Quantifying Thermal Regimes of Tributary Streams in the Allagash Wilderness Waterway

Funding provided by the Horizon Foundation & the Maine Outdoor Heritage Fund

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PROJECT SUMMARY

Ambient water temperatures are a leading habitat parameter driving the distribution and persistence of stream fishes like brook trout (*Salvelinus fontinalis)*, whose survival is reduced as stream temperatures increase (Xu et al. 2010). Relatively intact populations of native brook trout have been identified in parts of Maine. Particularly, the Allagash River watershed in north western Maine represents high quality native brook trout habitat, boasting a sought-after recreational fishery within the state-owned Allagash Wilderness Waterway. Additionally, and due to few non-native introductions, brook trout represent a top predator in lotic food webs in the Allagash River and its tributaries. Recent trends in water temperature and low flow events in the Allagash River have raised concern for the suitability of habitat for native brook trout, and future projections of stream temperature and flow events corroborate this concern (Lawrence et al. 2014; Chambers et al. 2017). Coldwater tributary streams likely play a key role in sustaining brook trout population during periods of elevated thermal stress, making the need for baseline temperature data from tributary streams in the watershed critical to understanding population maintenance at the watershed scale. To address this, the Allagash Wilderness Waterway Foundation has undertaken an effort to collect temperature data from streams entering the Allagash Wilderness Waterway. Twenty-two tributaries and four locations within the mainstem of the Allagash River were monitored for ambient stream temperature data during 2022 and 2023. The goals of this study were to characterize the thermal regimes of our study streams; and identify critical thermal refuge and areas of conservation concern with regard to brook trout thermal thresholds. We documented water temperatures in the Allagash River that exceed the thermal stress and lethal limits for brook trout, establishing a reliance on tributary streams for thermal refugia. Of the twenty-two tributaries monitored, fifteen appear to be providing some level of thermal refugia to the system. Many of the tributaries currently providing thermal refuge are likely threatened by warming regimes. These data represent two years of ambient water temperature data in an ongoing effort to document baseline thermal conditions of tributary streams in the Allagash Wilderness Waterway. The implications of this work are relevant to brook trout management and will inform conservation decisions and land management in the face of global climate change.

INTRODUCTION

Water temperature is one of the greatest limiting factors determining the distribution and persistence of aquatic biota (Reiter et al. 2015). Current stream temperature projections forecast warming regimes driven particularly by climatic changes (Ficklin et al. 2014; Chambers et al. 2017) and land use practices (Studinski et al. 2012). Ectothermic organisms like stream fishes are particularly vulnerable to changing thermal regimes. Brook trout (*Salvelinus fontinalis),* a cold water obligate native to eastern North America, have experienced local and regional extirpations across their native range as a result of habitat degradation and invasive species introductions (Hudy et al. 2008). Northern and western Maine offers some of the last intact populations of native brook trout in the United States, and recent hot and dry summers in the region raise concern for those populations. Stream temperatures and low flow events are expected to intensify across the remainder of brook trout habitat (Xu et al. 2010; Lawrence et al. 2014) heightening the need for information on the cold water tributaries critical to sustaining populations.

The Allagash Wilderness Waterway (AWW) is a 92-mile stretch of riverine and lentic environments federally designated as a Wild and Scenic River in north western Maine. The AWW includes the Allagash River and several large oligotrophic lakes. This watershed is unique in that its native fish assemblages remain intact. With little influence from invasive species, the Allagash River and its tributaries represent native brook trout habitat of state and national significance. Analysis of water temperature data from the USGS gauge in the Allagash River near Allagash, ME, has shown an increase in ambient summer water temperatures (Table 1; page 6). In response, the Allagash Wilderness Waterway Foundation has established a stream temperature monitoring project that will determine baseline thermal conditions in 22 tributary streams to the Allagash River, and four locations in the mainstem. The goals of the present study are to 1) identify critical thermal refuge and acute and chronic thermal stressors for brook trout within the system; 2) quantify thermal vulnerability and resilience to warming; and 3) offer insight into future monitoring sites and determine areas of conservation concern.

Brook trout have the adaptive capacity to avoid thermal stress via behavioral thermoregulation. Behavioral thermoregulation is the movement from areas of unsuitable temperature to areas of suitable temperature and is well documented in Maine streams and rivers (MDIFW Unpublished). Indeed, a fish’s ability to maximize growth, survival, and reproductive potential is closely tied to its capability to mitigate against spatial and temporal variability in water temperatures by utilizing cold water refugia in the form of tributary streams, confluences, and microhabitats within the river. Therefore, identifying thermal refugia entering the Allagash River is paramount to understanding how brook trout utilize the system during periods of elevated thermal stress. Even so, there has been little published research on the topic in Maine waters, despite Maine’s prevailing brook trout populations and the threat thereto. Many papers, however, have addressed thermal selection and critical thresholds for the species throughout their native range.

Thermal Criteria

Maximum daily water temperature is a key driver in brook trout movement (i.e., behavioral thermoregulation), specifically, movement tends to increase as maximum water temperatures exceeds 18°C, with selection against temperatures exceeding 19.5°C, while lower rates of movements are associated with water temperatures between 14°C and 17°C (Petty et al. 2012). Others suggest that the onset of thermal stress in brook trout may be higher, beginning at 21°C (Smith & Ridgway 2019). The onset of thermal stress is a focal point of our analysis because it represents the catalyst for behavioral thermoregulation, and even sublethal exposure to thermal stress can disrupt the normal functions of fish leading to decreased growth and delayed mortality (Wehrly et al. 2007). Identifying river temperatures that exceed the upper thermal threshold will chronicle the use and selection of thermal refugia in tributary streams within the Allagash watershed.

In addition to simple temperature thresholds, the length of exposure time to temperatures above these thresholds is critical to determining their impact. For example, brook trout can tolerate maximum mean daily water temperatures of 23.3°C for 7 days, with tolerance decreasing as time increases. The chronic effects of thermal stress and the probability of mortality are heightened as exposure (measured in days) to the stressor persists (Wehrly et al. 2007). To address this, our analysis will include a count of days in which water temperatures exceed thresholds considered both optimal and stressful to brook trout to discern acute vs chronic thermal stress events and appraise each tributary's value as critical refuge.

Studies of movement by brook trout (e.g. Petty et al. 2012) have established thermal optimums for the species, from which we can infer that selection for habitats at or below 18℃ may be occurring in Maine. Tributaries that remain in this thermal optimum should be considered high value brook trout habitats (Merry Gallagher, personal communication, December 19, 2022). Furthermore, the onset of thermal stress and lethal limits for brook trout have also been described widely in the literature (e.g. Smith and Ridgeway 2019). Though laboratory-based studies may overestimate thermal limits for brook trout when compared to field-based studies (Wehrly et al. 2007). Fish size is also an important consideration when establishing thermal criteria as habitat use is expected to change throughout ontogeny, i.e., sub-adult fish may select warmer temperatures that support faster growth, while adults may select cooler water temperatures to facilitate lower metabolic demands (Smith and Ridgeway 2019).

Considering our interest in tributaries that support different life history strategies, and that brook trout are likely adapted to the thermal cycling of a particular river or watershed (Butryn et al. 2013), we used relevant literature and historic knowledge of habitat selection by brook trout in Maine to establish region specific thermal criterion. Temperature values at or below 18℃ will be considered high-value thermal habitat; temperature values exceeding 20℃ will be considered the onset of thermal stress, UTT hereafter; and temperatures exceeding 23℃ for a period greater than seven days will be considered lethal or unsuitable habitats, UILT hereafter.

Varying Life History Strategies

This study coarsely covers a large geographic area with varying habitat features utilized by cold water fishes, particularly brook trout. As a result, we understand that brook trout inhabiting the Allagash River system utilize three life history strategies (MDIFW, Unpublished). Diverse life histories are an adaptive mechanism that allow brook trout to best use their physical habitat. The Allagash River watershed consists of lotic environments ranging from first order streams to large mainstem rivers; and lentic environments consisting of small to large ponds, thermally stratified oligotrophic lakes, and lakes with poor thermal stratification. Long term resilience and population viability in the Allagash River drainage is likely a function of metapopulation dynamics, i.e., the movement and dispersal rates of population units throughout the system (Nathan et al. 2018). Adfluvial brook trout hatch and develop in tributary streams before migrating to the lake environment to grow and achieve sexual maturity. Fluvial brook trout hatch and develop in their natal streams before migrating to larger rivers. While resident brook trout hatch, develop and spawn in their natal stream or river, typically lending to smaller size at age and maturity, especially in first order streams.

The role that seasonal thermal refuge plays differs by strategy, which may change a tributaries function in terms of species persistence. Adfluvial trout, for example, seek thermal refuge in areas at or below the thermocline in stratified lakes; fluvial trout seek thermal refuge at the confluent of or within smaller, cooler tributaries; and stream resident fish experience the thermal cycling of their environments, often migrating along a longitudinal gradient upstream to areas with suitable ambient temperatures.

Tributaries that flow into thermally stratified lakes will be considered separately from Allagash River tributaries as their roles may differ in importance to brook trout, in terms of thermal refugia. Despite this, lake tributaries likely maintain an overwhelming volume of brook trout spawning and rearing habitat, requiring specific physical parameters that fall outside of ambient temperature and the scope of this study. Geographical features (i.e., topography) typical of headwater lakes in the Allagash River watershed may lend towards different thermal regimes of tributaries when compared to steeper drainages downriver (Jeremiah Wood, Personal Communication, March 2, 2022). Decoupling these will better categorize thermal refuge in the Allagash River drainage.

Factors Influencing Thermal Regimes

Climate change is a driving factor in both air and water temperature regimes (Trumbo et al. 2014; Chambers et al. 2017), and contributes to habitat changes by influencing rainfall, floods, droughts, and invasive species range shifts (Wenger et al. 2011 cited by Trumbo et al. 2014). However, the increasing frequency and intensity of these events are difficult to predict. Anthropic activities remain one of the main drivers in the environmental characteristics of streams (Paiva et al. 2021) and should be the first tool used to mitigate larger issues such as climate change. There are a multitude of measurable in-stream habitat features that may be of interest in future work. Of particular importance is how land use may affect riparian vegetative cover, which comprises the aquatic-terrestrial interface and influences in-stream processes such as temperature regulation (Curry et al. 2002; Cross et al. 2013; Yonce et al. 2021).

The magnitude in which land use in the Allagash River watershed is affecting in-stream habitat features like temperature falls outside of the scope of this study, however relevant literature suggests it to be a worthwhile question to be addressed in a collaborative fashion with private landowners in future work.

Other uncontrollable factors like watershed area, are likely influencing temperature regimes, specifically, as watershed area increases, so will water temperature as it enters the Allagash River. Tributary streams tend to be dendritic in nature and have thermal regimes indicative of water source and fluvial properties. Likewise, larger mainstem rivers like the Allagash have thermal inputs that form a thermal gradient in pockets or microhabitats. Such sources can be influential enough to form thermal stratification in deep pools (MDIFW, Unpublished) providing complex physical and thermal habitat.

Implications

The coarse spatial grain of this study may make it difficult to identify factors influencing the thermal regimes of tributary streams in the AWW. We can, however, rely on literature to identify anthropogenic activities (factors in our control) that may exacerbate grander issues like climate change. Ultimately, the results of this study will supply preliminary, baseline data founding the grounds for future work in the AWW.

Historic Data

Table 1. Means of monthly mean water temperatures in the Allagash River at the USGS gauge site near Allagash, ME, for years 1975-80 and 2010-15 (https://nwis.waterdata.usgs.gov).

	Monthly Mean Water Temperature in the Allagash River (1975-80, 2010-15)				
Time Period	**May**	**June**	**July**	**August**	**September**
1975-1980	9.1℃	17.3℃	19.8℃	19.1℃	13.8℃
2010-2015	10.7℃	17.3℃	21.4℃	20.7℃	16.2℃
Increase	**1.6℃**	**0.0**℃	**1.6**℃	**1.6**℃	**2.4**℃

METHODS

Study Area

The state owned and managed AWW includes, from south to north, Telos Lake, Round Pond, Chamberlain Lake, Allagash Lake, Allagash Stream, Eagle, Churchill, Umsaskis, and Long Lakes, Round Pond, and the Allagash River flowing north almost to the village of Allagash (Figure 2). A buffer strip, known hereafter as the restricted zone, of state-owned land follows the contour of the shoreline and extends roughly 500 feet beyond the high-water mark. The study area encompasses twenty-two AWW tributary streams and four mainstem locations in the Allagash River. Study streams were selected based on Maine Department of Inland Fisheries and Wildlife (MDIFW) fisheries biologist recommendations and AWW Ranger recommendations with regard to historic brook trout use of those streams for thermal refugia. Emphasis was made to establish sampling locations within the restricted zone of the AWW to best represent water temperatures as they enter the AWW from the forested catchment. The study area comprises a representative array of aquatic environments typical of a northern Maine system. Forty-one percent (N=11) of sampling locations enter the Allagash River, 29% (N=8) enter lakes with weak summer thermal stratification, and 15% (N=4) enter a thermally stratified oligotrophic lake.

Stream	Confluent	Watershed Area
Telos Stream	Telos Lake	16.0 mi²
Lower Ellis Brook	Chamberlain Lake*	24.1 mi²
Upper Ellis Brook	Chamberlain Lake*	12mi²
Upper Allagash Stream	Allagash Lake*	50mi²
Allagash Stream	Chamberlain Lake	96.0 mi²
Thoroughfare Brook	Churchill Lake	42.7 mi²
Churchill Brook	Churchill Lake	8.9 mi²
Pleasant Stream	Churchill lake	20.7 mi²
Bissonnette Bride	Mainstem	325 mi²
Glazier Brook	Long Lake	23.2 mi²
Grey Brook	Long Lake	5.2 mi²
Ross Stream	Long Lake	217mi²
Shepherd Brook	Long Lake	15.9 mi²
Harding Brook	Allagash River	14.7 mi²
Sweeney Brook	Allagash River	3.7 mi²
Whittaker Brook	Allagash River	15.6 mi²
Henderson Bridge	Mainstem	722 mi²
Musquacook Stream	Allagash River	156mi²
Schedule Brook	Allagash River	24.7 mi²
Savage Brook	Allagash River	5.3 mi²
Five Finger Brook	Allagash River	32.0 mi²
McKinnon Brook	Allagash River	9.6 mi²
Ben Glazier Brook	Allagash River	17.3 mi²
Ramsay Brook	Allagash River	11.7 mi²
Ramsay Ledge	Mainstem	1,021mi²
Michaud Farm	Mainstem	1,025 mi²
Farm Brook	Allagash River	17.7 mi²

*Table 1. Temperature monitoring sites, their confluent and watershed area. Lakes marked * stratify thermally. Ross Stream and Henderson Bridge loggers have been lost. Summer data from Harding Brook in 2022 was lost due to technical malfunctions. Glazier Brook is included courtesy of MDIFW.*

Sampling

Twenty-one remote temperature loggers were deployed during June 2022, checked in August 2022, and re-visited in October 2022 to download data. Unseasonably high-water levels delayed deployment in the spring and made efforts to access the thalweg difficult.

Fall rain raised water levels again and made accessing sites difficult in October. Several sites were re-visited in November of 2022 when flows diminished. The August 2022 mid-summer check was incorporated into the project to ensure loggers stayed watered during the dry season, and several loggers were moved into deeper water, though none were dewatered. Of the 21 loggers deployed in 2022, 13 were left to overwinter (Appendix C), and 8 were removed in the fall as to not lose the hardware and data to high spring flows associated with snowmelt. Three sites were terminated for the 2022 season and those loggers were re-allocated to new tributaries in 2023. All sites were revisited in June 2023; five of the loggers removed in the fall of 2022 were re-deployed in their original location, and five new sites were established for 2023. Of the 23 loggers deployed in 2023, 14 loggers were left to overwinter, eight have been removed, and one was not recovered (Appendix C). Data collection effectively occurred from July 2022 through October of 2023, encompassing two summer seasons, when ambient water temperatures transcend thermal thresholds for brook trout.

HOBO MX TidbiT 400 temperature loggers by ONSET® were programmed to record temperature values in degrees Celsius at thirty-minute intervals. The accuracy of each logger was validated using a handheld thermometer before deployment and twice during the study. PVC cases were constructed using two-inch schedule 40 socket caps, two-inch schedule 40 female hub adapters, and two-inch schedule 40 male plugs. Components were adhered together using heavy duty PVC cement and primer. Two holes were drilled in the cases for an attachment point and to allow water exchange over the sensor. Each logger was anchored into the substrate with half-inch rebar, and each site was established behind a large rock within or adjacent to the thalweg to prevent damage and avoid dewatering. All sites were covered with large rocks to protect and hold down each encased logger (Figure 1). Sites were established above freshwater deltas to avoid inundation from the river or lake environment during high water events.

Of the 26 sites monitored for ambient water temperature data during 2022 and 2023, 30% (N=7) of sites were accessible by road, 10% (N=3) were accessible by lake with a boat, and 60% (N=16) were accessible by river with a canoe. The Allagash watershed flows south to north, so stations were typically visited in such a manner. AWW Rangers provided watercraft and personnel assistance for lake and river access-only sites, as well as shuttles to and from boat launches.

Figure 1: Temperature logger encased in PVC housing before deployment (left), and an example of a monitoring site behind a large rock in the middle of the channel (right).

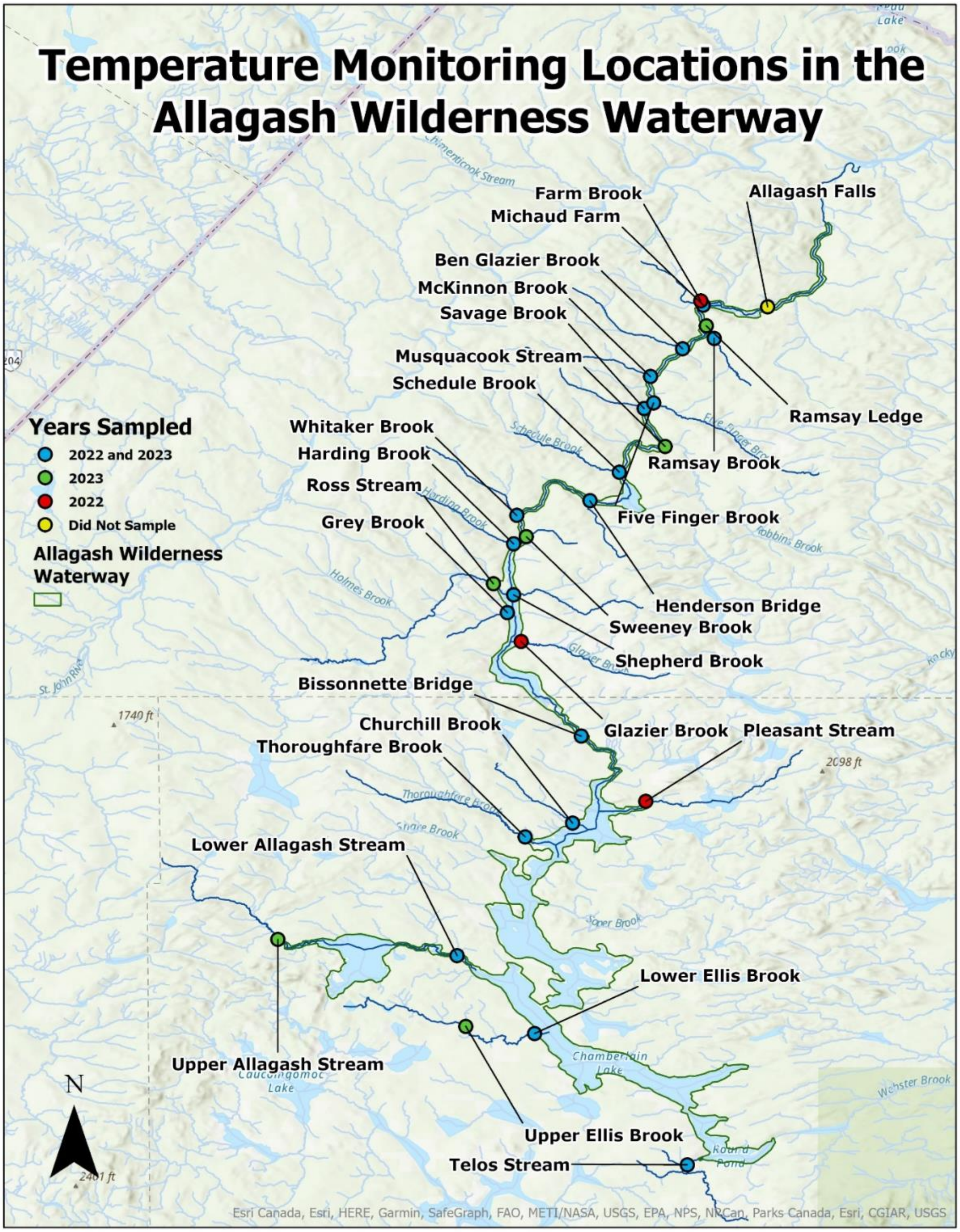


Figure 2: Map of study area and respective sampling locations. Points marked in red were sampled only during 2022, points marked in green were only sampled during 2023, and points marked in blue were sampled both during 2022 and 2023.

Statistical Analysis

All temperature data were cleaned for quality assurance/quality control and compiled in Microsoft Excel. Data summarization was conducted using the software system SAS 9.4. Output metrics were based on a literature search conducted before summer temperatures were downloaded. We looked for publications that best represented natural fluxes in experienced thermal stress. Field-based estimates or laboratory studies that incorporated thermal acclimation were considered for the critical thermal thresholds referenced presently. The daily mean, minimum, maximum, and range of temperature values were generated for each station. The sum of days (exposure) during sampling in which mean and maximum daily temperatures exceeded brook trout thermal thresholds of 18℃, 20℃, and 23℃ were computed for July and August. The monthly average of the daily ranges in temperatures were computed for July and August in 2022 and 2023. All computations in SAS 9.4 were exported into Microsoft Excel. To test whether watershed area has a significant impact on maximum daily water temperatures, we ran simple linear regressions using watershed area as the independent variable and the average daily maximum temperatures for the month of August (2022 and 2023) as the dependent variables. Flow data from the Allagash River were retrieved from the United States Geological Survey (USGS) website (waterdata.usgs.gov) using Program R (RStudio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/) and exported to Microsoft Excel for further analysis.

Variation in Temperature

Tributary streams likely constitute a thermal gradient indicative of their fluvial properties and solar inputs, and sources of cold water within the mainstem can be influential enough to form thermal stratification in deep pools (MDIFW, Unpublished). In an attempt to collect preliminary data on these thermal gradients, we placed temperature loggers above previously established sites in Ellis Brook and Allagash Stream, and in a known thermal refuge within the mainstem of the Allagash River at Ramsay Ledge (Figure 2).

RESULTS

Twenty-one temperature loggers were deployed in June 2022, checked in August, and data downloaded in October. Information from Harding Brook (2022) was lost due to technical malfunction associated with the logger. Sites established at Sweeney Brook, Farm Brook, and Pleasant Stream were terminated after the 2022 sampling season due to limited physical brook trout habitat, difficult access, and notably high water temperatures, respectively. Those loggers were reallocated to new sites in 2023; twenty-three temperature loggers recorded temperature in 2023. New sites were established higher up in the Ellis Brook and Allagash Stream watersheds, in the Allagash River at Ramsay Ledge, and in Ross and Musquacook Streams (Figure 2). Information from a temperature logger in the Allagash River at Henderson Bridge has been lost due to technical malfunctions associated with the logger, and information from Ross Stream was not recovered due to high water and ice cover that prevented access to the site. A temperature logger in Glazier Brook that was provided courtesy of MDIFW was recovered in

2022, but not recovered in the fall of 2023. In total, 27 sites were monitored for ambient water temperatures over the course of two years.

Exposure Time – Mean & Max Daily Temperatures

Temperatures at three sampling locations in the mainstem of the Allagash River exceeded the upper thermal threshold for brook trout, the point at which thermal avoidance occurs. Mean ambient water temperatures exceeded the UTT for brook trout in Maine (20℃) for 90%, 97%, and 72% percent of the days at Bissonnette Bridge, Henderson Bridge and Michaud Farm, respectively (Table 3). Maximum water temperatures at Bissonnette Bridge, Henderson Bridge and Michaud Farm exceeded the UTT for brook trout an average of 98%, 100%, and 91% of the days in July and August of 2022 and 2023, and the UILT (23℃) for 45%, 37% and 57% of the days, respectively (Table 6; Table 7). The additional mainstem sampling location, located at Ramsay Ledge (Figure 2), showed a noteworthy decrease in exposure time over the UTT and UILT, averaging 79% and 40% of the days in July and August of 2023. However, when separated by month, maximum daily temperatures at Ramsay Ledge exceeded the UTT every day in July, and the UILT for 25 days (Table 6; Table 7).

Upper Ellis Brook, Lower Ellis Brook, Lower Allagash, Pleasant, and Musquacook Streams were the warmest tributaries, with mean daily temperatures exceeding the UTT 48%, 52%, 77%, 60%, and 42% of the days in July and August, and maximum daily temperatures exceeding the UTT 71%, 81%, 95%, 92%, and 58% of the days in July and August, respectively (Table 3; Table 6). On average, maximum daily temperatures at Upper Ellis Brook, Lower Ellis Brook and Lower Allagash Stream exceeded the UILT for 39%, 42%, and 48% of the days in July and August, respectively (Table 7). Other locations with notably high ambient water temperatures were Telos Stream, Thoroughfare Brook, and Upper Allagash Stream, with maximum temperatures exceeding the UTT 69%, 40% and 45% of the days in July and August, and mean temperatures exceeding the UTT for 23%, 19%, and 27% of the days, respectively (Table 6; Table 3).

Maximum daily temperatures at Schedule, Five Finger, Churchill, and Glazier Brooks exceeded the UTT for more than 42%, 45%, 25%, and 34% of the days in July and August, though each stream's mean daily temperatures exceeded the UTT only 4%, 7%, 3%, and 3%, respectively (Table 6; Table 3). These tributaries exhibited the greatest separation in number of days above the UTT for maximum and mean daily temperatures. They also, intuitively, experienced higher magnitudes of diel fluxes in daily temperatures when compared to tributaries with cooler, more stable regimes (see *magnitude of diel fluxes* below).

Mean daily temperature values in Grey, Shepherd, Harding, Sweeney, Whittaker, Savage, McKinnon, Ben Glazier, Ramsay, and Farm Brooks did not exceed the UTT at all during July and August (Table 3). Mean daily temperatures at Schedule Brook and Five Finger Brook exceeded the UTT only 4% and 7% of the days, respectively (Table 3). Maximum daily temperatures at all of these sites exceeded the UTT for less than 14% of the days in July and August, not including Schedule Brook and Five Finger Brook (Table 6). Additionally, Ben Glazier, Grey, Shepherd, Farm, Harding, McKinnon, Savage, and Whittaker Brooks recorded mean daily temperatures that only exceeded 18℃ for 7%, 12%, 13%, 3%, 16%, 11%, 10%, and 10% of the days during July and August, respectively. Ramsay Brook did not experience mean temperatures above 18℃ during July and August (Table 2).

Table 2: A count of days in which mean temperatures exceeded 18℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Mean Temp GE 18℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	31	31	31	31	31	100%
U. Allagash Stream		30		1	16	50%
Ben Glazier Brook	1	6	2	0	2	7%
Bissonnette Bridge	31	31	31	31	31	100%
Churchill Brook	14	21	11	0	12	37%
Farm Brook	1		1		1	3%
Five Finger Brook	12	25	13	0	13	40%
Glazier Brook	9		7		8	26%
Grey Brook	0	15	0	0	4	12%
Harding		10		0	5	16%
Henderson Bridge	31		31		31	100%
L. Ellis Brook	29	31	23	23	27	85%
McKinnon Brook	2	10	2	0	4	11%
Michaud Farm	31	31	31	29	31	98%
Musquacook Stream		31		14	23	73%
Pleasant Stream	29		27		28	90%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge		31		29	30	97%
Savage Brook	3	8	1	0	3	10%
Schedule Brook	15	22	13	0	13	40%
Shepherd Brook	0	16	0	0	4	13%
Sweeney Brook	12		6		9	29%
Telos Stream	20	30	15	10	19	60%
Thoroughfare Brook	26	26	13	0	16	52%
U. Ellis Brook		31		26	29	92%
Whittaker Brook	3	7	2	0	3	10%

Table 3: A count of days in which mean temperatures exceeded 20℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Mean Temp GE 20℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	26	28	31	11	24	77%
U. Allagash Stream			17	0	9	27%
Ben Glazier Brook	0	0	0	0	0	0%
Bissonnette Bridge	30	31	31	19	28	90%
Churchill Brook	0	1	3	0	1	3%
Farm Brook	0	0			0	0%
Five Finger Brook	1	2	6	0	2	7%
Glazier Brook	1	1			1	3%
Grey Brook	0	0	0	0	0	0%
Harding Brook			0	0	0	0%
Henderson Bridge	30	30			30	97%
L. Ellis Brook	23	13	28	0	16	52%
McKinnon Brook	0	0	0	0	0	0%
Michaud Farm	28	24	31	6	22	72%
Musquacook Stream			26	0	13	42%
Pleasant Stream	19	18			19	60%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge			31	5	18	58%
Savage Brook	0	0	0	0	0	0%
Schedule Brook	2	1	2	0	1	4%
Shepherd Brook	0	0	0	0	0	0%
Sweeney Brook	0	0			0	0%
Telos Stream	7	4	17	0	7	23%
Thoroughfare Brook	9	6	8	0	6	19%
U. Ellis Brook			29	1	15	48%
Whittaker Brook	0	0	0	0	0	0%

Table 4: A count of days in which temperatures exceeded 23℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Mean Temp GE 23℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	10	6	22	0	10	31%
U. Allagash Stream			0	0	0	0%
Ben Glazier Brook	0	0	0	0	0	0%
Bissonnette Bridge	13	9	24	0	12	37%
Churchill Brook	0	0	0	0	0	0%
Farm Brook	0	0			0	0%
Five Finger Brook	0	0	0	0	0	0%
Glazier Brook	0	0			0	0%
Grey Brook	0	0	0	0	0	0%
Harding Brook			0	0	0	0%
Henderson Bridge	14	7			11	34%
L. Ellis Brook	5	3	7	0	4	12%
McKinnon Brook	0	0	0	0	0	0%
Michaud Farm	9	6	23	0	10	31%
Musquacook Stream			2	0	1	3%
Pleasant Stream	0	1			1	2%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge			17	0	9	27%
Savage Brook	0	0	0	0	0	0%
Schedule Brook	0	0	0	0	0	0%
Shepherd Brook	0	0	0	0	0	0%
Sweeney Brook	0	0			0	0%
Telos Stream	0	0	4	0	1	3%
Thoroughfare Brook	0	0	0	0	0	0%
U. Ellis Brook			14	0	7	23%
Whittaker Brook	0	0	0	0	0	0%

Table 5: A count of days in which maximum temperatures exceeded 18℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Max Temp GE 18℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	31	31	31	31	31	100%
U. Allagash Stream		31		9	20	65%
Ben Glazier Brook	20	19	13	0	13	42%
Bissonnette Bridge	31	31	31	31	31	100%
Churchill Brook	26	28	17	2	18	59%
Farm Brook	12		7		10	31%
Five Finger Brook	28	30	26	5	22	72%
Glazier Brook	27		20		24	76%
Grey Brook	4	26	5	0	9	28%
Harding		25		0	13	40%
Henderson Bridge	31		31		31	100%
L. Ellis Brook	31	31	30	30	31	98%
McKinnon Brook	13	24	8	0	11	36%
Michaud Farm	31	31	31	30	31	99%
Musquacook Stream		31		27	29	94%
Pleasant Stream	31		30		31	98%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge		31		30	31	98%
Savage Brook	10	25	5	0	10	32%
Schedule Brook	31	30	25	5	23	73%
Shepherd Brook	13	25	11	0	12	40%
Sweeney Brook	17		14		16	50%
Telos Stream	28	31	24	27	28	89%
Thoroughfare Brook	29	30	18	8	21	69%
U. Ellis Brook		31		30	31	98%
Whittaker Brook	22	26	13	0	15	49%

Table 6: A count of days in which maximum temperatures exceeded 20℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Max Temp GE 20℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	31	30	30	27	30	95%
U. Allagash Stream		28		0	14	45%
Ben Glazier Brook	3	6	3	0	3	10%
Bissonnette Bridge	31	31	31	29	31	98%
Churchill Brook	13	10	8	0	8	25%
Farm Brook	1		0		1	2%
Five Finger Brook	16	24	16	0	14	45%
Glazier Brook	12		9		11	34%
Grey Brook	0	7	0	0	2	6%
Harding Brook		6		0	3	10%
Henderson Bridge	31		31		31	100%
L. Ellis Brook	30	31	25	14	25	81%
McKinnon Brook	0	6	1	0	2	6%
Michaud Farm	31	31	31	20	28	91%
Musquacook Stream		31		5	18	58%
Pleasant Stream	30		27		29	92%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge		31		18	25	79%
Savage Brook	0	5	0	0	1	4%
Schedule Brook	20	21	11	0	13	42%
Shepherd Brook	0	10	3	0	3	10%
Sweeney Brook	4		2		3	10%
Telos Stream	26	29	17	14	22	69%
Thoroughfare Brook	22	18	10	0	13	40%
U. Ellis Brook		30		14	22	71%
Whittaker Brook	6	7	4	0	4	14%

Table 7: A count of days in which maximum temperatures exceeded 23℃ during July and August of 2022 and 2023 by monitoring location.

