had a magnitude that was roughly 1°C less.
9. Early indications suggest that water temperature conditions with the Alouette River were more likely to be beneficial to salmonid growth than harmful. More study would be required to explore this implication, which is beyond the scope of the present work.

Three recommendations should be considered moving forward:

1. The temperature logger installed at the 124m El mark on the LLO tower should be moved to 112m El to compliment the data collected at the other locations. The 124 m El logger is rarely in the water and is therefore not collecting any useful information. Data at 112m could provide an indication of possible additional cooling potential at the LLO intake, and could help directly address Management Question 5 listed in the Introduction.
2. Prior to redeployment of temperature loggers, readings should be compared to an independent thermometer to ensure proper calibration.
3. During the spring and summer, several simple surveys should be carried out to determine likely causes for the observed changes in water temperature between sites. This should include a cursory literature review on possible heat sources and sinks in a river system and an evaluation of applicability to the Alouette River system.

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Figures

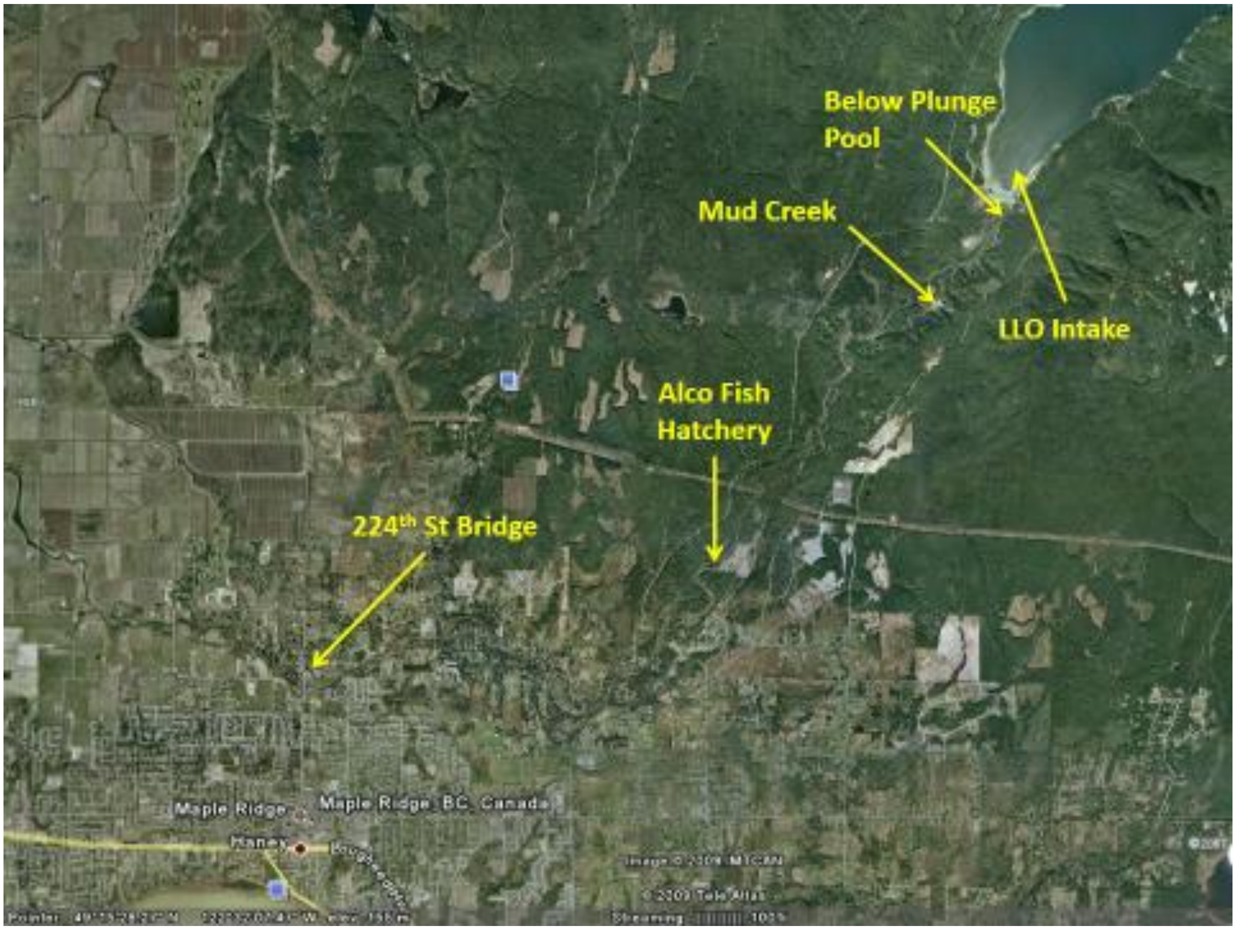

Figure 1. Location of temperature logger sites on the Alouette River watershed.

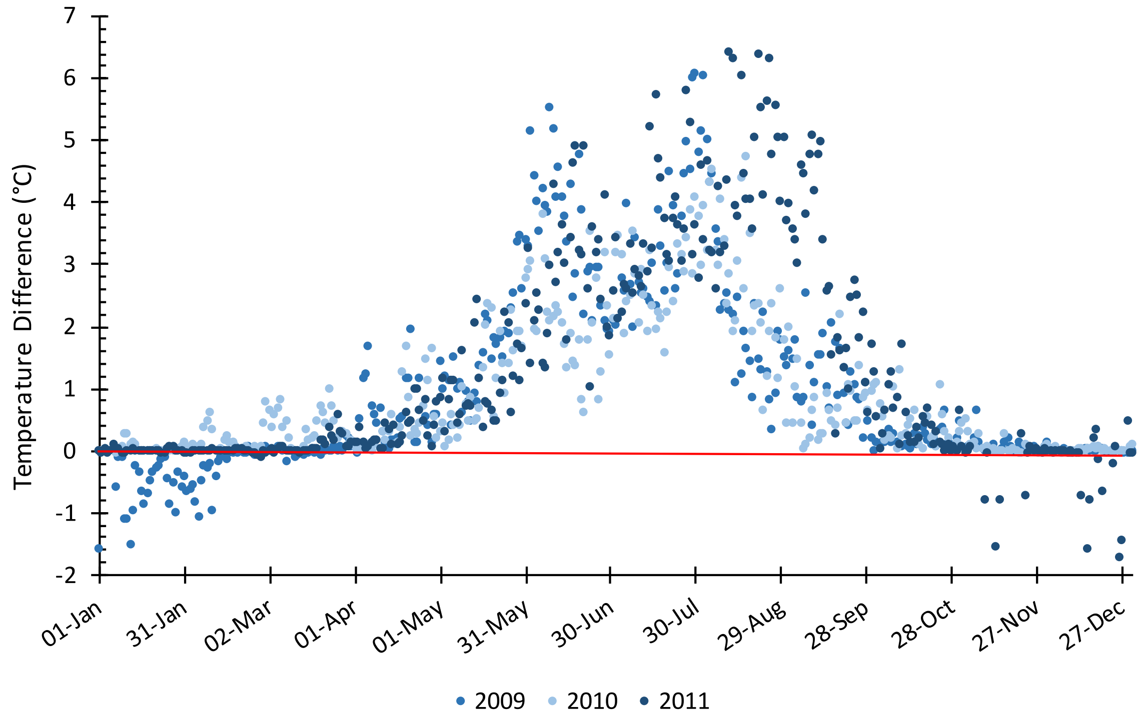

Figure 2. Temperature difference over time between near surface elevations at Alouette Lake Reservoir (El 120m) and at El 114m that is roughly 1 m above the elevation of the Low Level Outlet intake structure. The plot illustrates the timing and potential magnitude of thermoclines in the reservoir for years 2009 to 2011.

Figure 3. Plot of Alouette Lake Reservoir elevation (m) over time for year 2009 to 2011.

