

Alouette Water Use Plan

Water Temperature

ALUMON#5

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Alouette Water Temperature

Program No. ALUMON #5

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Prepared for:



Engineering Aboriginal Relation and Generation
6911 Southpoint Drive
Burnaby, BC
V3N 4X8

Prepared by:



GREENBANK
ENVIRONMENTAL INC.

Jeff Greenbank, RPBio. and Matt Townsend, MSc.
913 Baker Drive
Coquitlam, BC
V3J 6X3

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Alouette Water Temperature

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1 Introduction

1.1 Background

Water temperature in the Alouette River, downstream of the Alouette Dam continues to be a concern for BC Hydro, environmental agencies and stakeholders. In response to these concerns and other potential low-flow issues, BC Hydro changed the operation of the Alouette Dam by fully opening the low level outlet (LLO) in 1996 to increase the minimum flows. It has been agreed by the fisheries technical committee FTC that the increase in flows has improved the temperature conditions, however, uncertainties regarding the extent potential of high water temperature impacts remain.

To address these uncertainties, BC Hydro has commissioned a formal water temperature monitoring program to measure water temperatures throughout the watershed, including the reservoir, to better assess the possible range of operational changes that can be taken to mitigate for measured impacts. This Year 1 report summarizes the temperature data collected since the beginning of this monitoring program (October 2008) and also summarizes data collected earlier. This report does not address the reservoir temperature since only a few months of data are currently available. This report is preliminary and will be expanded to address all of the management questions as the program proceeds and more data is collected.

1.2 Management Questions

The FTC identified the following management questions that will be addressed by this temperature monitoring program.

1. How often are water temperature $\geq 25^{\circ}\text{C}$, 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.

In addition to the water temperature monitoring to address the management questions, a literature review will be undertaken to establish threshold temperatures and durations

that define warm water events that may have significant impact to the fish community during the critical summer growth period (July to September).

2 Methods

2.1 Literature Review

An internet based literature review was undertaken to determine the water temperature tolerances for coho, sockeye, chum and Chinook salmon as well as Rainbow Trout (Steelhead). The literature review provided information on upper lethal temperature (ULT), short term maximum survival temperature (SMT) Ultimate upper incipient lethal temperature (UUILT) and final temperature preferendum (FTP) for each species and life history stage (embryo, juvenile and adult).

2.2 Field Methods

Temperature data is collected from both the Alouette Lake reservoir and Alouette River between the Alouette Dam and 224th Street in Maple Ridge, BC (Figure 1). Temperature monitoring in the reservoir is completed with a string of temperature loggers hanging off the LLO structure. The string of loggers is orientated vertically with a 2 m spacing from 124 m el. down to 114 m el. The LLO intake is located at 113 m el.

Temperature data loggers are located at five location on the South Alouette River between the Alouette Dam and the 224th Street bridge crossing (Table 1).

Table 1. Loggers site reference names and locations

| Site Reference | Location |
|----------------------|---|
| LLO Outlet | 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. |
| 224 th St | On the right bank of the river approximately 100 m upstream of the 224 th Street bridge. |

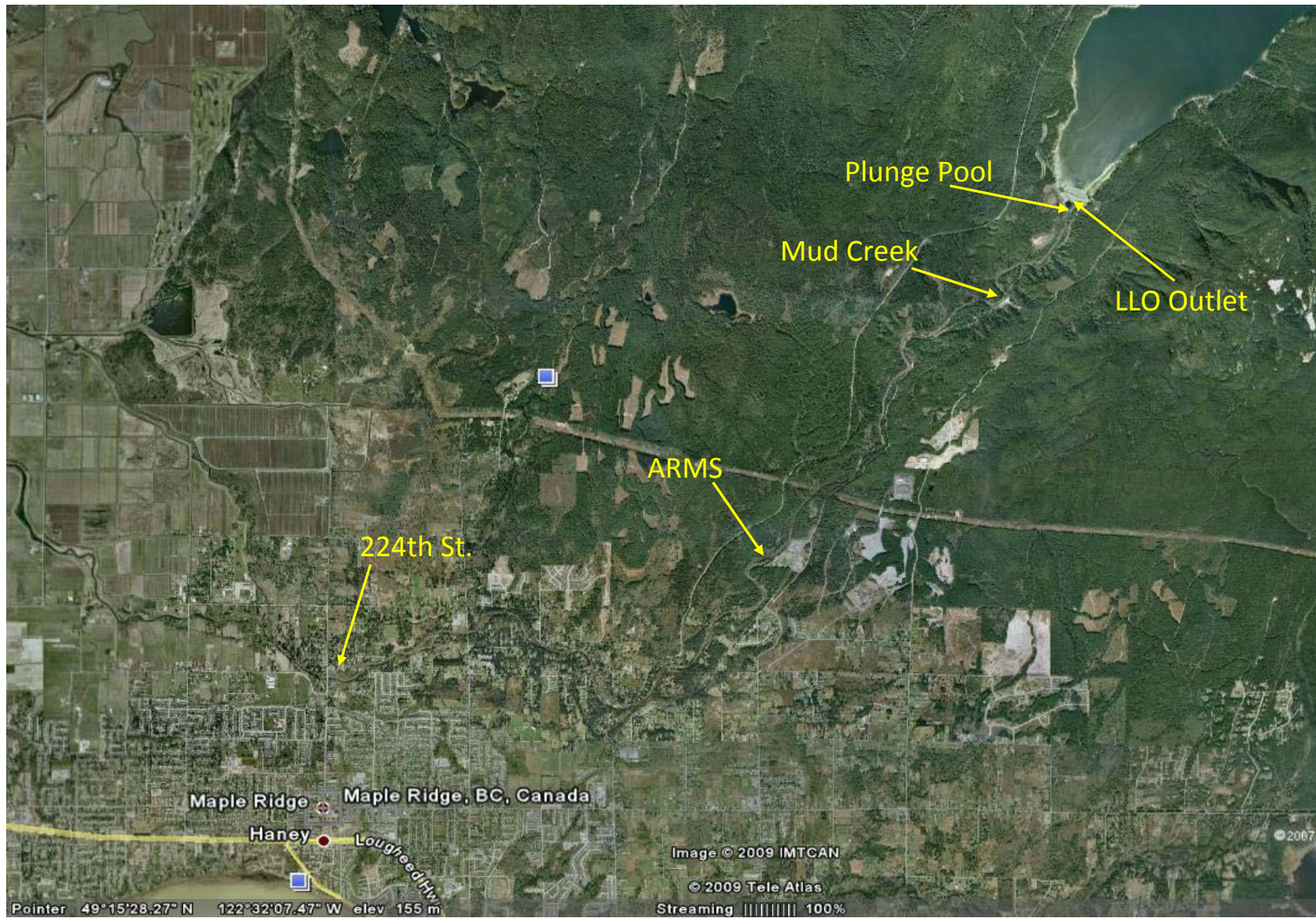


Figure 1. Location of Alouette River temperature loggers.

The temperature loggers are TidbiT V2 Temp Logger (Part # UTBI-001) manufactured by the Onset Computer Corporation. The operational temperature range of the loggers is from -20°C to 70°C in air and a maximum sustained temperature of 30°C in water. The accuracy of the loggers is 0.2°C over a range of 0 to 50°C. The loggers are set to log temperature measurements hourly at all locations.

2.3 Data Analysis

Temperature data was provided by BC Hydro in daily mean, maximum and minimum format for data prior to 2008. For subsequent data the daily mean, maximum and minimums were calculated. All daily mean, maximum and minimum for the plunge pool site were plotted.

Comparisons of daily mean temperatures from the Plunge Pool site and the downstream river sites were complete with two-tail pairwise t-tests.

3 Results

3.1 Temperature Preference Literature Review

3.1.1 Embryos (Eggs and Alevins)

Coho

Tang et al. (1987) found that, when held at constant incubation temperatures, coho embryos withstood temperatures between 1.3 and 12.4°C (Table 1). Nearly 100% mortality occurred above 14°C and below 1.3°C. Most mortality occurred in the early embryonic stages, usually before the blastopore closed. Abrupt temporary changes (8h) ranging from +8.4°C to -6.2°C (including a drop to 0.1°C) resulted in little or no increase in embryo mortality except at the highest (10.2°C) incubation temperature. Murray and McPhail (1988) found that coho egg survival to hatching was high for eggs held at 5C, 8C, and 11C, but survival dropped considerably for eggs held at 2°C and 14°C: embryo survival dropped to 50% for eggs held at 1°C.

Chum

Egg hatching and alevin development have occurred in Alaska at temperatures as low as 0.2-6.7°C: however, the optimum incubation temperature range is 4.4°C to 13.3°C (Alaska Department of Fish and Game, 1986). Schroder et al. (1974) found significantly higher mortalities of chum salmon eggs, alevin, and fry when the eggs were incubated in water temperatures below 1.5°C during the early stage of egg development (before blastopore closure).

Steelhead / Rainbow

Hatching success of rainbow trout eggs reaches its maximum (90%) at 10-12°C. The curve relating hatching success to temperature is bell-shaped and declines to 0% survival at 3°C and 18.5°C (Matighofen 1983, as cited by Humpesch 1985). Kwain (1975) measured a low survival rate (10%) of rainbow trout embryos to hatching at 15°C

Chinook

Reiser and Bjornn (1979) listed recommended incubation temperatures as 5.0 to 14.4°C. Water temperature of 14.4°C was cited as the upper limit of the optimum water

temperature range for incubation of salmon eggs (Bell 1991). However, a maximum temperature of 12.8°C was recommended by the US Environmental Protection Agency and the National Marine Fisheries Service (1971), and the California Department of Wildlife Resources (1988) identified the temperature range of 12.8-14.2°C as one that produces only 50% egg survival from egg to the sac-fry stage owing to abnormal physiological development and yolk coagulation. For eggs incubated at 16°C, mortality occurring post emergence can be much more severe than that occurring prior to emergence because of physiological difficulty in completing yolk absorption (CDWR 1988).

Table 2. Lethal and preferred water temperatures (°C) for embryos.

| | Lower Lethal | Lower Sustained | Optimum Range | Upper Sustained | Upper Lethal |
|-----------|---------------------|------------------------|----------------------|------------------------|---------------------|
| Coho | 1.3 | 2 | | 12.4 | 14 |
| Chum | 2 | 1.5 | 4.4 - 13.3 | 14 | |
| Steelhead | | 3 | 10 - 12 | 15 | |
| Chinook | | 3 | 5.0 - 12.8 | 14.4 | 16 |
| Sockeye | | 1 | 8 - 12 | 14 | 15.6 |

Confounding Factors

Upper Instantaneous Lethal Temperature (UILT) is not a constant for any individual egg of any species: the degree of temperature change and the previous incubation temperature have a significant effect on the survival of eggs that are briefly exposed to high temperatures (e.g. Tang et al.1987).

