# Muskeg River Watershed 2021 Stream Temperature Monitoring Report

**Prepared by:**

Nathan A. Medinski, M.Sc.

Aquatic Habitat Stewardship Coordinator

ASENIWUCHE WINEWAK NATION

# Executive Summary

The Aseniwuche Winewak Nation (AWN) worked with Alberta Environment and Parks (AEP) in 2021 to monitor summer water temperatures in the Muskeg River HUC 8 watershed. We deployed temperature loggers at 25 sample sites in 19 streams to understand how stream temperatures are likely influencing juvenile (≤ 150 mm) bull trout (*Salvelinus confluentus*) habitat suitability, based on published thermal thresholds. Average August water temperature, a proxy for summer temperature, exceeded thermal suitability thresholds (i.e., > 11 $^{o}$C) at 11 sites, whereas 14 sites were thermally suitable for juvenile bull trout occupancy. When compared to a fisheries survey conducted in 1993 that identified several important juvenile rearing streams in the watershed based on electrofishing surveys, we determined that lower Lone Teepee Creek may no longer be thermally suitable, however Isaac, Mahon and Chapman creeks still meet thermal habitat requirements. Finally, we found that thermal regimes and sensitivities varied among sample sites, with streams located across the watershed responding differently to increases in air temperature. Monitoring sites located in A la Peche Creek, upper Susa Creek, lower Muskeg River and lower Lone Teepee Creek were the most sensitive to air temperature increases, possibly due to factors such as groundwater input, riparian shading, channel slope, stream order, streamflow, and/or upstream standing water areas that can influence stream thermal regimes. This project was beneficial in improving our understanding of summer water temperatures in the Muskeg River watershed, establishing a productive working relationship between AWN and AEP, and building aquatic monitoring capacity within the AWN community. Furthermore, this report provides updated information for developing future stream temperature monitoring programs and modelling in this important watershed for bull trout conservation and recovery.

# Acknowledgements

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# 1. Introduction

In 2021, Aseniwuche Winewak Nation (AWN) worked in collaboration with Alberta Environment and Parks (AEP) to conduct a temperature monitoring program within the Muskeg River HUC 8 watershed. This project was highly beneficial to both AWN and AEP, as it fulfilled several mutual objectives, including developing technical capacity in aquatic monitoring within the AWN community, and filling a data gap on summer stream temperatures in an important watershed for bull trout (*Salvelinus confluentus*) conservation and recovery planning in Alberta (Alberta Environment and Parks 2020). Bull trout were historically an important traditional food source for indigenous people in the Grande Cache region, and AWN community members have expressed interest in contributing to bull trout recovery efforts in their Traditional Land Use (TLU) area. Bull trout populations within the Western Arctic Designatable Unit, which includes the Muskeg River watershed, have been designated as *Special Concern* by COSEWIC (2012) and as *Threatened* under Alberta's *Wildife Act* (Alberta Environment and Parks 2020), due to ongoing stressors which threaten future population viability. Increased summer water temperatures associated with climate change may reduce the amount of thermally suitable habitat for cold-water obligate species such as bull trout, therefore, this is considered a threat to the future viability of the species (Isaak et al. 2010).

Bull trout spawn in flowing water (rivers and/or creeks) in the fall, generally between September and October in Alberta, with eggs commonly hatching in April after incubating through the winter months (Nelson and Paetz 1992). Incubation times are water temperature dependant and can range from as little as 35 days to over 4 months in colder climates (Gould 1987; Bowerman et al. 2014; Austin et al. 2019). Female bull trout typically construct redds (spawning nests) in areas where groundwater inputs stabilize stream temperatures through the winter months, particularly in areas of high groundwater downwelling and inter-gravel flows where course gravel and cobble form the dominant stream-bed substrate (Baxter and Hauer 2000). Bull trout spawning timing is thought to be temperature dependant, with spawning typically beginning when water temperatures drop below 10 $^{o}$C, and suspended at temperatures below 5 $^{o}$C (COSEWIC 2012), though ripe bull trout have recently been captured between 2 °C and 5 °C (N. Mochnacz, *personal comm.*). Following hatching, young-of-year (age-0) and juvenile bull trout typically occupy areas in their natal streams where there is in-stream or overhead cover, such as along stream margins with large substrate (Spangler and Scarnecchia 2001). Juvenile bull trout posses amongst the lowest upper thermal growth optima compared to other North American salmonids (Selong et al. 2001). Taken together, stream temperature is a critical water quality component needed to ensure the sustainability of bull trout populations in the Muskeg River watershed.

Previous fisheries assessments in the Muskeg River watershed were conducted in 1993 (Brewin 1996) and in 2013-2014 (Rodtka and Judd 2015). Within the Muskeg River watershed, Veronique, Chapman, Mahon, Isaac and lower Lone Teepee creeks were identified as important rearing habitat, and redds were identified in both Mahon and Isaac creeks (Brewin 1996). Rodtka and Judd (2015) assessed salmonid relative abundance and distribution in 25 randomly distributed sites in the Muskeg River watershed above Muskeg falls. They determined that brook trout was the most captured species ($n = 231$), followed by rainbow trout ($n = 159$) and then bull trout ($n = 89$). Bull trout were, however, the most widely distributed species and the only salmonid captured upstream of the Mahon Creek confluence with the Muskeg River (Rodtka and Judd 2015). In the 2014 survey, no bull trout were captured in Veronique or Chapman creeks, and no sampling was conducted in lower Lone Teepee Creek. Bull trout were, however, captured in Isaac, Mahon and middle Lone Teepee creeks (Rodtka and Judd 2015). This leads to uncertainty in our understanding of whether the streams identified as important rearing streams by Brewin (1996) are still suitable for juvenile bull trout today.

Here, we present a stream temperature dataset from the Muskeg River watershed, an important watershed for bull trout conservation in west-central Alberta. We calculated the thermal sensitivities collected from 25 monitoring sites within 19 different streams to infer the thermal regimes across the watershed, and to determine variation among tributaries and watershed locations. Finally, we compare our measured stream temperature values with published thermal habitat suitability thresholds for juvenile (≤ 150 mm) bull trout, to infer contemporary locations in the watershed where thermally suitable habitat conditions persist.

# 2. Methods

## 2.1. Study Area Overview & Temperature Logger Installation

The Muskeg River originates in the Persimmon Mountain range within Wilmore Wilderness Park, at an elevation of 1900 m. The river flows north-northwest for approximately 100 km before joining the Smoky River about 20 km north-east of the hamlet of Grande Cache, Alberta. A notable landscape feature and natural barrier to fish movement occurs at Muskeg Falls, a 12 m high waterfall located roughly 22 km upstream of the Muskeg – Smoky confluence. Land-use activities within the watershed include oil and gas exploration and production, forestry, coal mining infrastructure, recreational uses (motorized and non-motorized) and residential/municipal development. Industrial activities are primarily located in the middle and lower portions of the watershed, whereas the upper watershed areas are protected within Wilmore Wilderness Park (**Figure 1**). Fish species found in the Muskeg River watershed include non-native rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*), as well as native bull trout, Arctic grayling (*Thymallus arcticus*), mountain whitefish (*Prosopium williamsoni*), longnose dace (*Rhinichthys cataractae*), longnose sucker (*Catostomus catostomus*), white sucker (*Catostomus commersonii*) and slimy sculpin (*Cottus cognatus*) (FWMIS; https://www.alberta.ca/fisheries-and-wildlife-management-information-system-overview.aspx).