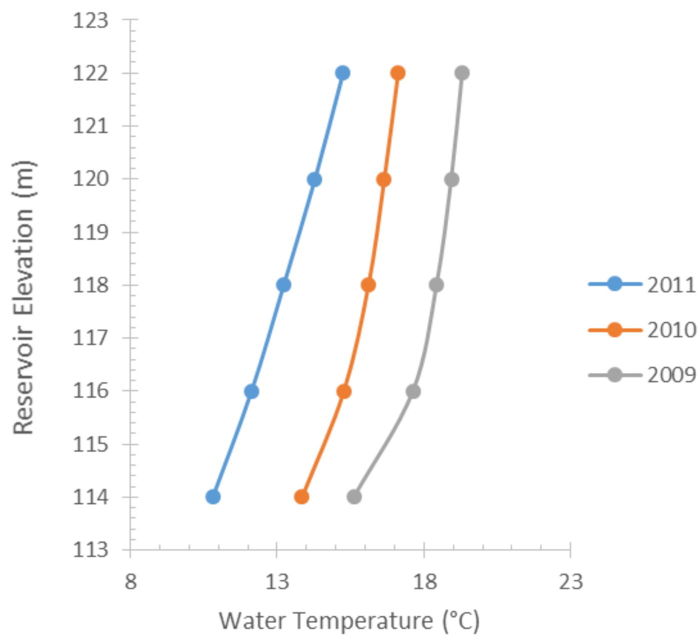

Figure 4. Average thermocline temperature profile above the Low Level Outlet (LLO) intake gate for the month of July in years 2009 to 2011. Plot illustrates that a strong thermocline develops each year above the LLO intake, but depth integrated average temperature can vary considerably.

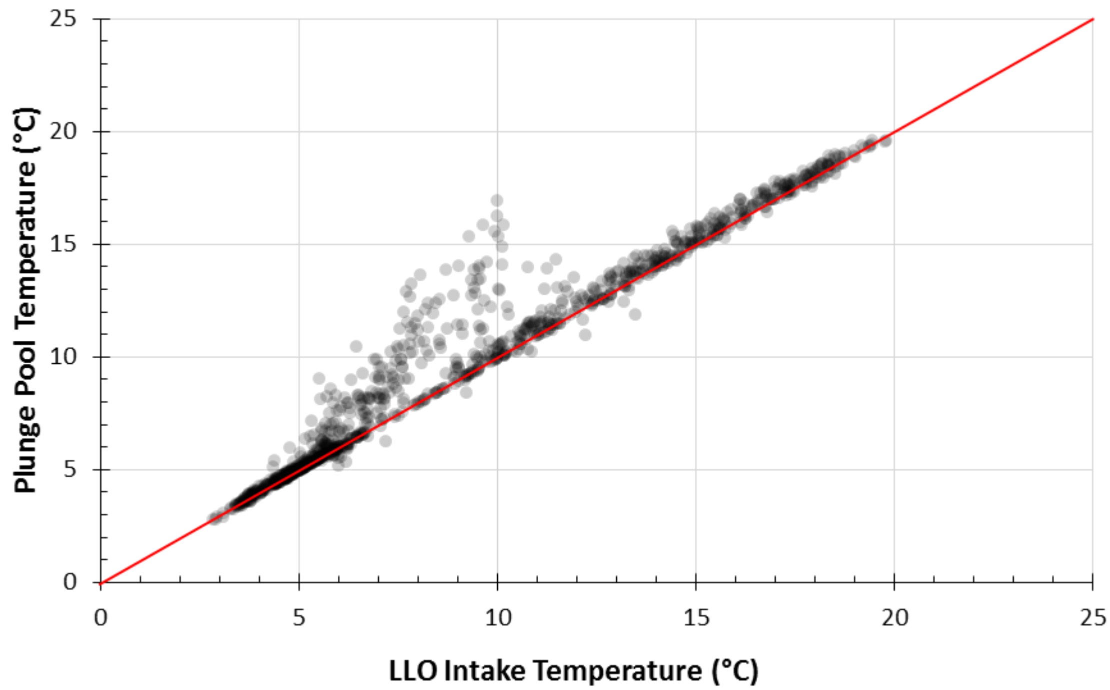

Figure 5. Comparison of Alouette River water temperatures collected at El 114 in Alouette Lake Reservoir (Intake water temperature) and immediately below the dam at the head of the plunge pool. The red line mark the line of equality between the two data sets. Data above the line tend to be warmer than at the plunge pool data while below the line tend to be cooler.