Timing of thermal exposure is also important. Embryos are quite resistant to thermal and physical shock for the first two days after fertilization. They are then more vulnerable until the blastopore closes, about 11 days later (depending on temperature), but are later quite tolerant until hatching (Quinn 2005). Another vulnerable period occurs between 80-120 TU's (thermal units, or "degree days": 80-120 TU's could be 20-30 days, depending on temperature), when eggs are once again more likely to succumb to the effects of physical or thermal shock (Johnson et al. 1989).

3.1.2 Juveniles

Coho

Brett (1952) determined the upper lethal temperature for coho fry to be 25.1°C and preferred temperature 12-13°C. LT50 for Alaskan coho held under variable temperature regimes was 28°C for age-0 fish and 26°C for age-2 fish (pre-smolts). Juveniles held under a more variable temperature regime (6.5-20°C) showed more signs of physiological stress than those held under a more stable temperature regime (10-13°C, 9-15°C: Thomas et al. 1986). Welsh et al. (2001) surveyed juvenile coho populations in a California watershed. They found that all surveyed streams with a Mean Weekly Maximum Temperature (MWMT) of 16.3°C or with a Mean Weekly Average Temperature (MWAT) of 14.5°C or less had juvenile coho populations present. Conversely, no streams with a MWMT greater than 18.0°C or a MWAT greater than 16.7°C had juvenile coho present.

Chum

Fry (1952) experimentally determined the ultimate upper lethal temperature of chum juveniles to be 23.8°C and the preferred temperature range to be 12 to 14°C.

Downstream migration in Alaska has occurred at temperatures as low as 3.0-5.5°C, but peak migrations occur in water that is 5.0-14.0°C, with the optimum temperature range being 6.7-13.3°C (Alaska Department of Fish and Game, 1986). The upper and lower lethal temperature limits for British Columbia chum fry have been found to be 23.8°C and 0.3°C, respectively (Alaska Department of Fish and Game, 1986).

Rainbow / Steelhead

Steelhead appear to have the highest thermal tolerance of all of the *Oncorhynchus* species, which is reflected in the southern and interior expanses of their range. Hokanson et al. (1977) found the physiological optimum temperature for rainbow trout to be 16-18°C, but juvenile steelhead in California streams hold focal points at temperatures between 17.4°C and 24.8°C (Spina 2007). Kaya (1977) found Yellowstone rainbow trout to have an upper incipient lethal temperature of 26.2°C, regardless of temperature acclimation. Similarly, Lake Superior rainbow trout were found to have an upper incipient lethal temperature of 25.6°C (Hokanson et al. 1977). However, this same study found the maximum temperature at which a rainbow trout population can be expected to maintain its weight for 40 days was a constant temperature of 23°C or a fluctuating mean temperature ($\pm 3.8^\circ\text{C}$) of 21°C. The temperature range from 21 to 23°C has also been reported by various authors as representing the upper limits of natural rainbow trout distribution (Burton and Odum 1945; Horak and Tanner 1964; Pierce 1966; McCauley and Pond 1971; but see Spina 2007).

Chinook

Fry (1952) experimentally determined the ultimate upper lethal temperature of chinook juveniles to be 25.1°C and the preferred temperature range to be 12-14°C. Nakatani (1969) measured chinook alevin and fry mortality under differing temperature regimes. He found that fish raised in 13°C water began experiencing significant mortality (28%) when the temperature was raised and maintained at 17°C, and suffered 100% mortality at 19°C. Fish raised in 12°C water did not experience significant mortality (43%) until 18°C, but still suffered nearly 100% mortality at 19°C.

Researchers in California found that juvenile chinook from the Sacramento River could survive temperatures up to 24°C. However, the optimal range was 13-16°C, while temperatures from 17-24°C caused decreased growth rates, impaired smoltification indices, and increased vulnerability to predation (Marine and Cech 2004).

Sockeye

Fry (1952) experimentally determined the ultimate upper lethal temperature of sockeye juveniles to be 24.4°C and the preferred temperature range to be 12-14°C.

Table 3. Lethal and preferred water temperatures (°C) for juveniles.

| | Lower Lethal | Lower Sustained | Optimum Range | Upper Sustained | Upper Lethal |
|-----------|---------------------|------------------------|----------------------|------------------------|---------------------|
| Coho | | | 12 - 13 | 16 - 18 | 26 - 28 |
| Chum | 0.3 | | 12 - 14 | | 23.8 |
| Steelhead | 0.5 | | 16 - 18 | 21 - 23 | 26.2 |
| Chinook | | | 12 - 14 | 18 - 19 | 25.1 |
| Sockeye | | | 12 - 14 | 17 | 24.4 |

Confounding factors

There are indirect effects of thermal shocks as well. Coutant (1973) observed that chinook and steelhead juveniles showed a significant loss of equilibrium after undergoing a thermal shock. Even though the shock was not directly lethal, predators captured significantly more thermally shocked juveniles than control fish.

3.1.3 Adults

Adult salmonids in general have preferences for colder water than juveniles of the same species (McCullough 1999, Fowler et al. 2009).

Coho

Andrew and Geen (1960) reported that coho, chinook, and sockeye all spawn on falling temperatures, starting at peak temperatures of 10.6-12.8°C. Temperatures above 12.8°C corresponded with an increasing number of pre-spawn mortality in females.

Chum

Alaska Department of Fish and Game (1986) lists records of adult chum salmon migrating up streams with temperatures between 4.4°C to 19.4°C. Peak migration counts suggested a preferred range between 8.3°C to 15.6°C, with an optimum of 10°C. Spawning has occurred in Alaskan waters at temperatures from 6.9°C to 12.8°C, with preferred temperature ranges of 7.2°C to 12.8°C (Alaska Department of Fish and Game, 1986). In the state of Washington, a drop in water temperature below 2.5°C was shown to inhibit redd construction and spawning by chum (Schroder 1973).

Steelhead

Of the pacific salmonids, steelhead are frequently considered to be among the least sensitive to thermal stress. Reynolds and Casterlin (1979) summarize several studies and report a preferred temperature for adult steelhead of 13.5°C. Migrating Columbia River steelhead acclimated to 19°C had a lethal threshold of 21°C (Coutant 1970)

Chinook

The optimal temperature for holding chinook broodstock in hatchery ponds is considered to be 6-14°C (Leitritz and Lewis 1976, Piper et al. 1982). Holding females at 3.3°C totally inhibits maturation and results in complete mortality prior to spawning (Leitritz and Lewis 1976). Even before eggs are deposited in gravels, exposure of adult females holding ripe eggs to temperatures above 14°C can cause egg mortality and delayed alevin development (Rice 1960, Leitritz and Lewis 1976).

Sockeye

Major and Mighell (1966) observed that migrating Okanogan sockeye avoided the Okanogan River when temperatures were above 21°C, holding in the Columbia River until temperatures dropped.

Table 4. Lethal and preferred water temperatures (°C) for adults.

| | Lower Lethal | Lower Sustained | Optimum Range | Upper Sustained | Upper Lethal |
|-----------|--------------|-----------------|---------------|-----------------|--------------|
| Coho | | | 10.6 - 12.8 | 20 | |
| Chum | | 2.5 | 7.2 – 12.8 | 19.4 | |
| Steelhead | | | 5.6 – 13.3 | 21 | |
| Chinook | | 3.3 | 6 - 14 | 18 - 21 | |
| Sockeye | | | 10.6 - 12.8 | 21 | |

3.2 Water Temperature

Temperature monitoring in the Alouette River commenced in 1999. Temperature records are not complete for the period extending from 1999 through 2003 but are much more complete from 2004 through 2008. This temperature monitoring program commenced in the Fall of 2008 with the replacement of all temperature loggers and the addition of two sites as described above in Section 2.2.

Water temperatures in the plunge pool just downstream of the Alouette Dam generally ranged from a low of about 4°C in December and January and generally increased from February with peak temperatures observed in late August and early September. Appendix 1 provides a plot of daily mean, maximum and minimum temperatures for all years (1999-2008) from the Plunge Pool site. Water temperatures reached a high of 19°C to 22°C from 2000 through 2008 (Table 5). Daily maximum temperatures did not reach the upper incipient lethal temperature for any salmonid species present (Table 2) during the period of record.

Table 5. Range of daily maximum temperatures at all 4 river sites over the summer months (July through September). Temperatures over 20°C are highlighted in yellow.

| Year | Plunge Pool | | Mud Creek | | ARMS | | 224th St | |
|------|-------------|-------|------------|-------|------------|-------|------------|-------|
| | Daily Max. | Range | Daily Max. | Range | Daily Max. | Range | Daily Max. | Range |
| 2000 | 12.59 | 19.03 | 12.56 | 18.88 | 12.86 | 19.53 | 13.42 | 20.09 |
| 2001 | 15.22 | 19.03 | ND | ND | ND | ND | ND | ND |
| 2002 | 14.98 | 22.59 | ND | ND | ND | ND | 13.74 | 20.28 |
| 2003 | 16.09 | 21.26 | 16.51 | 21.69 | 16.00 | 21.99 | 15.31 | 21.93 |
| 2004 | 14.97 | 22.88 | 14.36 | 22.44 | 14.36 | 22.44 | 13.95 | 22.14 |
| 2005 | 14.34 | 20.56 | 13.58 | 20.44 | 12.49 | 20.13 | 13.18 | 20.66 |
| 2006 | 15.44 | 20.62 | 13.58 | 18.33 | 15.97 | 21.63 | 14.89 | 21.64 |
| 2007 | 12.97 | 18.99 | 12.19 | 17.85 | 13.31 | 19.51 | 12.98 | 19.49 |
| 2008 | 14.68 | 18.67 | 14.39 | 18.07 | 13.62 | 15.18 | 13.91 | 19.17 |

ND = No Data

One addition to the current monitoring program over the previous data is a temperature logger at the LLO outfall (located about 50 m upstream of the plunge pool site). The LLO outlet logger will help to determine whether the residence time in the plunge increases water temperature through solar heating in the summer months. Since the LLO site was established in October of 2008 there was very little data for comparison and none over the warm weather period. A pair-wise comparison (Paired t-test) of daily mean temperatures resulted in a small (0.09°C) but significant (P {two-tail}=1.36E-05)

decrease in temperature from the LLO to the downstream end of the plunge pool from October 18 to December 12, 2008. This small difference in temperature was likely due to the very low ambient temperatures encountered in early December which resulted in freezing of some peripheral areas of the river. Analysis of future data will allow us to determine whether solar heating is occurring in the plunge pool.

Flow conditions, riparian structure, tributary inflows and groundwater inflows can all play a role in shifting water temperatures within a river. In the Alouette River there is a potential to increase or decrease water temperatures in areas downstream of the Alouette Dam. To estimate this effect we compared summer temperatures (July through September) between the Plunge Pool Site and the 3 downstream sites for 2000 to 2008 where sufficient data was present. We compared both daily mean and daily maximum temperatures using a paired t-test (Tables 5 and 6).