	Count of Days Max Temp GE 23℃					
Stream	**Jul-22**	**Jul-23**	**Aug-22**	**Aug-23**	**Mean**	**%**
L. Allagash Stream	16	28	16	0	15	48%
U. Allagash Stream		5		0	3	8%
Ben Glazier Brook	0	0	0	0	0	0%
Bissonnette Bridge	18	19	19	0	14	45%
Churchill Brook	0	2	0	0	1	2%
Farm Brook	0		0	0	0	0%
Five Finger Brook	3	4	2	0	2	7%
Glazier Brook	0		0	0	0	0%
Grey Brook	0	0	0	0	0	0%
Harding Brook		0		0	0	0%
Henderson Bridge	20		14	0	11	37%
L. Ellis Brook	22	19	11	0	13	42%
McKinnon Brook	0	0	0	0	0	0%
Michaud Farm	23	28	18	2	18	57%
Musquacook Stream		13		0	7	21%
Pleasant Stream	16		14	0	10	32%
Ramsay Brook	0	0	0	0	0	0%
Ramsay Ledge		25		0	13	40%
Savage Brook	0	0	0	0	0	0%
Schedule Brook	3	3	2	0	2	6%
Shepherd Brook	0	0	0	0	0	0%
Sweeney Brook	0		0	0	0	0%
Telos Stream	14	11	4	0	7	23%
Thoroughfare Brook	3	3	3	0	2	7%
U. Ellis Brook		24		0	12	39%
Whittaker Brook	0	0	1	0	0	1%

Variation in Temperature

Additional monitoring locations were established in 2023 in two tributaries and one location in the mainstem above previously established monitoring sites. One site was in the upper reaches of Allagash Stream upstream of Allagash Lake, one higher in the Ellis Brook watershed, and another in the mainstem Allagash River at Ramsay Ledge, below the confluence of Ramsay Brook, a cold tributary with stable water temperatures. Comparisons were made from mean daily temperatures in 2023.

Temperatures at the Upper Ellis Brook site do not appear to be significantly cooler (in terms of UTT and UILT) than the Lower Ellis Brook site, and in many cases, temperatures at the upper site surpass those at the lower site (Figure 3).

Notable differences in mean daily temperatures were recorded at the Upper Allagash Stream site when compared to the Lower Allagash Stream site. Temperatures at the upper site remained below those at the lower site for the entire duration of sampling (June 2023-September 2023), and often remained below the UTT while the lower site surpassed the UTT (Figure 4).

Mean daily temperatures at the Ramsay Ledge site in the mainstem of the Allagash River tracked closely the temperatures recorded just downstream at the Michaud Farm site. Despite slightly cooler temperatures at Ramsay Ledge, when considering critical thermal thresholds for brook trout, the differences are insignificant (Figure 5).

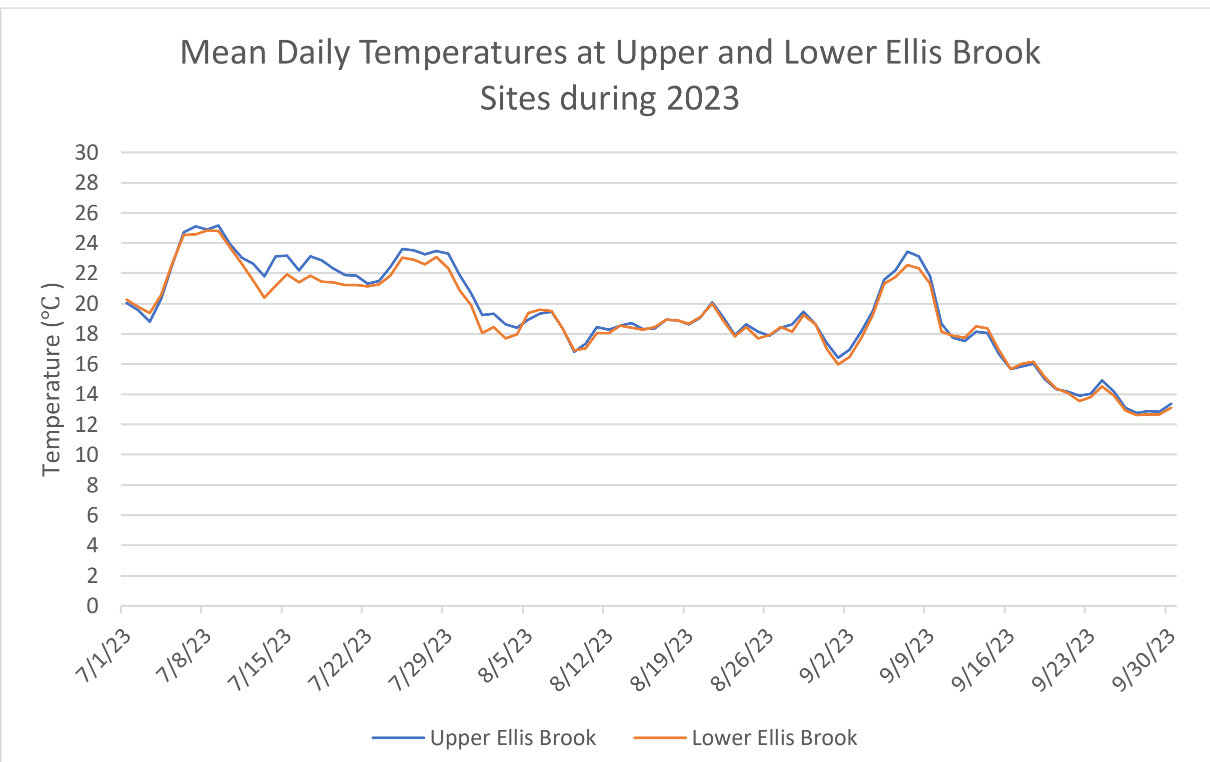


Figure 3: A comparison of mean daily temperatures at two sites located in Ellis Brook from July through September 2023.

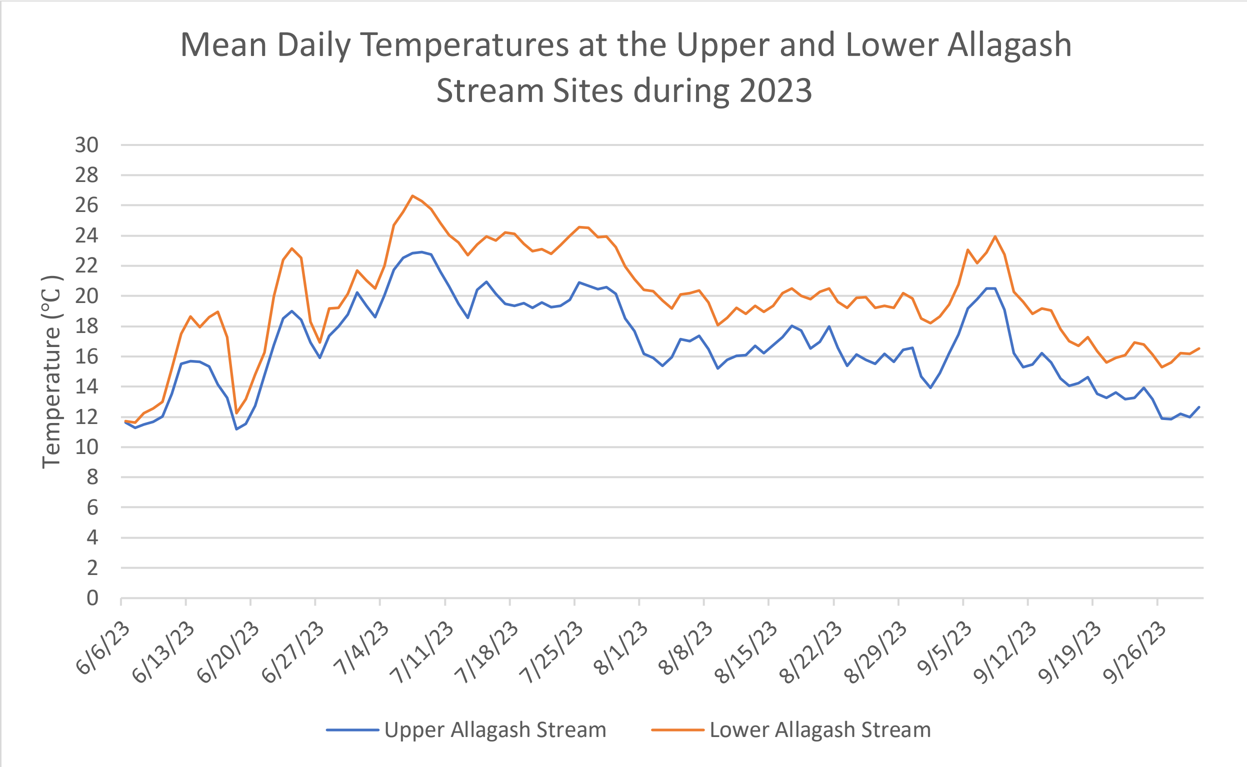


Figure 4: A comparison of mean daily temperatures at two sites located in Allagash Stream from June through September 2023.

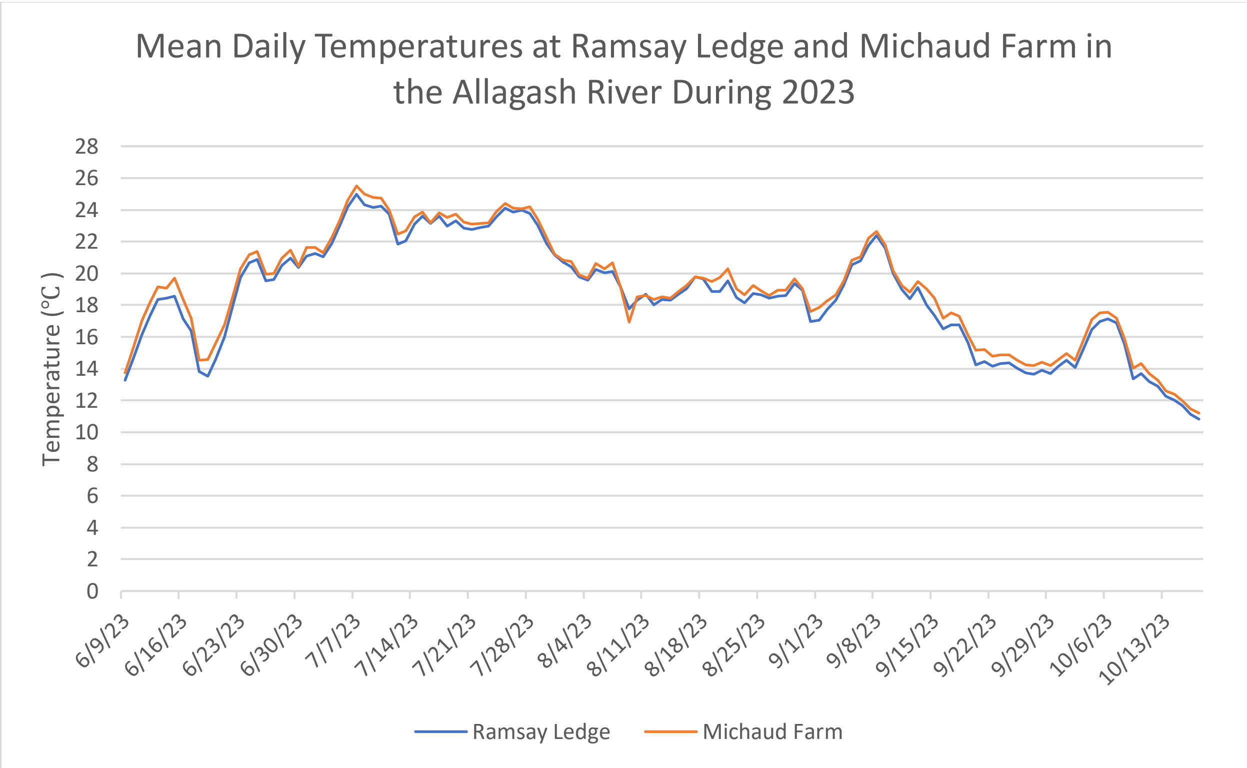


Figure 5: A comparison of mean daily temperatures at two sites located in the Allagash River from June through October 2023.

The summers of 2022 and 2023 were generally wet, with flows rarely dropping below the median (Figure 9; https://nwis.waterdata.usgs.gov). Despite this, our data highlights a large difference in ambient water temperatures at sites that were sampled during both years. The number of days maximum temperatures exceeded the UTT was notably greater in August 2022 than in August 2023 (Figure 6).

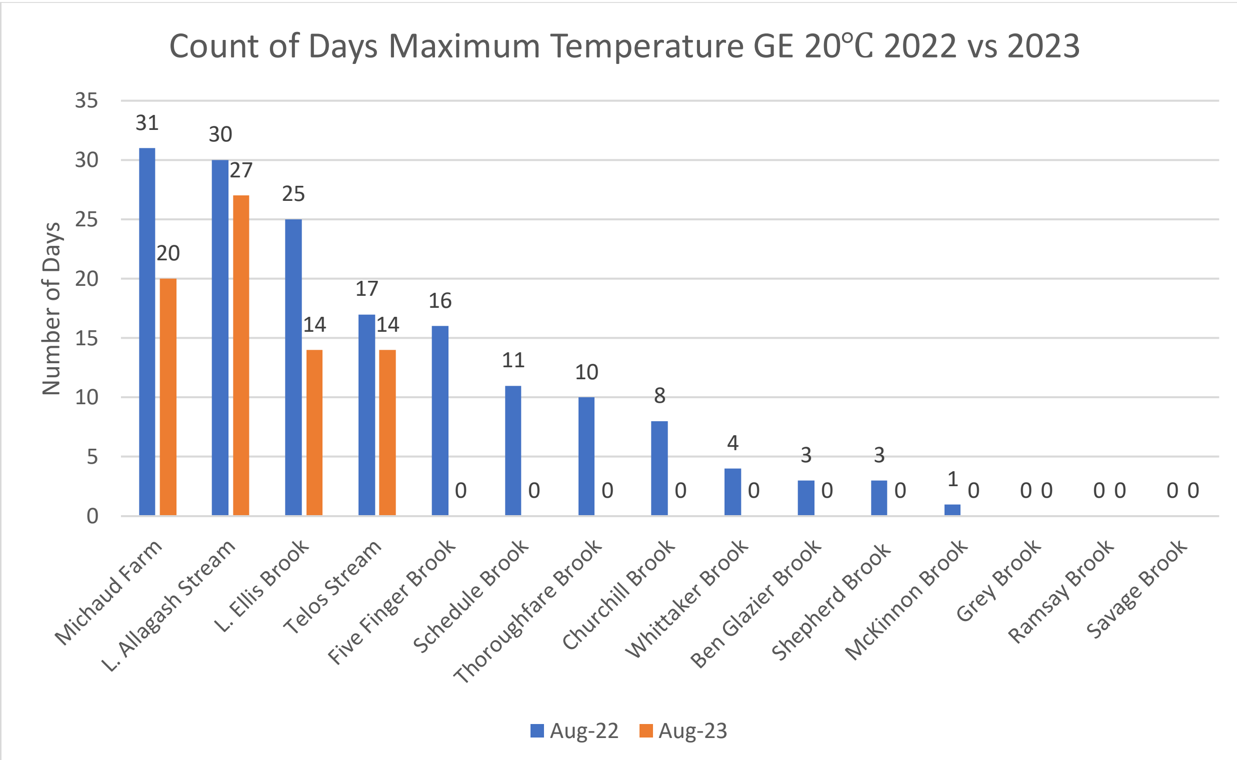


Figure 6: The total number of days in which daily maximum temperatures exceeded 20℃ during August of 2022 and 2023.

Magnitude of Diel Fluxes

Tributaries previously noted as having warm thermal regimes tended to have greater magnitudes of diel fluxes. Telos, Lower Ellis, Thoroughfare, Glazier, Schedule, and Five Finger Brooks, and Pleasant Stream all had daily fluctuations that averaged greater than 3°C for the months of July and August. Of note, these streams are characterized by warmer summer temperatures, and higher maximum temperatures than other sites. Surprisingly, both sites in Allagash Stream, and the site in Musquacook Stream averaged daily fluctuations in temperature below 3°C. Locations in the mainstem of the Allagash River also recorded only slight daily fluctuations, on par with smaller cooler tributaries, despite having warmer thermal regimes.

In general, streams with cooler thermal regimes had smaller daily fluctuations in temperature (Figure 7), suggesting relatively stable thermal cycling at these sites. Ramsay Brook, for example, averaged daily fluctuations in temperature around 1°C during 2022 and 2023.

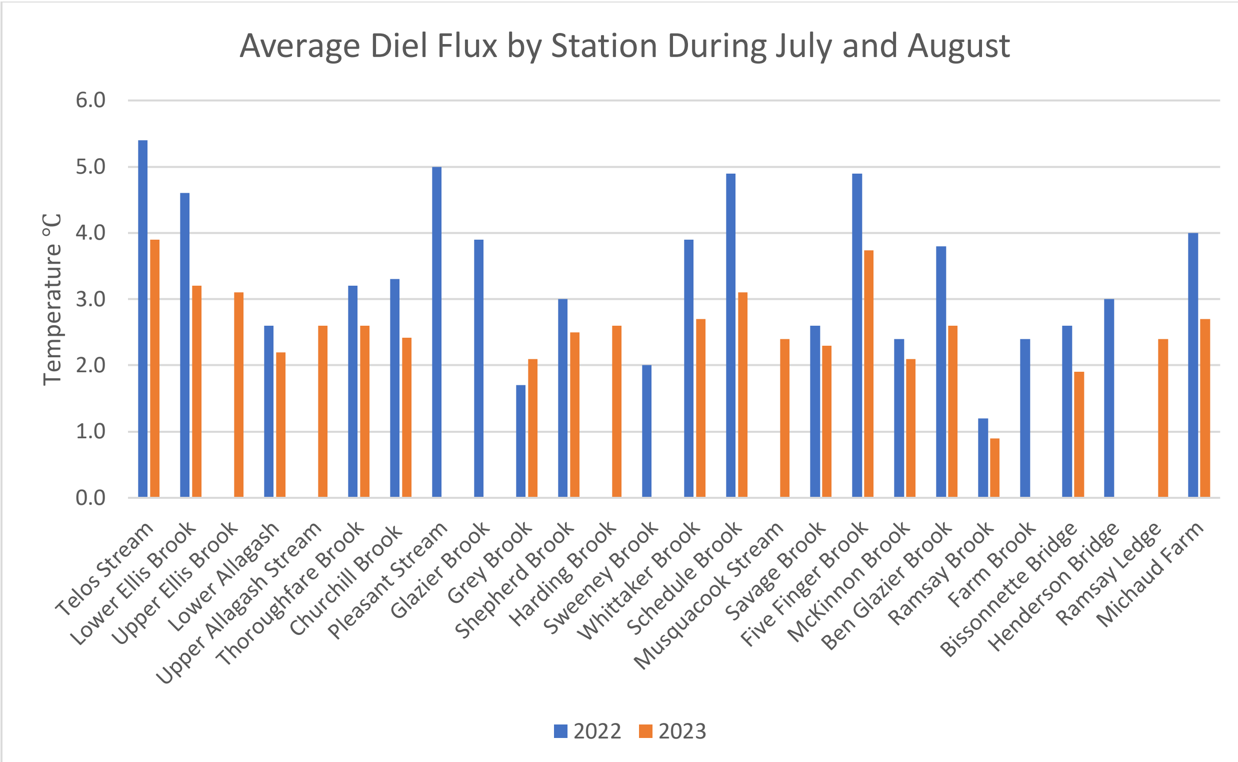


Figure 7. The average magnitude of diel fluxes for each monitoring location during July and August 2022 and 2023.

Factors Effecting Thermal Regimes

Watershed area and its relationship to average maximum temperatures varied by year. We documented a significant (P= .03), though weak relationship (r^2= .27) between watershed area and average maximum temperatures during August of 2022 (Figure 8). However, there was a weak (r^2= .17) and statistically insignificant (P= .11) relationship between watershed area and average maximum temperature in August of 2023 (Figure 9).

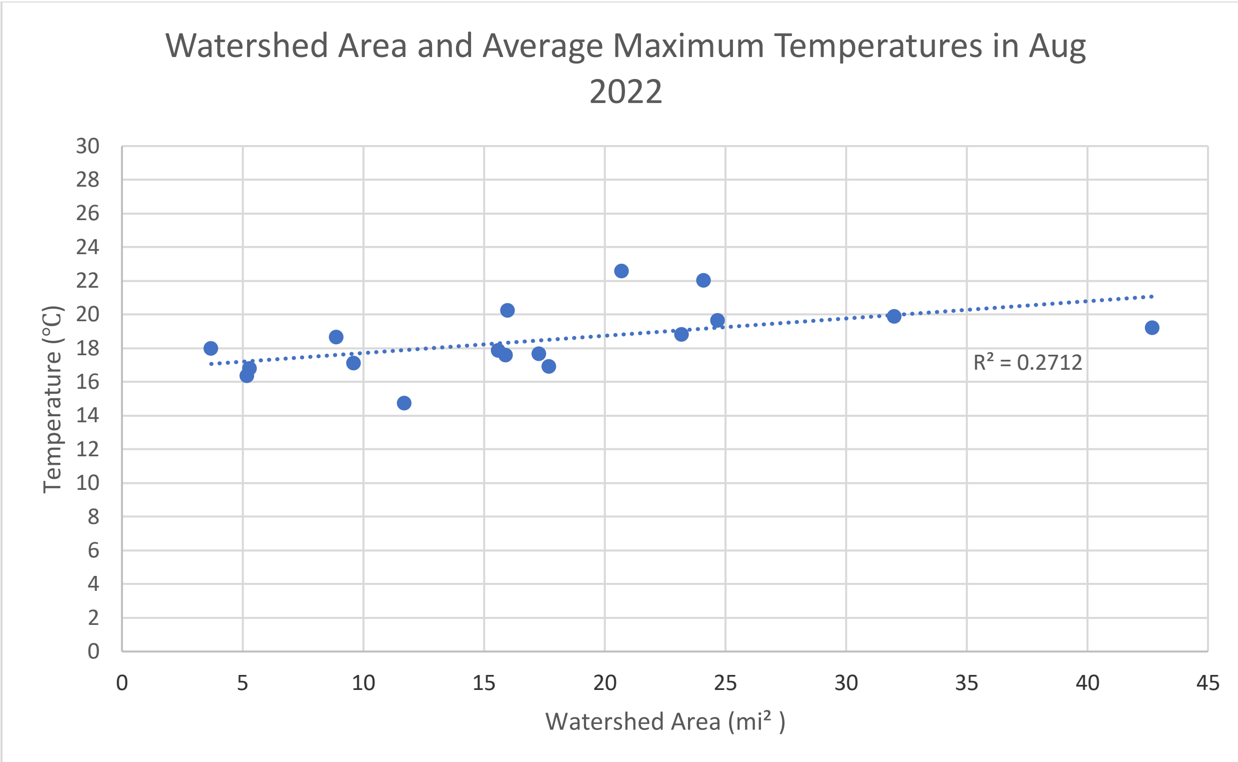


Figure 8: Average daily maximum water temperatures as they relate to watershed area during August 2022

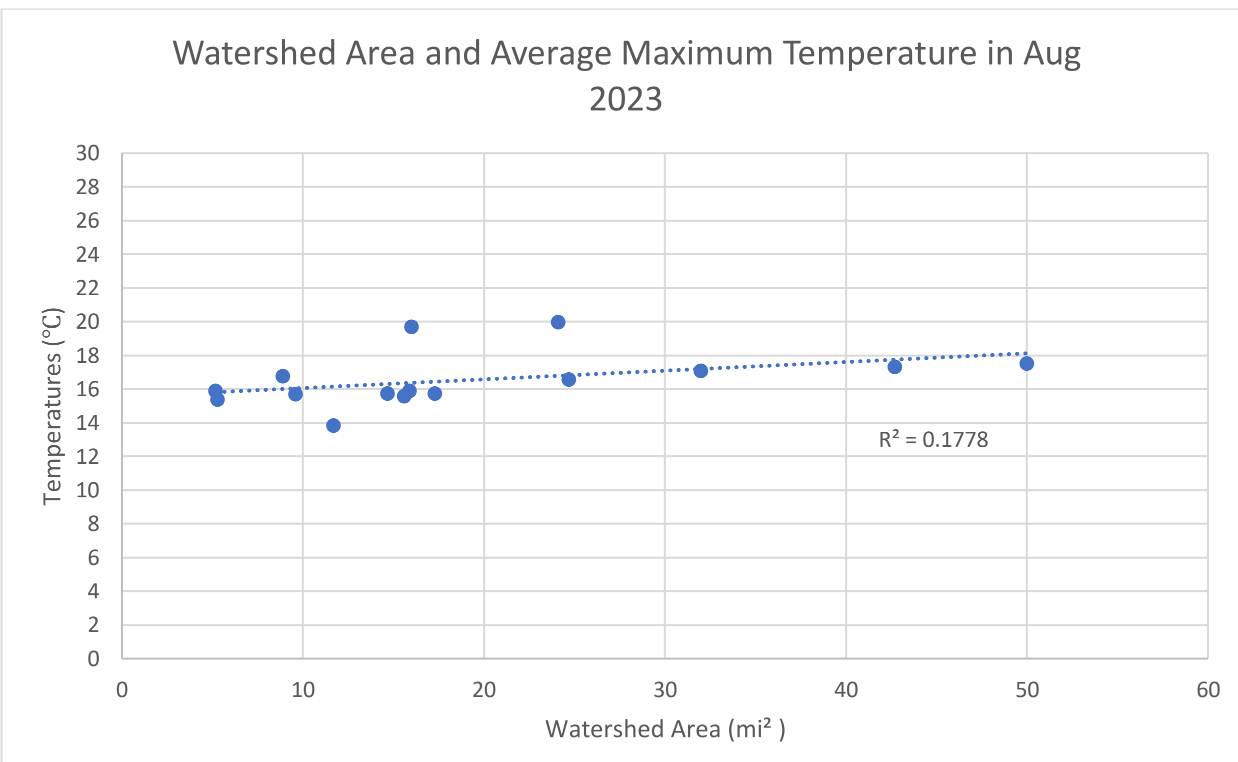


Figure 9: Average daily maximum water temperatures as they relate to watershed area during August 2023.

Flow Regimes During 2022, 2023

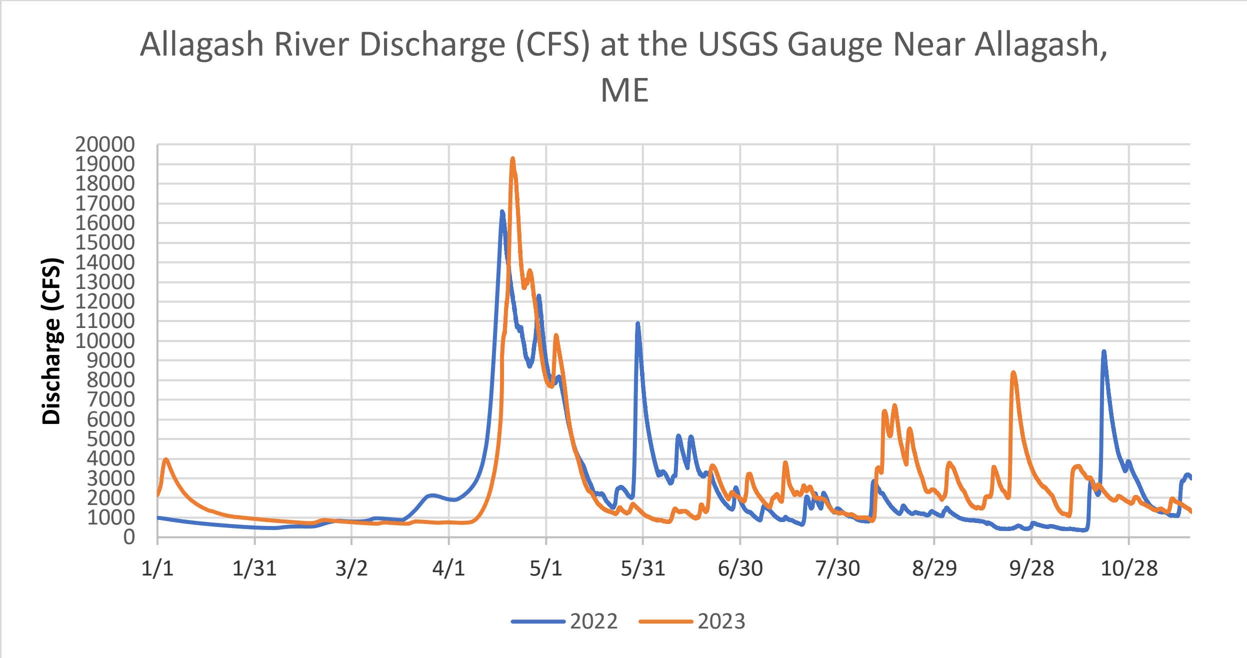


Figure 8: Discharge measured in cubic feet per second at the USGS gauge site in the Allagash River near Allagash, ME. Data curtesy https://nwis.waterdata.usgs.gov.

DISCUSSION

Water temperature is an important habitat parameter limiting the distribution and persistence of stream fishes. Brook trout survival is significantly reduced as summer temperatures increase (Xu et al. 2010). As such, access to cold water refugia is critical during periods of elevated water temperatures. The Allagash River watershed above Allagash Falls (Figure 2) is unique in that its native fish assemblage remains intact, offering critical habitat to native brook trout with little influence from invasive species. Physical habitat parameters are likely the greatest limiting factor for brook trout in the Allagash River watershed above Allagash Falls, and current temperature regimes in the Allagash River underscore the importance of cold water sources to the persistence of native brook trout here.

Water temperatures in the mainstem of the Allagash River are not suitable for brook trout survival during the summer months and have increased since the late 1970's when they were first recorded by the USGS gauge in Allagash.

Table 8: Means of monthly mean water temperature in the Allagash River at the USGS gauge site near Allagash, ME, for years 1975-80, 2010-15, 2022, and 2023 (https://nwis.waterdata.usgs.gov).

	Monthly Mean Water Temperature in the Allagash River (1975-80, 2010-15, 2022, 2023)				
Time Period	**May**	**June**	**July**	**August**	**September**
1975-1980	9.1℃	17.3℃	19.8℃	19.1℃	13.8℃
2010-2015	10.7℃	17.3℃	21.4℃	20.7℃	16.2℃
2022	12.1⁰C	17.0⁰C	21.9⁰C	21.7⁰C	16.8⁰C
2023	11.1⁰C	17.7⁰C	23.4⁰C	19.1⁰C	17.4⁰C
2022-2023	11.6⁰C	17.4⁰C	22.7⁰C	20.4⁰C	17.2⁰C

The August 2022 average water temperature was higher than that of any month in the previous two time periods; the July and September 2023 water temperatures were also higher than any month in the previous two time periods.

Maximum daily water temperatures at Bissonnette Bridge, Henderson Bridge and Michaud Farm exceeded the UTT (20℃) for brook trout an average of 98%, 100%, and 91% of the days in July and August of 2022 and 2023, and the UILT (23℃) for 45%, 37% and 57% of the days, respectively. Exposure to the latter temperatures of that magnitude for greater than seven-days is not tolerated by brook trout (Wehrly et al. 2007). Summer water temperatures, therefore, exceed the stress threshold and lethal limit for brook trout in the mainstem Allagash River. We can infer that fluvial brook trout that exploit the mainstem during favorable temperatures for growth and development must be mobile and seek thermal refuge in tributary streams along a longitudinal gradient, in spring seeps, and micro habitats that likely occur within the mainstem.