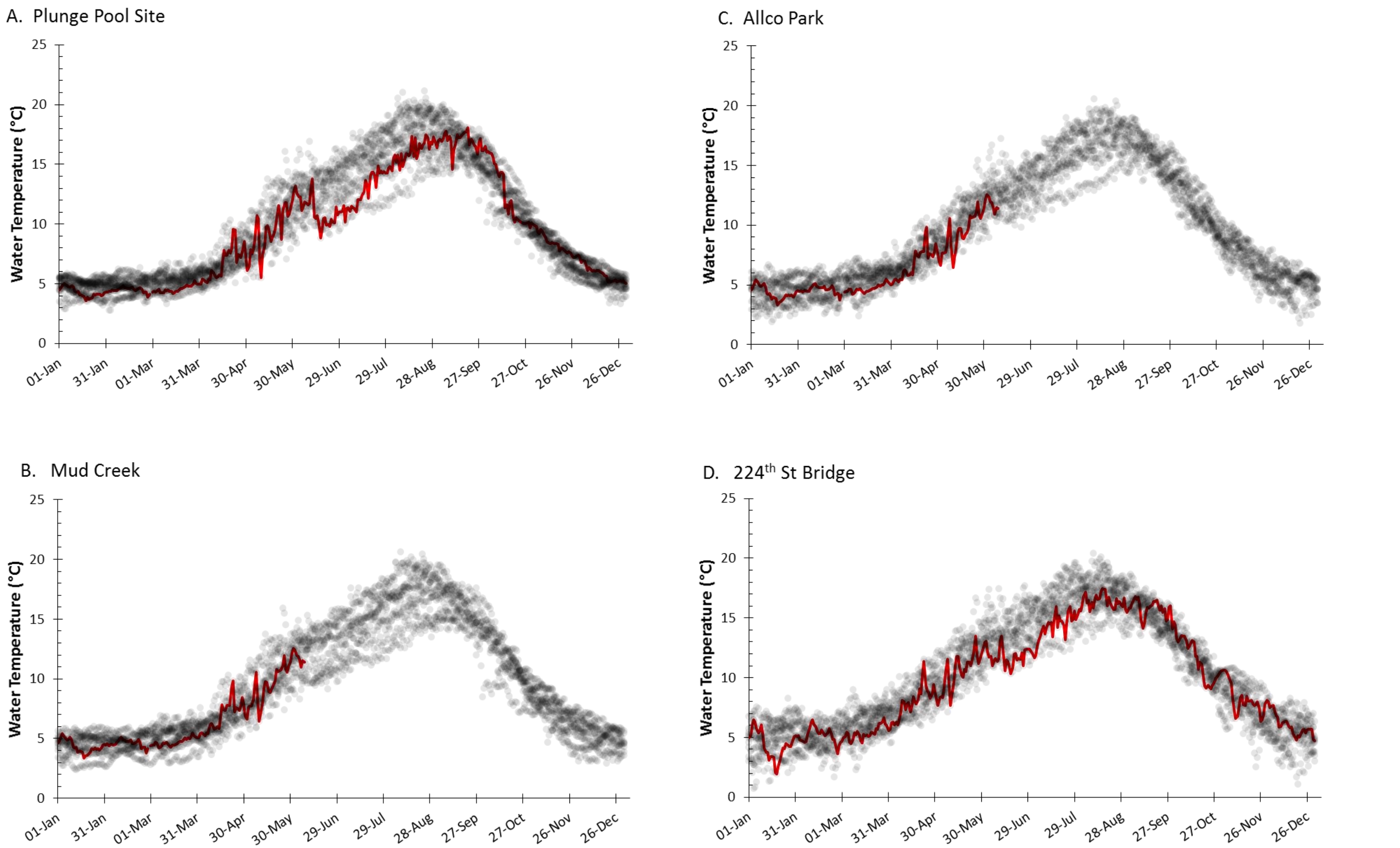

Figure 6. Plot of 2012 Alouette River water temperatures (red line) at four locations in the watershed downstream of Alouette Dam. These are plotted against a backdrop of all data collected at each site since year 2000. For these latter data, the darker the symbol, the greater the local density of observations.