Table 6. Direction of temperature shift and two-tail P-values from paired t-test between daily mean temperatures from the plunge pool site and downstream river sites during the summer months (July through September). Values in red indicate a statistically significant difference.

| Plunge Pool | Mud Creek | | ARMS | | 224 St | |
|-------------|-------------------|----------|-------------------|----------|-------------------|-----------|
| | Temperature Shift | P-Value | Temperature Shift | P-Value | Temperature Shift | P-Value |
| 2000 | Cooler | 5.68E-11 | Cooler | 0.003 | Warmer | 0.181 |
| 2001 | No Data | | No Data | | No Data | |
| 2002 | No Data | | No Data | | Cooler | 2.609E-05 |
| 2003 | Cooler | 1.16E-10 | Cooler | 1.08E-12 | Cooler | 9.882E-08 |
| 2004 | Cooler | 9.05E-14 | Cooler | 5.26E-14 | Cooler | 0.001 |
| 2005 | Cooler | 1.66E-25 | Cooler | 7.09E-28 | Cooler | 3.88E-06 |
| 2006 | Cooler | 4.88E-52 | Cooler | 1.72E-23 | Cooler | 1.257E-07 |
| 2007 | Cooler | 5.05E-42 | Warmer | 0.983 | Warmer | 0.080 |
| 2008 | Warmer | 0.00042 | No Data | | Cooler | 0.059 |

Table 7. Direction of temperature shift and two-tail P-values from paired t-test between daily maximum temperatures from the plunge pool site and downstream river sites during the summer months (July through September). Values in red indicate a statistically significant difference.

| Plunge Pool | Mud Creek | | ARMS | | 224 St | |
|-------------|-------------------|----------|-------------------|------------|-------------------|---------|
| | Temperature Shift | P-Value | Temperature Shift | P-Value | Temperature Shift | P-Value |
| 2000 | Cooler | 1.63E-09 | Warmer | 0.095 | Warmer | 0.002 |
| 2001 | No Data | | No Data | | No Data | |
| 2002 | No Data | | No Data | | Cooler | 0.127 |
| 2003 | Cooler | 0.026 | Warmer | 0.220 | Cooler | 0.228 |
| 2004 | Cooler | 1.12E-07 | Cooler | 9.6242E-05 | Cooler | 0.127 |
| 2005 | Cooler | 5.30E-24 | Cooler | 4.4798E-11 | Cooler | 0.355 |
| 2006 | Cooler | 2.25E-60 | Cooler | 0.134 | Cooler | 0.076 |
| 2007 | Cooler | 1.31E-41 | Warmer | 0.246 | Warmer | 0.037 |
| 2008 | Cooler | 0.059 | No Data | | Cooler | 0.071 |

In general, the temperatures in the downstream sites were slightly cooler when compared to the plunge pool site and the differences were statistically significant ($P < 0.05$) in many cases (Tables 5 and 6). Summer water temperatures are plotted for all sites by year and are provided in Appendix 2 for a visual comparison of summer temperature between sites. Temperatures were warmer at the 224th St site in 2000 and at both the ARMS and 224th St sites in 2007 although only significant when comparing daily maximum temperatures from the 224th St site. In 2008, temperatures were warmer at the Mud Creek site when comparing the daily mean temperatures. Cooler water temperatures in downstream areas suggest there is cooler groundwater or cooler tributary inflows entering the system.

Management question 4 asks whether temperature conditions will reduce salmonid smolt survival and promote a shift in community structure from salmonids to species more tolerant to warm water. A persistent loss in smolt production due to high water temperature events could promote this shift in community structure. We compared production of coho and steelhead smolts to the number of warm water days experienced during the previous summer (Table 8). Smolt production is defined as the annual steelhead and coho smolt population estimates which are provided by the Alouette River Smolt Monitor. The warm water days were defined in a number of ways, as follows:

- Number of days with a mean daily temperature > 16°C
- Number of days with a mean daily temperature > 18°C
- Number of days with a maximum daily temperature > 16°C
- Number of days with a maximum daily temperature > 18°C

Table 8. Alouette River smolt production and warm water days.

| Year | Smolt Production | | Temperatures from previous summer | | | |
|------|------------------|-----------|-----------------------------------|-----|-----------------|-----|
| | | | Days above 16°C | | Days above 18°C | |
| | Coho | Steelhead | Mean | Max | Mean | Max |
| 2001 | 13789 | 2286 | 28 | 66 | 0 | 25 |
| 2002 | 12102 | 3768 | 61 | 89 | 1 | 20 |
| 2003 | 19358 | 2364 | | | | |
| 2004 | 16880 | 3355 | 92 | 103 | 42 | 55 |
| 2005 | 13020 | 2493 | 71 | 84 | 31 | 60 |
| 2006 | 14591 | 784 | 67 | 94 | 46 | 52 |
| 2007 | 3040 | | 89 | 110 | 56 | 68 |
| 2008 | 6508 | 6204 | 41 | 76 | 0 | 19 |

There was no correlation between coho smolt production and any of the warm water variables ($R^2 < 0.04$ in all cases, Appendix 3). Correlation between steelhead smolt production and the warm water variables was also poor ($R^2 < 0.5$ in all cases, Appendix 3). There are a number of significant variables that effect smolt production, such as broodyear escapement, that are not considered in these regressions. Increasing the temperature threshold to 20°C did not improve the correlations.

4 Discussion

The highest water temperatures are observed in late August in the Alouette River. Of the salmonid species present, these temperatures potentially impact summer rearing coho and steelhead as well as resident trout species. Other salmonid species will emigrate from the system prior to August.

The literature review has confirmed that the upper lethal temperature for rearing salmonids is near 25°C. There have been no observations of temperature over 23°C to date. The highest temperatures are observed near the end of August and temperatures over 20°C are observed in only some years. For example, for year 2000 through 2008 at the plunge pool site water temperatures exceed 20°C on 5 of the 9 years and only for one day in one of those years (2002). Water temperatures have been slightly cooler in the downstream sites compared to the Plunge Pool site over most years. Water temperatures are, however, above the optimum range for a portion of the year.

5 Recommendations

Weekly average temperatures will be completed as described in the terms of reference as the program progresses. Weekly averages were not completed here since little new data has been collected and all of the data collected prior to 2008 is has only been received in daily mean maximum and minimum format. We will obtain the raw data from BC Hydro in order to extend the weekly averages back over the period of record. This data will also be required for the analysis of variance described in the terms of reference which will also be completed in subsequent years.

There were three recommendations for this program that came from the 2008 FTC meeting.

1. It was recommended that an additional temperature logger is deployed in Millionaire Creek to determine if this is an inflow of cooler water into the Alouette River.
2. An additional logger should also be considered upstream of the Alco Park Hatchery site to determine of the outflow of groundwater from the hatchery influences water temperature.
3. The Davis pool may have a groundwater inflow source. This source should be investigated through field temperature measurements and a logger deployed if required.