AWN worked with AEP fisheries biologists to develop a stream temperature monitoring study design and to obtain the required monitoring equipment for conducting the watershed scale survey. The required stream temperature monitoring equipment included 25 HOBO TidbiT MX 400 Temperature loggers, 25 pieces of 3’ rebar with washers welded to the rebar frame for logger housing attachment, 25 3” PVC logger housings (cap and plugs), a 4 lb sledgehammer, a rebar pounder and associated hardware (bolts, washers and locking nuts). We used an android tablet with the HOBOmobile app to configure loggers prior to installation and to download logger data following removal from the stream. Stream temperature loggers were installed at 25 study locations, in 19 waterbodies (**Figure 1; Table 1**) following procedures outlined in “Stream Temperature Monitoring in Alberta – Recommended Practices for External Agencies”

(Government of Alberta 2020). Logger locations were selected based on ease of access (i.e., truck or ATV accessible) and distributed among a diversity of hydrological and landscape factors (i.e., stream order, elevation, gradient, habitat type) following recommendations from Jackson et al. (2016). Loggers were secured in white PVC housing with holes drilled into the cap and plug to allow water to pass freely through the housing and maintain continuous flow past the logger. Geographic coordinates of each logger location are provided in Appendix A (**Table A1**).

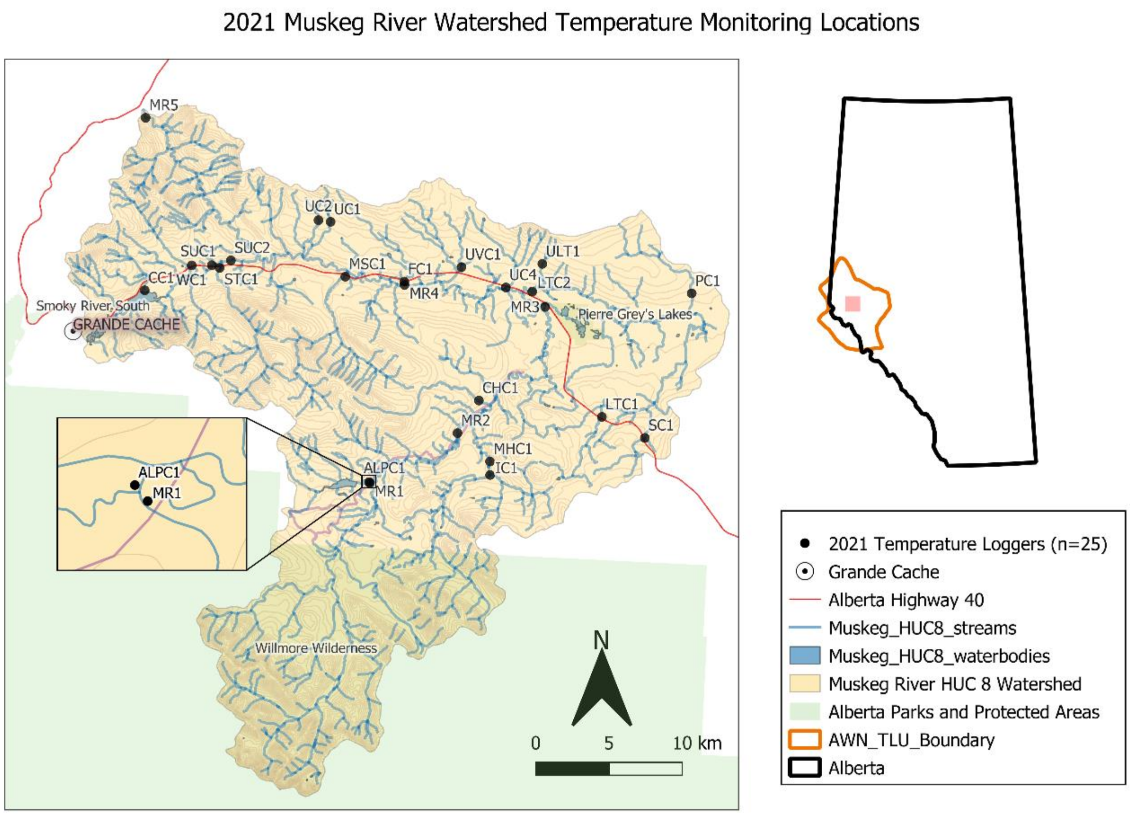


**Figure 1.** Location of the 25 sample sites within the Muskeg River HUC 8 watershed. Map on the upper right side of the figure shows the location of the study area within the province of Alberta, and the Aseniwuche Winewak Nation's Traditional Land Use area.

Logger housings were bolted to rebar and hammered into the stream bed in a location where the logger was protected from being struck by material moving downstream (i.e., behind in-stream cover such as large sturdy boulders) (**Appendix A; Figure A1**). Loggers were typically installed in approximately 30 – 50 cm of well-mixed (not stagnant) water to ensure that recovery would be possible if water levels increased. Occasionally, loggers had to be installed in shallow (< 30 cm) or in slow-moving areas, such as upstream of beaver dams given available stream conditions. Logger housings were positioned to be slightly elevated above the stream bed so not to be filled with sediment or buried in bottom substrate. All loggers were programmed to record stream temperature every 30 minutes on the full and half-hour (e.g., 11:00, 11:30). Additional water quality parameters (pH and conductivity) were measured from an undisturbed upstream area during logger installation and removal. The water quality meter was calibrated prior to data collection using certified calibration standards. Overall, stream temperature monitoring timing varied by site, with loggers installed as early as June 24$^{th}$ and the last loggers removed on September 14$^{th}$ (**Figure 2**). All loggers were completely submerged when retrieved in September and following QA/QC procedures were presumed to have been in water throughout the monitoring period.

## 2.2. Data QA/QC, Mapping and Analysis

All field data was recorded on standardized data sheets provided by AEP and subsequently entered into Microsoft Excel for further QA/QC and analysis. Data management, including QA/QC procedures followed recommendations provided in the "Stream Temperature Monitoring in Alberta – Recommended Practices for External Agencies" document (Government of Alberta 2020). Field maps were generated using QGIS Desktop version 3.16.15. Figures were created using the 'ggplot2' package in R, and all statistical analyses were conducted in R version 4.1.2 (R Core Team 2022).

### *2.2.1. Data Summary and Monthly Comparisons*

Stream temperature data was summarized to determine the average (mean), standard deviation, and minimum and maximum temperatures at monitoring sites during the months of July ($n = 12$) and August ($n = 25$). We used a paired t-test to determine if there was a difference in mean stream temperature between July and August from sites where data for both complete months was available and a Welch's t-test (assuming unequal variance) to determine if mean air temperature was different in July and August. All air temperature data used in this study was obtained from the Alberta Climate Information Service's Grande Cache station (https://acis.alberta.ca/weather-data-viewer.jsp, **Appendix A; Figure A3**).