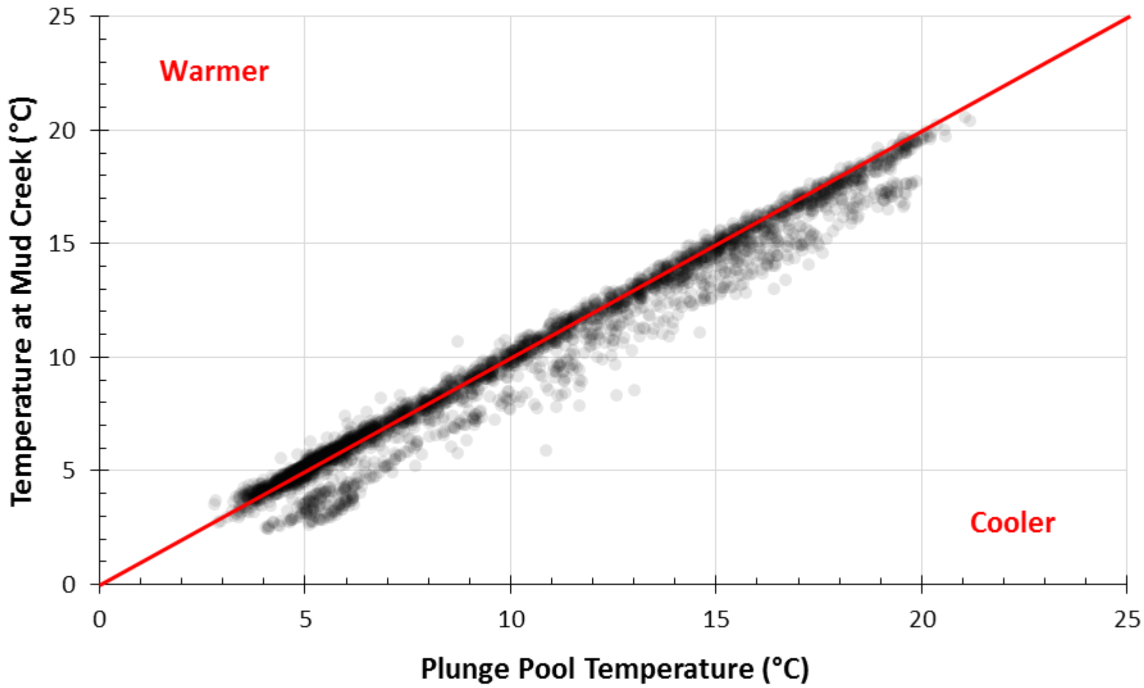

Figure 7. Comparison of Alouette River water temperatures collected at the Plunge Pool site immediately below Alouette Dam and a site just above the Mud Creek confluence. The red line mark the line of equality between the two data sets. Data above the line tend to be warmer than at the plunge pool data while below the line tend to be cooler.