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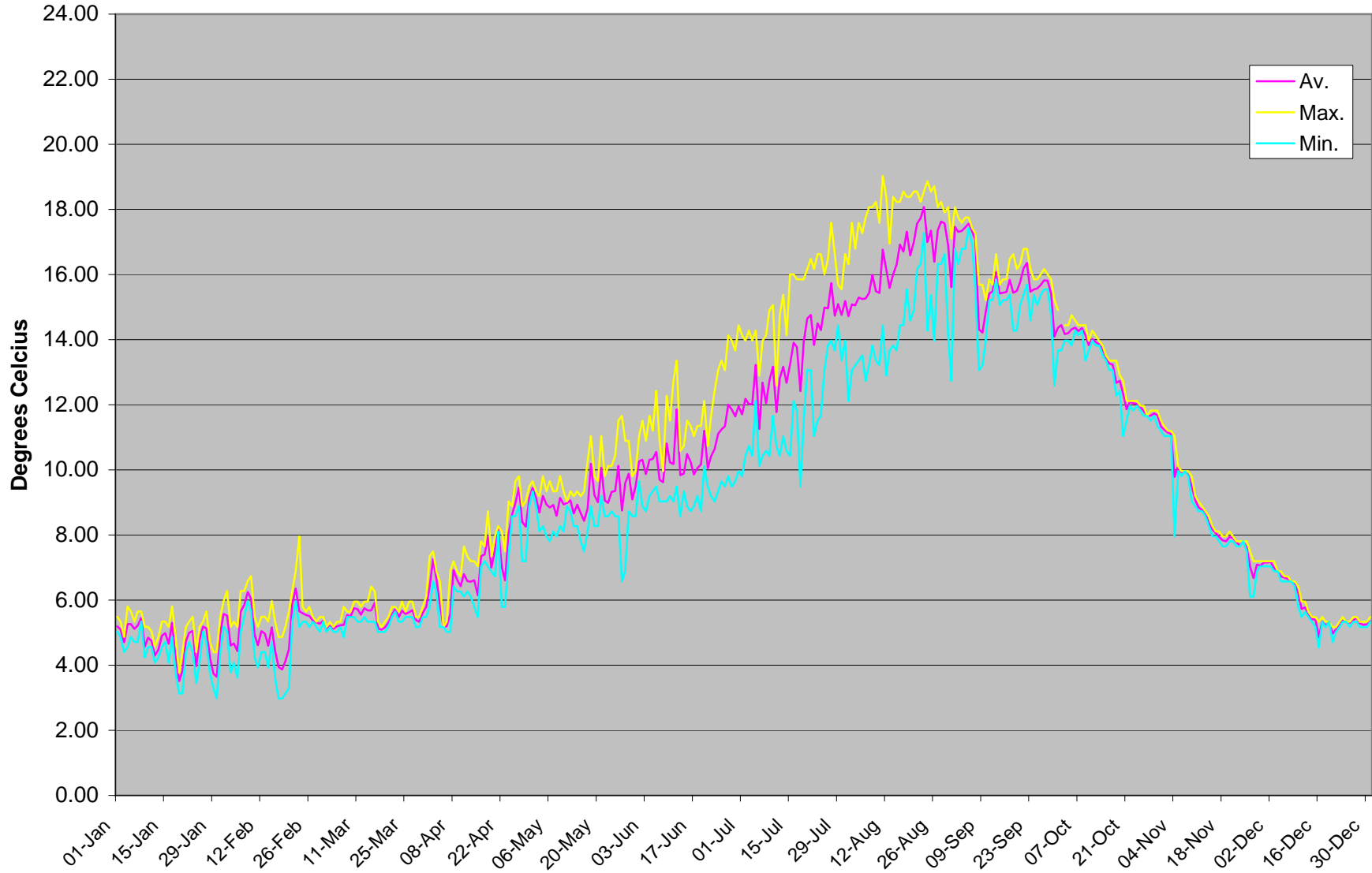
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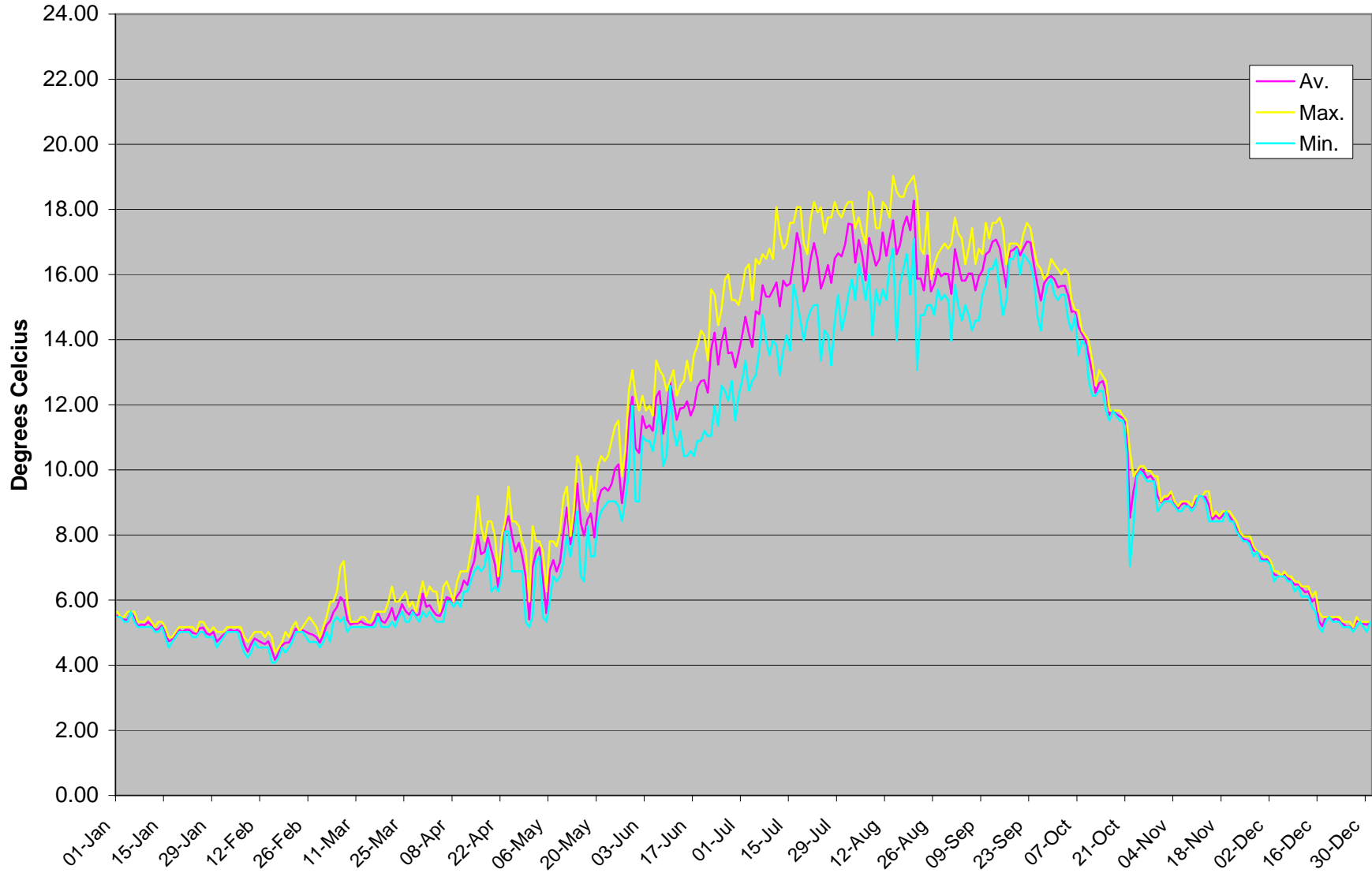
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Appendix 1. Plot of daily mean, maximum and minimum temperatures for all years (1999-2008) from the Plunge Pool site.

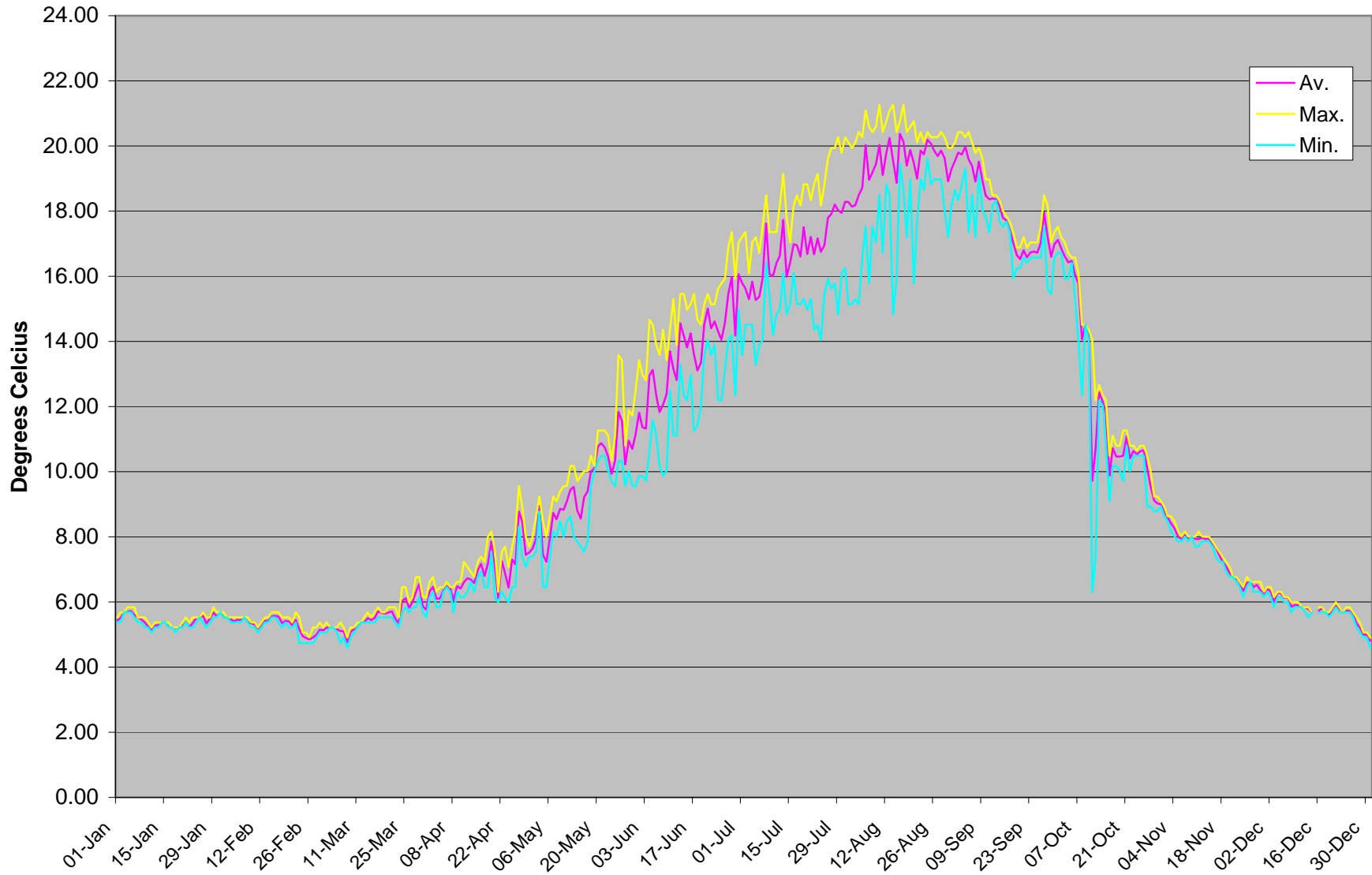
Alouette River Temperatures - Dam Site 2000



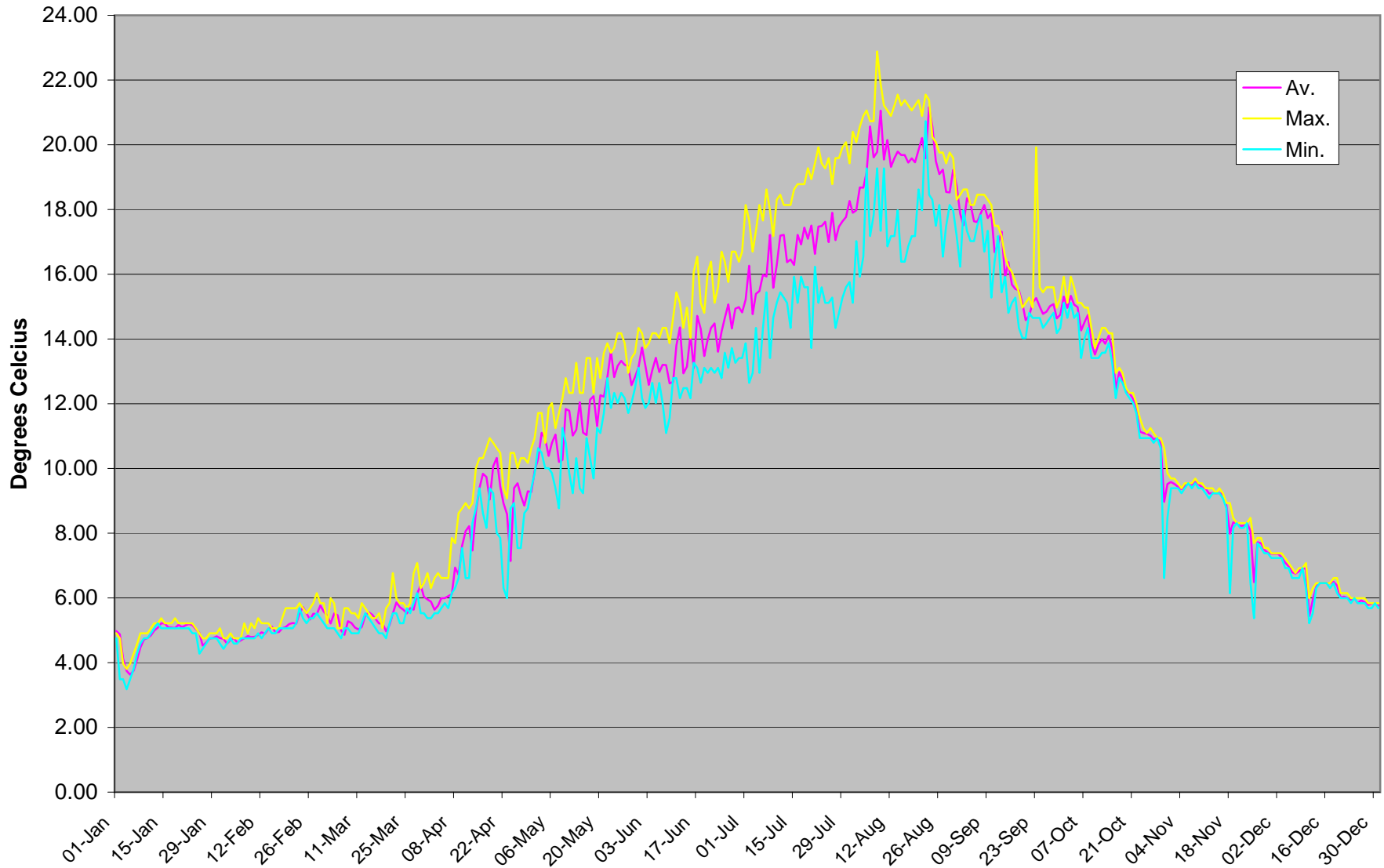
Alouette River Temperatures - Dam Site 2001