Similar to the main river, temperatures in Upper Ellis Brook, Lower Ellis Brook, Lower Allagash, Pleasant, and Telos Stream commonly exceeded thresholds considered lethal to trout. Maximum water temperatures at these sites exceeded the UTT for more than 69% of the days in July and August. However, sampling locations in streams that enter thermally stratified lakes (Table 1), where there is adequate cold water and dissolved oxygen below the thermocline, may not be providing critical thermal refuge for adfluvial brook trout. Resident brook trout populations are likely limited in these locations and stream connectivity is crucial for the upstream movements of resident fish to thermal refuge during the summer months. More work is needed to better understand the extent of movement and the thermal gradient in these dendritic tributary streams. Also of note, these tributaries likely provide the greatest volume of spawning habitat for adfluvial brook trout. Highwater conditions decreased visibility such that redds were not visible in October and could not be counted during field work. Identifying tributaries that provide spawning habitat and conserving their fluvial properties should be considered in future work.

Similar to other river systems in northern Maine, brook trout persistence in the Allagash is highly dependent on cold water refugia. During this study, several tributaries remained cold enough to support brook trout throughout the summer. Grey, Shepherd, Harding, Sweeney, Whittaker, Savage, Schedule, Ben Glazier, Ramsay, Farm, and McKinnon Brooks provided cold water refugia to the river when conditions in the mainstem were unfavorable. Further, Ben

Glazier, Grey, Shepherd, Farm, Harding, McKinnon, Savage, and Whittaker Brooks recorded mean daily temperatures that exceeded 18℃ less than 16% of the days during July and August, while mean temperatures at Ramsay Brook did not exceed 18℃ for the duration of our study. These tributaries represent a thermal category indicative of high value brook trout habitat, and their importance to the persistence of brook trout in the system should be highlighted. Despite the population services that these tributaries are contributing to brook trout, they are likely the most vulnerable to land use change and anthropic disruptions due to their small watershed areas (Meyer et al. 2007; Kanno et al. 2015), highlighting a need to prioritize them as critical brook trout habitat moving forward.

Lacking in this study is an understanding of how and when brook trout are using these tributaries for refuge. While we can imply selection based on thermal criterion, a fine scale movement study should be explored in the future, building upon the baseline data presented herein.

Many of our study streams recorded maximum daily temperatures that exceeded the UTT for a significant amount of time, however, they showed mean daily temperatures that rarely exceed this threshold. For example, maximum daily temperatures at Schedule, Five Finger, Churchill, and Glazier Brooks, on average, exceeded the UTT more than 36% of the days in July and August, though each stream's mean daily temperatures exceeded the UTT an average of 4% of the days in July and August. This discrepancy between maximum and mean daily temperatures may indicate acute rather than chronic thermal stress events at these sites, and air temperatures and solar radiation may have had a greater influence on these streams relative to other sampling locations. Regardless, exposure to thermal stress at these sites may be minimal, and their value as refuge remains. However, they are likely more vulnerable to perturbations and tipping points in the form of land use and climatic changes. These 'marginal' streams also tend to be larger in size, lending themselves to easier brook trout migration from the Allagash, and supporting a much greater overall volume of physical refuge habitat than smaller streams. If these streams become unsuitable for brook trout survival, this can have a disproportionally large impact on overall brook trout habitat available in the river system (Jeremiah Wood, personal communication, December 23, 2022).

The range of daily temperatures, or the fluctuation from the minimum to maximum temperature over the course of a day can have limiting effects on brook trout because diel fluxes of high magnitude exacerbate chronic thermal stress events when coupled with high mean temperatures and exposure time (Wehrly et al. 2007).The magnitude of daily ranges in temperature can also be indicative of thermal inputs; surface water and interflow sources are likely more affected by air temperature and solar radiation than groundwater dominated sources. Telos Stream, Pleasant Stream, Ellis, Schedule, and Five Finger Brooks recorded some of the highest average daily fluctuations among our study sites. Still, daily fluctuations in temperature remained low enough to limit any amplifying effects. Ramsay, Grey, and Sweeney Brooks had average daily fluxes less than 2℃ and represented the smallest fluctuation in temperature among our study sites. This may be indicative of greater groundwater influence or represent the riparian composition and fluvial properties needed to buffer against the influence of air temperature and solar radiation. The monitoring locations in the Allagash River, and at Musquacook and Allagash Streams, recorded diel fluxes that were average among all study streams. One commonality among these locations is their increased watershed area. The inverse relationship between watershed area and daily fluctuation in temperature may be the result of sustained warmer temperatures, and the relationship between volume of water per unit increase in temperature given all sites experienced relatively similar climatic conditions.

When addressing factors influencing thermal regimes, it is difficult to consider just one variable, as water temperature is influenced by a host of factors that should be considered in the aggregate. We documented interannual variation in the effects of watershed area on temperature, supporting the idea that several factors influence ambient water temperature, and such factors may be exacerbated by differences in watershed area. Moving forward, and in the interest of discerning the cause of changing temperatures, if any, more variables should be considered and tested for significance. Such factors may include stream slope, percent forest cover, flow, beaver activity, and canopy closure.

Water temperatures can vary significantly within individual streams, and it is important to note that our temperature loggers were stationed at the confluences of headwater lakes and the Allagash River and reflect conditions entering the AWW from the forested catchment. These data, therefore, represent macrohabitat at the lowest point in each tributary's watershed area, and likely omit microhabitat and other cold water sources higher in the watershed, or within the mainstem. We attempted to examine this phenomenon at Ellis Brook, Allagash Stream, and in the mainstem of the Allagash River. Cooler temperatures were identified in the upstream reaches of Allagash Stream. Upper and Lower Ellis Brooks flow out of a series of ponds and peat bogs, respectively, which likely explains the high temperatures at each site. Sampling higher in the watersheds of our study streams will be an effective way to better understand the thermal cycling that occurs there. The two sites compared in the mainstem Allagash River, one at Ramsay Ledge and one at Michaud Farm did not show marked differences in daily temperatures. This was the first attempt at identifying micro-refugia in the mainstem. These mainstem habitats provide depth, complexity, and resources to larger fluvial brook trout and should be identified. To locate and better understand these habitats, fine scale temperature data from the mainstem is needed moving forward.

We saw significant interannual variation of temperatures at sites sampled in both 2022 and 2023. The sites with the largest difference had thermal regimes generally categorized as vulnerable to warming. These sites are likely most affected during low flow and high temperature years when compared to sites with cooler regimes. They also, generally, offer the greatest volume of refuge habitat and navigability to brook trout.

Short-term temperature data should be interpreted with caution as they are vulnerable to anomalous findings. We anticipate year to year variability to be large, with increasing frequency and intensity of high and low flows and temperatures. This study represents two years of summarized temperature data, both of which were influenced by generally wet and mild summers. Flows in the Allagash River remained at or above the median daily value (over 91 years of flow data) for most of the summer in 2022 and 2023 (https://nwis.waterdata.usgs.gov). The value of this information, however, will increase in importance and merit as sampling duration increases. Continued monitoring will likely yield temperature and flow regimes most representative of an average northern Maine summer and increase the confidence in our findings. Adequate maintenance of ongoing monitoring, as well as increased sites, spatial grain, and statistical rigor will improve our understanding of cold water habitats in the Allagash Wilderness Waterway.

CONCLUSION

Summer water temperatures in the Allagash River exceed the lethal limits for brook trout, documenting a need for cold water refugia. Several tributaries are contributing critical thermal refuge to the Allagash River, some of which appear to be vulnerable to warming and land use practices. These data represent baseline thermal conditions with implications for coldwater biota in the face of a warming climate. The relevance of this work, and its implications on the ecological, cultural, and intrinsic value of the Allagash Wilderness Waterway's resources, especially it's native brook trout, cannot be understated.

ACKNOWLEDGEMENTS

I would like to thank the Horizon Foundation, and the Maine Outdoor Heritage Fund for funding this project in 2022 and 2023, respectively. Maine fisheries biologists Jeremiah Wood for recommending monitoring locations and offering thoughtful edits and suggestions, Merry Gallagher for offering preliminary data and recommendations for monitoring locations, Tim Obrey for assistance with SAS programming and edits; and Jeff Bagley, Stephen Seeback, Derrick Cote, and Frank Frost for edits. Thanks to Alex Stacy for providing a map of the study area. And the Allagash Wilderness Waterway for staff and use of equipment, with special thanks to Waterway Superintendent Mark Deroche, Chief Ranger Kevin Brown, Rangers Trevor O'Leary, Bob Johnston, and Jay Young, and Assistant Rangers Alissa Lutz and Cameron McIntosh for their expertise and assistance. Appreciation also goes to Allagash Wilderness Waterway Foundation board member and project coordinator Paul Johnson for his regional knowledge and coordination of this effort. This project would not have moved forward were it not for the aforementioned contributors.

LITERATURE CITED

Butryn, R. S., D. L. Parrish, and D. M. Rizzo. 2013. Summer stream temperature metrics for predicting brook trout (*Salvelinus fontinalis)* distribution in streams. Hydrobiologia 703:47—57.

Chambers, B., S. M. Pradhanang, and A. J. Gold. 2017. Assessing thermally stressful events in a Rhode Island coldwater fish habitat using SWAT Model. Water 9, 667.

Cross, B. K., M. A. Bozek, and M. G. Mitro. 2013. Influences of riparian vegetation on trout stream temperatures in central Wisconsin. North American Journal of Fisheries Management 33:682—692.

Curry, R. A., D. A. Scruton, and K. D. Clarke. 2002. The thermal regimes of brook trout incubation habitats and evidence of changes during forestry operations. Canadian Journal of Forest Resources 32:1200–1207.

Ficklin, D. L., B. L. Barnhart, J. H. Knouft, I. T. Stewart, E. P Maurer, S. L. Letsinger, and G. W. Whittaker. 2014. Climate change and stream temperature projections in the Columbia River basin: habitat implications of spatial variation in hydrologic drivers. Hydrology and Earth System Sciences 18:4897—4912.

Hudy, M., T. M. Theiling, N. Gillespie, and E. P. Smith. 2008. Distribution, status, and land use characteristics of subwatersheds within the native range of brook trout in the eastern United States. North American Journal of Fisheries Management 28:1069—1085.

Kanno, Y., B. H. Letcher, A. L. Rosner, K. P. O'Neil, and K. H. Nislow. 2015. Environmental factors affecting brook trout occurrence in headwater stream segments. Transactions of the American Fisheries Society 144:373—382.

Lawrence, D. J., B. Stewart-Koster, J. D. Olden, A. S. Ruesch, C. E. Torgersen, J. J. Lawler, D. P. Butcher, and J. K. Crown. 2014. The interactive effects of climate change, riparian management, and a nonnative predator on stream-rearing salmon. Ecological Applications 24(4):895—912.

Nathan, L. R., A. B. Welsh, and J. C. Vokoun. 2018. Watershed-level brook trout genetic structuring: Evaluation and application of riverscape genetics models. Freshwater Biology 64:405—420.

National Water Information System. United States Geological Survey. https://nwis.waterdata.usgs.gov. Accessed 16 Dec 2022.

Paiva, C. K. S., A. P. J. Faria, L. B. Calvao, and L. Juen. 2021. The anthropic gradient determines the taxonomic diversity of aquatic insects in Amazonian streams. Hydrobiologia 848:1073—1085.

Petty, T. J., J. L. Hansbarger, B. M. Huntsman, and P. M. Mazik. 2012. Brook trout movement in response to temperature, flow, and thermal refugia within a complex Appalachian Riverscape. Transactions of the American Fisheries Society 141:1060—1073.

Reiter, M., R. E. Bilby, S. Beech, and J. Heffner. 2015. Stream temperature patterns over 35 years in a managed forest of western Washington. Journal of the American Water Resources Association 51(5):1418—1435.

Smith, D. A., and M. S. Ridgway. 2019. Temperature selection in brook charr: lab experiments, field studies, and matching the fry curve. Hydrobiologia 840:143—156.

Studinksi, J. M., K. J. Hartman, J. M. Niles, and P. Keyser. 2012. The effects of riparian forest disturbance on stream temperature, sedimentation, and morphology. Hydrobiologia 686:107—117.

Trumbo, B. A., K. H. Nislow, J. Stallings, M. Hudy, E. P. Smith, D. Y. Kim, B. Wiggins, and C. A. Dolloff. 2014. Ranking site vulnerability to increasing temperatures in Southern Appalachian brook trout streams in Virginia: An exposure-sensitivity approach. Transactions of the American Fisheries Society 143:173—187.

Wehrly, K. E., L. Wang, and M. Mitro. 2007. Field-based estimates of thermal tolerance limits for trout: incorporating exposure time and temperature fluctuation. Transactions of the American Fisheries Society 136:365—374.

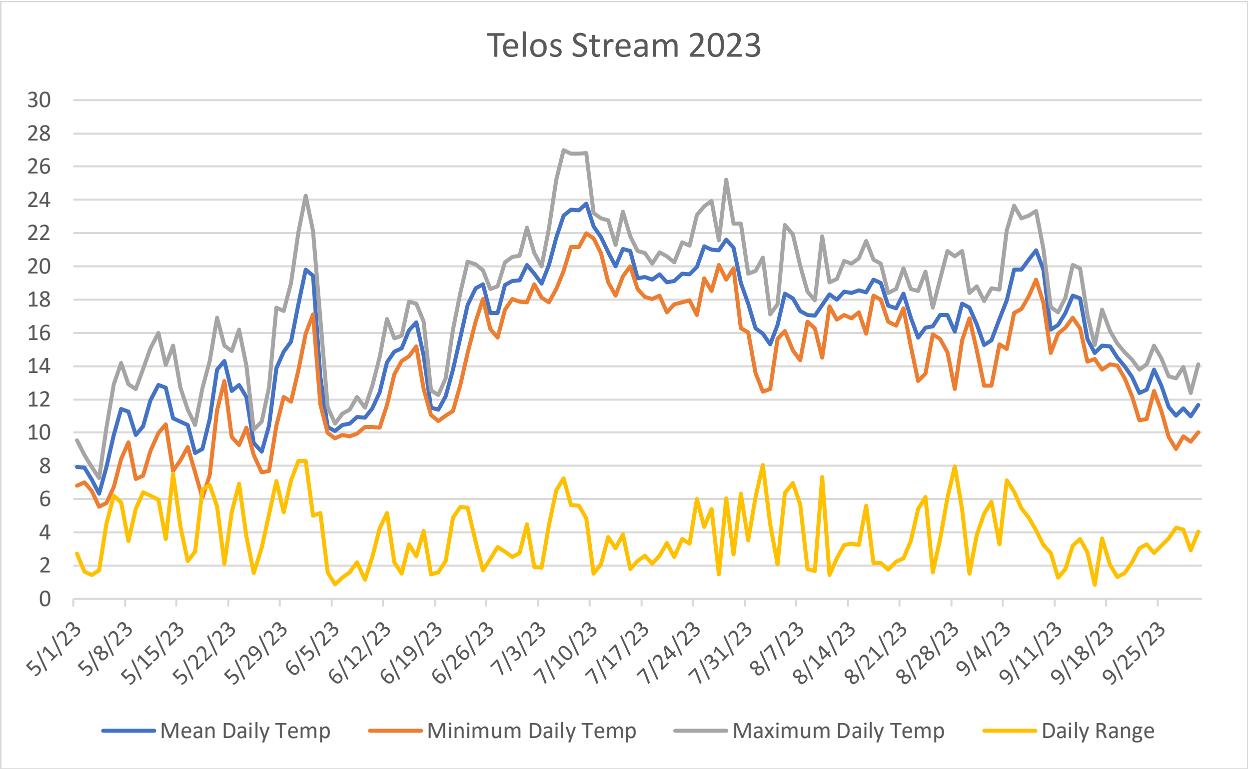
Wenger, S. J., D. J. Isaak, C. H. Luce, H. M. Neville, K. D. Fausch, J. B. Dunham, D. C. Dauwalter, M. K. Young, M. M. Elsner, B. E. Rieman, A. F. Hamlet, and J. E. Williams. 2011. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. Proceedings of the National Academy of Sciences of the USA 108:14175– 14180.

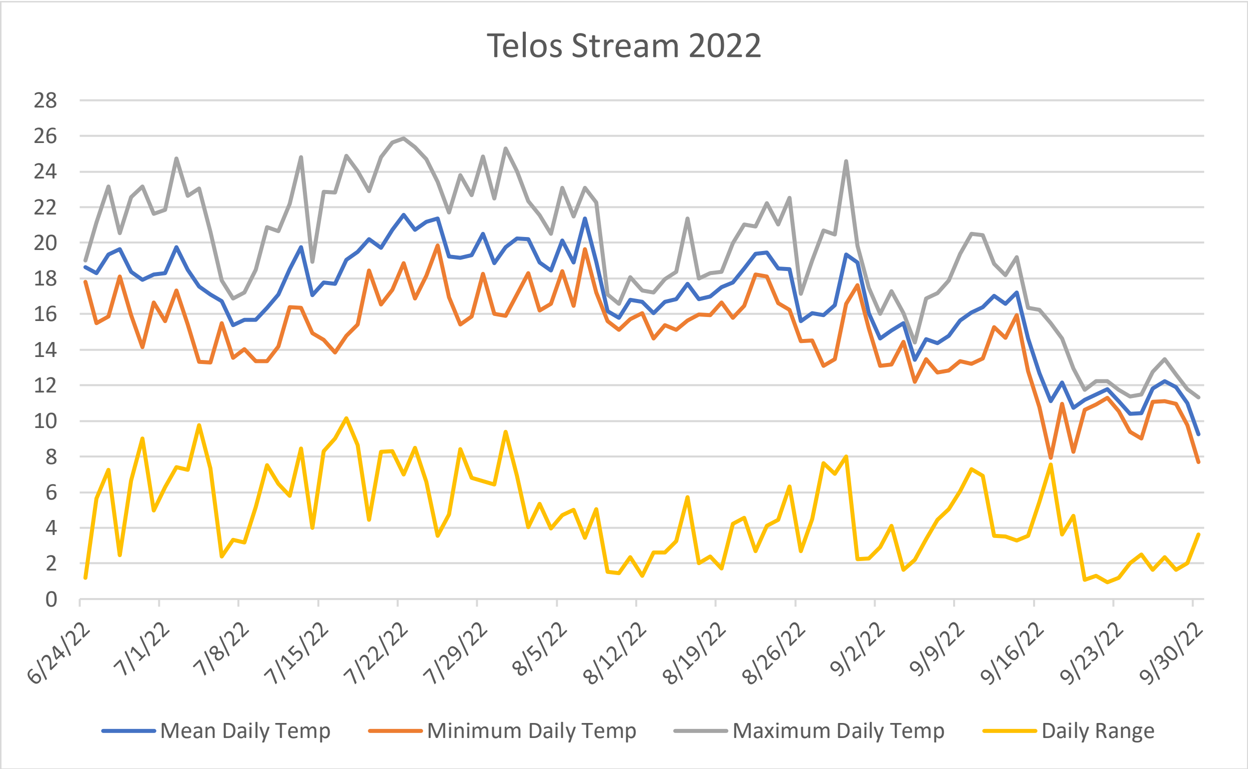
Xu, C. L., B. H. Letcher, and K. H. Nislow. 2010. Size-dependent survival of brook trout *Salvelinus fontinalis* in summer: effects of water temperature and stream flow. Journal of Fish Biology 76:2342—2369.

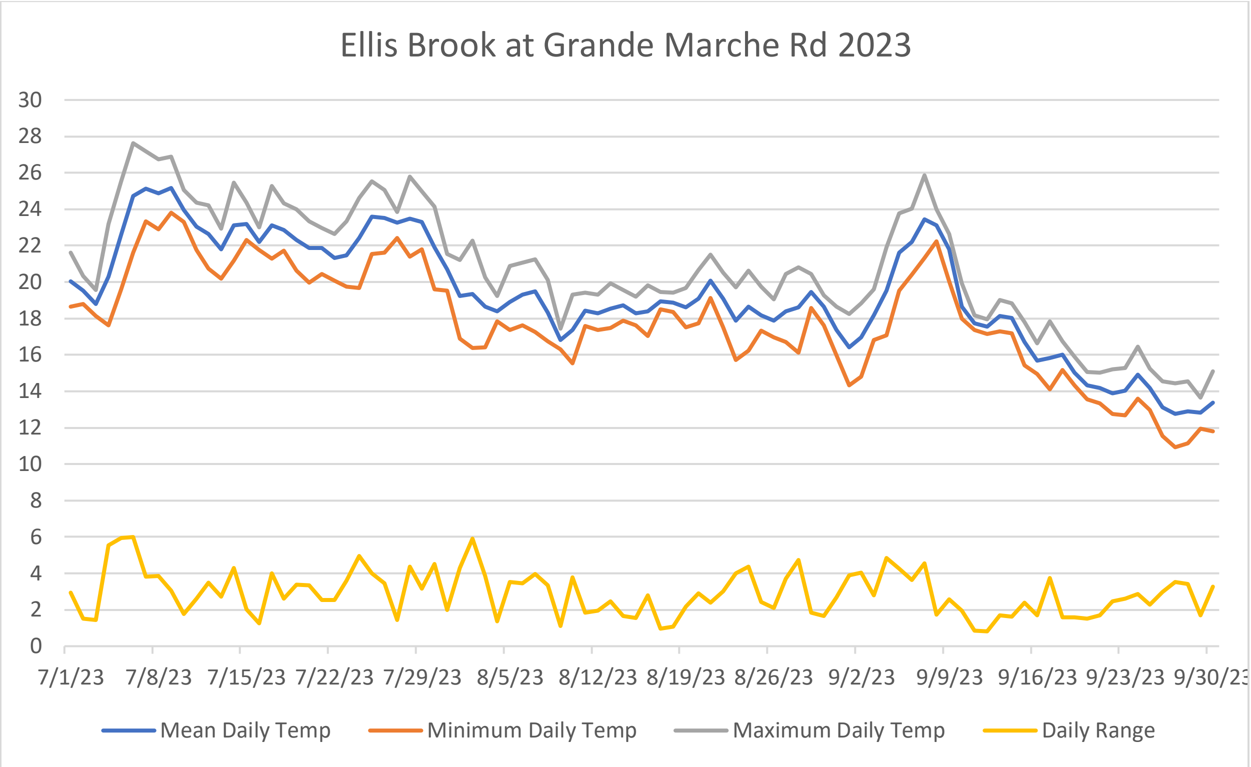
Yonce, H. N., S. Sarkar, J. B. Butcher, T. E. Johnson, S. H. Julius, and S. D. LeDuc. 2021. Forest riparian buffers reduce timber harvesting effect on stream temperature, but additional climate adaptation strategies are likely needed under future conditions. Journal of Water and Climate Change 12.5:1404–1419.

Appendix A

Summer Thermal Regimes at Monitoring Locations






Ellis Brook at Grande Marche Rd 2023
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28
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24
22
20
18
16
14
12
10
8
6
4
2
0
7/1/23
7/8/23
7/15/23
7/22/23
7/29/23
8/5/23
8/12/23
8/19/23
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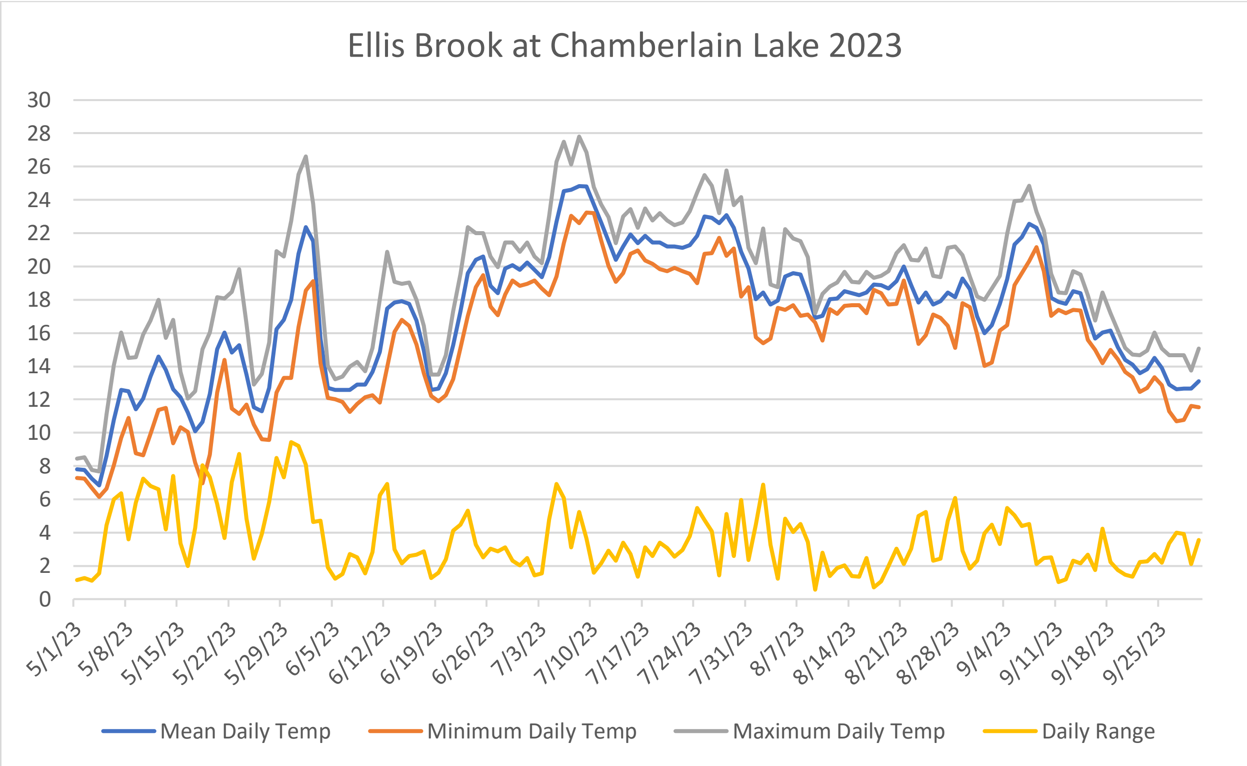
Minimum Daily Temp
Maximum Daily Temp
Daily Range