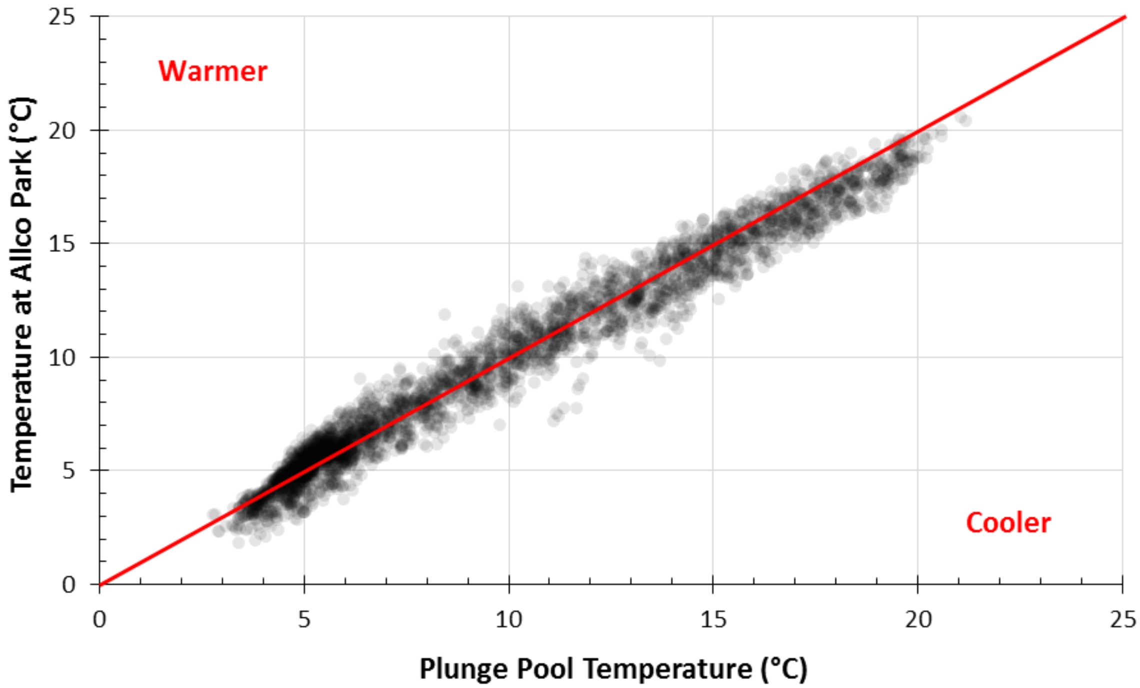

Figure 8. Comparison of Alouette River water temperatures collected at the Plunge Pool site immediately below Alouette Dam and a site at Allco Park. The red line mark the line of equality between the two data sets. Data above the line tend to be warmer than at the plunge pool data while below the line tend to be cooler.