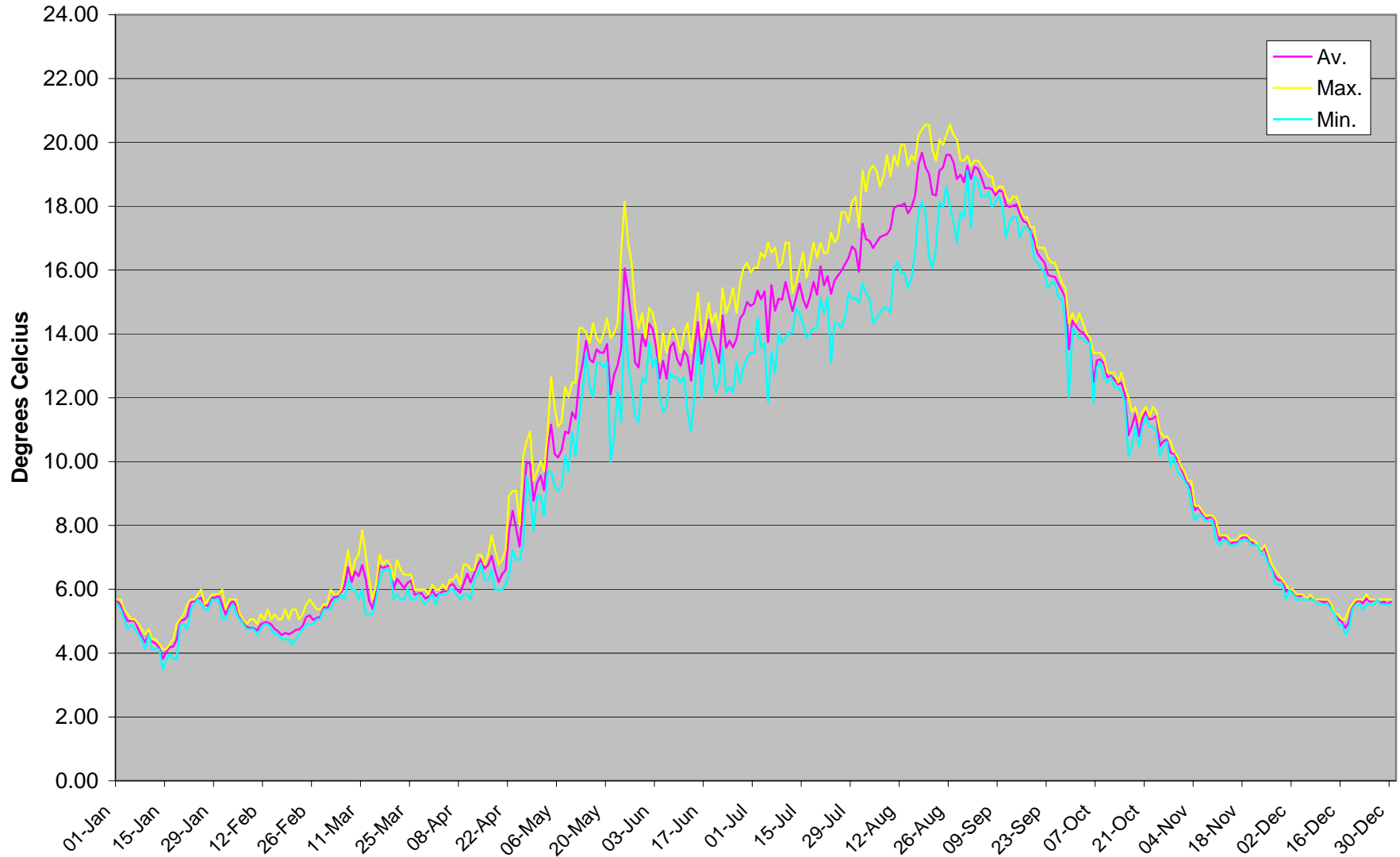
Alouette River Temperatures - Dam Site 2003



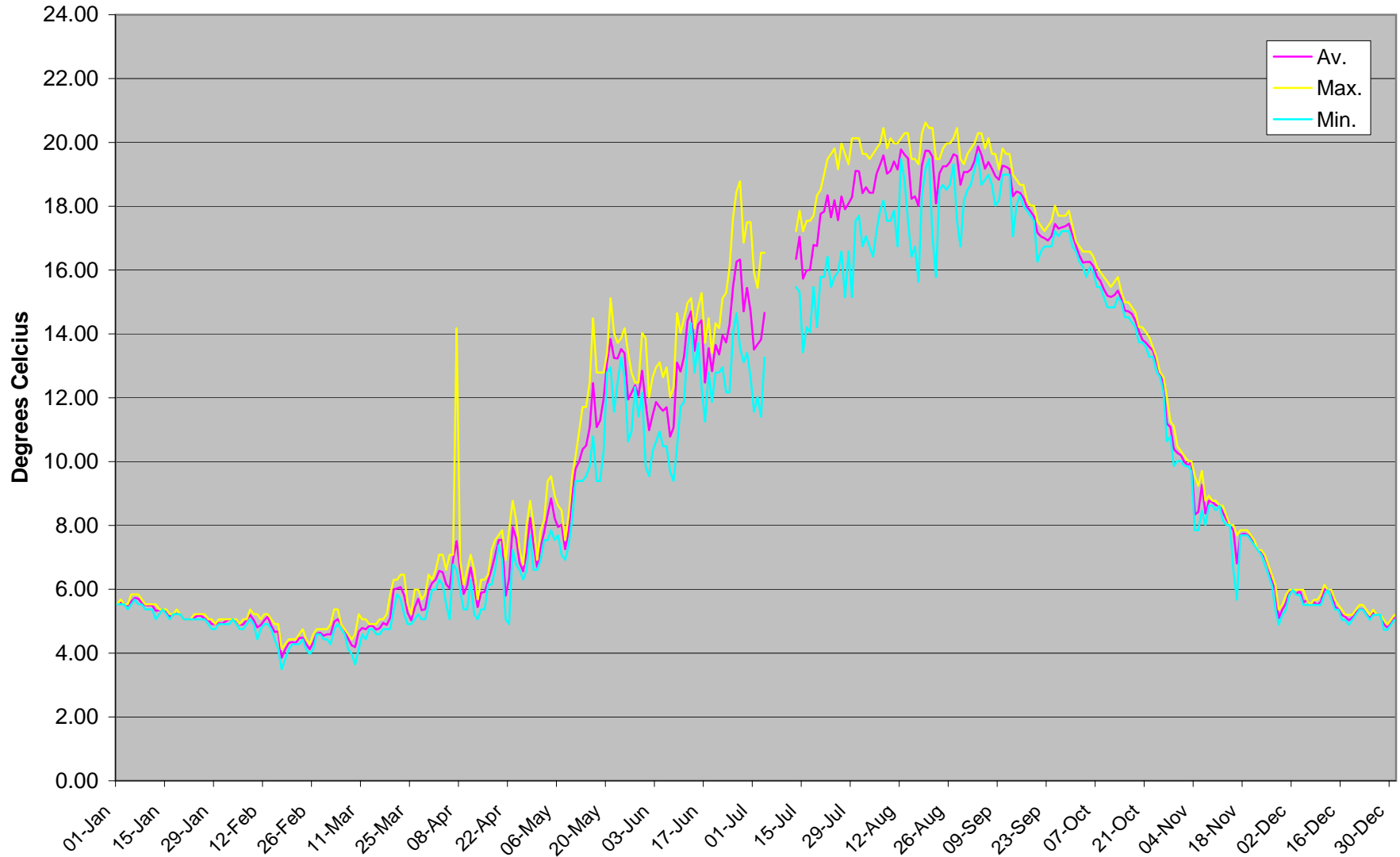
Alouette River Temperatures - Dam Site 2004



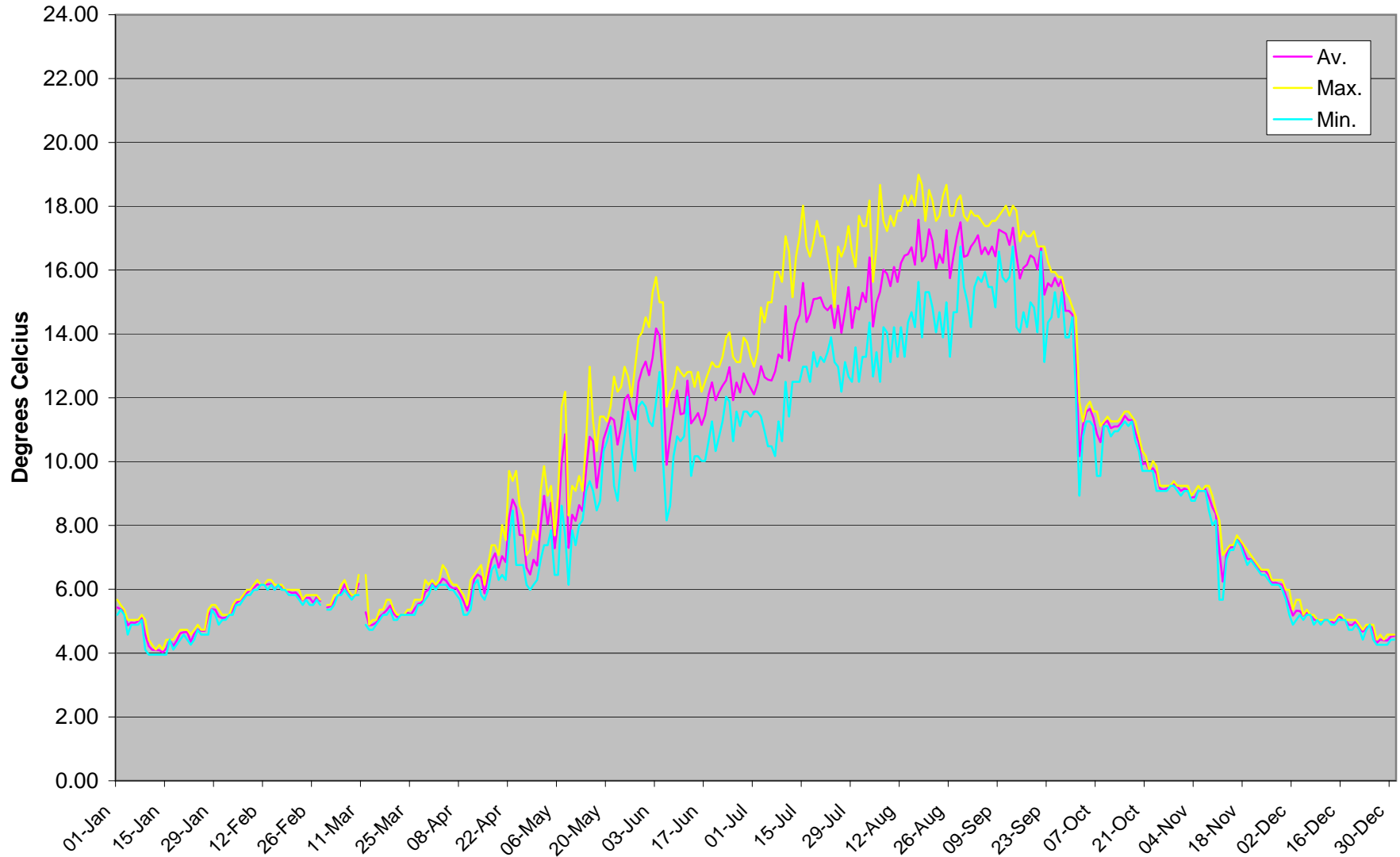
Alouette River Temperatures - Dam Site 2005