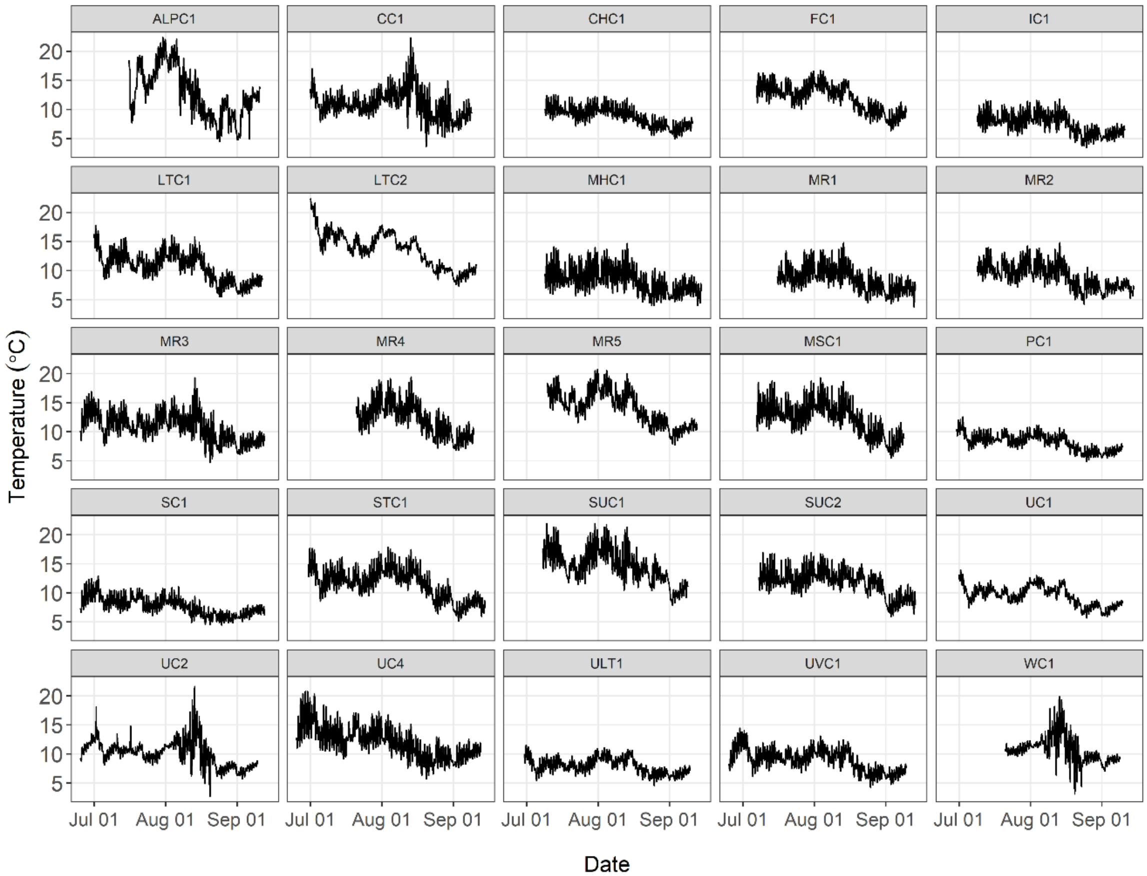


**Figure 2**. Stream temperature data recorded at 25 sample sites the Muskeg River watershed between June 25th and September 14th, 2021.

### *2.2.2. Site Specific Thermal Sensitivities*

Thermal sensitivity is a measure a stream's ability to buffer against environmental change, such as increasing air temperature (Kelleher et al. 2012; Mayer 2012). Knowledge of a stream's thermal sensitivity is important to better understand the potential impacts of climate change and increased air temperature on water temperature (Kelleher et al. 2012; Mayer 2012), and subsequently how this may affect sensitive stream salmonids (Isaak et al. 2011). To determine the potential impacts of air temperature on measured stream water temperature ("thermal sensitivity") at each sample site, we used linear regression to determine the slopes and strength of the relationship ($R^2$ values) between 7-day averaged air and water temperatures (Mayer 2012). Thermal sensitivities can be interpreted as steeper slopes corresponding to a greater increase in water temperature per unit change in air temperature. Average 7-day air temperature was used as an explanatory variable in linear regression models to determine site-specific thermal sensitivities. To maximize the number of observations available for analysis, we included air and water temperature data from all 25 sample sites recorded between July 21st to September 7th, 2021 (*n = 7 time periods*). When required, the response variable (7-day averaged water temperature) was log-transformed to best meet model assumptions. Model residuals were visually inspected for normality and homogeneity of variance through Q-Q and residuals vs. fitted plots.

Other studies have shown that including additional explanatory variables, such as stream order, baseflow index (groundwater contribution) and streamflow, can improve thermal sensitivity model fit (Kelleher et al. 2012; Mayer 2012). To determine the importance of streamflow on thermal sensitivity at one site in the Muskeg River (MR4), located near the only streamflow gauging station in the watershed (Station ID 07GA002), we ran a separate multiple linear regression model for this site with 7-day averaged streamflow included as an explanatory variable. Additionally, we regressed our site-specific thermal sensitivity values against stream order (Strahler) to infer whether this variable was important in explaining the variance observed in thermal sensitivity among sites. Unfortunately, we are unaware of any available baseflow index datasets collected in this watershed, therefore were not able to assess the contribution of this variable on thermal sensitivities. Finally, we categorized sample sites based on Strahler stream order into small (≤ 3) or large (≥ 4) streams and compared average thermal sensitivity values between these categories using two-sample t-tests.

### *2.2.3. Juvenile Bull Trout Thermal Habitat Suitability*

August temperatures have been used as a proxy for summer water temperatures in previous studies, as they typically encompass the maximum annual stream temperature and show less variability from factors associated with snowmelt, streamflow and air temperature than do July water temperature (Mayer 2012). To assess site-specific thermal habitat suitability for juvenile bull trout (i.e., ≤ 150 mm), we calculated the average August water temperature at each monitoring site and compared our values with thresholds provided in Isaak et al. (2015).

# 3. Results

## 3.1. Muskeg River HUC 8 Watershed Temperatures

Water temperature varied among study sites, with the unnamed Lone Teepee Creek tributary site (ULT1) and Shand Creek site (SC1) being the coldest on average in July and August, respectively (**Table 1**). The coldest minimum temperature during either the July or August monitoring period was 2.7 $^{o}$C, recorded from site UC2 (**Table 1**). Conversely, the warmest site on average was Lone Teepee Creek 2 (LTC2) in July and Susa Creek 1 (SUC1) in August (**Table 1**). The warmest temperature recorded amongst all sites during the July and August monitoring period was 22.3 $^{o}$C, measured at both site CC1 in August, and site LTC2 in July (**Table 1**). Among measured water quality parameters during logger removal, pH was highest at site MR2 and lowest at site WC1 (**Appendix A; Figure A2**). Conductivity was highest at site UC4 and lowest at site UC2 (**Appendix A; Figure A2**). Based on a paired t-test, there was a significant statistical difference detected in average water temperatures in July and August between the 12 study sites where data was available for both months (**Figure 3**).