Ellis Brook at Chamberlain Lake 2023
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18
16
14
12
10
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6
4
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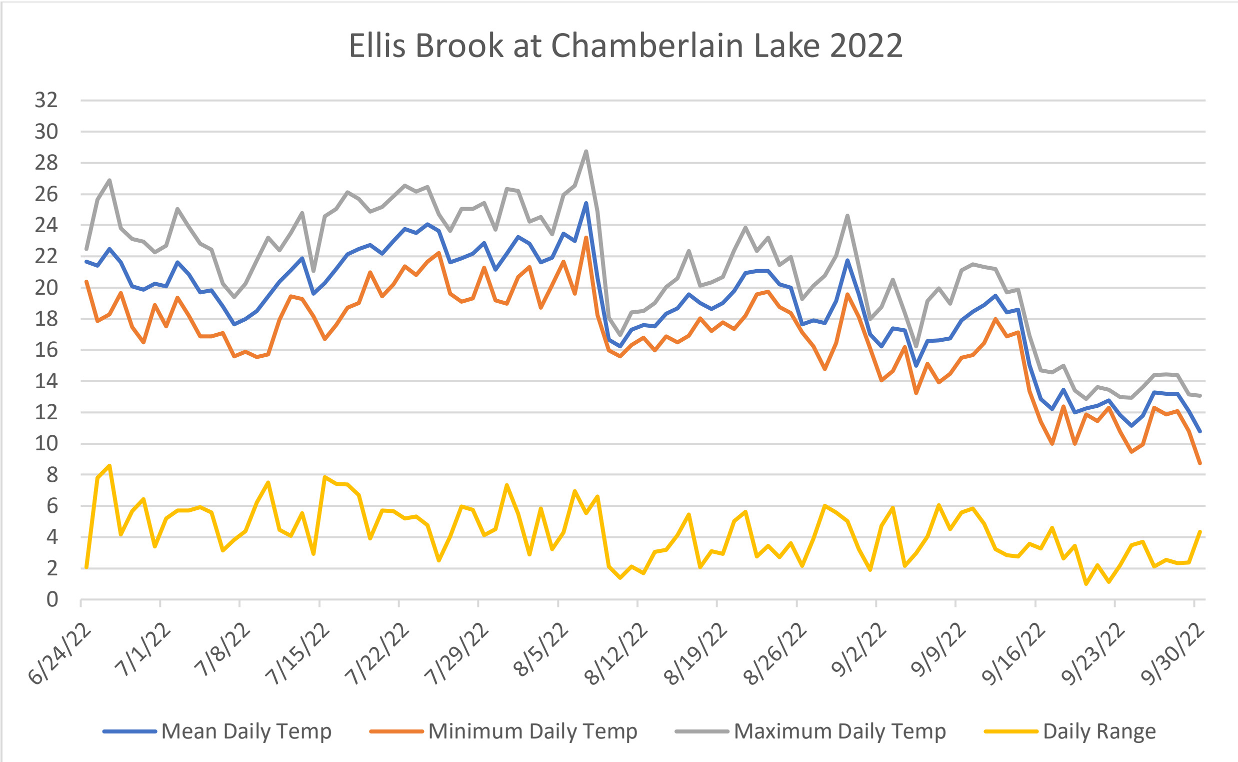
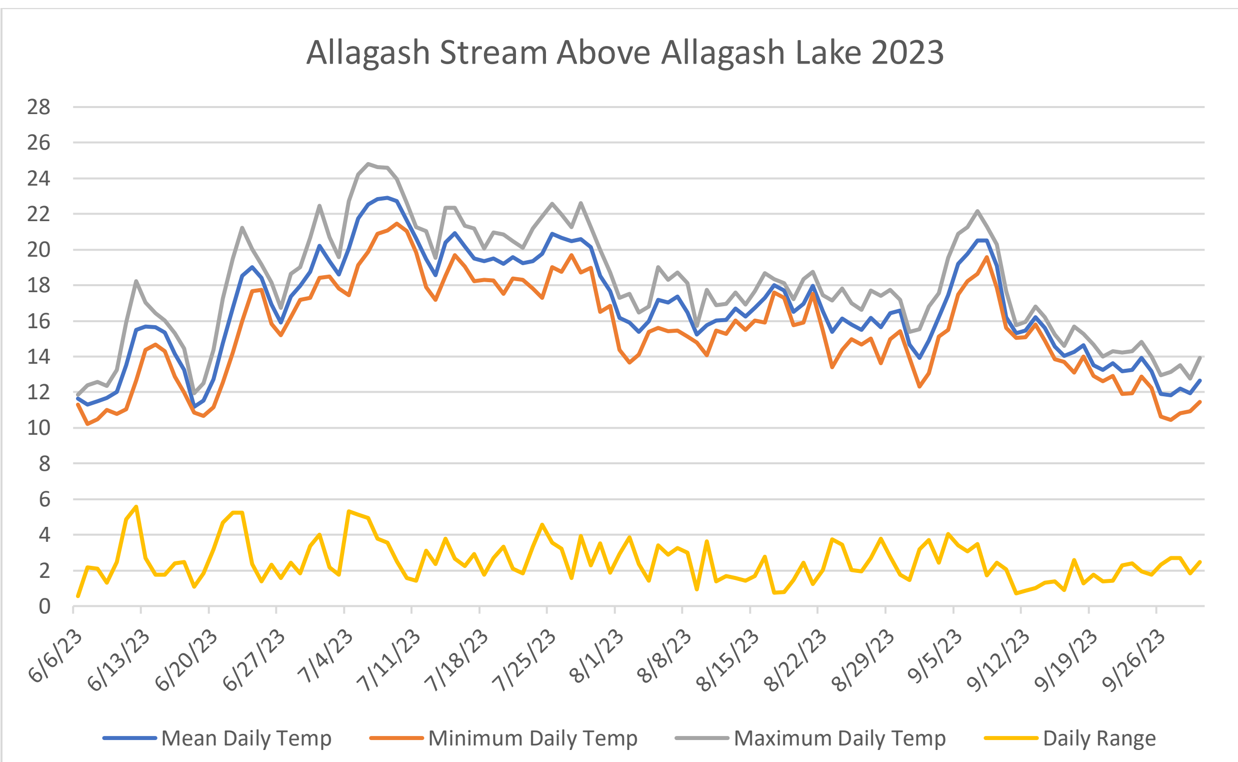
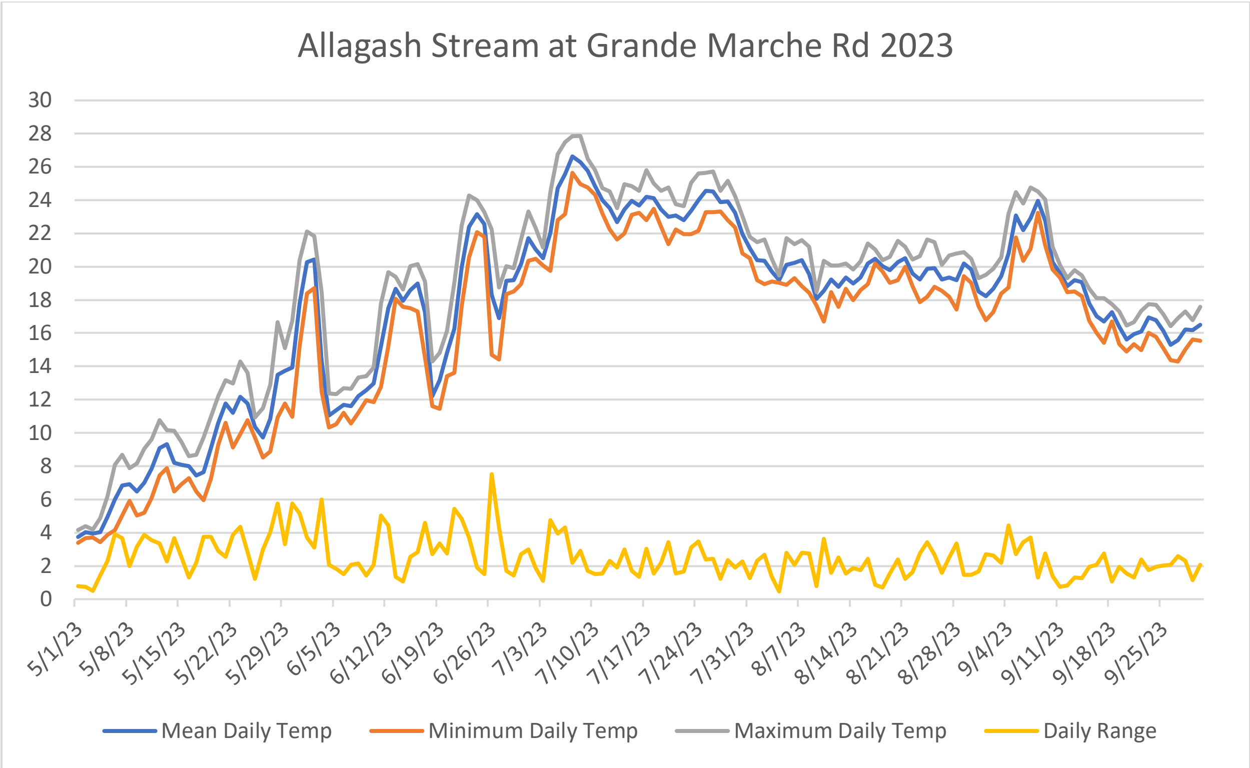
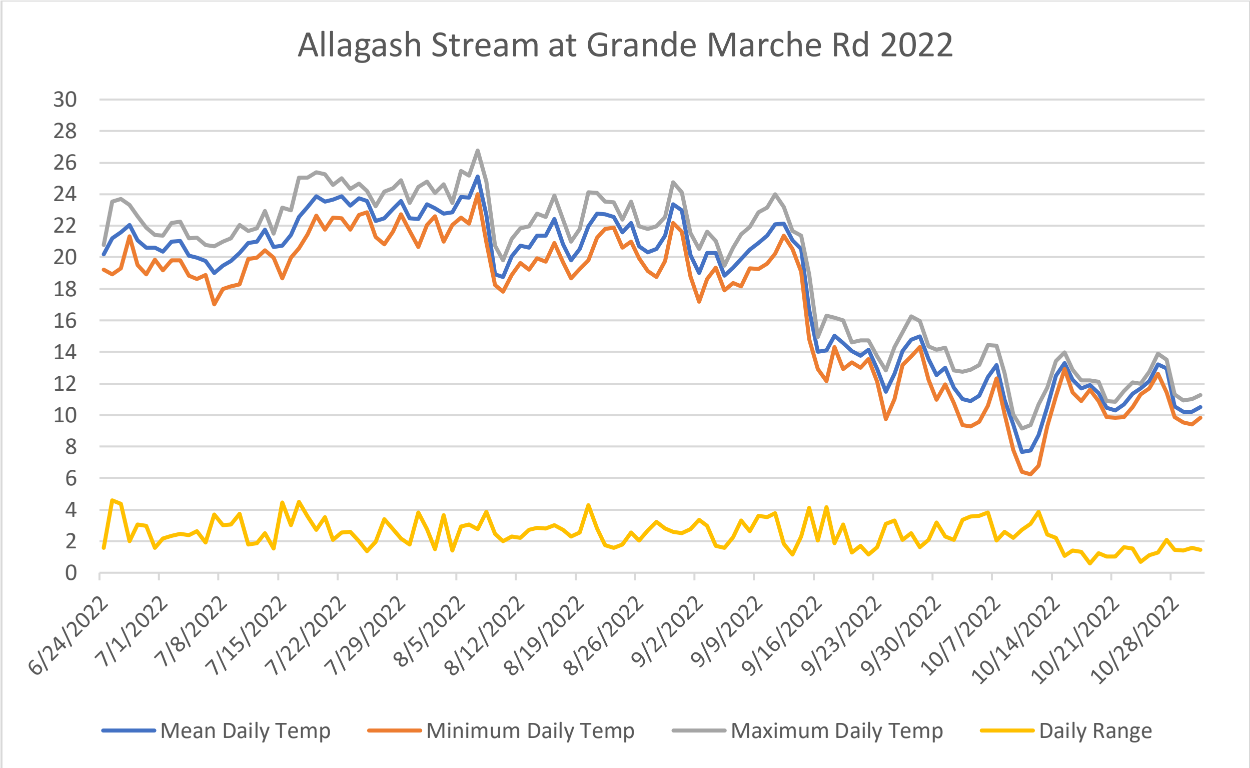
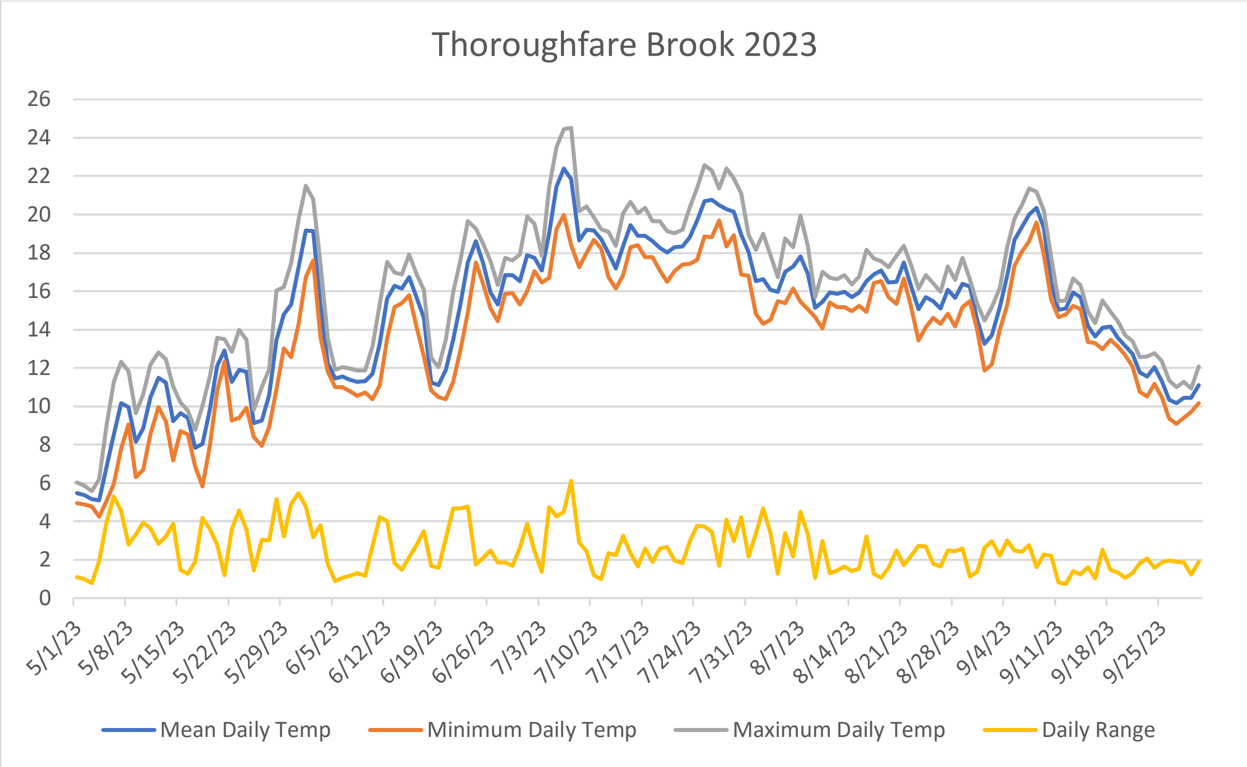
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

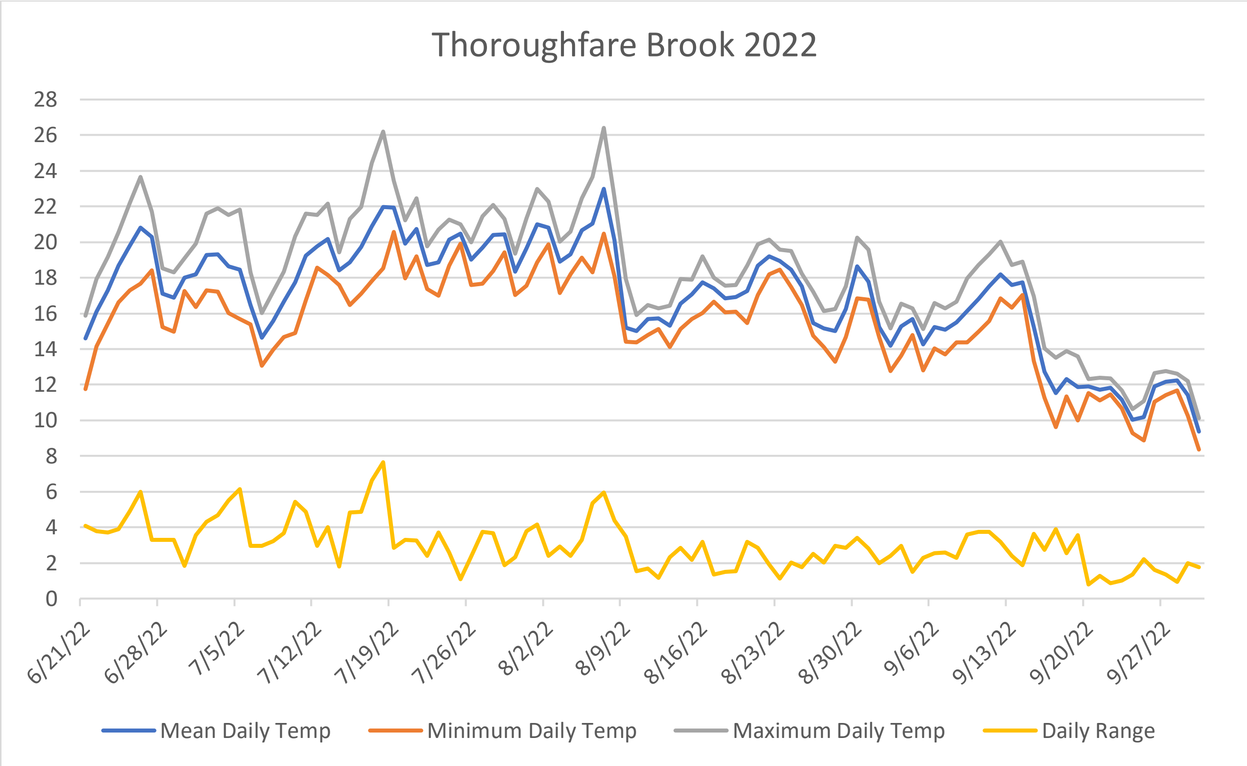

Ellis Brook at Chamberlain Lake 2022
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/24/22
7/1/22
7/8/22
7/15/22
7/22/22
7/29/22
8/5/22
8/12/22
8/19/22
8/26/22
9/2/22
9/9/22
9/16/22
9/23/22
9/30/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

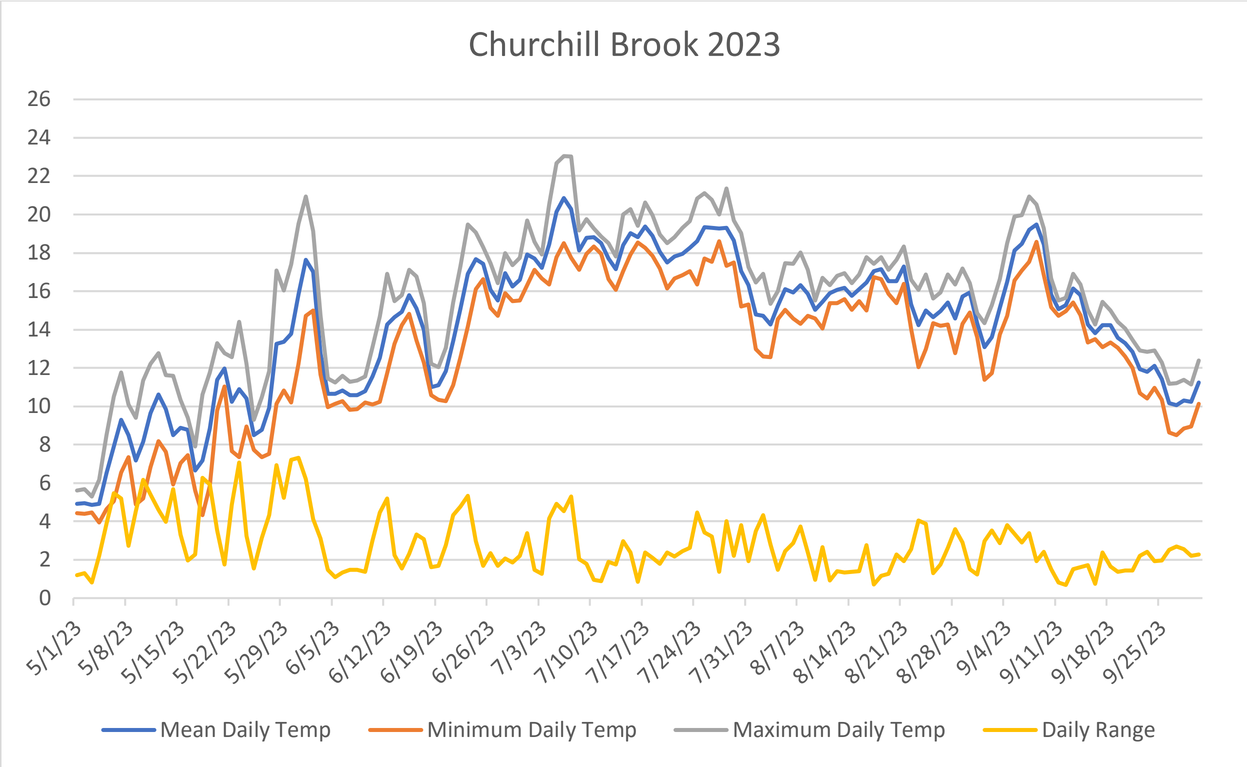

Allagash Stream Above Allagash Lake 2023
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/6/23
6/13/23
6/20/23
6/27/23
7/4/23
7/11/23
7/18/23
7/25/23
8/1/23
8/8/23
8/15/23
8/22/23
8/29/23
9/5/23
9/12/23
9/19/23
9/26/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

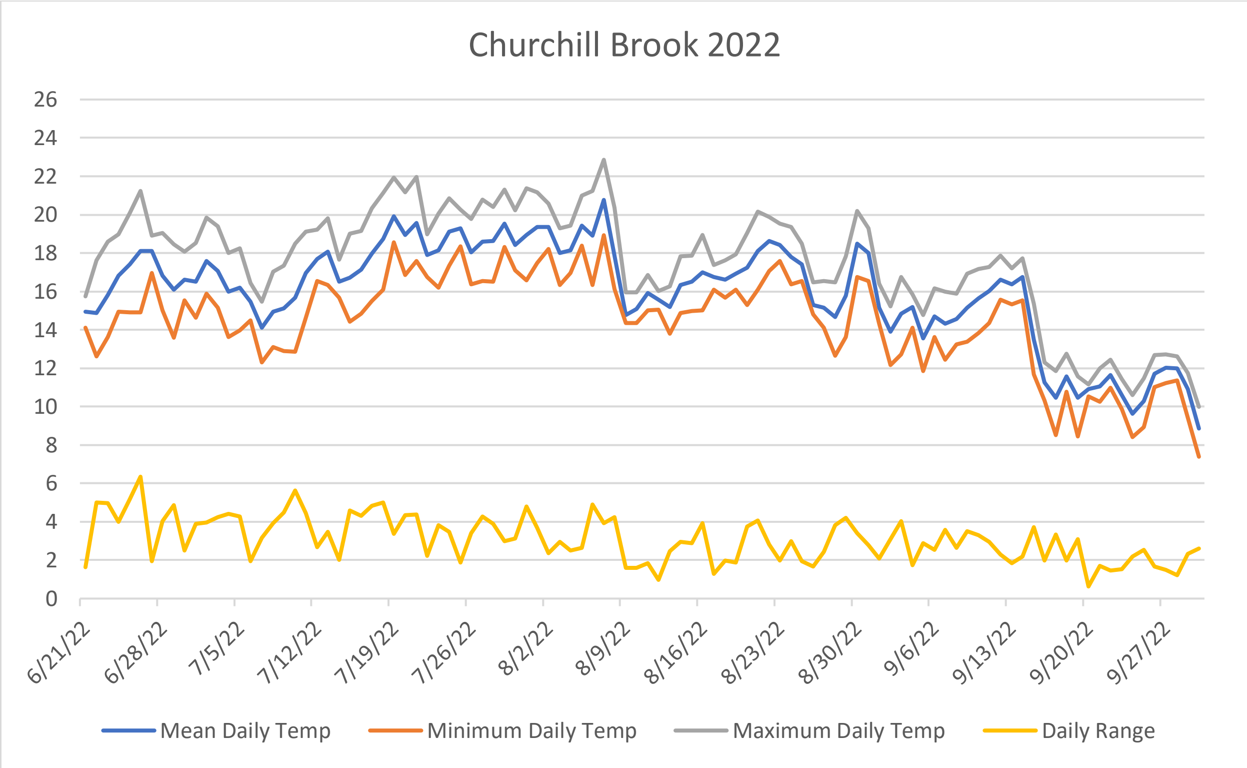

Allagash Stream at Grande Marche Rd 2023
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

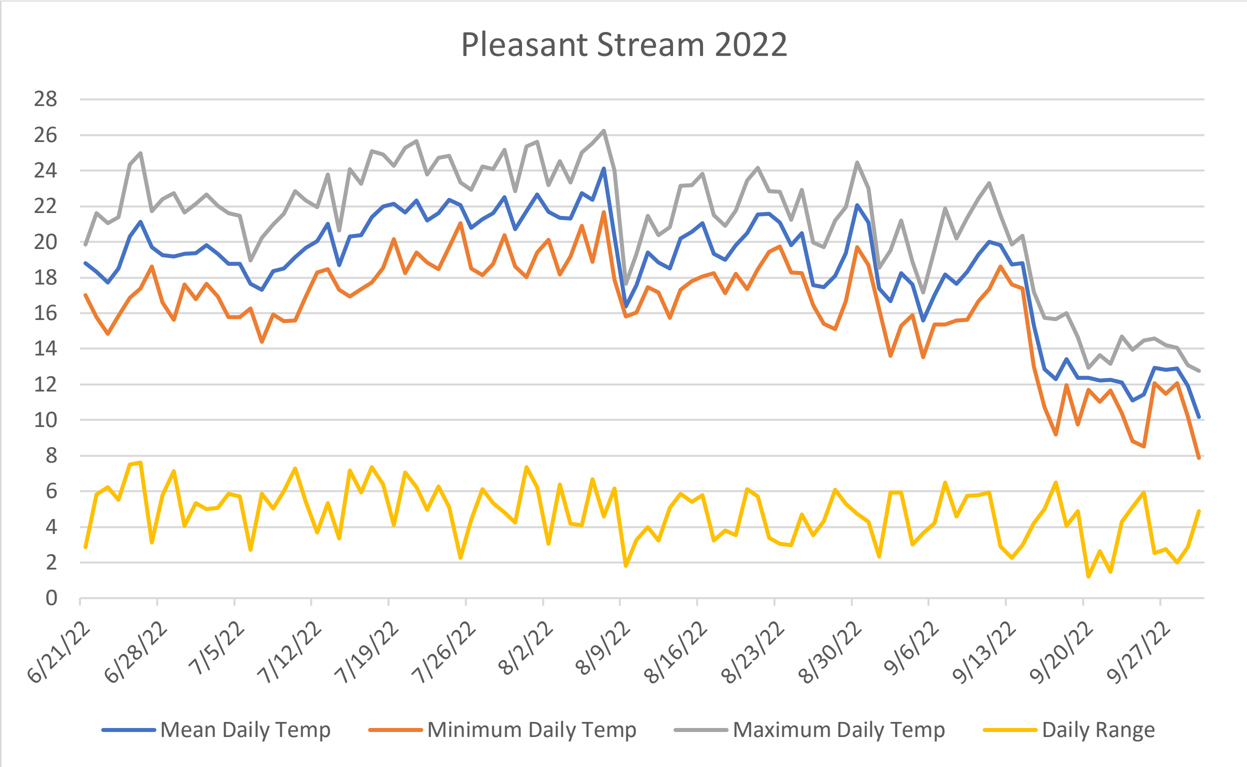

Allagash Stream at Grande Marche Rd 2022
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/24/2022
7/1/2022
7/8/2022
7/15/2022
7/22/2022
7/29/2022
8/5/2022
8/12/2022
8/19/2022
8/26/2022
9/2/2022
9/9/2022
9/16/2022
9/23/2022
9/30/2022
10/7/2022
10/14/2022
10/21/2022
10/28/2022
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

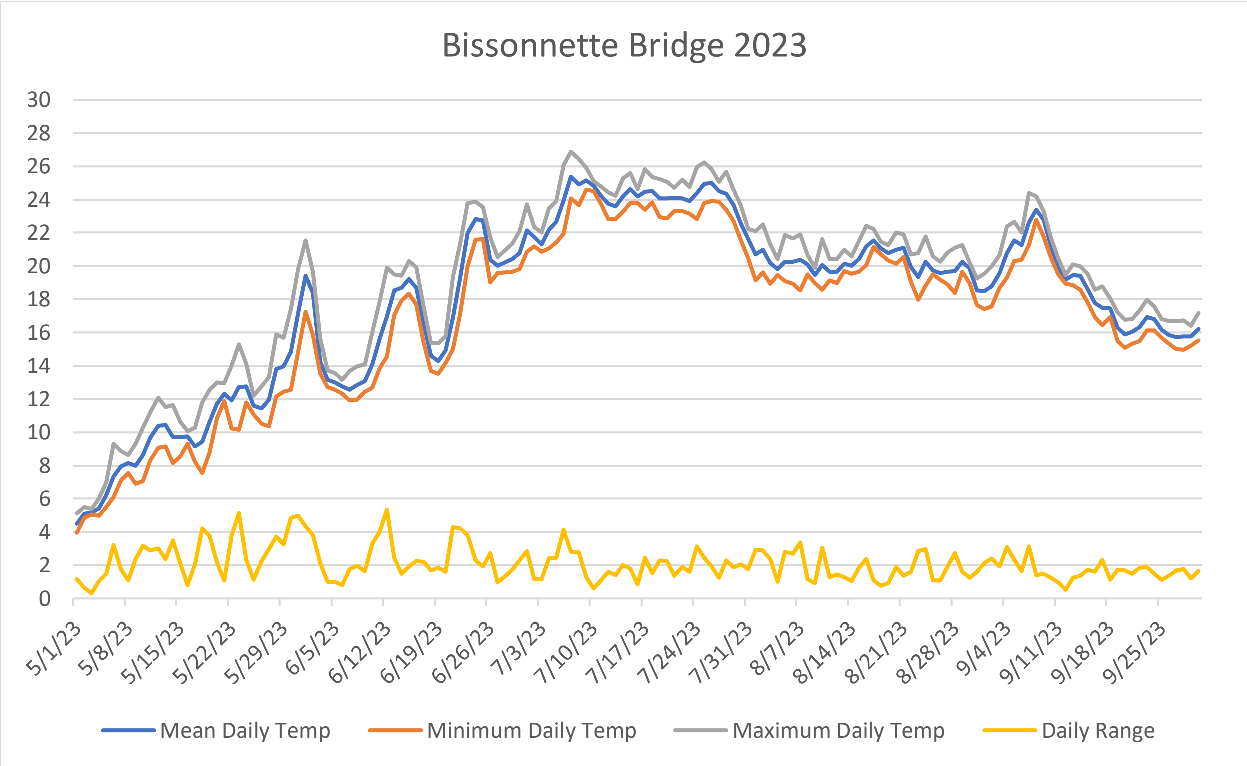

Thoroughfare Brook 2023
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

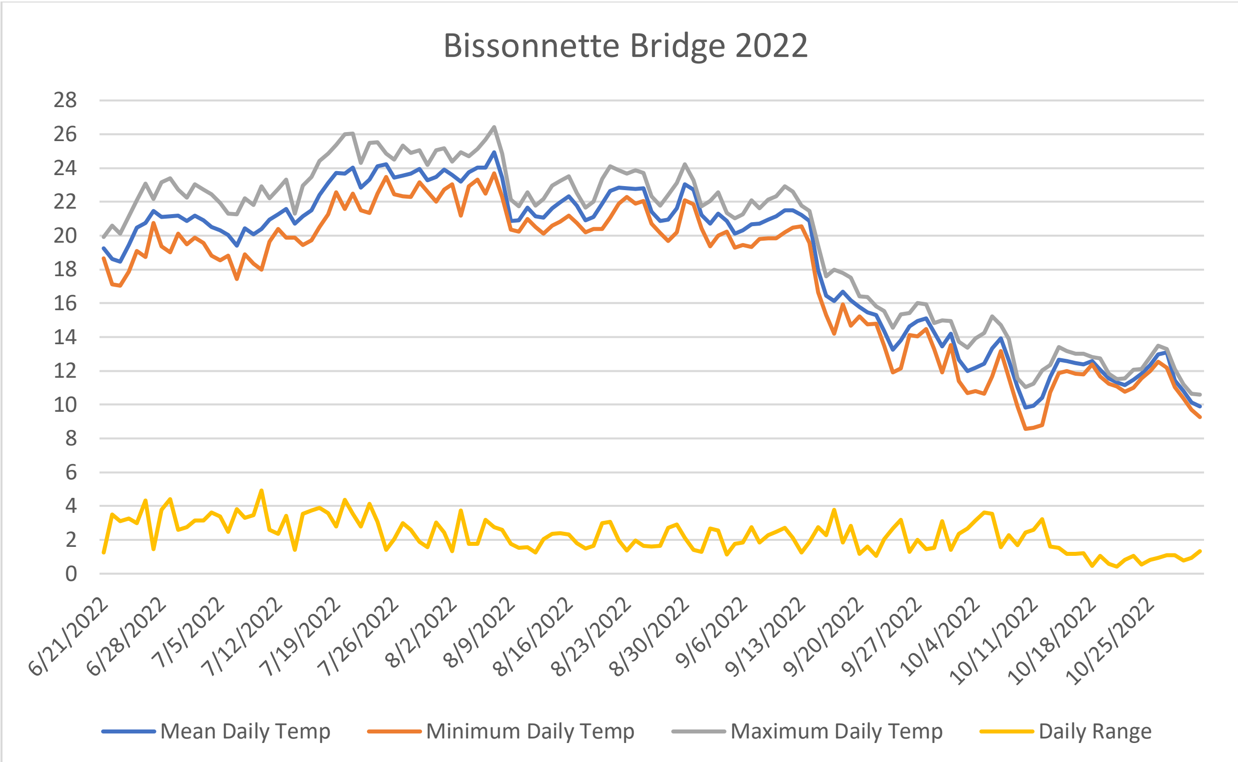

Thoroughfare Brook 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/21/22
6/28/22
7/5/22
7/12/22
7/19/22
7/26/22
8/2/22
8/9/22
8/16/22
8/23/22
8/30/22
9/6/22
9/13/22
9/20/22
9/27/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

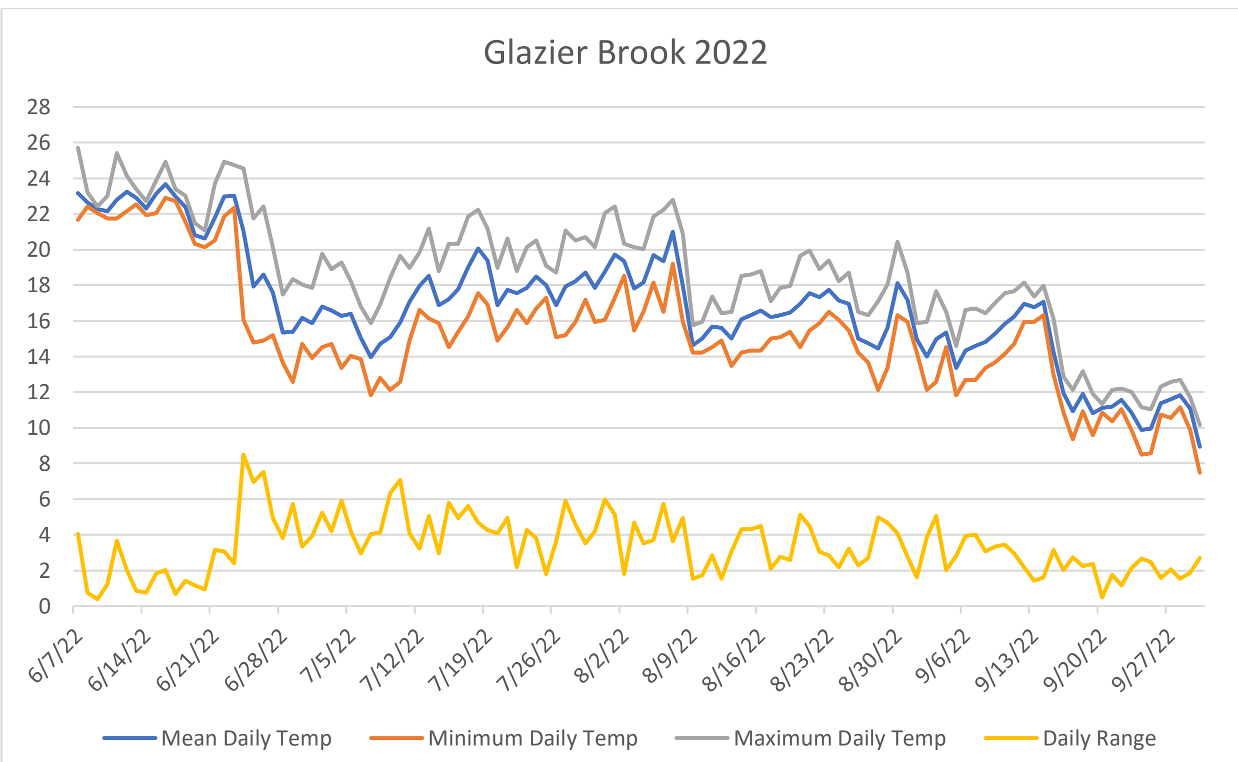

Churchill Brook 2023
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

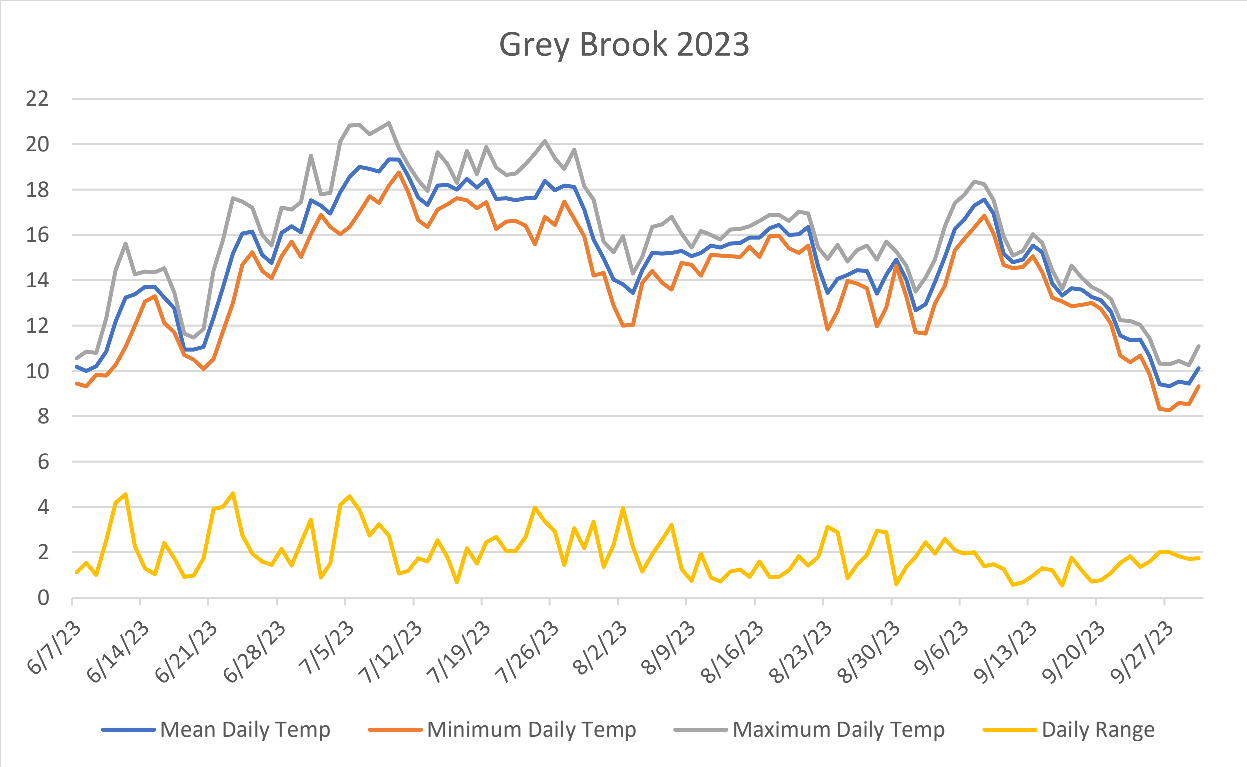

Churchill Brook 2022
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/21/22
6/28/22
7/5/22
7/12/22
7/19/22
7/26/22
8/2/22
8/9/22
8/16/22
8/23/22
8/30/22
9/6/22
9/13/22
9/20/22
9/27/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