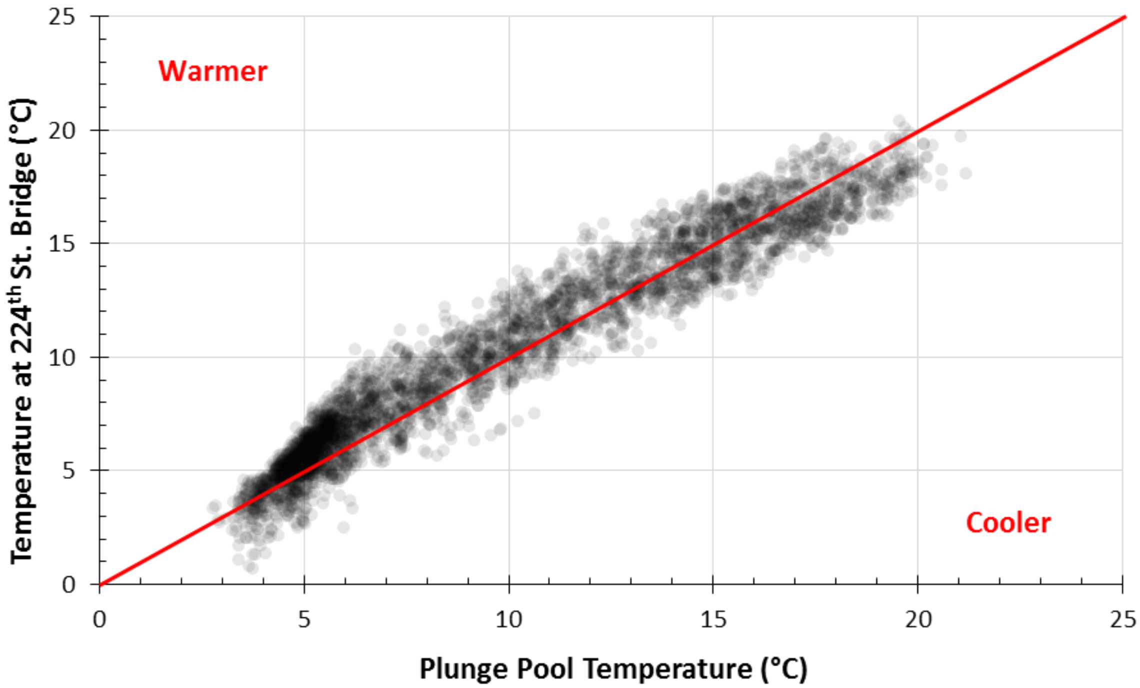

Figure 9. Comparison of Alouette River water temperatures collected at the Plunge Pool site immediately below Alouette Dam and a site at 224 Street bridge. The red line mark the line of equality between the two data sets. Data above the line tend to be warmer than at the plunge pool data while below the line tend to be cooler.

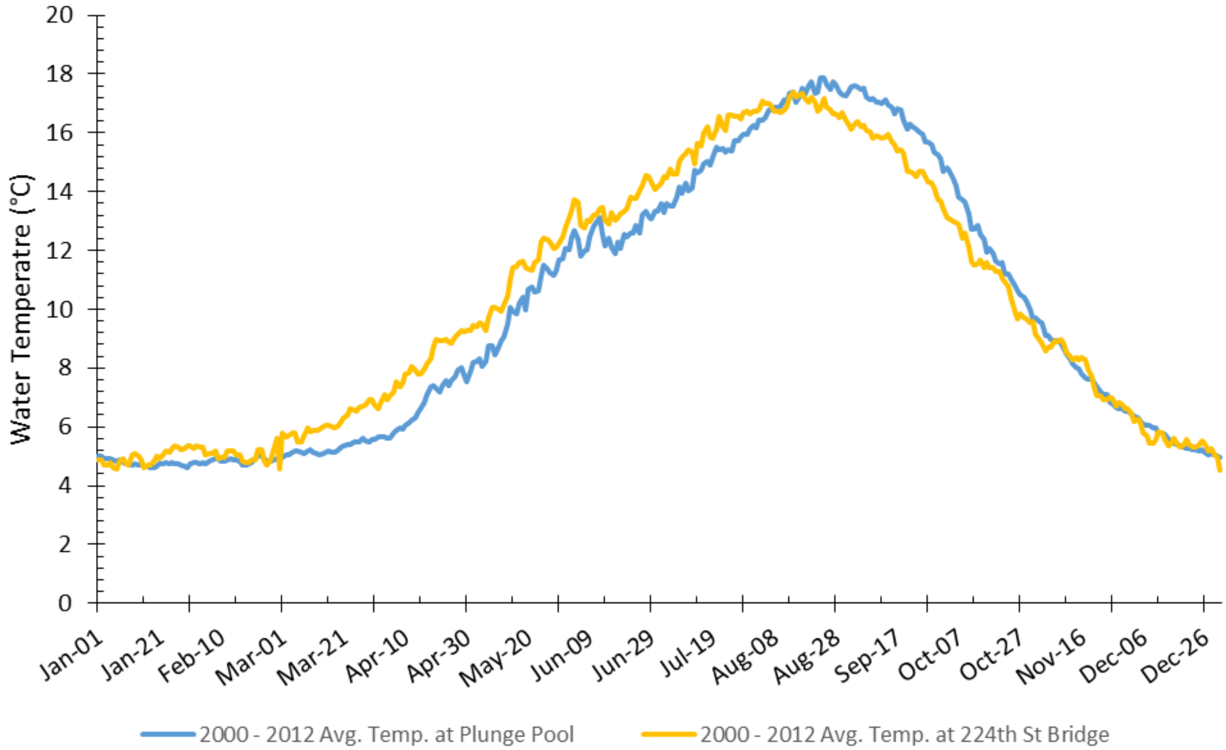

Figure 10. A comparison of 12-year daily average water temperature collected immediately below the Alouette dam in the Plunge pool and at the 224th St bridge site showing the attenuating effects of heat transfer as water travels downstream from the Dam.