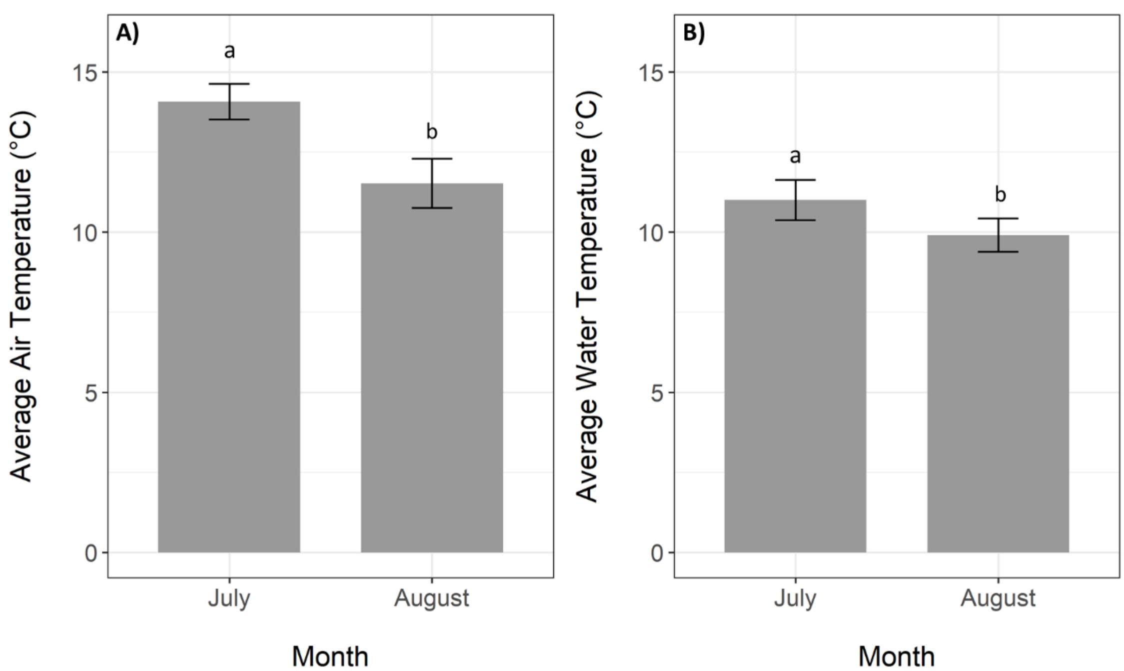


**Figure 3.** Comparison of A) average air temperature measured in Grande Cache, and B) average monthly water temperature from 12 sites where data was available for both months. Error bars show 1 SE, and letter denote a significant difference ($p < 0.05$) between months.

The average July temperature (11 °C) was significantly higher than the average August temperature (9.9 °C) ($t_{11} = 3.94$, $p < 0.01$). Likewise, the average air temperature in the month of July (14.1 °C) was significantly higher than in August (11.5 °C) ($t_{31} = 2.69$, $p < 0.01$).

**Table 1.** Summary statistics for each of the 25 sample sites sample sites monitored in the Muskeg River watershed in 2021.

| Sample Site | Waterbody | Stream Order (Strahler) | Month | Min. water temp (°C) | Max. water temp (°C) | Average water temp (SD) |
|---|---|---|---|---|---|---|
| ALPC1 | A la Peche Creek | 3 | August | 4.5 | 22.1 | 12.0 (4.4) |
| CC1 | Carconte Creek | 4 | August | 3.6 | 22.3 | 11.4 (3.1) |
| CHC1 | Chapman Creek | 3 | August | 5.5 | 12.3 | 8.6 (1.4) |
| FC1 | Findley Creek | 3 | August | 7.6 | 16.7 | 12.0 (2.2) |
| IC1 | Isaac Creek | 4 | August | 3.4 | 11.8 | 7.4 (1.8) |
| LTC1 | Lone Teepee Creek | 3 | July | 8.4 | 17.8 | 11.8 (1.9) |
| | | | August | 5.5 | 16.0 | 10.4 (2.4) |
| LTC2 | Lone Teepee Creek | 4 | July | 12.1 | 22.3 | 15.6 (2.1) |
| | | | August | 8.4 | 17.8 | 13.1 (2.5) |
| MHC1 | Mahon Creek | 5 | August | 4.0 | 14.7 | 8.4 (2.2) |
| MR1 | Muskeg River | 5 | August | 4.5 | 14.8 | 8.8 (2.1) |
| MR2 | Muskeg River | 5 | August | 4.2 | 14.8 | 8.9 (2.1) |
| MR3 | Muskeg River | 6 | July | 7.6 | 15.7 | 11.6 (1.7) |
| | | | August | 4.7 | 19.3 | 10.6 (2.5) |
| MR4 | Muskeg River | 6 | August | 7.2 | 19.4 | 12.6 (2.7) |
| MR5 | Muskeg River | 6 | August | 9.5 | 20.6 | 14.4 (2.7) |
| MSC1 | Mason Creek | 4 | August | 6.5 | 19.3 | 12.3 (2.7) |
| PC1 | Plante Creek | 2 | July | 6.7 | 12.6 | 8.9 (1.0) |
| | | | August | 4.8 | 11.1 | 7.9 (1.4) |
| SC1 | Shand Creek | 3 | July | 6.1 | 12.9 | 8.6 (1.2) |
| | | | August | 4.5 | 11.1 | 6.9 (1.3) |
| STC1 | Sterne Creek | 4 | July | 8.6 | 17.6 | 12.5 (1.8) |
| | | | August | 6.4 | 17.8 | 11.9 (2.4) |
| SUC1 | Susa Creek | 4 | August | 10.4 | 21.7 | 14.8 (2.4) |
| SUC2 | Susa Creek | 5 | August | 8.4 | 16.7 | 12.5 (1.5) |
| UC1 | Unnamed Creek 1 | 3 | July | 7.4 | 13.9 | 10.1 (1.2) |
| | | | August | 5.7 | 13.0 | 9.5 (1.8) |
| UC2 | Unnamed Creek 2 | 2 | July | 8.1 | 18.1 | 10.5 (1.2) |
| | | | August | 2.7 | 21.6 | 10.0 (2.7) |
| UC4 | Unnamed Creek 4 | 4 | July | 9.1 | 20.3 | 13.5 (2.0) |
| | | | August | 5.7 | 16.7 | 10.6 (2.2) |
| ULT1 | Unnamed Lone Teepee Creek | 2 | July | 5.5 | 11.2 | 8.1 (1.1) |
| | | | August | 4.6 | 11.1 | 8.1 (1.5) |
| UVC1 | Unnamed Veronique Creek tributary | 3 | July | 6.2 | 14.1 | 9.6 (1.4) |
| | | | August | 4.3 | 13.1 | 8.6 (1.9) |
| WC1 | Washy Creek | 3 | August | 3.1 | 19.9 | 11.1 (2.7) |

## 3.2. Site Specific Thermal Sensitivities

Average 7-day air and water temperatures were significantly associated at all 25 sample sites ($p < 0.05$), with $R^2$ values averaging 0.83, ranging from 0.53 (site SC1), to 0.95 (sites MR1 & MR5) (**Table 2**). Thermal sensitivity averaged 0.52 $^oC\ ^oC^{-1}$ among all sites sampled in 2021, ranging from a minimum of 0.31 $^oC\ ^oC^{-1}$ at site ULT1 to 1.16 $^oC\ ^oC^{-1}$ at the ALPC1 site (**Table 2**). Streamflow was negatively but not significantly associated with water temperature at site MR4 (coefficient= -0.15, p value = 0.51).

**Table 2.** Site specific thermal sensitivities (slope), standard error (SE), model fit ($R^2$) for 7-day averaged air temperature and water temperature from linear regression analysis.

| Sample Site | Slope | SE | $R^2$ | P-value |
|---|---|---|---|---|
| ALPC1$^+$ | 1.16 | 0.18 | 0.88 | ** |
| CC1 | 0.47 | 0.15 | 0.68 | * |
| CHC1 | 0.35 | 0.04 | 0.93 | *** |
| FC1 | 0.55 | 0.08 | 0.91 | *** |
| IC1 | 0.38 | 0.08 | 0.82 | ** |
| LTC1 | 0.57 | 0.10 | 0.86 | ** |
| LTC2 | 0.66 | 0.12 | 0.87 | ** |
| MHC1 | 0.44 | 0.06 | 0.92 | *** |
| MR1 | 0.45 | 0.05 | 0.95 | *** |
| MR2 | 0.51 | 0.06 | 0.94 | *** |
| MR3$^+$ | 0.59 | 0.06 | 0.94 | *** |
| MR4 | 0.67 | 0.10 | 0.92 | *** |
| MR5 | 0.73 | 0.07 | 0.95 | *** |
| MSC1 | 0.63 | 0.10 | 0.90 | ** |
| PC1 | 0.32 | 0.08 | 0.75 | * |
| SC1$^+$ | 0.39 | 0.15 | 0.53 | * |
| STC1 | 0.60 | 0.11 | 0.87 | ** |
| SUC1 | 0.64 | 0.08 | 0.85 | *** |
| SUC2 | 0.43 | 0.07 | 0.94 | ** |
| UC1 | 0.43 | 0.09 | 0.84 | ** |
| UC2 | 0.47 | 0.14 | 0.70 | * |
| UC4$^+$ | 0.46 | 0.15 | 0.65 | * |
| ULT1 | 0.31 | 0.07 | 0.82 | ** |
| UVC1 | 0.43 | 0.09 | 0.80 | ** |
| WC1 | 0.34 | 0.12 | 0.64 | * |
| *Overall average (SD)* | *0.52 (0.18)* | *0.10 (0.04)* | *0.83 (0.11)* | |

*Note: Significance codes: ***, < 0.001; **, < 0.01; *, < 0.5*

+ Log transformed. Slope coefficients back-calculated for interpretation.