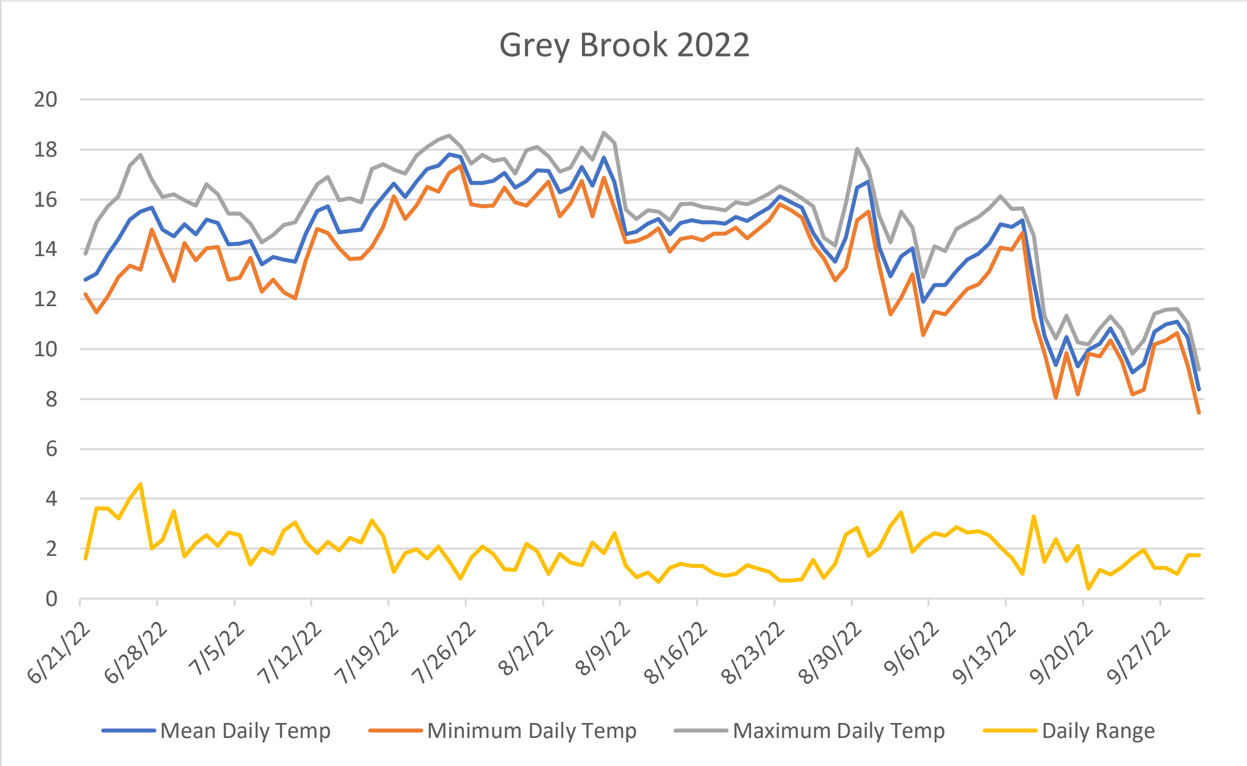

Pleasant Stream 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/21/22
6/28/22
7/5/22
7/12/22
7/19/22
7/26/22
8/2/22
8/9/22
8/16/22
8/23/22
8/30/22
9/6/22
9/13/22
9/20/22
9/27/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

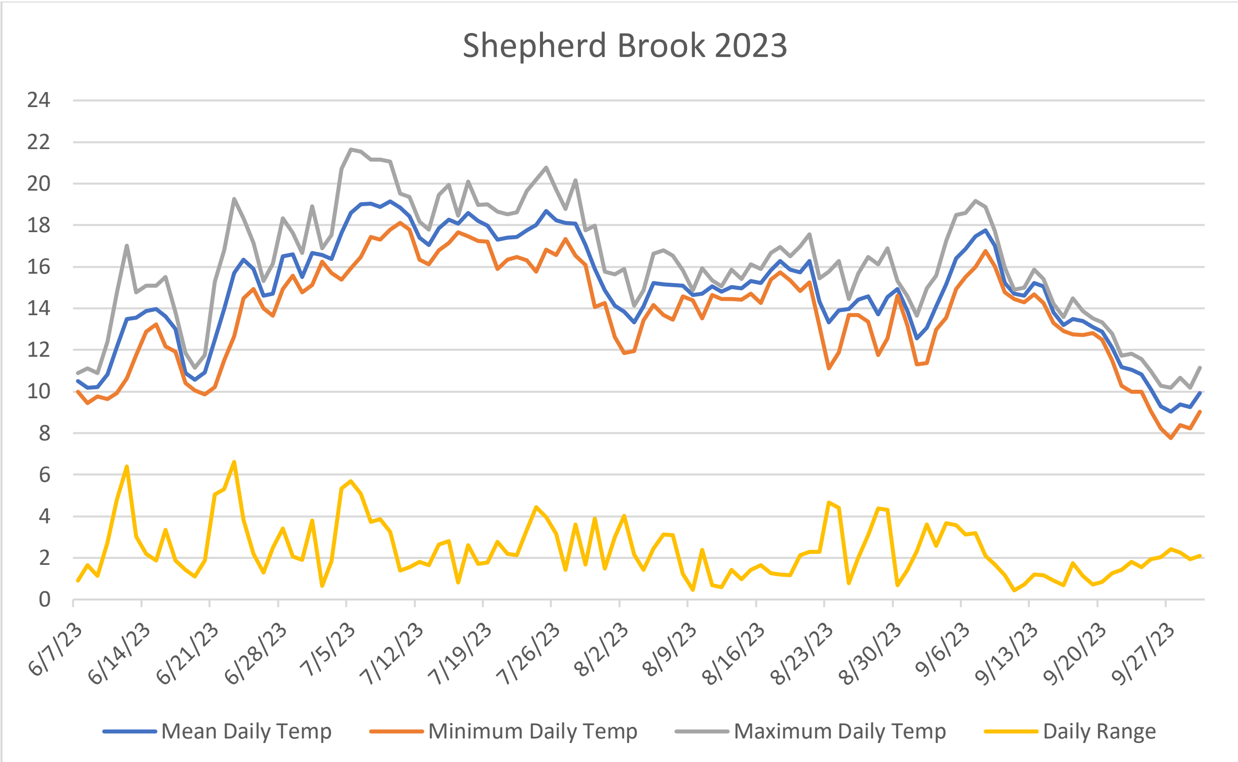

Bissonnette Bridge 2023
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

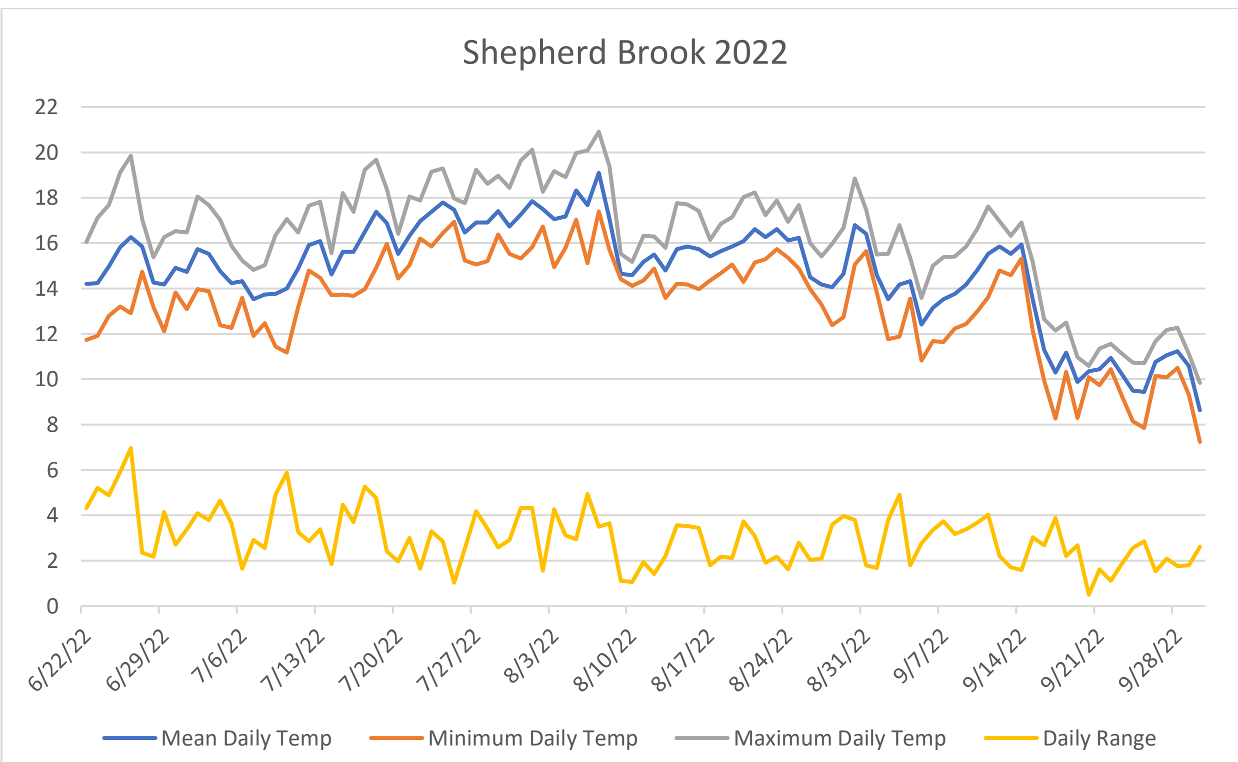

Bissonnette Bridge 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/21/2022
6/28/2022
7/5/2022
7/12/2022
7/19/2022
7/26/2022
8/2/2022
8/9/2022
8/16/2022
8/23/2022
8/30/2022
9/6/2022
9/13/2022
9/20/2022
9/27/2022
10/4/2022
10/11/2022
10/18/2022
10/25/2022
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

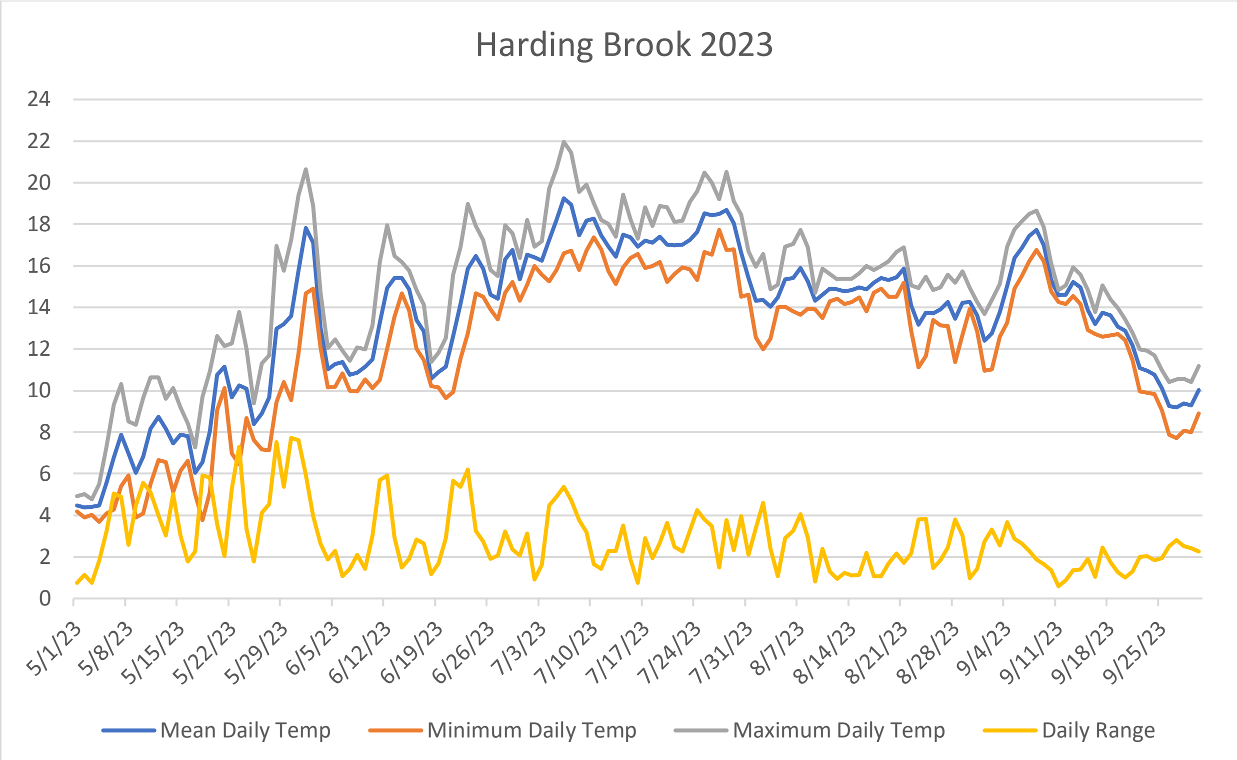

Glazier Brook 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/7/22
6/14/22
6/21/22
6/28/22
7/5/22
7/12/22
7/19/22
7/26/22
8/2/22
8/9/22
8/16/22
8/23/22
8/30/22
9/6/22
9/13/22
9/20/22
9/27/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

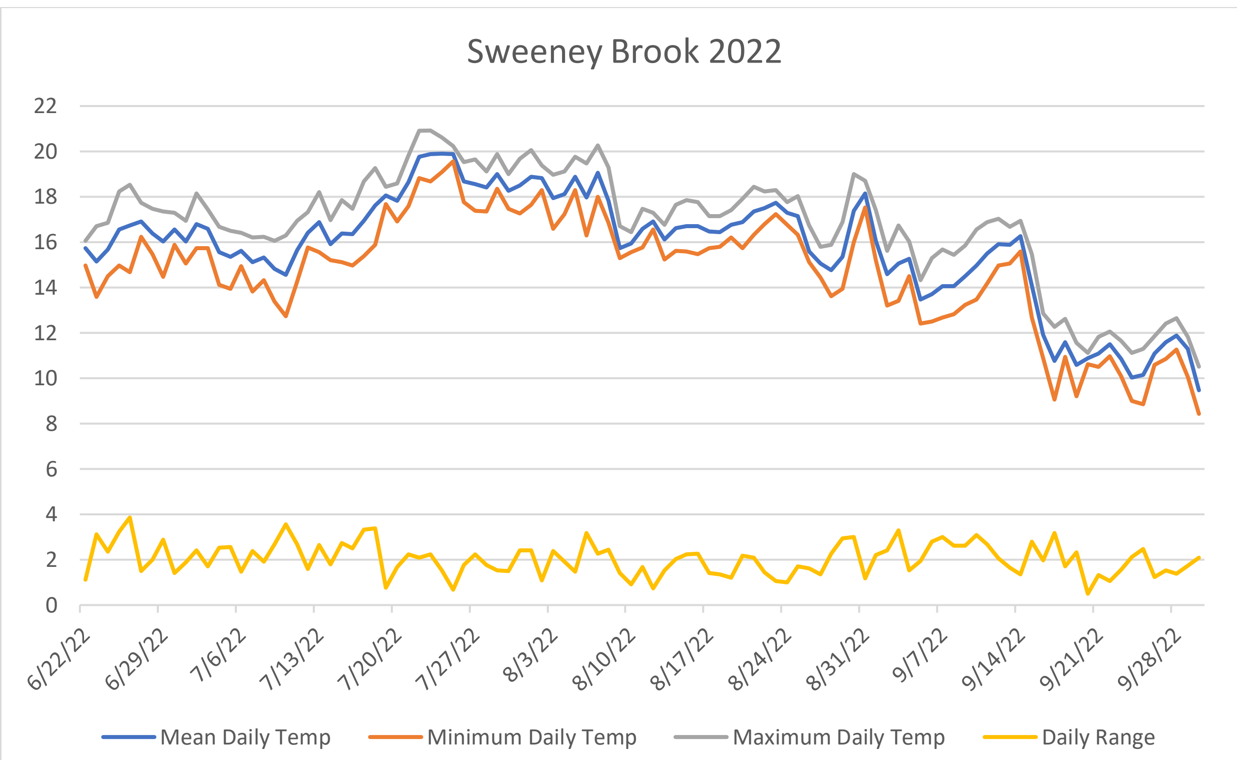

Grey Brook 2023
22
20
18
16
14
12
10
8
6
4
2
0
6/7/23
6/14/23
6/21/23
6/28/23
7/5/23
7/12/23
7/19/23
7/26/23
8/2/23
8/9/23
8/16/23
8/23/23
8/30/23
9/6/23
9/13/23
9/20/23
9/27/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

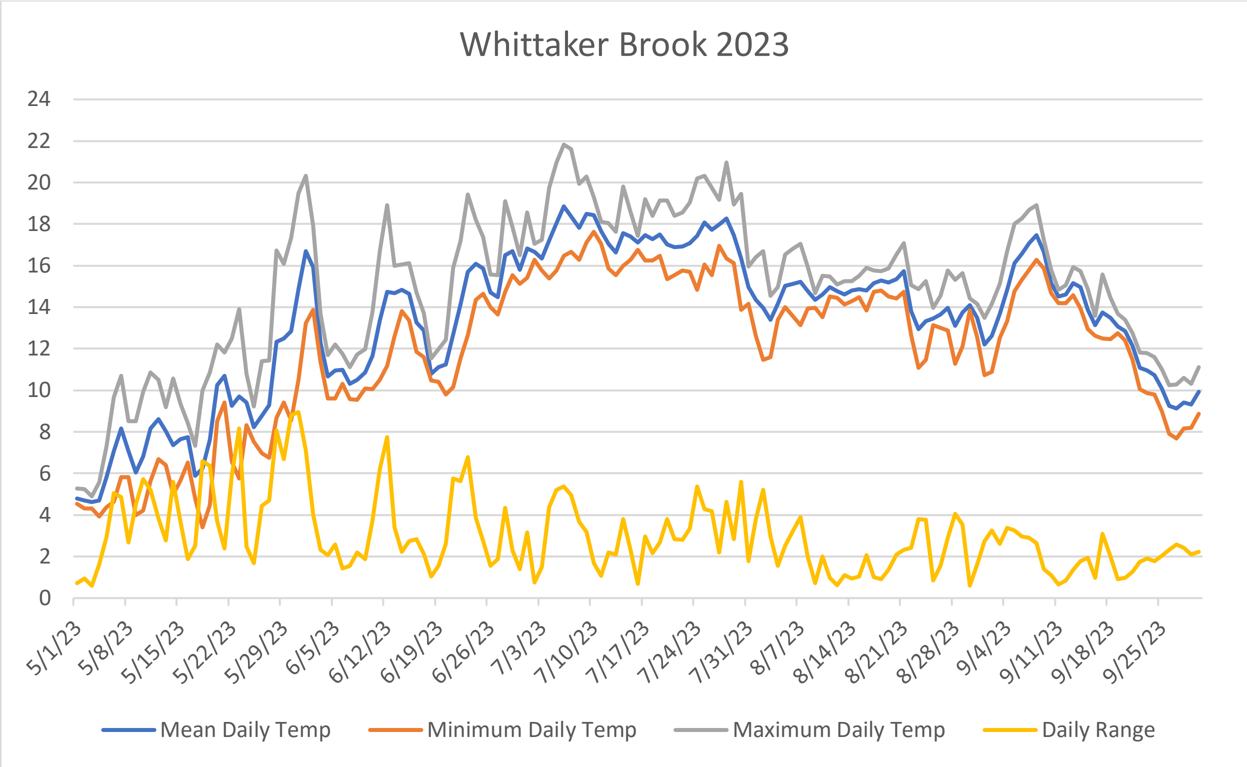

Grey Brook 2022
20
18
16
14
12
10
8
6
4
2
0
6/21/22
6/28/22
7/5/22
7/12/22
7/19/22
7/26/22
8/2/22
8/9/22
8/16/22
8/23/22
8/30/22
9/6/22
9/13/22
9/20/22
9/27/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

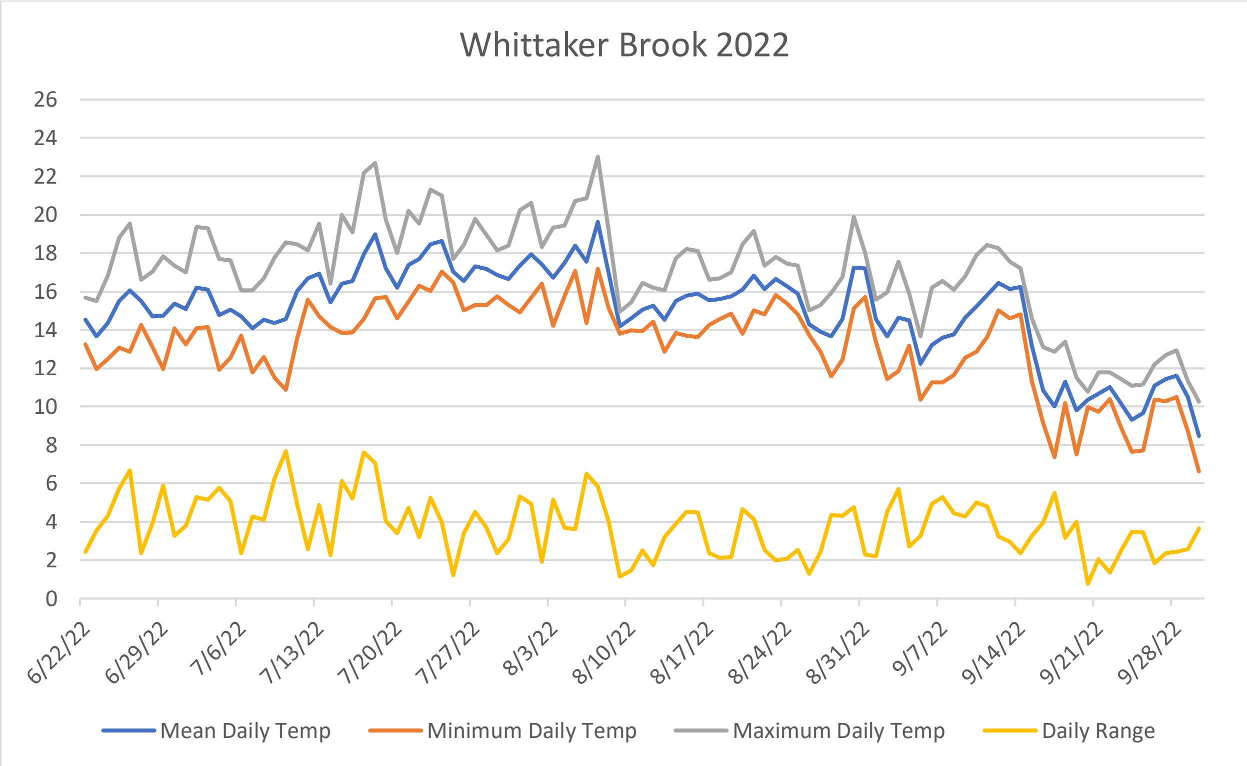

Shepherd Brook 2023
24
22
20
18
16
14
12
10
8
6
4
2
0
6/7/23
6/14/23
6/21/23
6/28/23
7/5/23
7/12/23
7/19/23
7/26/23
8/2/23
8/9/23
8/16/23
8/23/23
8/30/23
9/6/23
9/13/23
9/20/23
9/27/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

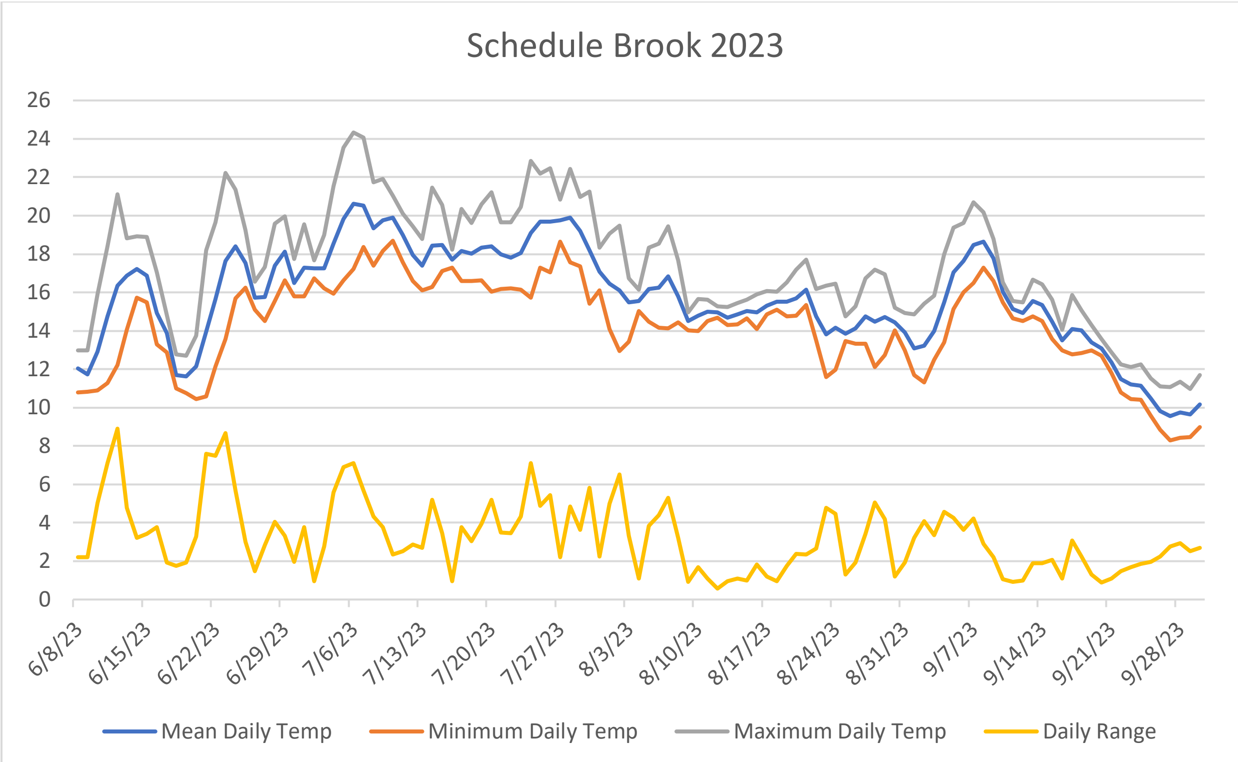

Shepherd Brook 2022
22
20
18
16
14
12
10
8
6
4
2
0
6/22/22
6/29/22
7/6/22
7/13/22
7/20/22
7/27/22
8/3/22
8/10/22
8/17/22
8/24/22
8/31/22
9/7/22
9/14/22
9/21/22
9/28/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

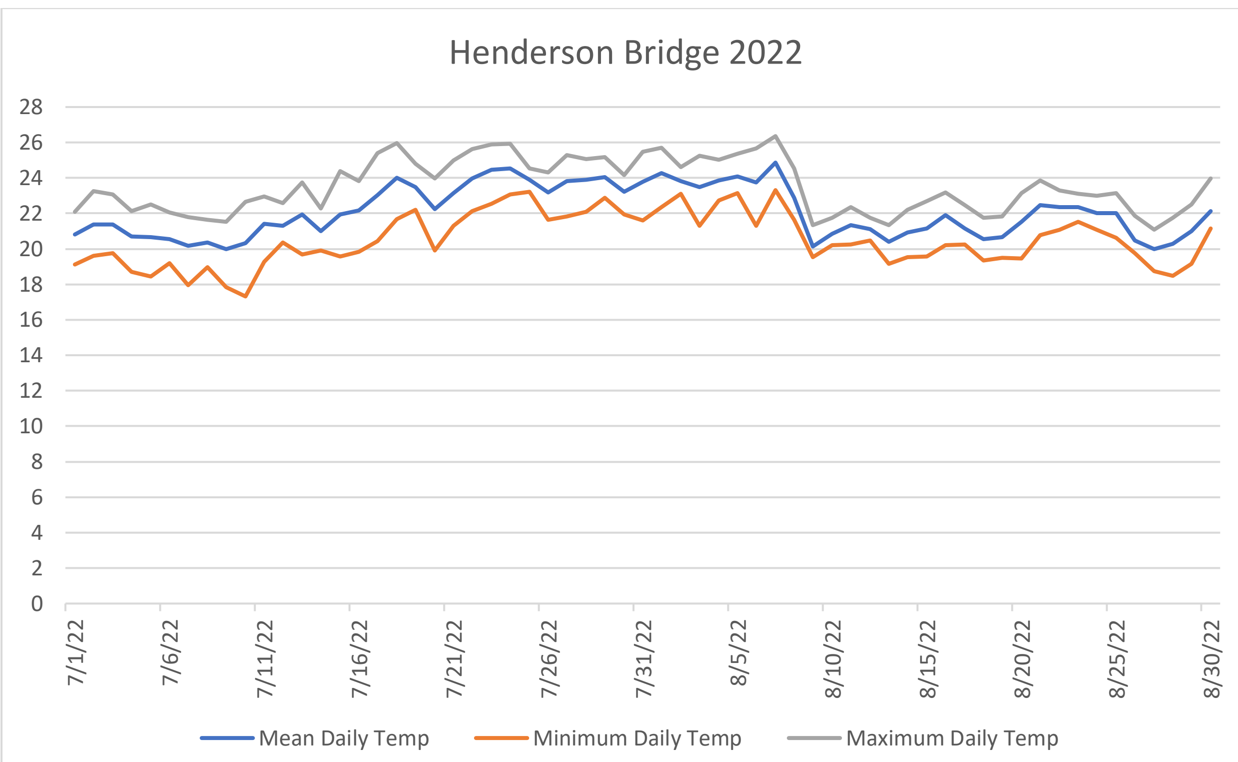

Harding Brook 2023
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

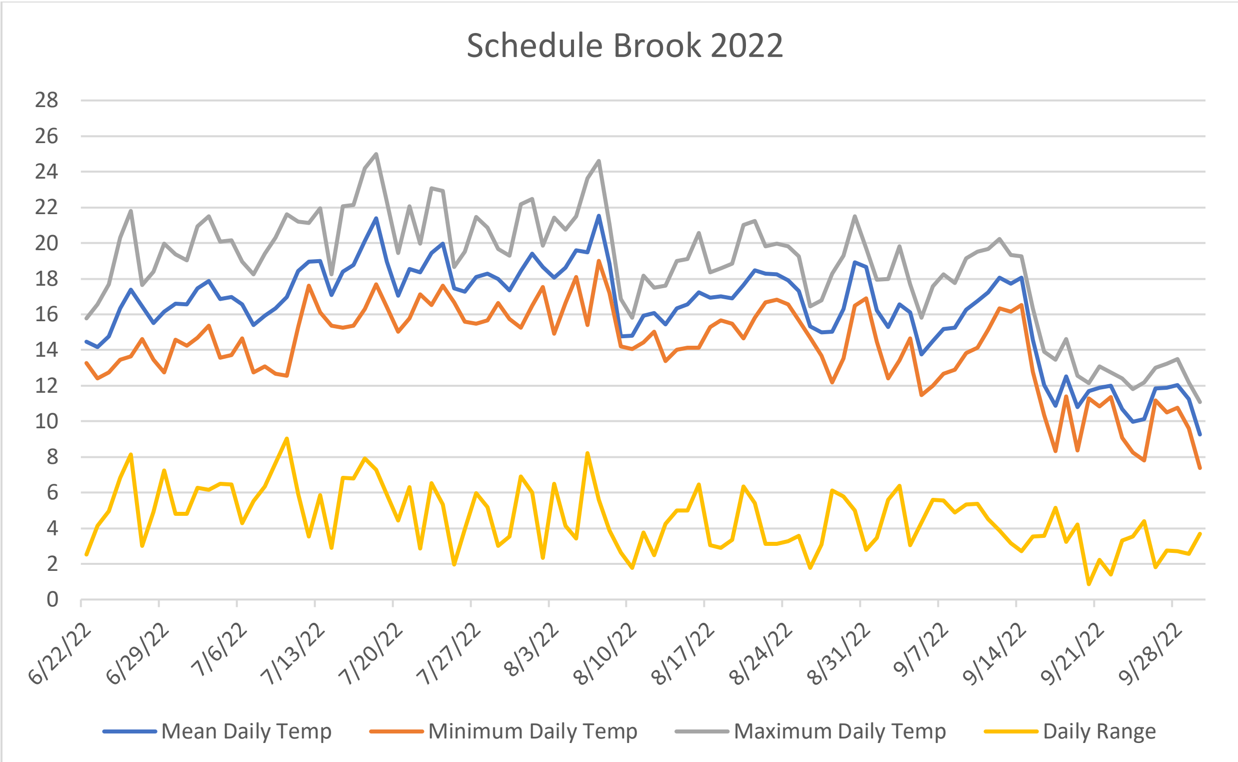

Sweeney Brook 2022
22
20
18
16
14
12
10
8
6
4
2
0
6/22/22
6/29/22
7/6/22
7/13/22
7/20/22
7/27/22
8/3/22
8/10/22
8/17/22
8/24/22
8/31/22
9/7/22
9/14/22
9/21/22
9/28/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