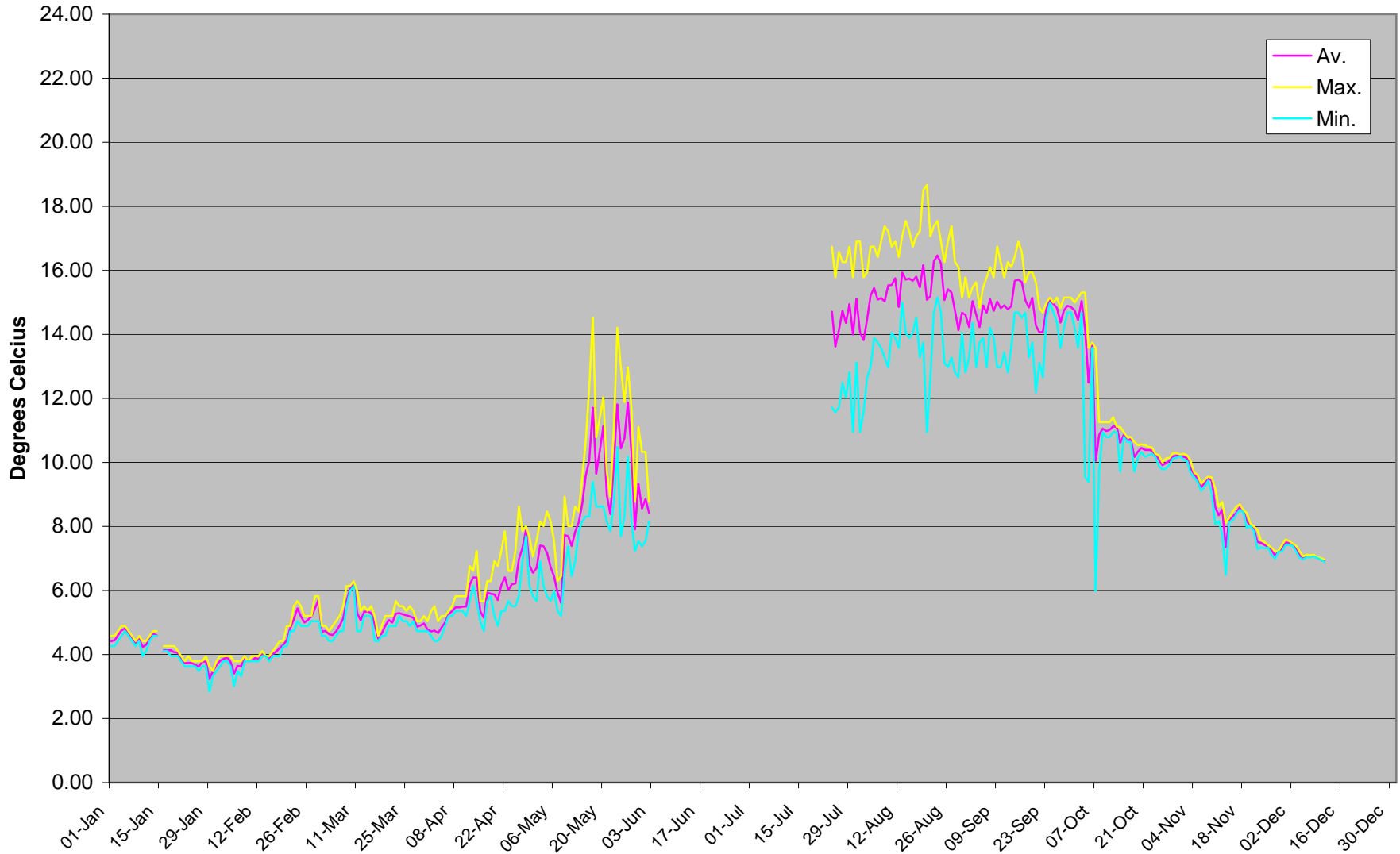
Alouette River Temperatures - Dam Site 2006