Site-specific thermal sensitivity was significantly associated with stream order ($F_{1,22}$ = 12.05, $R^2$ = 0.32, $p < 0.01$), after a major outlier (site ALPC1) was removed from the dataset for linear regression analysis (**Figure 4**). When sites were categorized as either small streams (stream order ≤ 3, *n = 11*) or large streams (stream order ≥ 4, *n = 14*) (Kelleher et al. 2012), larger streams showed higher average thermal sensitivities (avg. = 0.48 (range: 0.31 – 1.16) *vs.* avg. = 0.52 (range: 0.38 – 0.73), respectively), but there was no statistical difference between stream size categories ($t_{23}$ = -0.87, p = 0.39). However, when site ALPC1 is removed, the average thermal sensitivity value for small streams becomes 0.42 and is significantly different from large streams ($t_{22}$ = -3.07, $p < 0.01$).

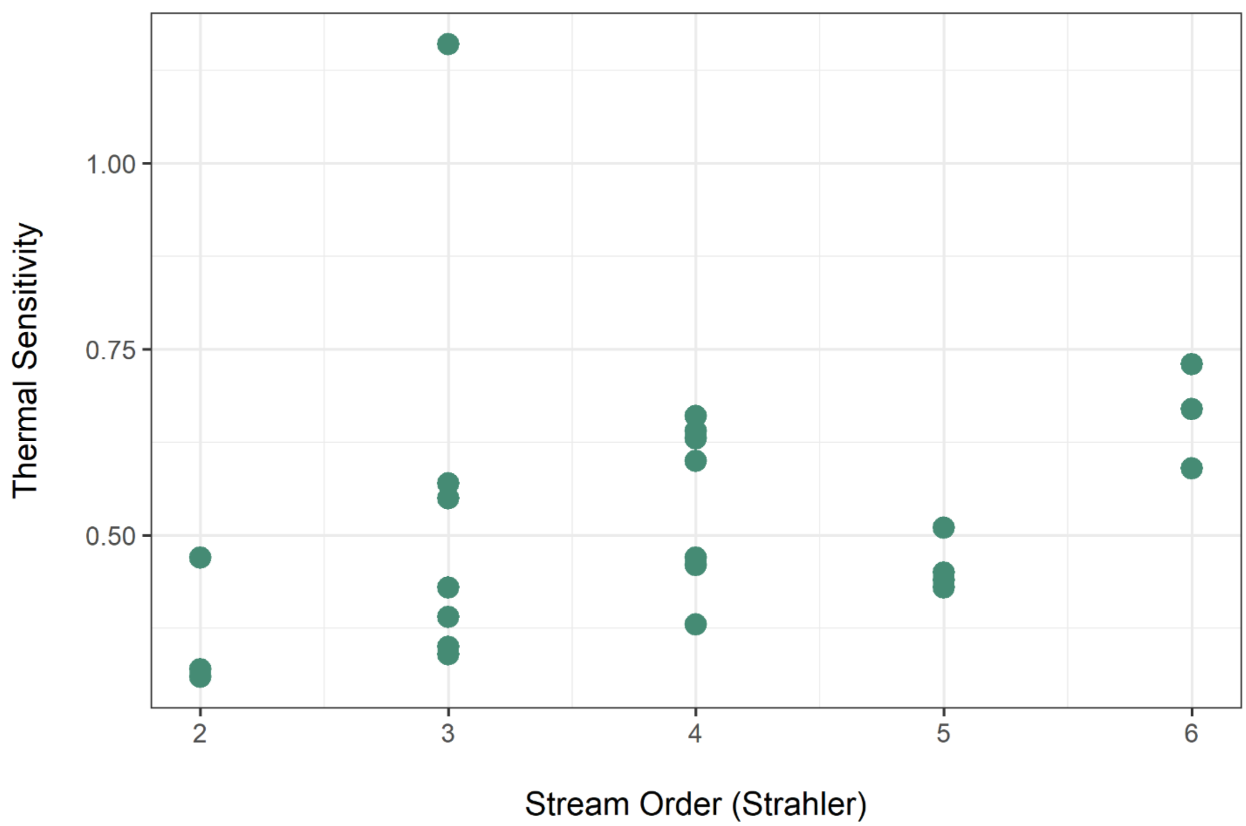


**Figure 4**. Site-specific thermal sensitivity of the 25 sample sites monitored in 2021, categorized by Strahler stream order. The outlier in the stream order 3 category is site ALPC1.

## 3.3. Comparison of Stream Temperature with Juvenile Bull Trout Thermal Habitat Suitability

When compared to average August water temperature thresholds for juvenile bull trout habitat suitability (Isaak et al. 2015), 11 sites were categorized as "Above Suitable" (> 11 °C), whereas 14 sites were categorized as falling within the "Suitable" threshold value (≤ 11 °C) (**Figure 5; Figure 6**).