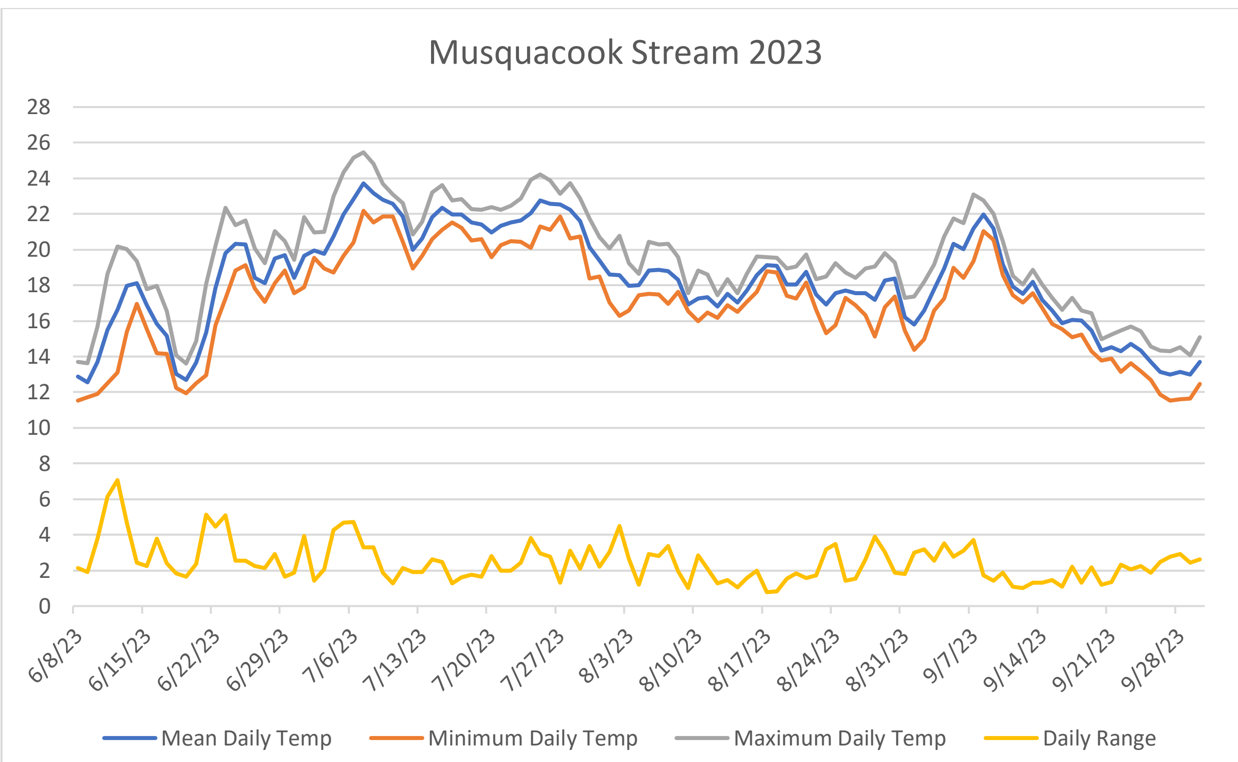

Whittaker Brook 2023
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

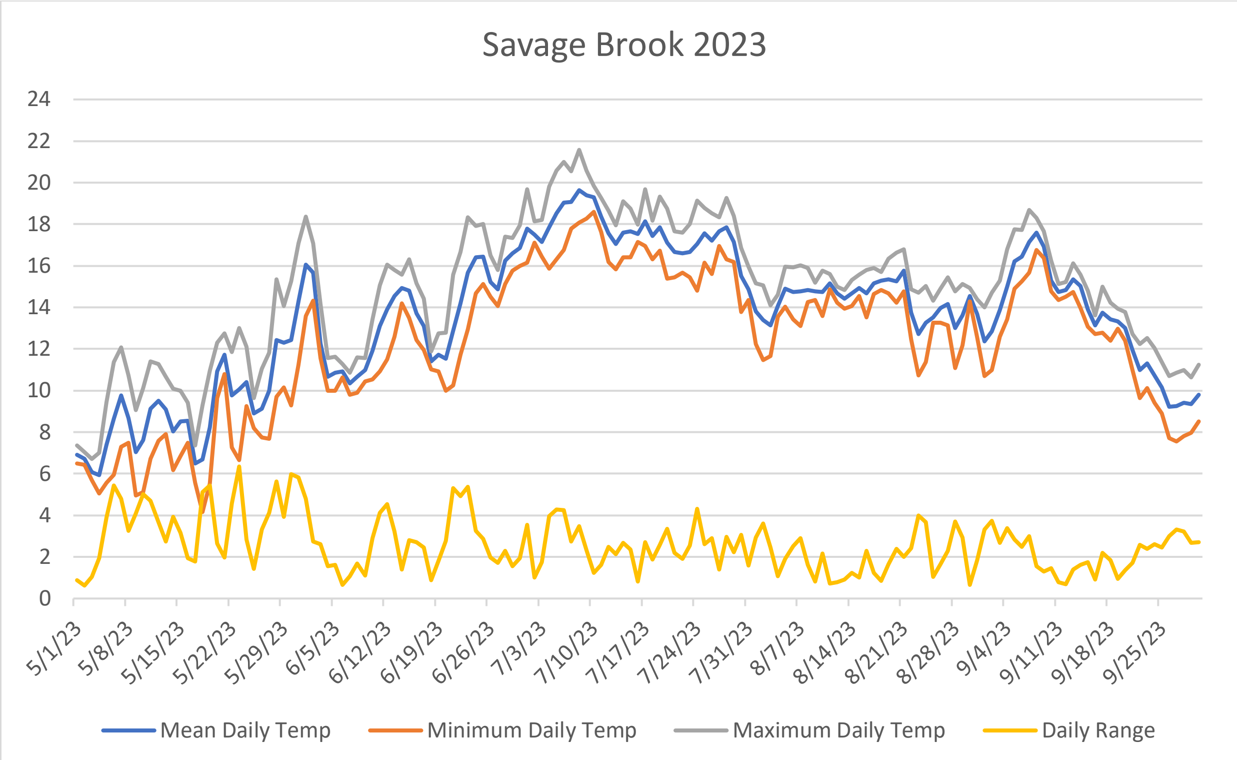

Whittaker Brook 2022
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/22/22
6/29/22
7/6/22
7/13/22
7/20/22
7/27/22
8/3/22
8/10/22
8/17/22
8/24/22
8/31/22
9/7/22
9/14/22
9/21/22
9/28/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

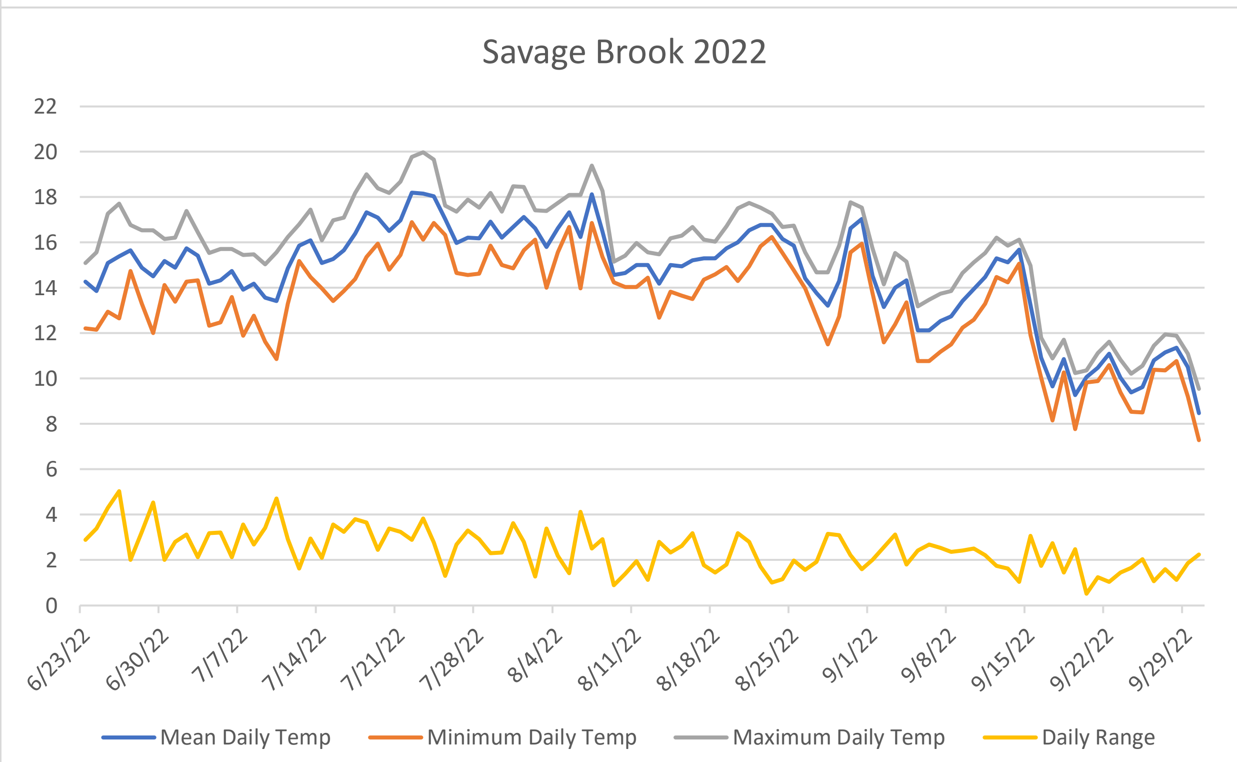

Schedule Brook 2023
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/8/23
6/15/23
6/22/23
6/29/23
7/6/23
7/13/23
7/20/23
7/27/23
8/3/23
8/10/23
8/17/23
8/24/23
8/31/23
9/7/23
9/14/23
9/21/23
9/28/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

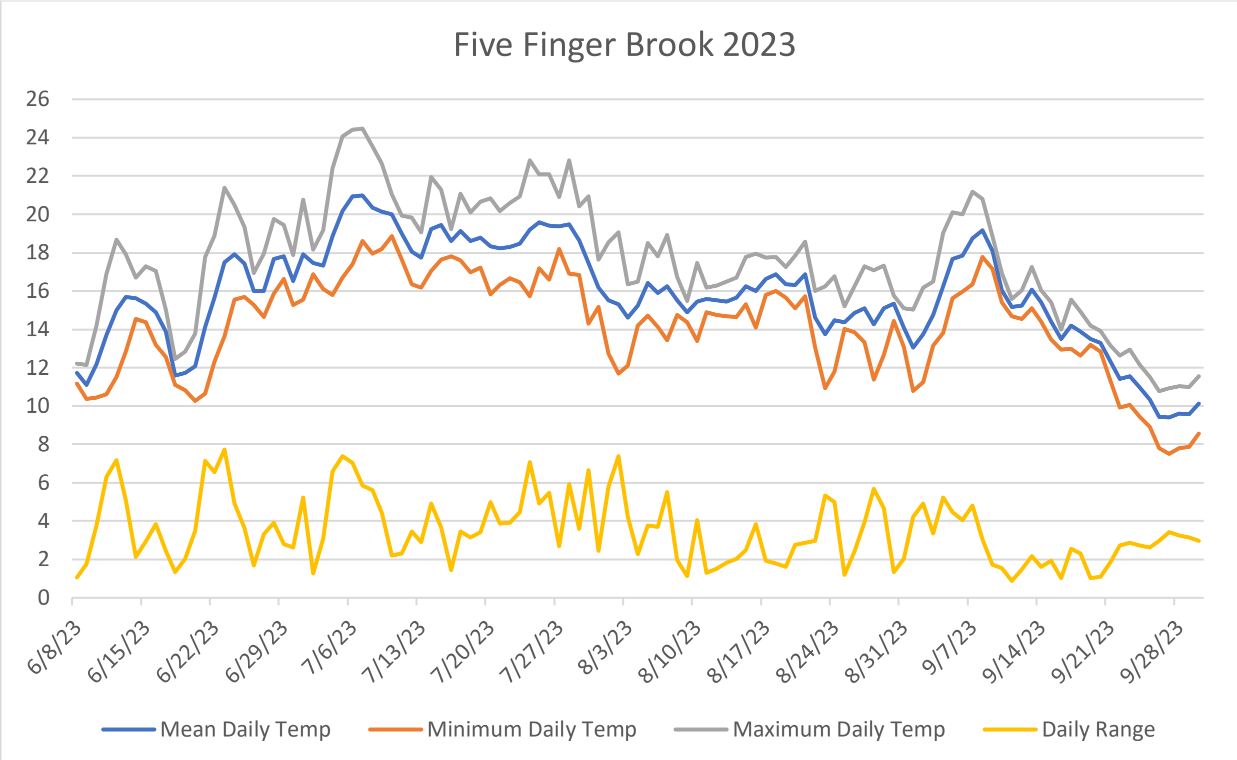

Henderson Bridge 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
7/1/22
7/6/22
7/11/22
7/16/22
7/21/22
7/26/22
7/31/22
8/5/22
8/10/22
8/15/22
8/20/22
8/25/22
8/30/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp

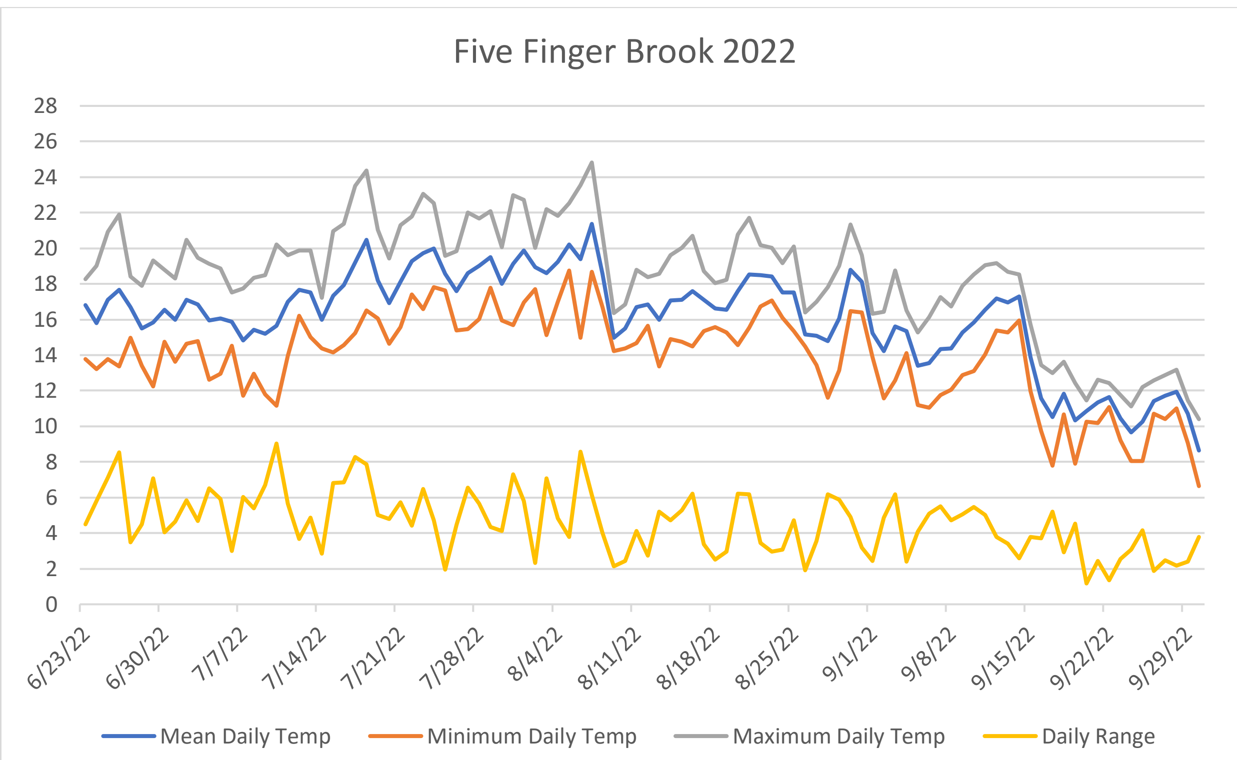

Schedule Brook 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/22/22
6/29/22
7/6/22
7/13/22
7/20/22
7/27/22
8/3/22
8/10/22
8/17/22
8/24/22
8/31/22
9/7/22
9/14/22
9/21/22
9/28/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

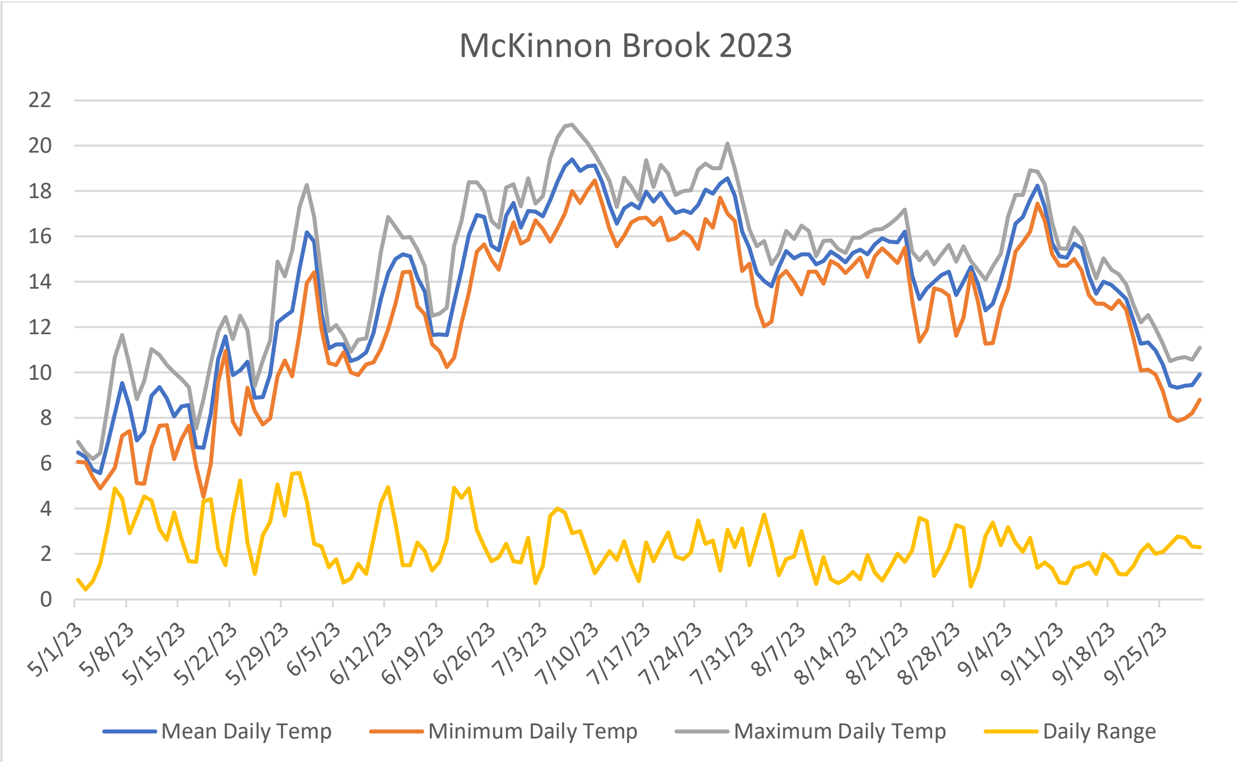

Musquacook Stream 2023
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/8/23
6/15/23
6/22/23
6/29/23
7/6/23
7/13/23
7/20/23
7/27/23
8/3/23
8/10/23
8/17/23
8/24/23
8/31/23
9/7/23
9/14/23
9/21/23
9/28/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

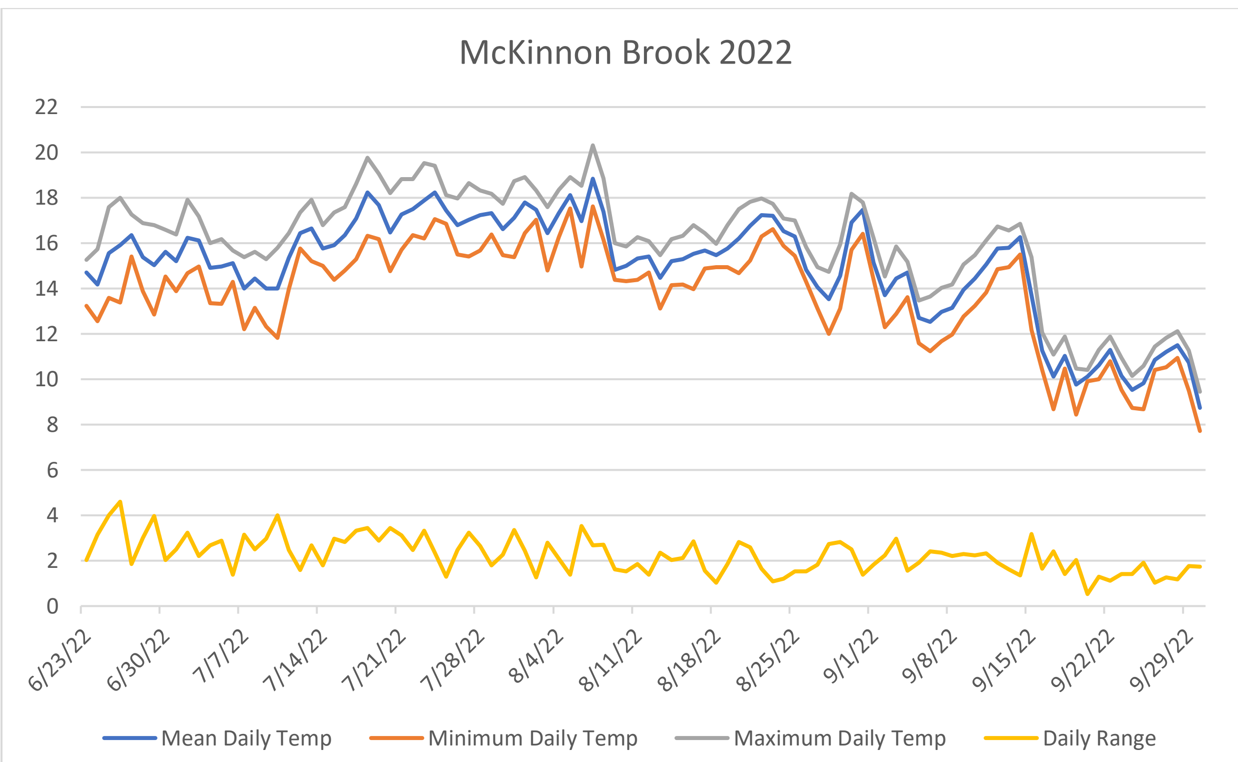

Savage Brook 2023
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

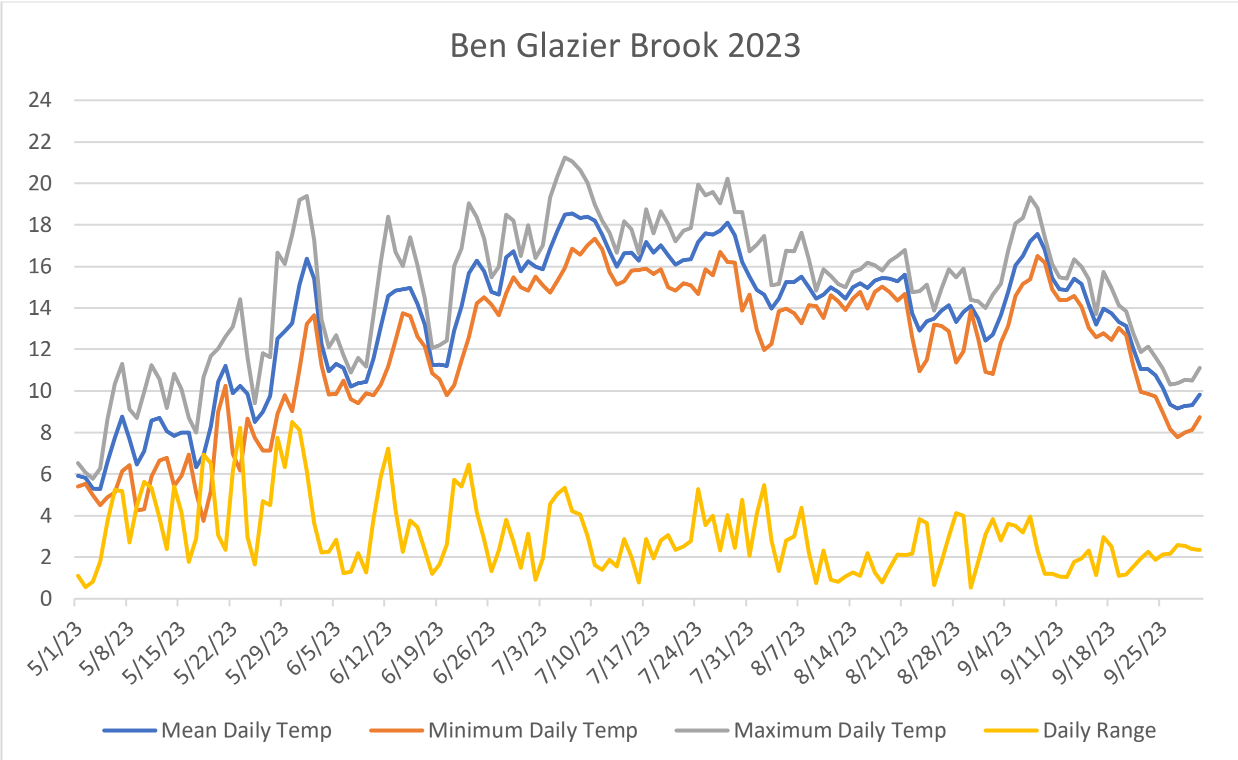

Savage Brook 2022
22
20
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

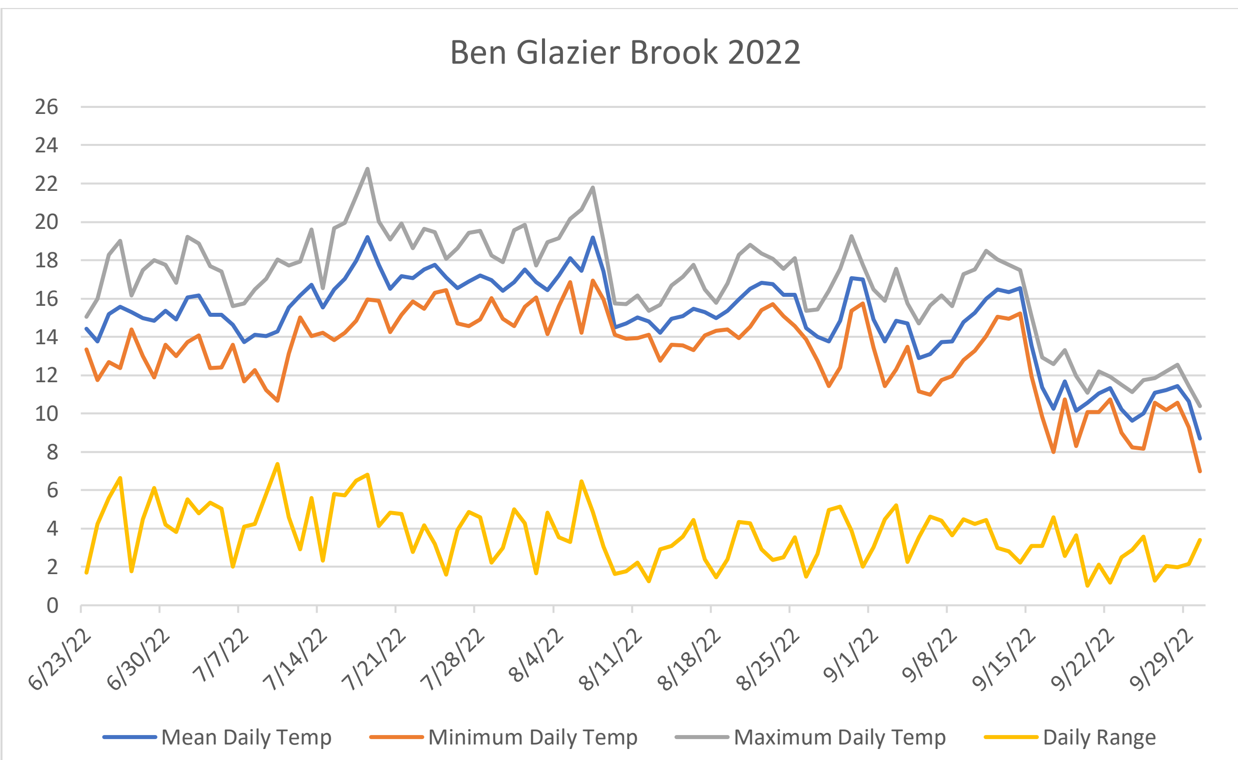

Five Finger Brook 2023
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/8/23
6/15/23
6/22/23
6/29/23
7/6/23
7/13/23
7/20/23
7/27/23
8/3/23
8/10/23
8/17/23
8/24/23
8/31/23
9/7/23
9/14/23
9/21/23
9/28/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