Alouette River Temperatures - Dam Site 2007

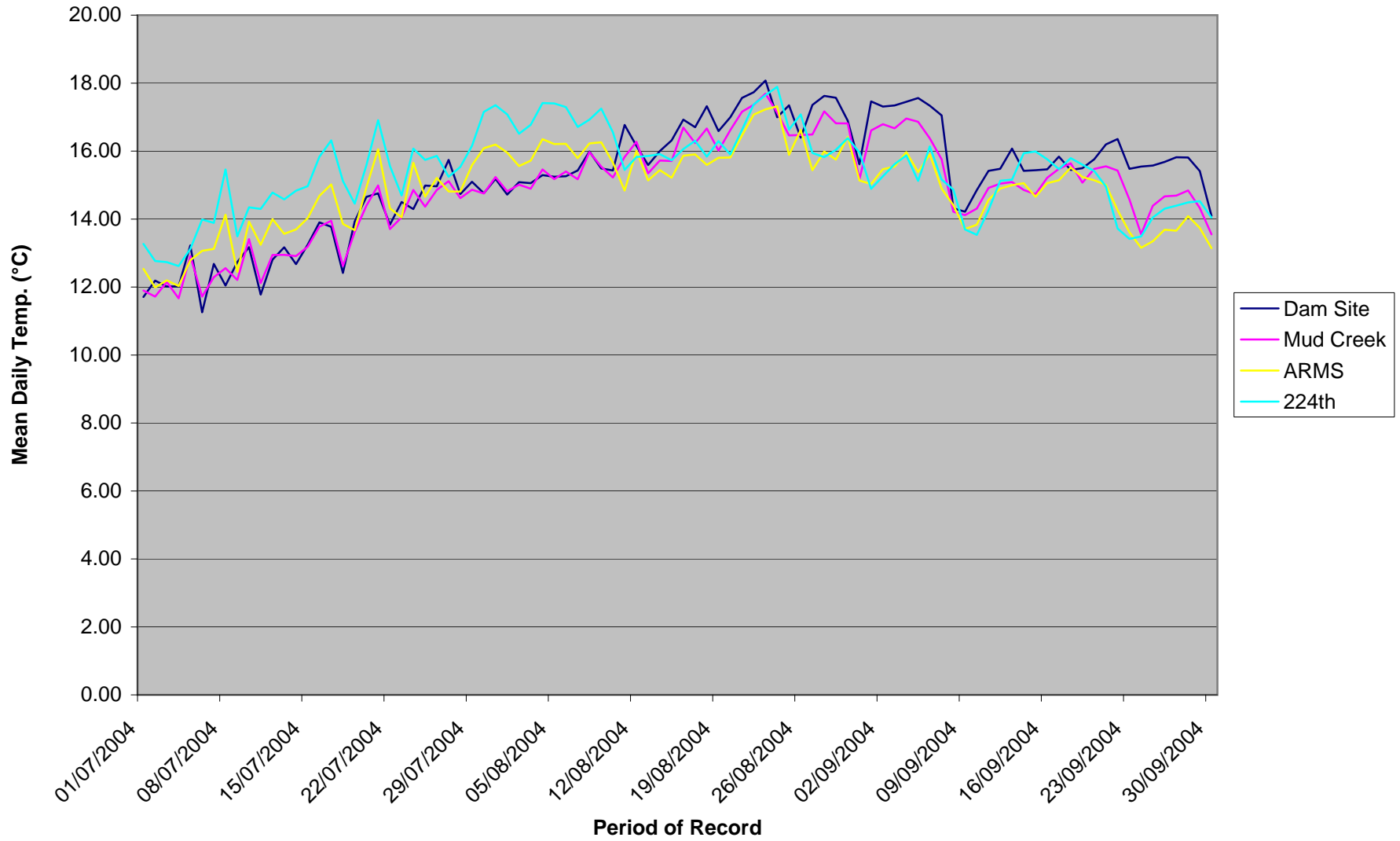


Alouette River Temperatures - Dam Site 2008

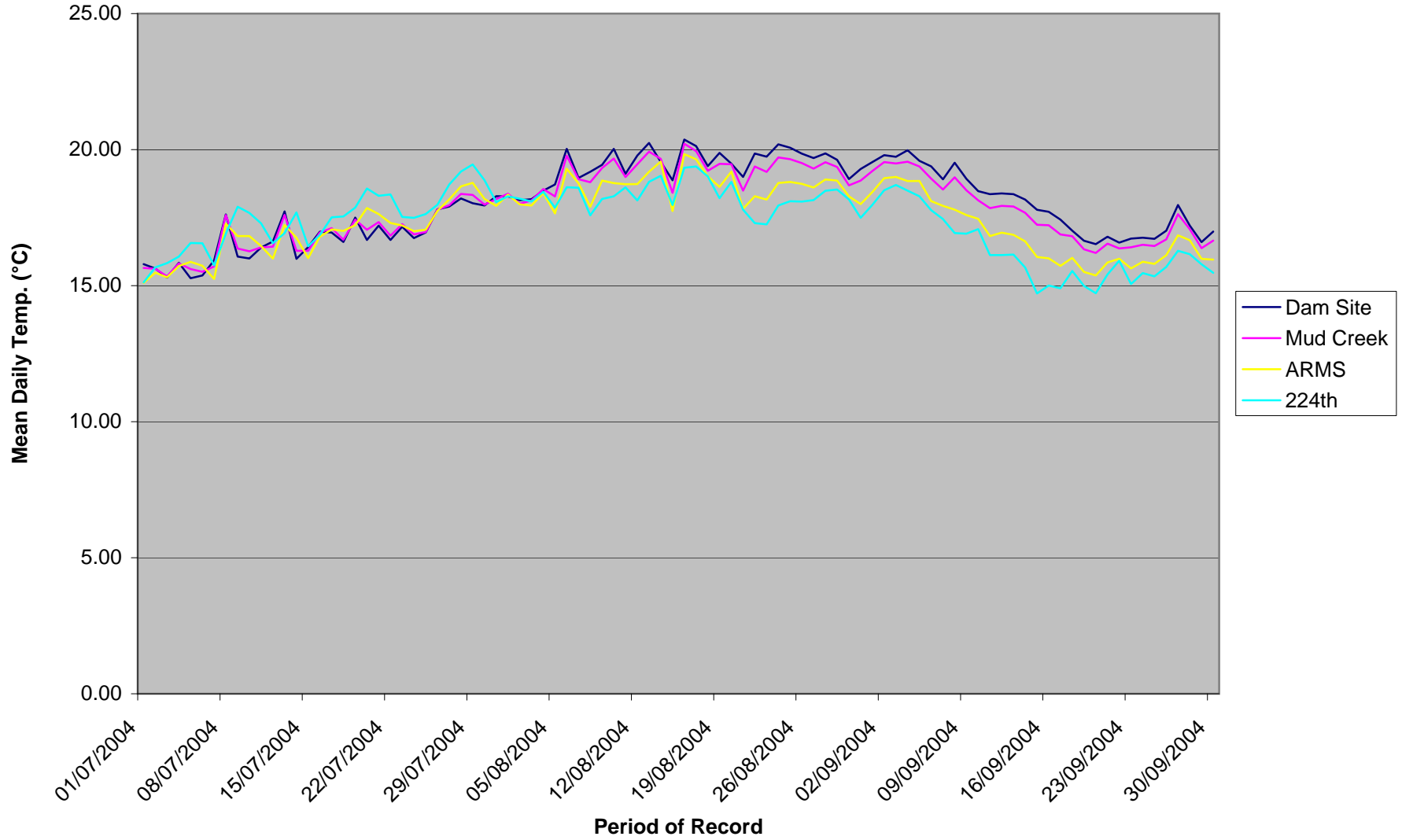


Appendix 2. Summer water temperatures for all sites by year.