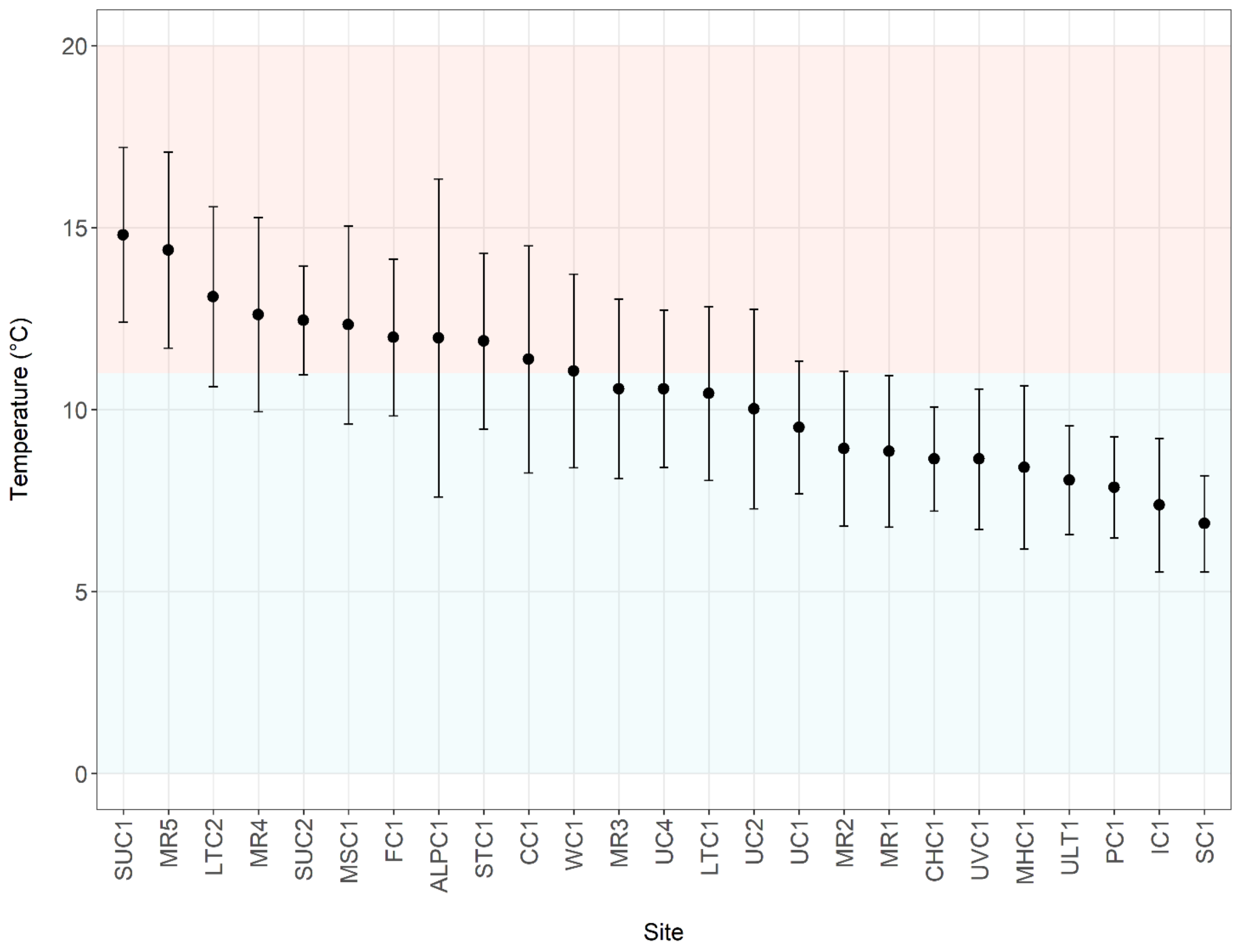


**Figure 5.** Thermal suitability within the Muskeg River watershed for juvenile bull trout (≤ 150 mm) based on average August water temperature**.** Shaded regions denote "Suitable" (≤ 11 °C; blue) or "Above Suitable" (> 11 °C; red) thermal habitat. Error bars show 1 SD from the mean.

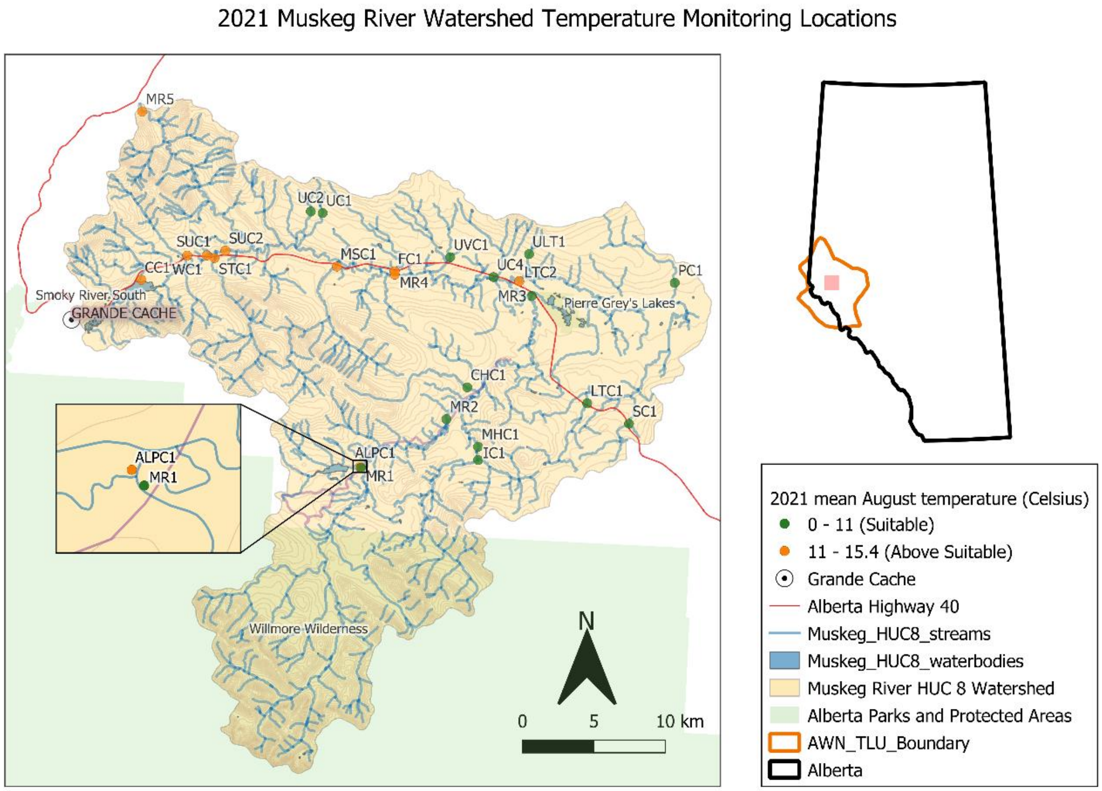


**Figure 6.** Spatial overview of the 25 sample sites monitored in the Muskeg River watershed, categorized by mean August stream temperature as either “Above Suitable” (orange circles) or “Suitable” (green circles) thermal habitat for juvenile bull trout.

## 4. Discussion

Here, we have documented summer stream temperatures in the Muskeg River HUC 8 watershed, located near the hamlet of Grande Cache in west-central Alberta. Bull trout populations in the Muskeg River HUC 8 watershed have been identified as a “core population” for conservation in Alberta, indicating that there is a high degree of confidence that this population can be maintained or restored to a “moderate to very low-risk state” based on provincial assessment criteria (Alberta Environment and Parks 2020). An important habitat requirement for the conservation or restoration of bull trout populations is the maintenance of suitably cold-water temperatures needed to complete all stages of the species’ life-history requirements (COSEWIC 2012). This project has provided an updated dataset on summer thermal regimes in this critical watershed for bull trout conservation in Alberta.

Stream temperatures in the Muskeg River watershed varied in their thermal suitability for juvenile bull trout (≤ 150 mm) habitat use. Eleven sample sites exceeded average August stream temperature thresholds (i.e., > 11 $^{o}$C), whereas 14 sample sites were identified as suitable for juvenile bull trout rearing habitat (i.e., ≤ 11 $^{o}$C) (Isaak et al. 2015). A previous study identified several important juvenile rearing streams in the Muskeg River watershed, including Veronique, Chapman, Mahon, Isaac and lower Lone Teepee creeks (Brewin 1996). Our 2021 stream temperature data shows that Mahon, Isaac and Chapman creeks still appear to provide thermally suitable juvenile rearing habitat, however, lower Lone Teepee Creek exceeded threshold values and therefore likely no longer appears to be thermally suitable habitat for juvenile rearing (Veronique Creek was not monitored in 2021 due to a logger malfunction). An upcoming watershed scale fisheries survey planned for the 2022 field season will further improve our understanding of thermal habitat suitability and juvenile bull trout distribution throughout the Muskeg River basin. Water temperatures at all sites were below 7-day ultimate upper incipient lethal temperatures (23.5 $^{o}$C) for age-0 bull trout (Selong et al. 2001), but temperature was not monitored at most sites in late June when a period of unseasonably hot weather occurred in western Canada. In future assessments it may be beneficial to collect annual data to ensure that highly variable weather events, such as heat waves, are captured in stream temperature monitoring programs.