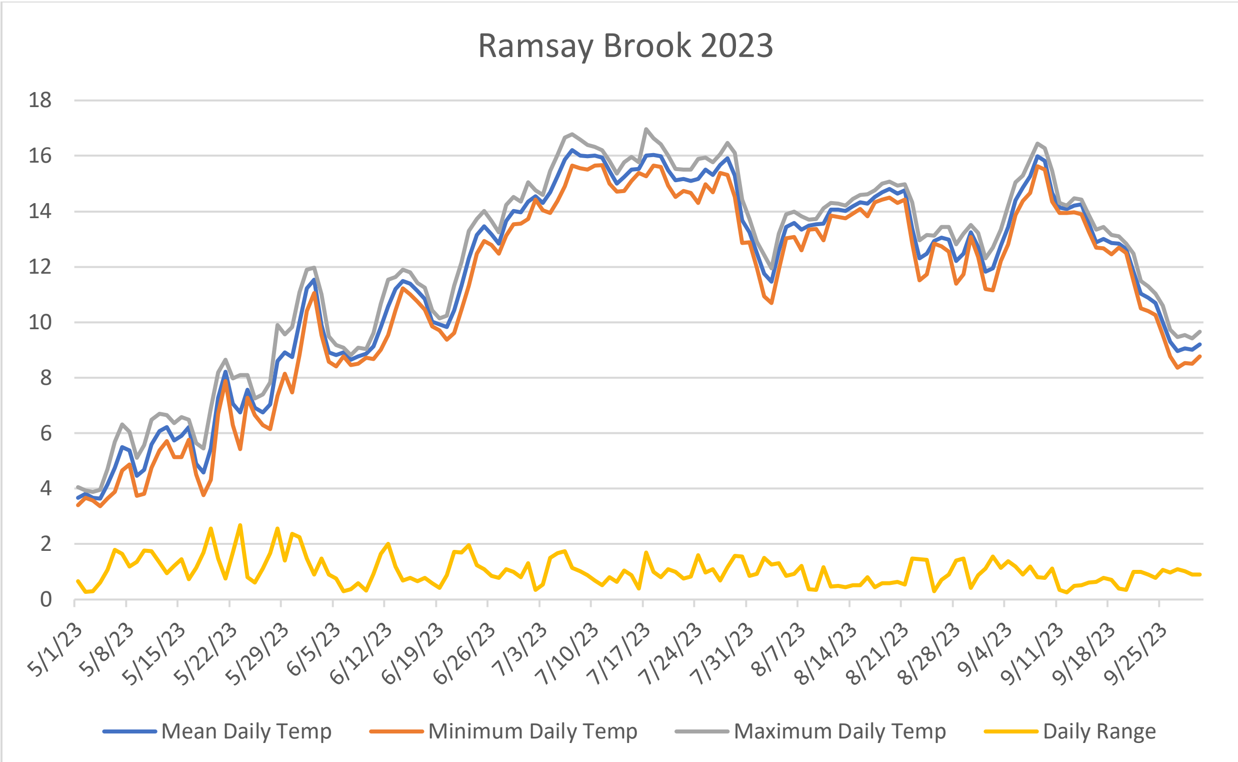

Five Finger Brook 2022
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

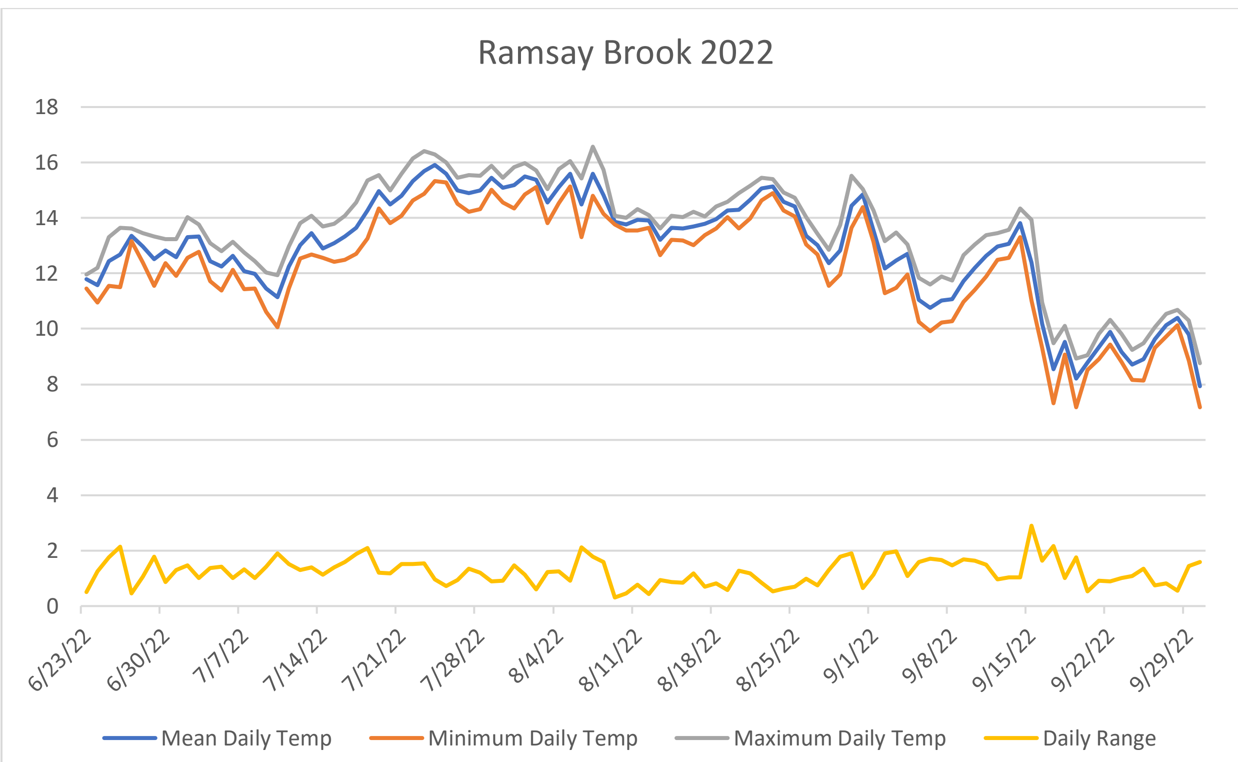

McKinnon Brook 2023
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

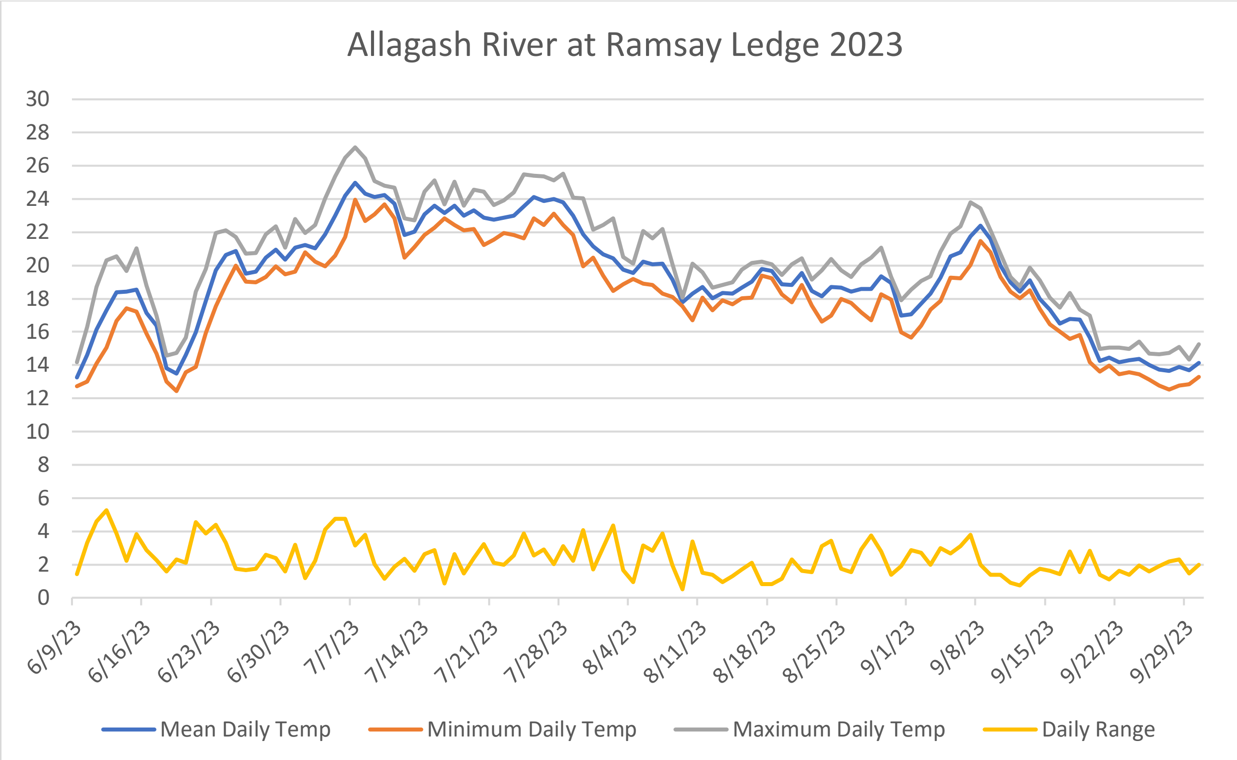

McKinnon Brook 2022
22
20
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

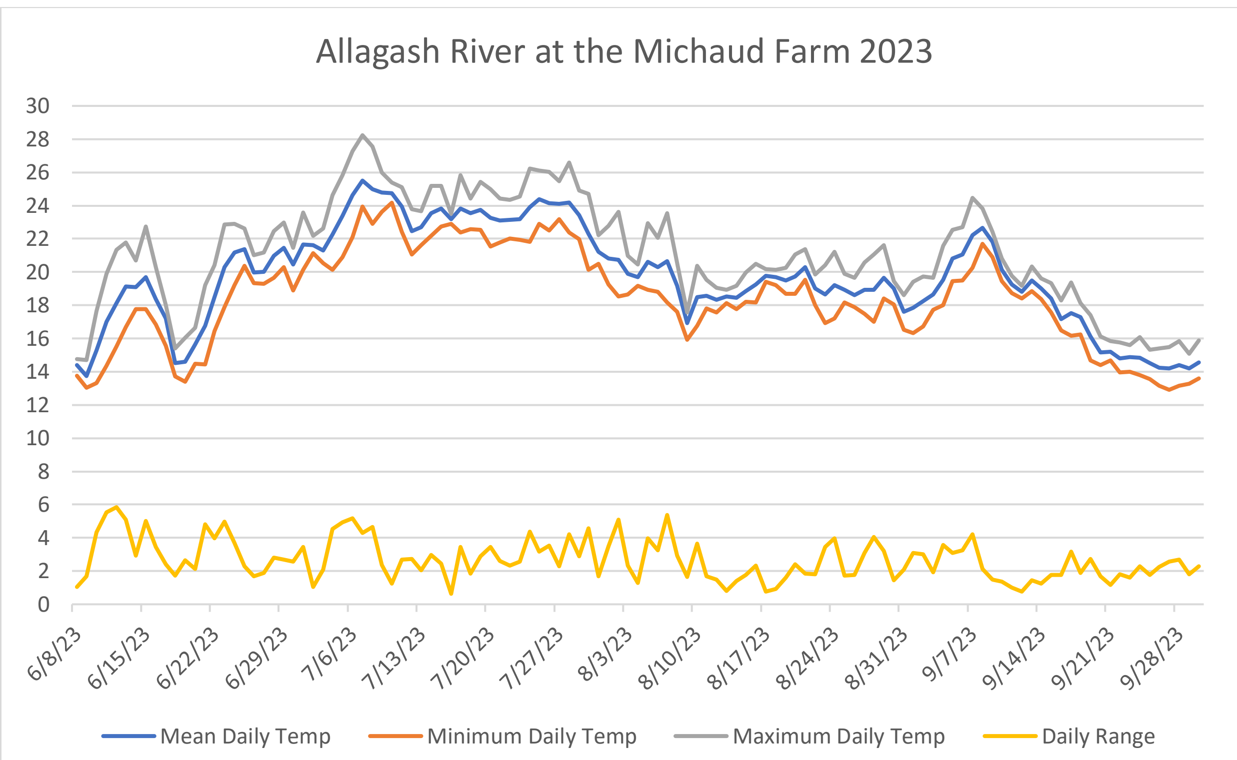

Ben Glazier Brook 2023
24
22
20
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

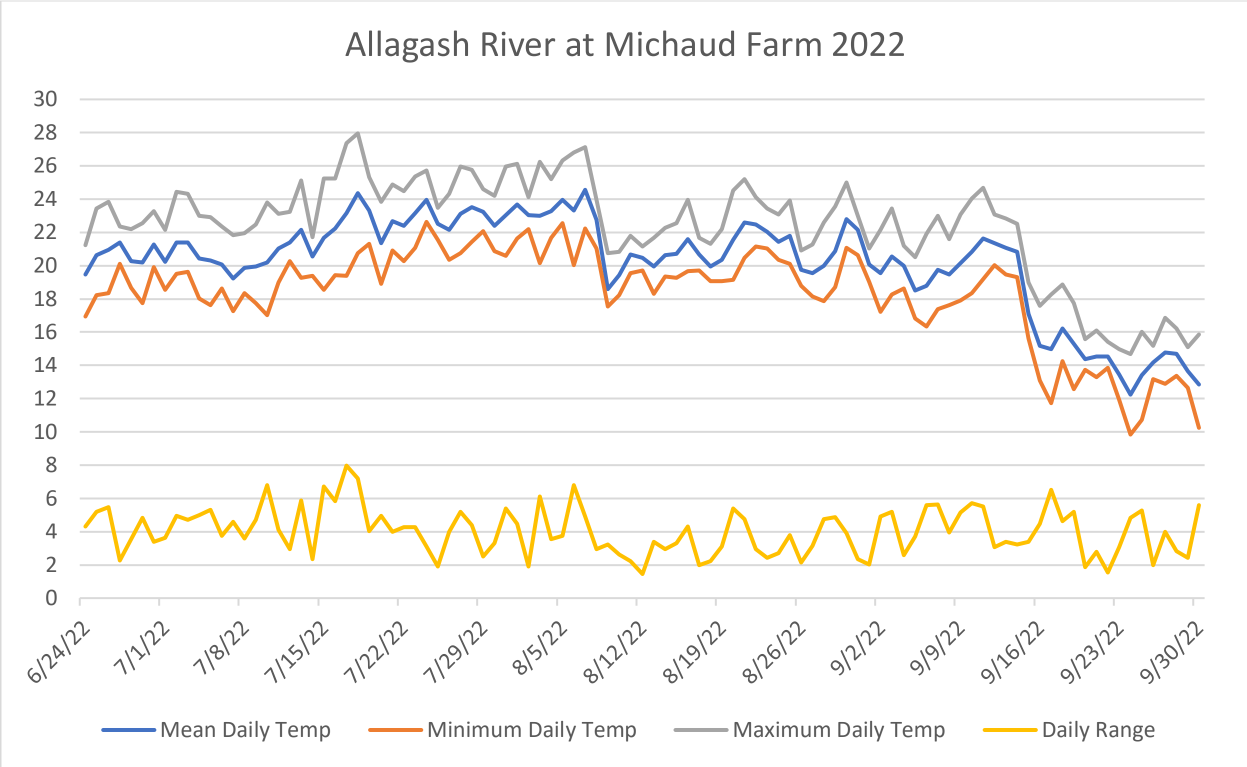

Ben Glazier Brook 2022
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

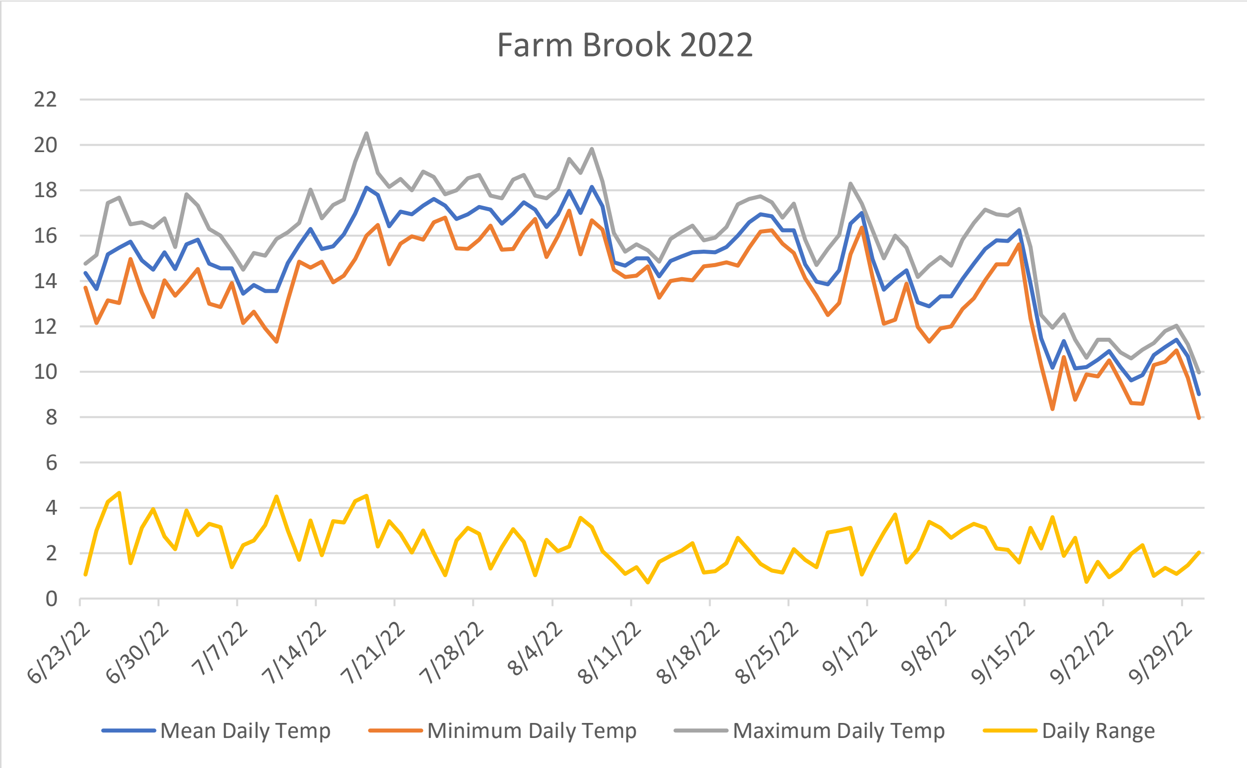

Ramsay Brook 2023
18
16
14
12
10
8
6
4
2
0
5/1/23
5/8/23
5/15/23
5/22/23
5/29/23
6/5/23
6/12/23
6/19/23
6/26/23
7/3/23
7/10/23
7/17/23
7/24/23
7/31/23
8/7/23
8/14/23
8/21/23
8/28/23
9/4/23
9/11/23
9/18/23
9/25/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range


Ramsay Brook 2022
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range


Allagash River at Ramsay Ledge 2023
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/9/23
6/16/23
6/23/23
6/30/23
7/7/23
7/14/23
7/21/23
7/28/23
8/4/23
8/11/23
8/18/23
8/25/23
9/1/23
9/8/23
9/15/23
9/22/23
9/29/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

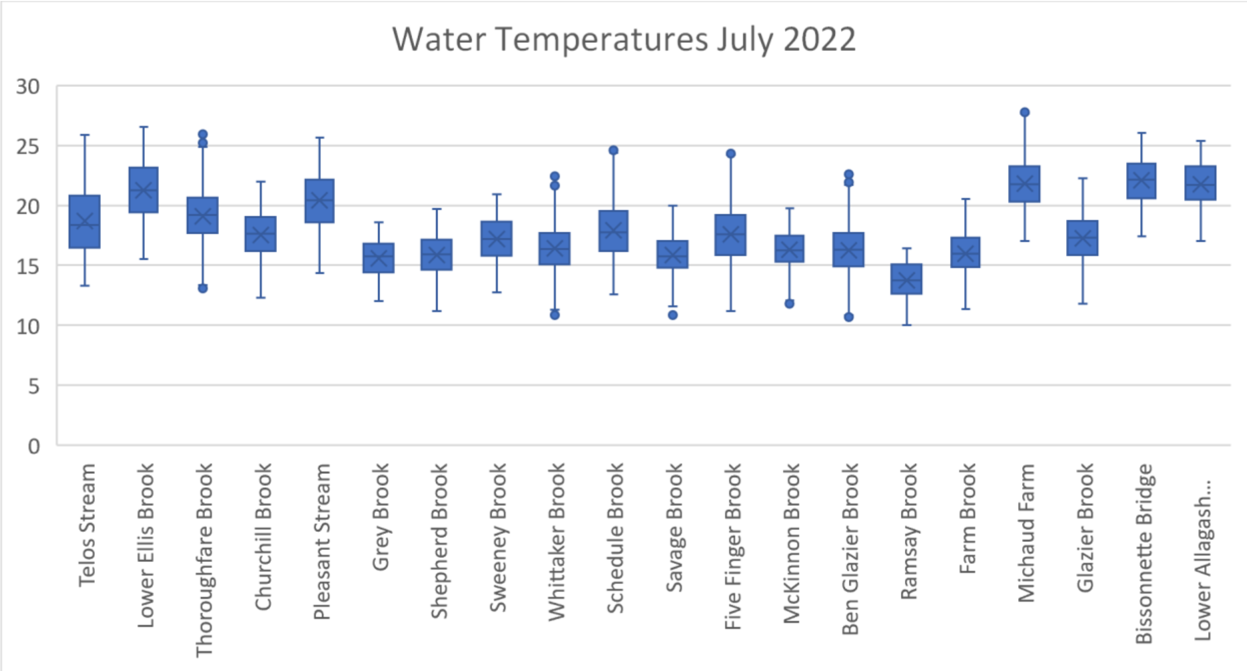

Allagash River at the Michaud Farm 2023
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/8/23
6/15/23
6/22/23
6/29/23
7/6/23
7/13/23
7/20/23
7/27/23
8/3/23
8/10/23
8/17/23
8/24/23
8/31/23
9/7/23
9/14/23
9/21/23
9/28/23
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

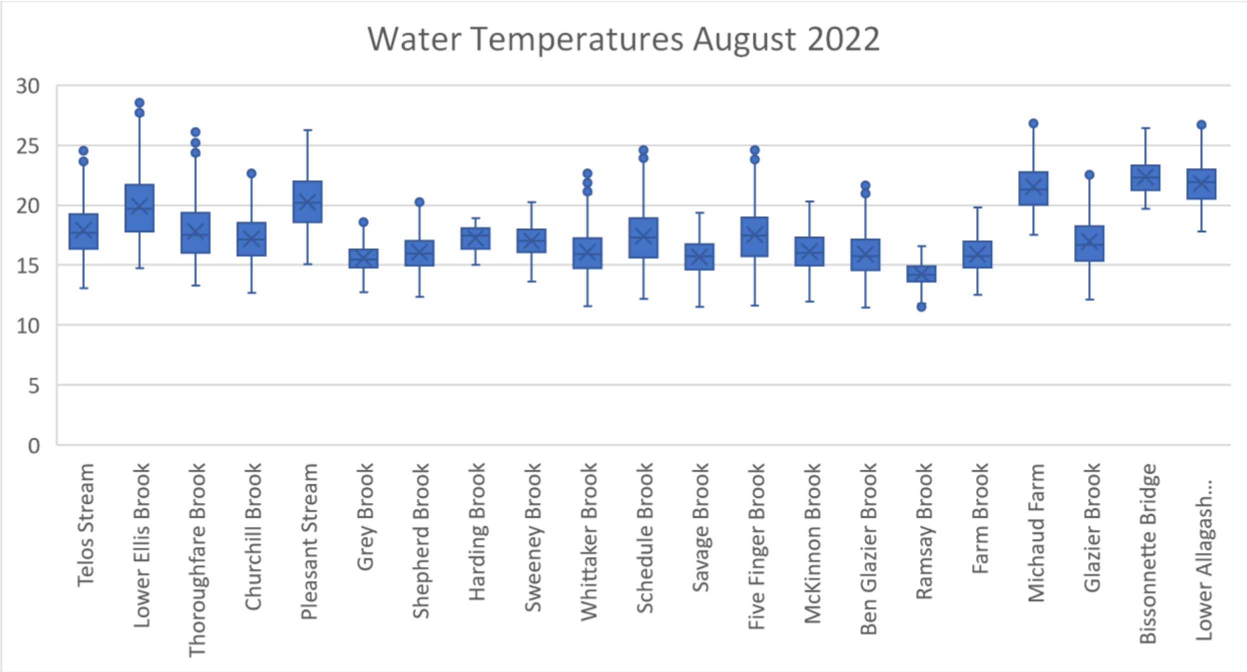

Allagash River at Michaud Farm 2022
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6/24/22
7/1/22
7/8/22
7/15/22
7/22/22
7/29/22
8/5/22
8/12/22
8/19/22
8/26/22
9/2/22
9/9/22
9/16/22
9/23/22
9/30/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

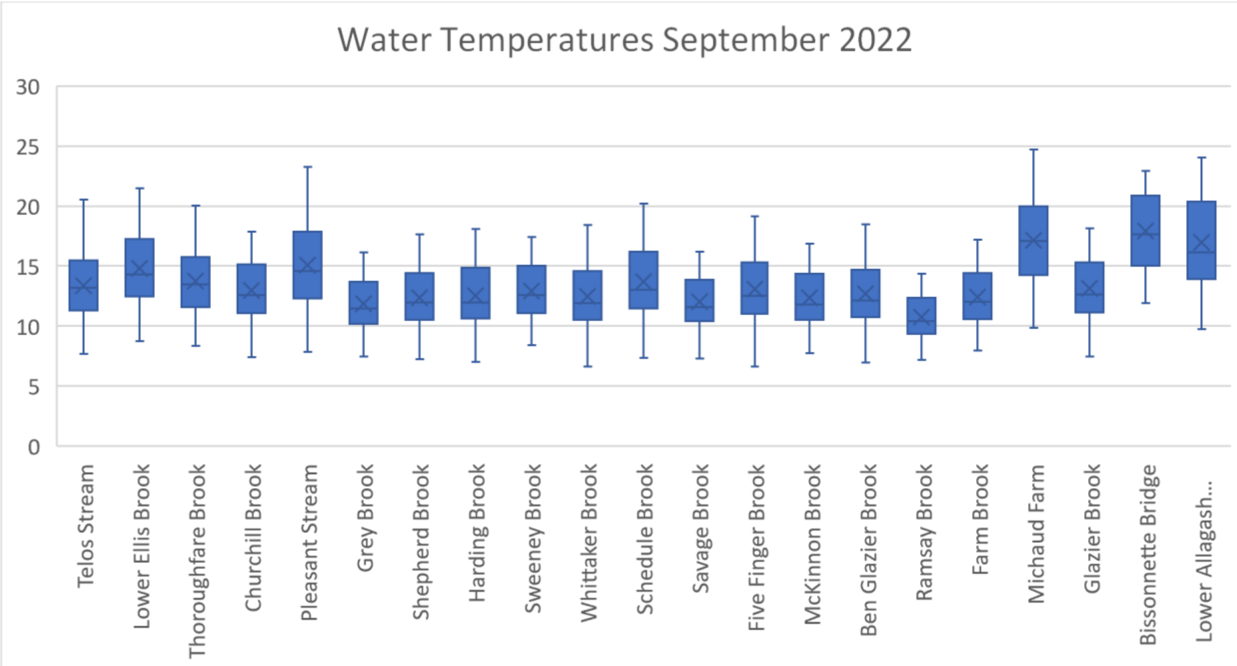

Farm Brook 2022
22
20
18
16
14
12
10
8
6
4
2
0
6/23/22
6/30/22
7/7/22
7/14/22
7/21/22
7/28/22
8/4/22
8/11/22
8/18/22
8/25/22
9/1/22
9/8/22
9/15/22
9/22/22
9/29/22
Mean Daily Temp
Minimum Daily Temp
Maximum Daily Temp
Daily Range

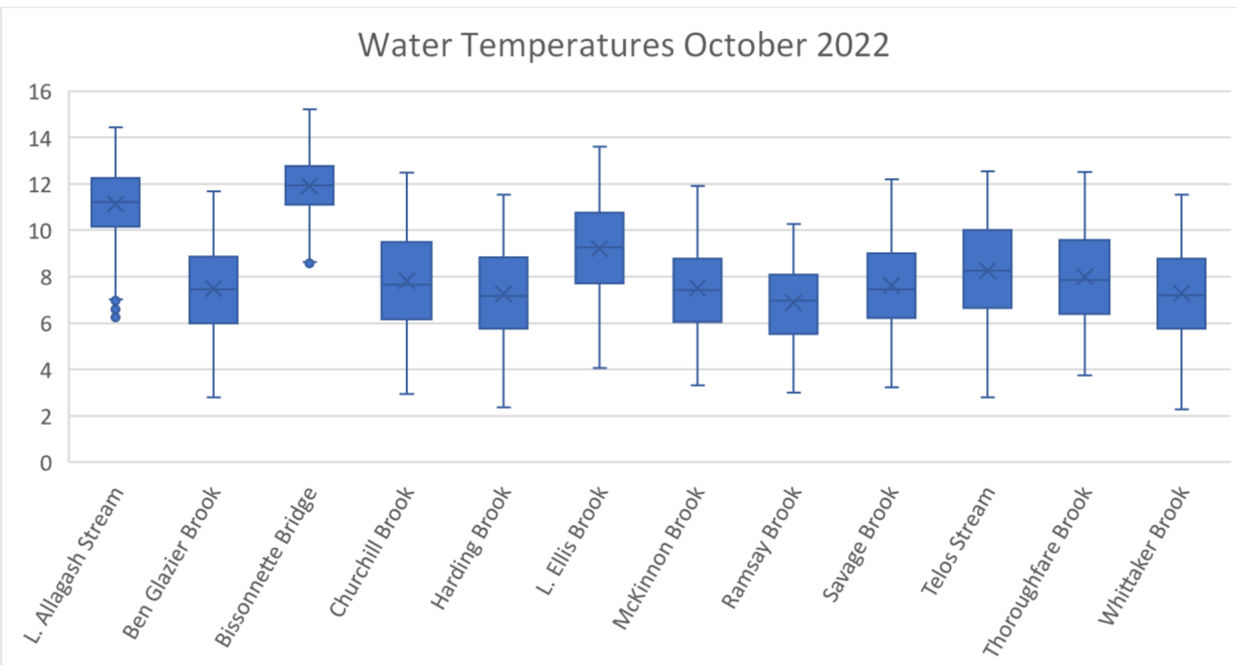
Appendix B

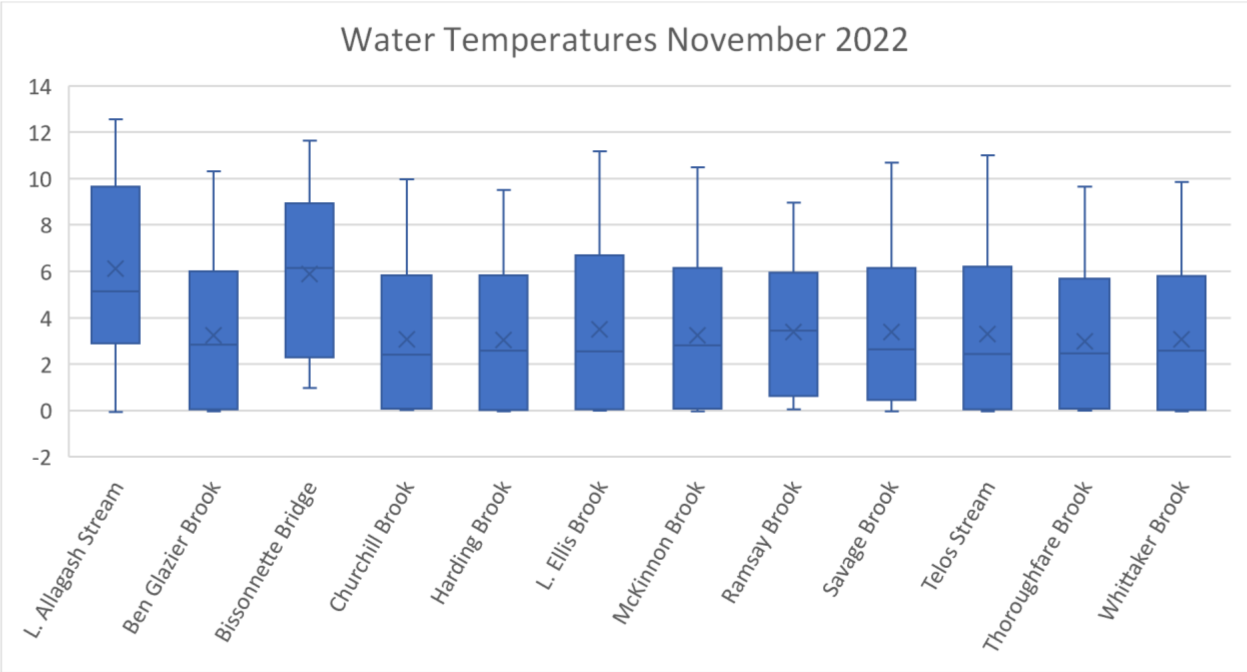
Annual Thermal Regimes at Monitoring Locations