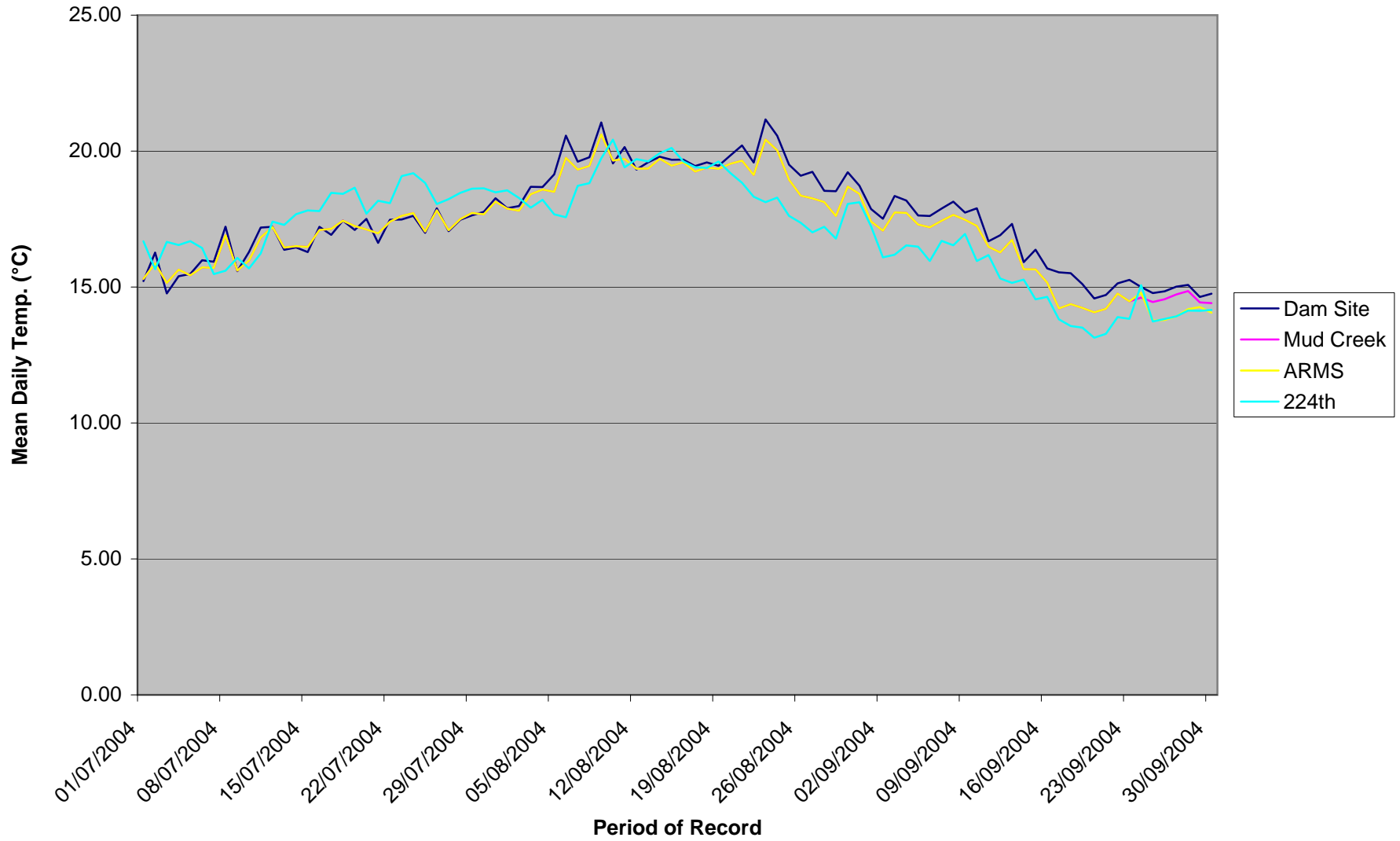
Summer 2000



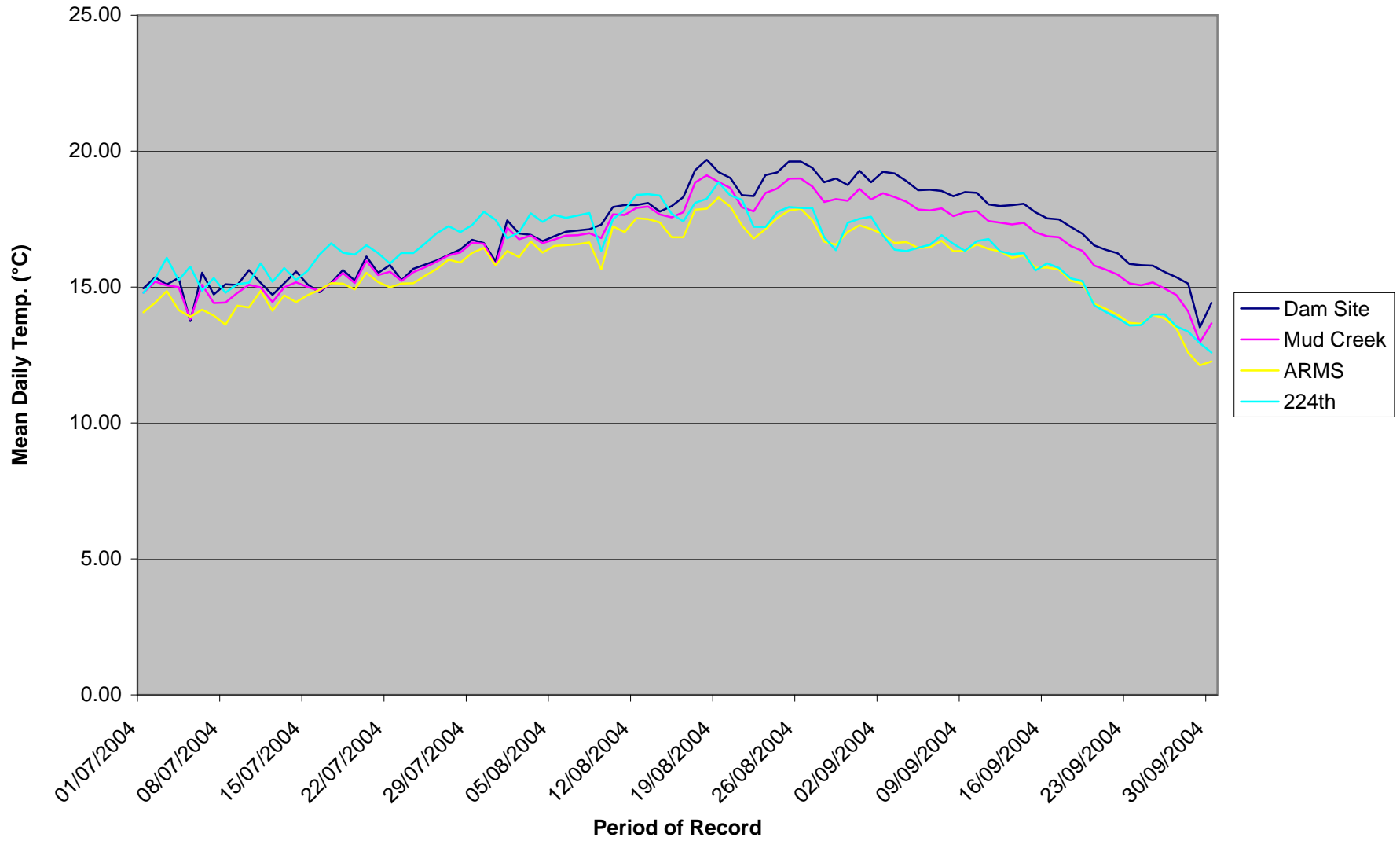
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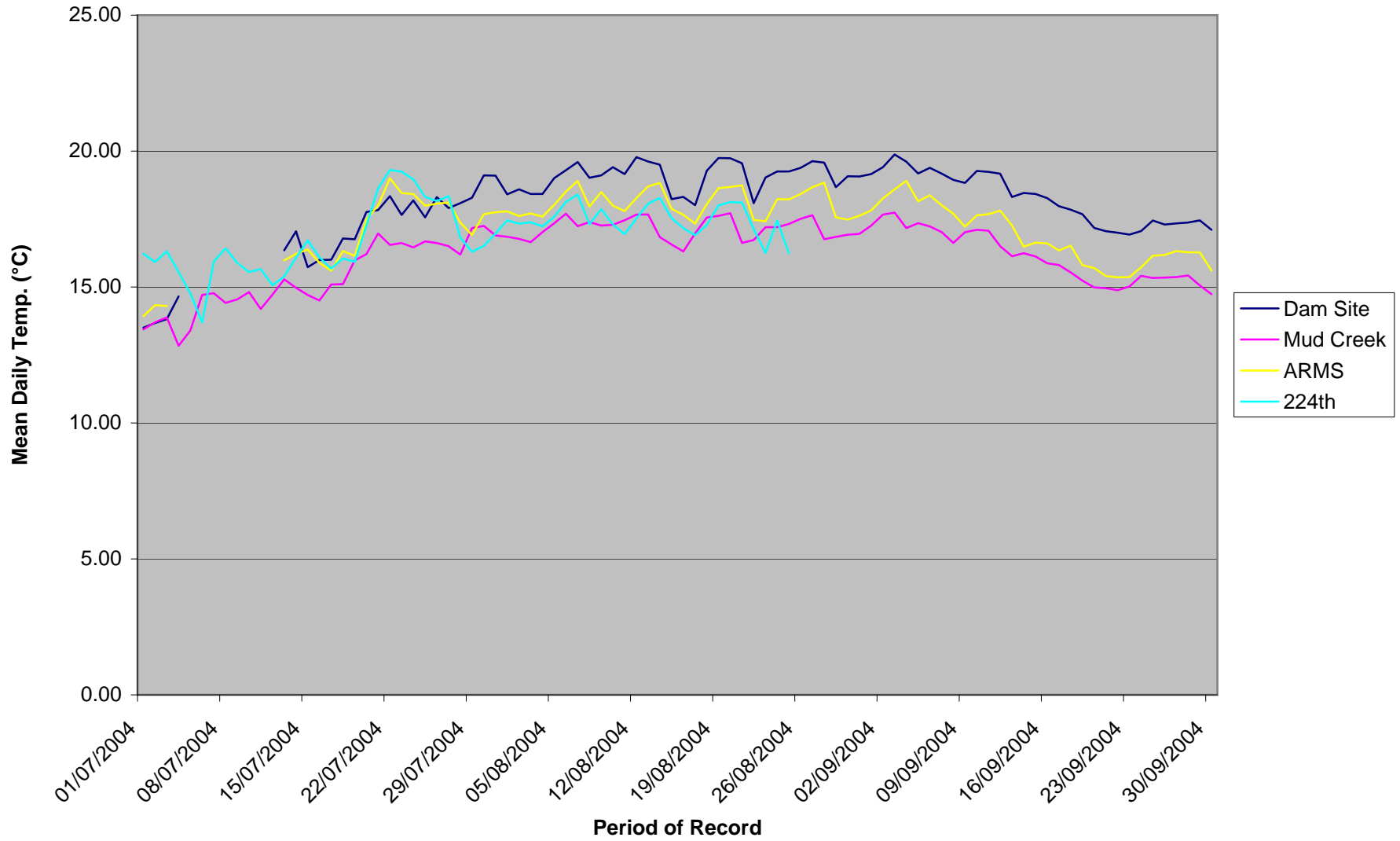
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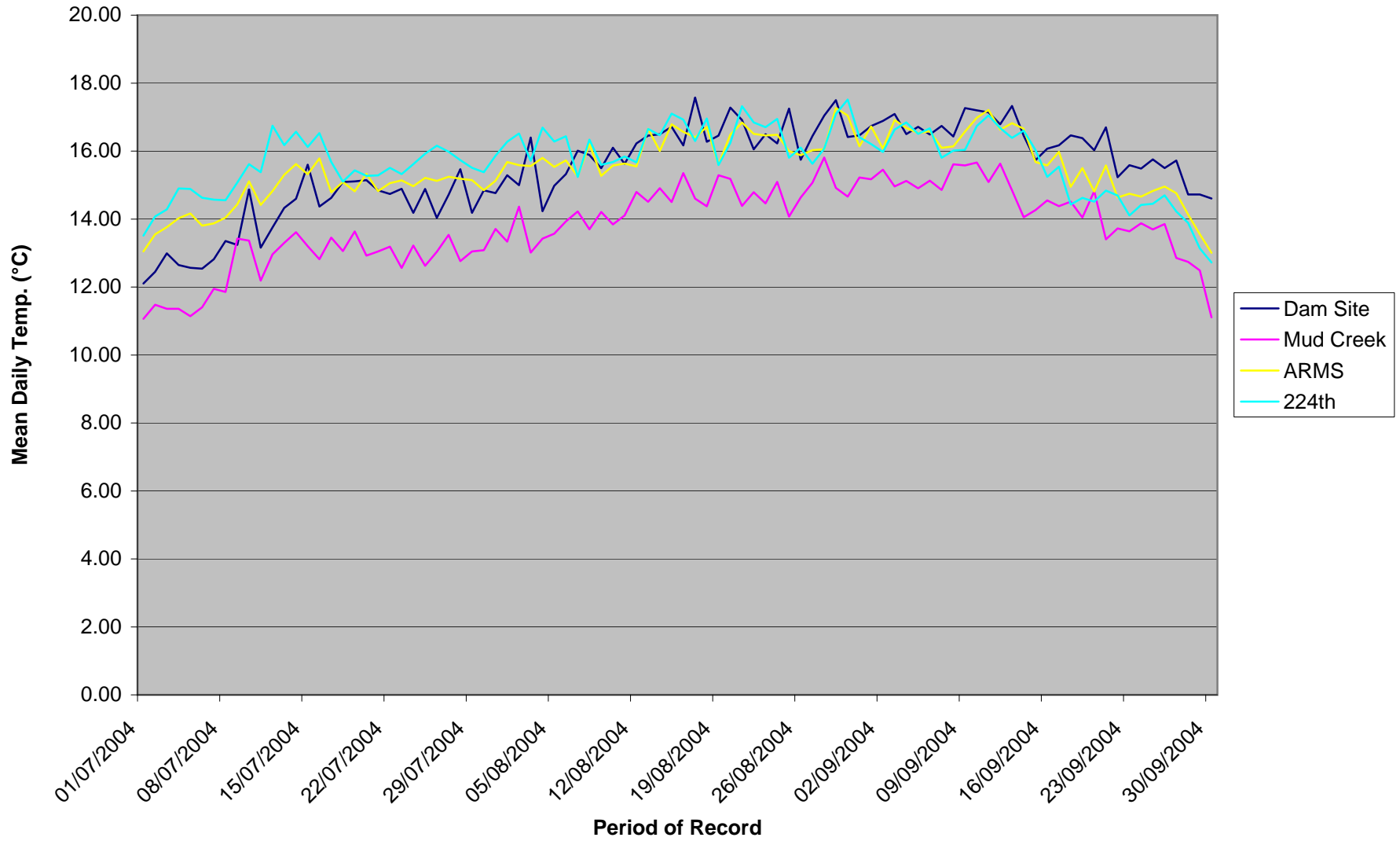
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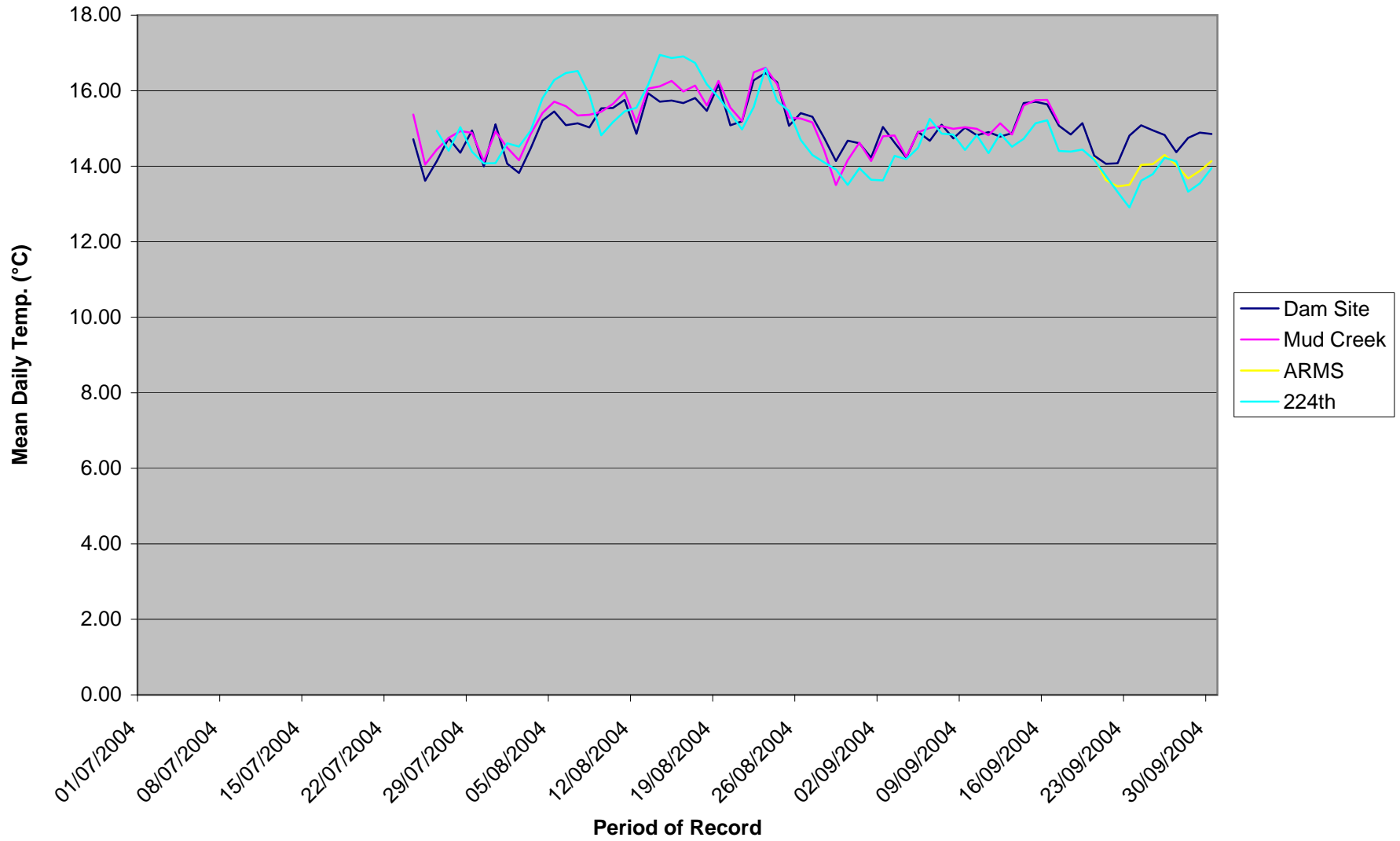
Summer 2006



Summer 2007



Summer 2008



Appendix 3. Plots of smolt production versus warm water days.