Our results suggest thermal buffering capacity at several locations within the watershed, possibly due to groundwater inputs, however streamflow and channel slope have been shown to be other important factors explaining summer thermal sensitivities (Mayer 2012). Mountainous headwater streams in Oregon that were influenced by inputs from deep groundwater reservoirs were on average colder, showed less variability and lower thermal sensitivity compared with systems characterized by shallow subsurface flow (Tague et al. 2007). Other variables such as riparian shading, site elevation, and percent forested area have also been reported to be important in stream temperature monitoring studies (Risley et al. 2003), and the inclusion of these variables in future predictive modelling studies in the Muskeg River watershed may prove beneficial. Plante Creek (PC1), Shand Creek (SC1), Isaac Creek (IC1), Chapman Creek (CHC1), Mahon Creek (MHC1), Unnamed Lone Teepee Tributary (ULT1) and the uppermost site on the Muskeg River mainstem (MR1) showed particularly low thermal sensitivity, indicating that factors other than air temperature are important in determining the thermal regime at these sites.

Our overall mean thermal sensitivity value (0.52 $^oC$ $^oC^{-1}$) is comparable to previously reported values, where mean thermal sensitivities ranged between 0.33 $^oC$ $^oC^{-1}$ in groundwater dominated headwater streams in Oregon (Tague et al. 2007), to between 0.47 $^oC$ $^oC^{-1}$ (Mayer 2012) and 0.6 $^oC$ $^oC^{-1}$ (Isaak et al. 2011) over a broad region in the Pacific Northwest. When we directly compare average thermal sensitivities according to stream order, our small stream (0.48) and large stream (0.52) values are lower than those measured in the Delaware Basin (0.70 and 0.79, respectively) and the Susquehanna Basin (0.52 and 0.83, respectively), located in Pennsylvania (Kelleher et al. 2012). The similarity in measured thermal sensitivity between our study and that of Mayer (2012) indicates that thermal regimes in the Muskeg River watershed are likely controlled by similar factors to those in other mountainous regions of western North America, such as monthly baseflow index, channel slope and/or channel length. Further detailed field data collection is needed to explore the exact mechanisms responsible in this watershed. Some caution should be exercised when comparing our results to those of previous studies due to slight differences in the timing of data collection between studies. However, when we regress site specific thermal sensitivity (log transformed) against average August water temperature, the relationship between variables is highly significant ($F_{1,22} = 22.5$, $R^2 = 0.49$, $p < 0.001$).

We documented that site ALPC1 showed the highest thermal sensitivity of any site monitored in 2021. A potential explanation for this finding is that this creek is the outlet of A la Peche Lake, a shallow headwater lake (< 3 m max depth, B. Kissinger, *personal comm.*) in the upper Muskeg River watershed. It appears that solar inputs and energy exchange in the lake may be contributing to greater variability in water temperatures and indicates that this system is potentially at higher risk of impacts from warming associated with climate change. Low channel gradient and beaver activity in A la Peche Creek may be further contributing to increased solar energy exchange, as streamflow has been altered near the Muskeg River confluence by dam construction. Our results show that water temperature in A la Peche Creek exceeded thermally suitable conditions for juvenile bull trout, however the author of this report captured several individuals < 250 mm in the creek by sample angling in 2021. Therefore, there may be localized areas where groundwater inputs are creating suitable microhabitat for sub-adult or adult bull trout occupancy. A la Peche Lake is a historically important location for AWN community fishing and harvesting, and community members have expressed concerns that the quality of fishing in this system has diminished through time. Therefore, an investigation into changes in fisheries productivity, whether associated with thermal conditions, movement barriers or other factors such as competition with non-native salmonids, is warranted.

A general pattern is seen in our data where within a waterbody, downstream sites show greater thermal sensitivity compared with upstream sample sites. We would expect that sites lower in a drainage network would be warmer and more thermally sensitive compared to the upstream locations, and stream length and stream order have been shown here and in previous studies to be positively correlated with both thermal sensitivity and water temperature (Kelleher et al. 2012; Mayer 2012). Lone Teepee Creek and Muskeg River follow this pattern, whereas in Susa Creek the uppermost sample site (SUC1) was more thermally sensitive than the downstream site (SUC2). The difference observed at Susa Creek is likely because the upstream monitoring location, much like site ALPC1, was in an area characterized by low stream channel gradient and velocity, with high amounts of beaver activity, and downstream of a lake complex (Victor, Grande Cache and Peavine lakes). Site SUC2, located downstream of the Sterne Creek confluence, appears to be moderated by the colder water inputs from Sterne Creek and potentially other unmeasured environmental factors.

Apart from thermal suitability, other factors such as habitat fragmentation (Dunham and Rieman 1999), habitat pollution or alteration (Palace et al. 2004; Ripley et al. 2005), interspecific competition (Nakano et al. 1998; Rieman et al. 2005) and/or hybridization with introduced species such as brook trout, may threaten the future viability of bull trout populations in the Muskeg River watershed (Fisheries and Oceans Canada 2020). Bull trout are a historically important fish species for food and ceremonial purposes to the Aseniwuche Winewak Nation and continuing to develop technical capacity to support species-at-risk assessments and recovery planning is a priority for the Nation. This project provided an excellent opportunity to collaborate with the Government of Alberta in a watershed that is important for both bull trout recovery, and to the AWN community who have a long history of habitation and detailed traditional ecological knowledge of the area. Continued partnership and collaboration between these organizations will benefit all stakeholders through the inclusion of diverse insights, leading to a multi-faceted approach to species recovery and conservation.

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# 6. Appendix A. Additional Supporting Information


**Figure A1.** Example of a temperature logger installation at a monitoring site (STC1). Location of the logger is outside the main thalweg, behind a large sturdy boulder to protect it from debris flows, within the perennial confined channel and at a depth where can be easily retrieved if water levels rise.