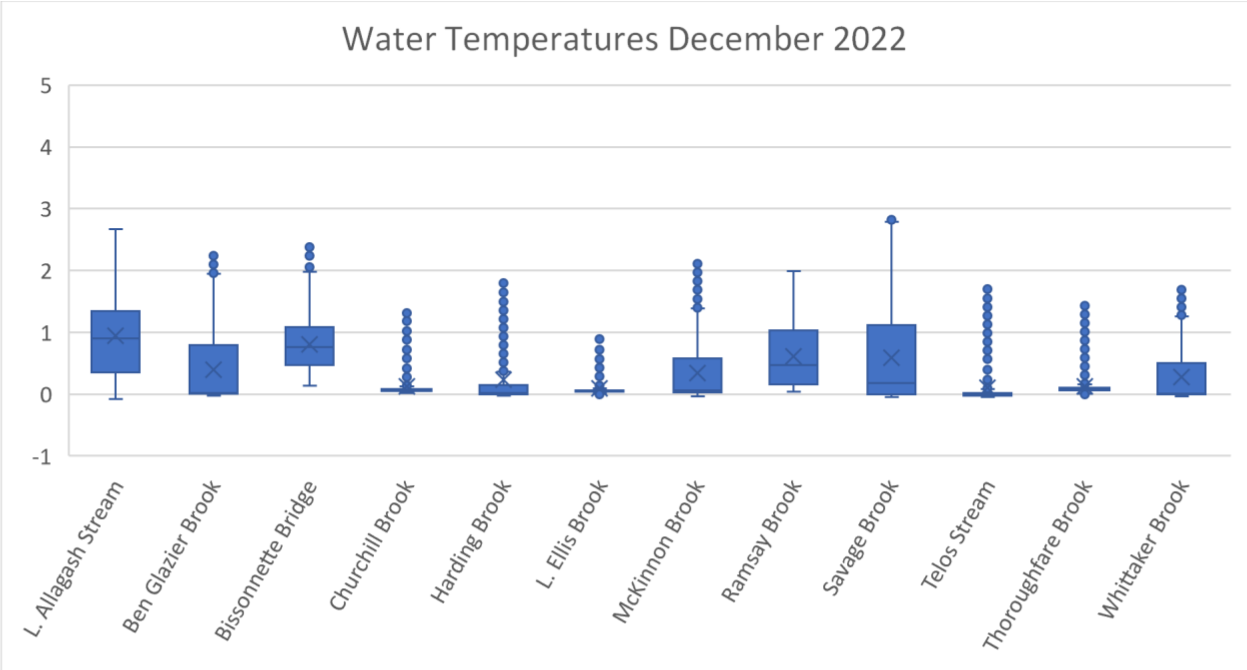


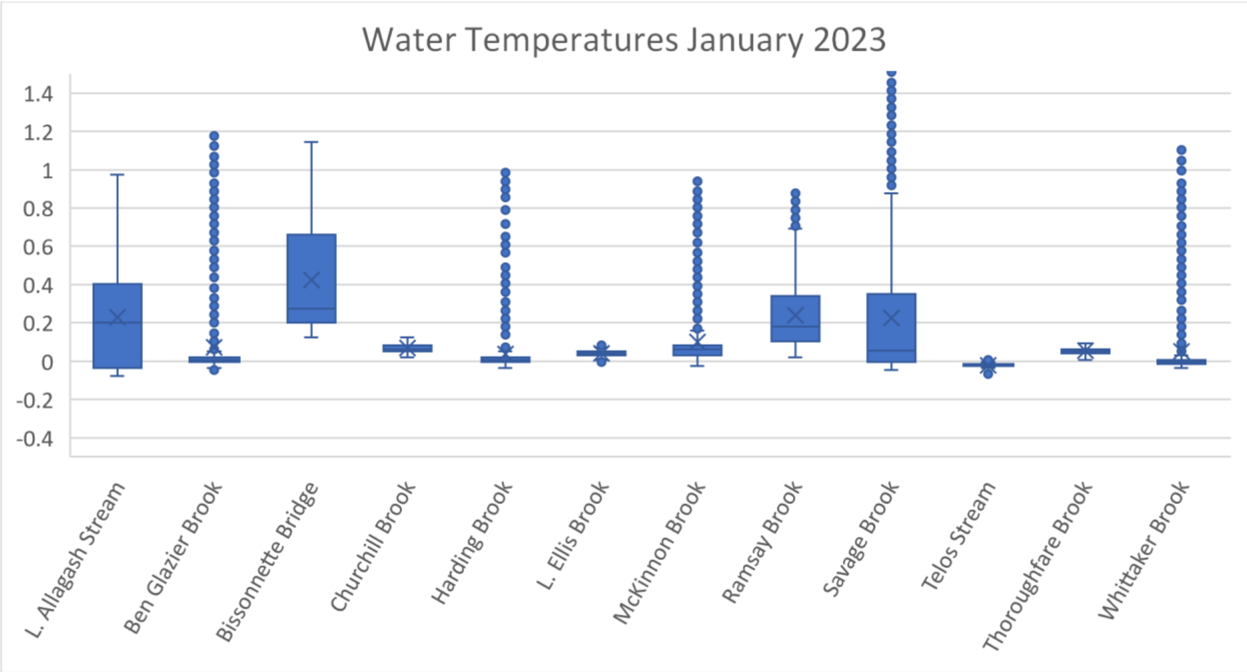


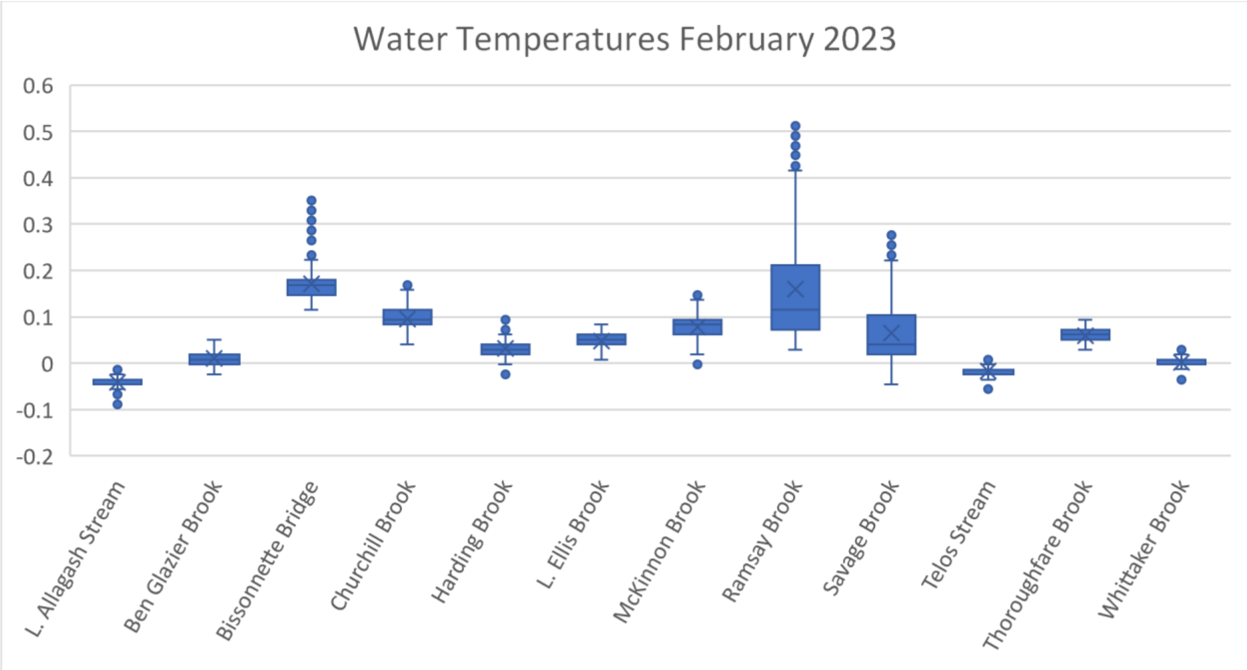

Water Temperatures September 2022
30
25
20
15
10
5
0
Telos Stream
Lower Ellis Brook
Thoroughfare Brook
Churchill Brook
Pleasant Stream
Grey Brook
Shepherd Brook
Harding Brook
Sweeney Brook
Whittaker Brook
Schedule Brook
Savage Brook
Five Finger Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook
Farm Brook
Michaud Farm
Glazier Brook
Bissonnette Bridge
Lower Allagash...

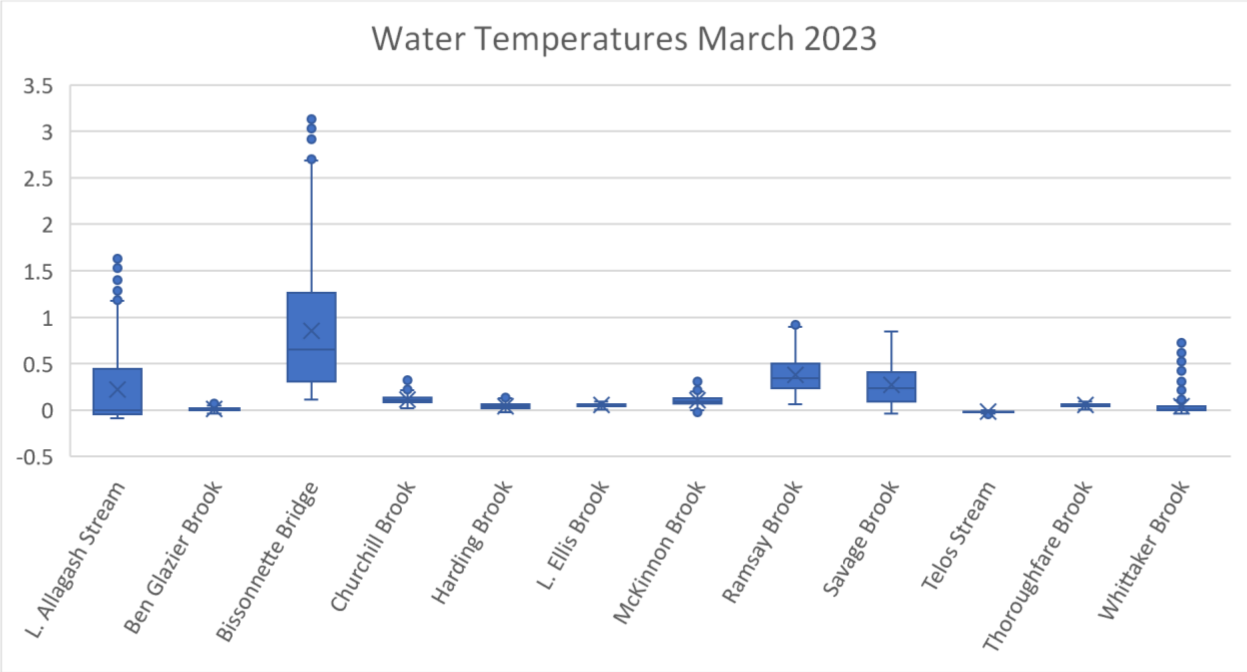

Water Temperatures October 2022
16
14
12
10
8
6
4
2
0
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

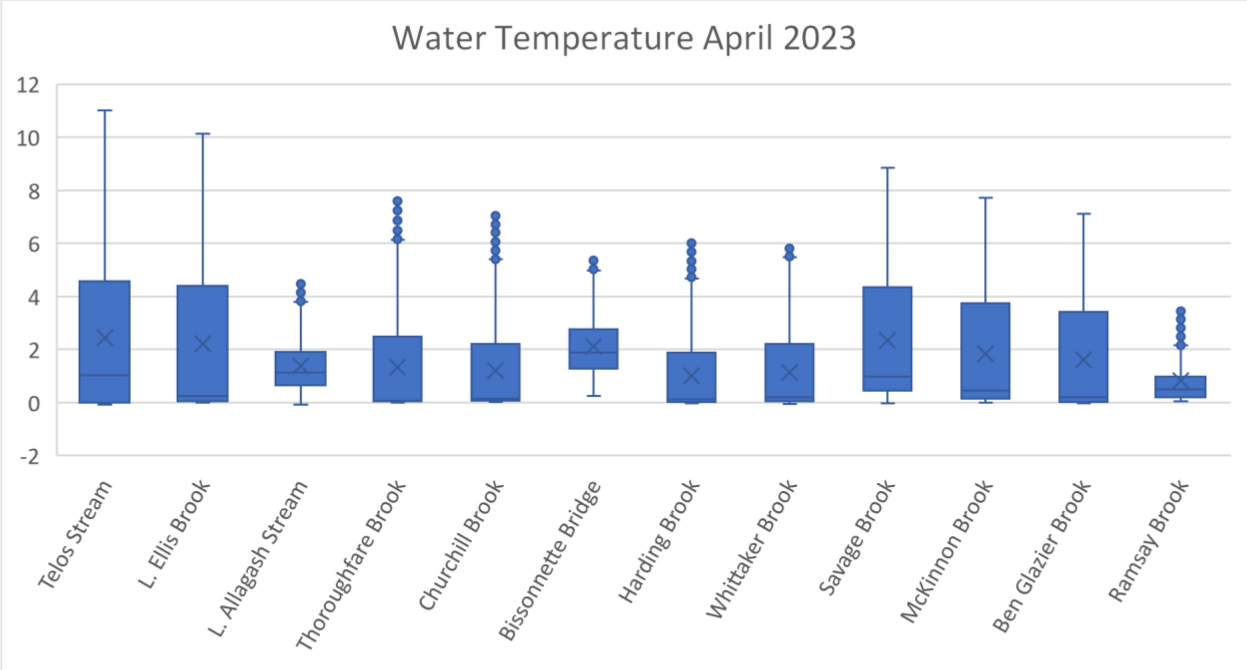

Water Temperatures November 2022
14
12
10
8
6
4
2
0
-2
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

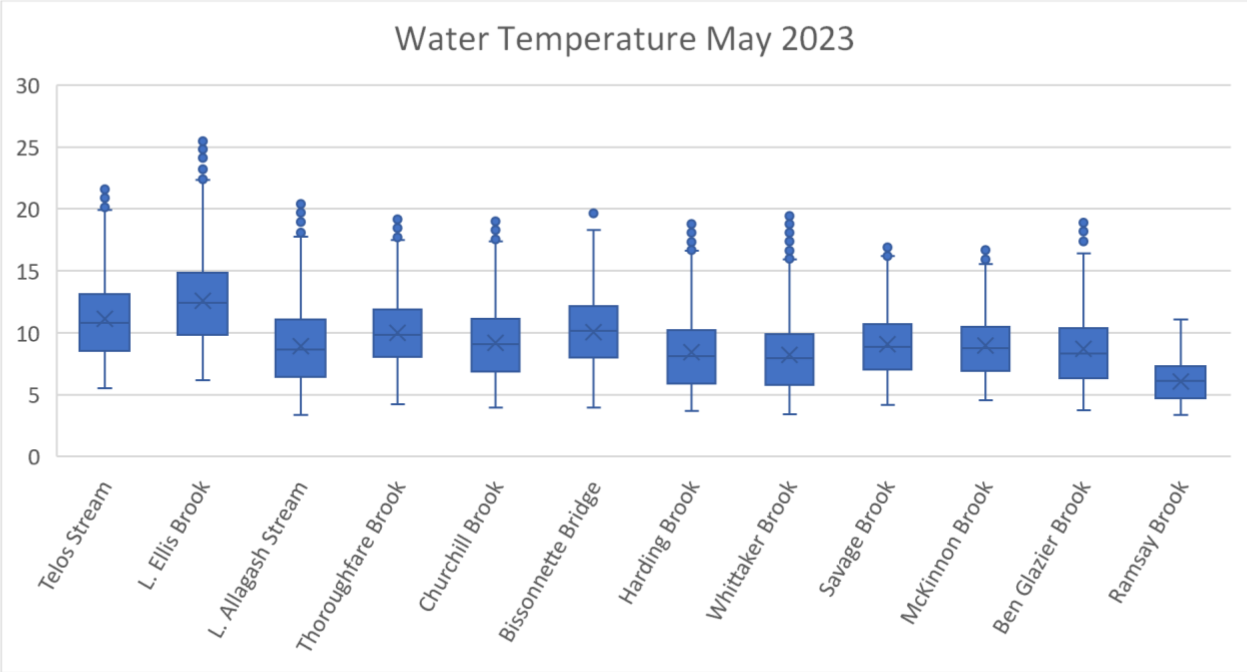

Water Temperatures December 2022
5
4
3
2
1
0
-1
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

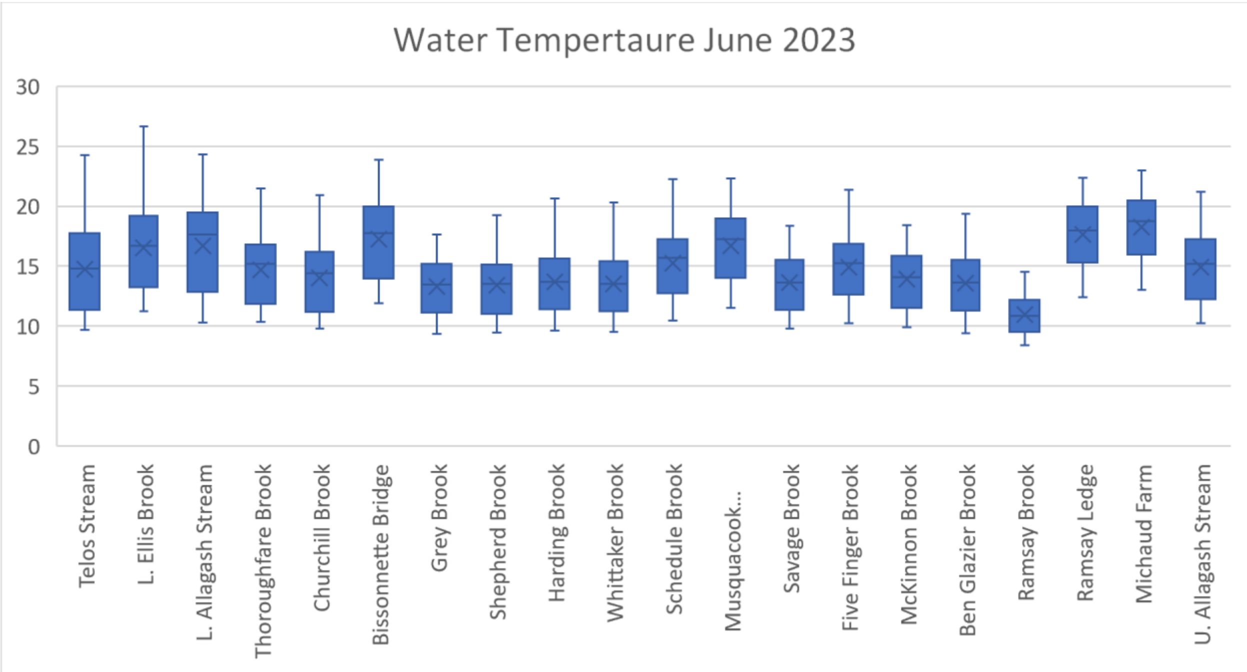

Water Temperatures January 2023
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

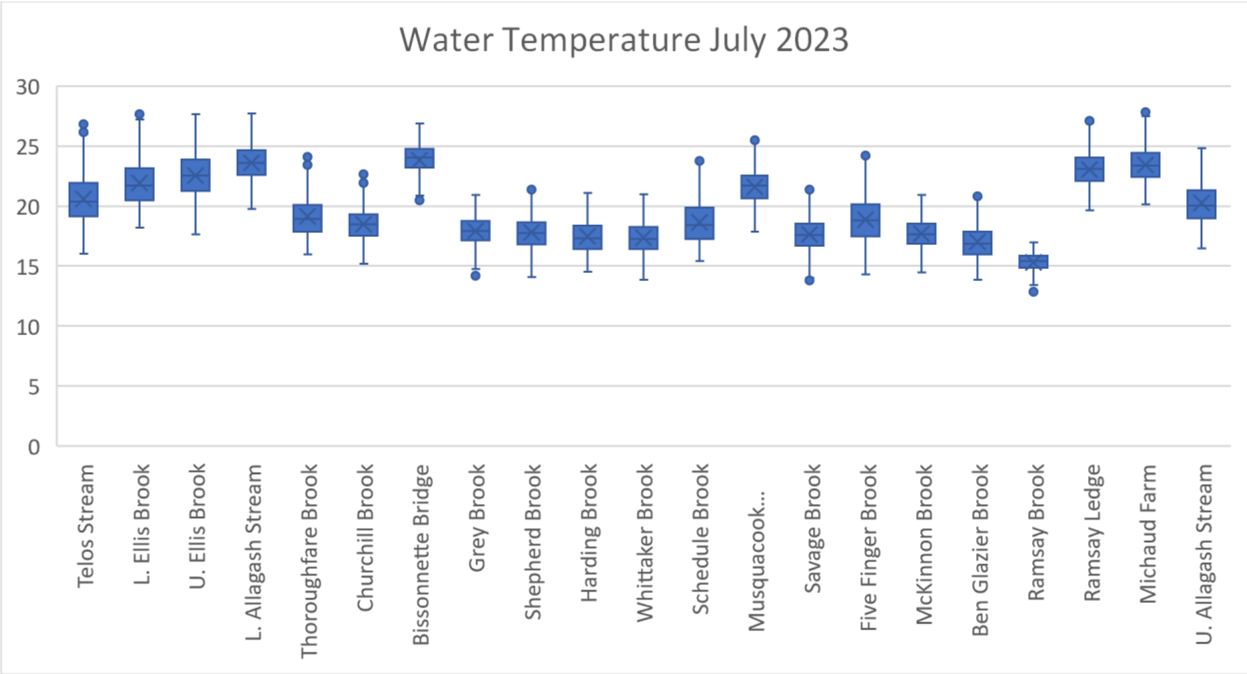

Water Temperatures February 2023
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

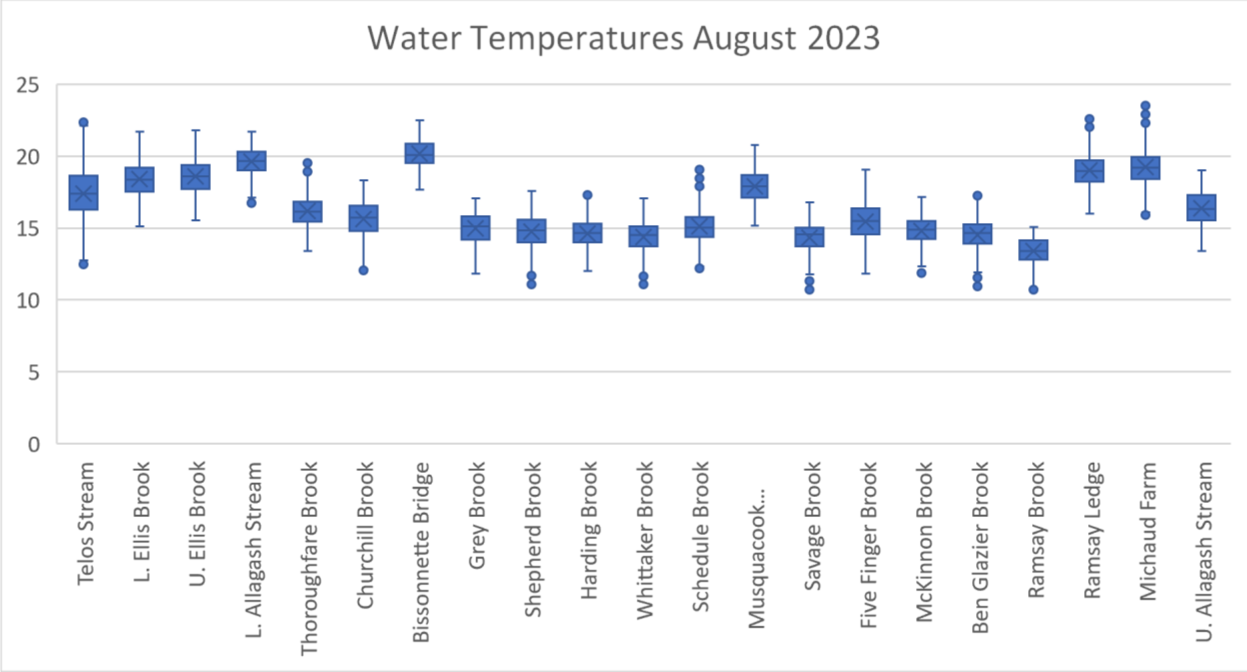

Water Temperatures March 2023
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
L. Allagash Stream
Ben Glazier Brook
Bissonnette Bridge
Churchill Brook
Harding Brook
L. Ellis Brook
McKinnon Brook
Ramsay Brook
Savage Brook
Telos Stream
Thoroughfare Brook
Whittaker Brook

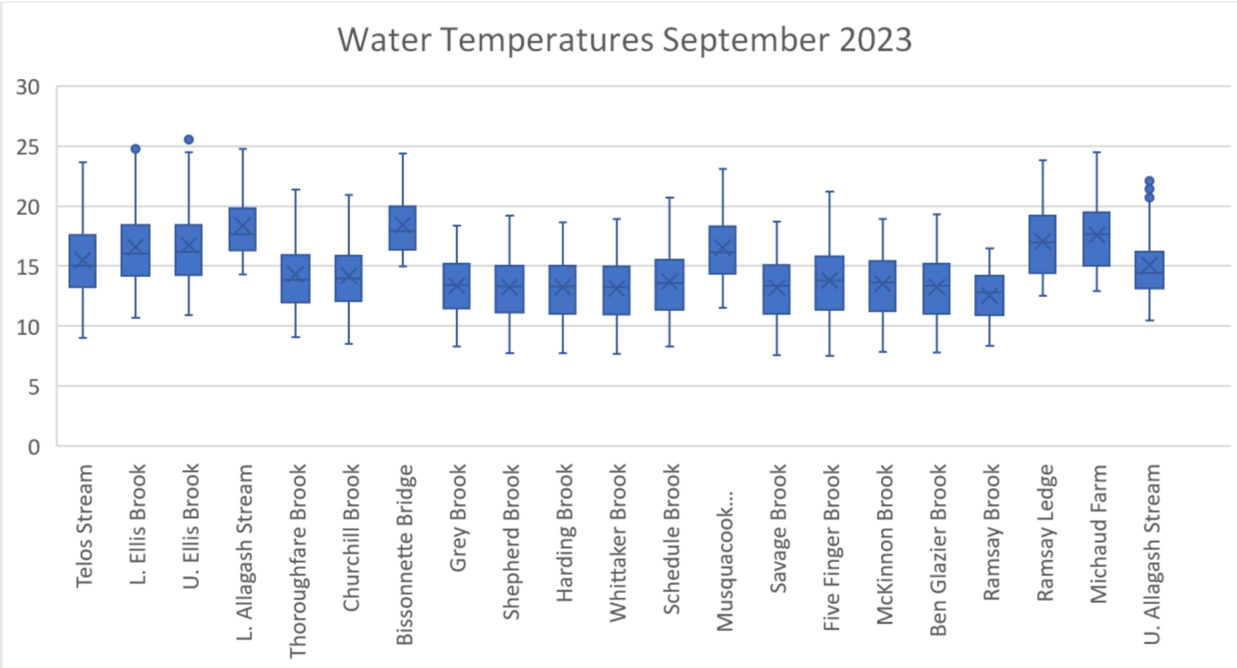

Water Temperature April 2023
12
10
8
6
4
2
0
-2
Telos Stream
L. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Harding Brook
Whittaker Brook
Savage Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook


Water Temperature May 2023
30
25
20
15
10
5
0
Telos Stream
L. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Harding Brook
Whittaker Brook
Savage Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook


Water Tempertaure June 2023
30
25
20
15
10
5
0
Telos Stream
L. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Grey Brook
Shepherd Brook
Harding Brook
Whittaker Brook
Schedule Brook
Musquacook...
Savage Brook
Five Finger Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook
Ramsay Ledge
Michaud Farm
U. Allagash Stream


Water Temperature July 2023
30
25
20
15
10
5
0
Telos Stream
L. Ellis Brook
U. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Grey Brook
Shepherd Brook
Harding Brook
Whittaker Brook
Schedule Brook
Musquacook...
Savage Brook
Five Finger Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook
Ramsay Ledge
Michaud Farm
U. Allagash Stream


Water Temperatures August 2023
25
20
15
10
5
0
Telos Stream
L. Ellis Brook
U. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Grey Brook
Shepherd Brook
Harding Brook
Whittaker Brook
Schedule Brook
Musquacook...
Savage Brook
Five Finger Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook
Ramsay Ledge
Michaud Farm
U. Allagash Stream


Water Temperatures September 2023
30
25
20
15
10
5
0
Telos Stream
L. Ellis Brook
U. Ellis Brook
L. Allagash Stream
Thoroughfare Brook
Churchill Brook
Bissonnette Bridge
Grey Brook
Shepherd Brook
Harding Brook
Whittaker Brook
Schedule Brook
Musquacook...
Savage Brook
Five Finger Brook
McKinnon Brook
Ben Glazier Brook
Ramsay Brook
Ramsay Ledge
Michaud Farm
U. Allagash Stream

Appendix C

Site Information and Sampling Datasheets

Remote Temperature Logger Deployment in AWW Tributaries

Water: ____________________ Logger ID #: ___________ Date: __________

Township: __________________ Latitude: ___________ Longitude: __________

Time Deployed: _______ Water Temp (C): _______ Water Depth: _______

Site Capable of Over-Wintering (Yes/No): _______

Site Description: ____

Site Sketch:

Comments:

Figure 1: Physical data sheet used during study.

Table 1: Temperature monitoring locations and their status throughout the study.

Stream	Tributary to	Watershed Area	2022 Data	Winter Status	2023 Status
Telos Stream	Telos Lake	16.0 mi²	Recovered	Deployed	Recovered; deployed
Lower Ellis Brook	Chamberlain Lake	24.1 mi²	Recovered	Deployed	Recovered; terminated
Upper Ellis Brook	Chamberlain Lake	12mi²	Not Deployed	Not Deployed	Recovered; deployed
Upper Allagash Stream	Chamberlain Lake	50mi²	Not Deployed	Not Deployed	Recovered; deployed
Lower Allagash Stream	Chamberlain Lake	96.0 mi²	Not Recovered	Deployed	Recovered; terminated
Thoroughfare Brook	Churchill Lake	42.7 mi²	Recovered	Deployed	Recovered; deployed
Churchill Brook	Churchill Lake	8.9 mi²	Recovered	Deployed	Recovered; deployed
Pleasant Stream	Churchill lake	20.7 mi²	Recovered	Removed	Terminated
Bissonnette Bridge	Mainstem	325 mi²	Not Recovered	Deployed	Recovered; terminated
Glazier Brook	Long Lake	23.2 mi²	Recovered	Removed	Not Recovered
Grey Brook	Long Lake	5.2 mi²	Recovered	Removed	Recovered; terminated
Ross Stream	Long Lake	217mi²	Not Deployed	Not Deployed	Not Recovered
Shepherd Brook	Long Lake	15.9 mi²	Recovered	Removed	Recovered; deployed
Harding Brook	Allagash River	14.7 mi²	Not Recovered	Deployed	Recovered; deployed
Sweeney Brook	Allagash River	3.7 mi²	Recovered	Removed	Terminated
Whittaker Brook	Allagash River	15.6 mi²	Recovered	Deployed	Recovered; deployed
Henderson Bridge	Mainstem	722 mi²	Not Recovered	Deployed	Recovered; terminated
Schedule Brook	Allagash River	24.7 mi²	Recovered	Removed	Recovered; deployed
Musquacook Stream	Allagash River	156 mi²	Not Deployed	Not Deployed	Recovered; terminated
Savage Brook	Allagash River	5.3 mi²	Recovered	Deployed	Recovered; deployed
Five Finger Brook	Allagash River	32.0 mi²	Recovered	Removed	Recovered; deployed
McKinnon Brook	Allagash River	9.6 mi²	Recovered	Deployed	Recovered; deployed
Ben Glazier Brook	Allagash River	17.3 mi²	Recovered	Deployed	Recovered; deployed
Ramsay Ledge	Mainstem	1,021mi²	Not Deployed	Not Deployed	Recovered; terminated
Ramsay Brook	Allagash River	11.7 mi²	Recovered	Deployed	Recovered; deployed
Michaud Farm	Mainstem	1,025 mi²	Recovered	Removed	Recovered; terminated
Farm Brook	Allagash River	17.7 mi²	Recovered	Removed	Terminated