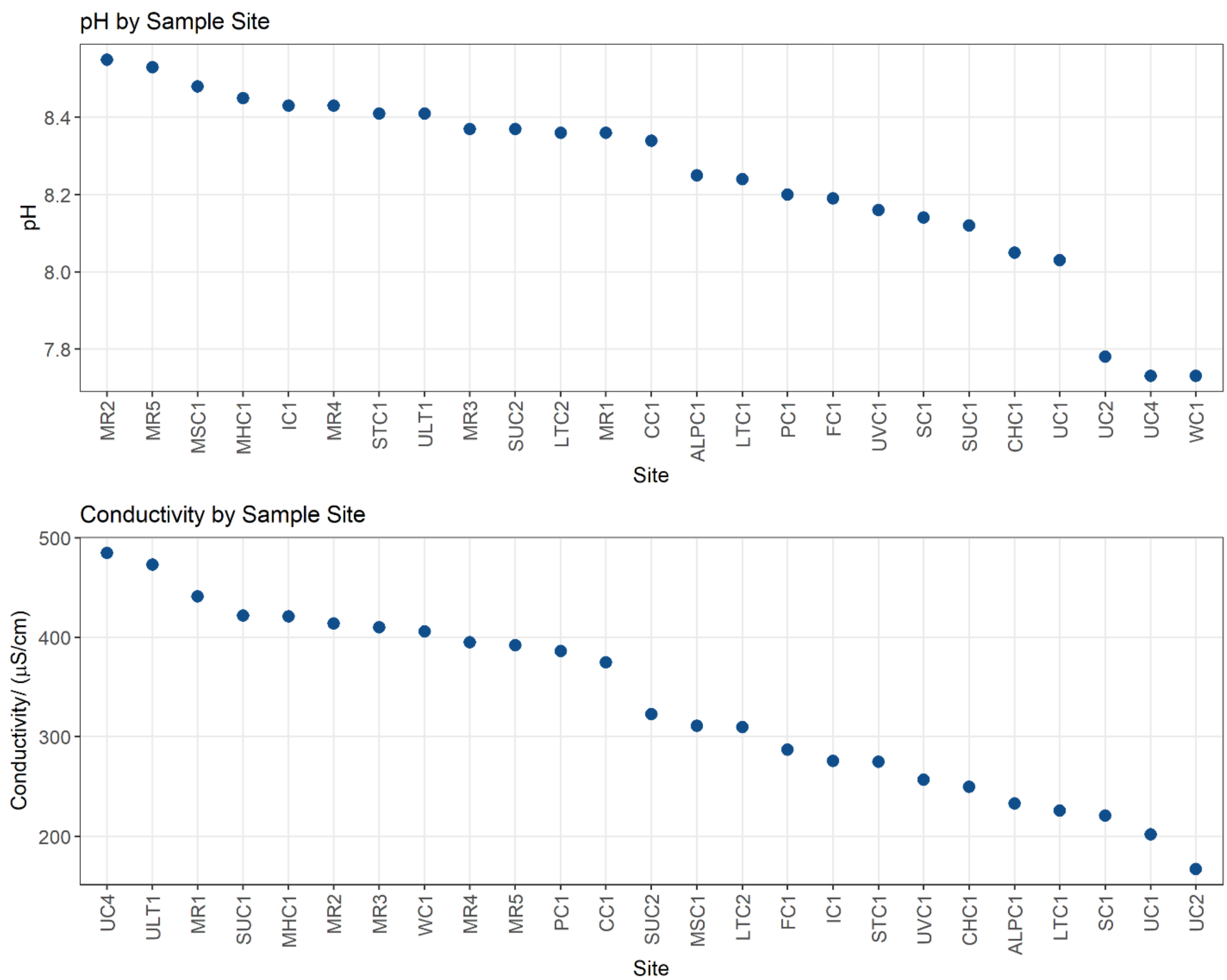


**Figure A2.** Point measurements of stream pH (top panel) and conductivity (bottom panel) at each of the 25 sample sites monitored in the Muskeg River HUC 8 watershed. All measurements were taken in September 2021 when temperature loggers were downloaded and removed.

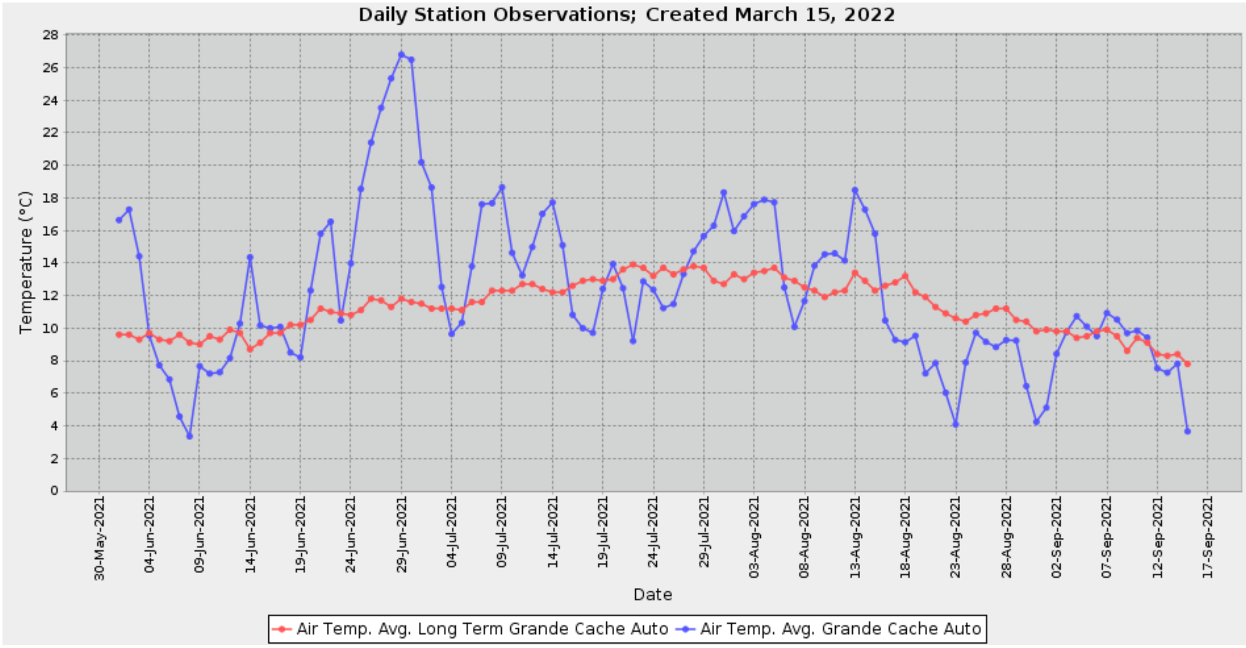


**Figure A3.** Long term and 2021 daily average air temperature data recorded between June 1$^{st}$ and September 15$^{th}$ from the Grande Cache, Alberta station. Figure was generated by the Alberta Climate Information Service (https://acis.alberta.ca/weather-data-viewer.jsp).

**Table A1.** Geographic coordinates of the 25 sample sites monitored in 2021 within the Muskeg River HUC 8 watershed.

| Sample Site | Location | Lat | Long |
|---|---|---|---|
| ALPC1 | A la Peche Creek | 53.7999 | -118.8001 |
| CC1 | Carconte Creek | 53.9097 | -119.0436 |
| CHC1 | Chapman Creek | 53.8534 | -118.6908 |
| FC1 | Findley Creek | 53.9238 | -118.7746 |
| IC1 | Isaac Creek | 53.8081 | -118.6752 |
| LTC1 | Lone Teepee Creek (upper) | 53.8472 | -118.5624 |
| LTC2 | Lone Teepee Creek (lower) | 53.9218 | -118.6413 |
| MHC1 | Mahon Creek | 53.8164 | -118.6760 |
| MR1 | Muskeg River above A la Peche | 53.7993 | -118.7992 |
| MR2 | Muskeg River (upper) | 53.8327 | -118.7112 |
| MR3 | Muskeg River (middle) | 53.9128 | -118.6272 |
| MR4 | Muskeg River above Findlay Creek | 53.9218 | -118.7743 |
| MR5 | Muskeg River (lower) | 54.0154 | -119.0529 |
| MSC1 | Mason Creek | 53.9249 | -118.8362 |
| PC1 | Plante Creek | 53.9256 | -118.4756 |
| SC1 | Shand Creek | 53.8357 | -118.5168 |
| STC1 | Sterne Creek | 53.9260 | -118.9672 |
| SUC1 | Susa Creek above Sterne Creek | 53.9274 | -118.9754 |
| SUC2 | Susa Creek below Sterne Creek | 53.9310 | -118.9560 |
| UC1 | Unnamed Creek 1 | 53.9580 | -118.8546 |
| UC2 | Unnamed Creek 2 | 53.9586 | -118.8672 |
| UC4 | Unnamed Creek 4 | 53.9235 | -118.6689 |
| ULT1 | Unnamed Lone Teepee tributary | 53.9391 | -118.6323 |
| UVC1 | Unnamed Veronique tributary | 53.9346 | -118.7161 |
| WC1 | Washy Creek | 53.9266 | -118.9963 |