2023

Report on the Health of the Nashwaak Watershed

Lauren Murdock

Nashwaak Watershed Association

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Executive Summary

In 2017, following an almost 15-year gap in data, the Nashwaak Watershed Association Inc. (NWAI) began regular water quality and temperature monitoring within the Nashwaak River watershed. Water quality monitoring sites were selected based on both historic and current environmental significance. Sites were distributed throughout the upper and lower portions of the watershed. In 2023, the NWAI conducted regular water quality monitoring, once a month between the months of May to October. Water quality samples were collected by NWAI and submitted to the Research and Productivity Council (RPC) for Laboratory testing in Fredericton, NB. The tests analyzed surface water contaminants, including heavy metals, nutrients, and *Escherichia coli* (*E. coli*). These results were compared to the Canadian Councils of the Ministers of the Environment (CCME) guidelines. Historic (pre-2010) data was used to infer trends in parameters over time. Temporal thermal changes were monitored via 39 HOBO loggers, set to 1-hour intervals, and spread throughout the mainstem and select tributaries between May and November.

In general, sites closer to the mouth of the river had inferior water quality compared to the more rural sites in the headwaters. Although water quality in 2023 was generally good throughout the watershed, some measured parameters differed from levels that would be considered optimal. Exceedances of some parameters such as aluminum and iron can be attributed to the underlying geology. We have attributed other exceedances in water quality guidelines to an increase in sedimentation of the streams due to several anthropogenic activities including soil mining, agriculture, and removal of riparian vegetation. The increase of fluoride in the watershed over the past six years is not so easily explained. We plan to follow up on these levels.

Sedimentation remains a primary threat to water quality in the watershed. Heavy erosion is concentrated largely in the more urbanized section of the lower watershed. Historical agricultural expansion and urban development have led to the destruction of vital riparian habitat responsible for flood mitigation and bank stability. The NWAI Natural Edge Program aims to restore the riparian buffer along these degraded areas of shoreline by replanting native vegetation and promoting the importance of an intact riparian ecosystem.

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Introduction and Background

Historically, there were large temporal gaps in monitoring the health of the Nashwaak Watershed. Water quality and temperature were noted as data deficient areas in the organization's 2017-2020 Action Plan. Sustained, long-term monitoring is valuable for determining baseline water quality conditions, and through statistical trend assessment can help evaluate the influences and cumulative effects of human activities and other factors on the watershed over long periods. The Department of Fisheries and Oceans (DFO)'s Ecological Restoration of Degraded Habitats handbook recognizes both water quality and high temperatures as limiting factors to sustaining fish populations.

Maintaining the quality of the surface water is important for ensuring a healthy watershed and community. Due to a broad range of natural and anthropogenic influences, the quality and temperature of a river's water can vary substantially over time and space. Much has changed in the watershed over the last 15 years, most notably urbanization. This has elevated the stress on the river system due to an increased human population, and land-use changes resulting in the degradation of wetlands, the removal of riparian vegetation and the release of pesticides, fuels, nutrients, and bacteria. The 2016 geomorphic survey of the lower Nashwaak recognized large areas of stream bank erosion, which were most extreme downriver from the community of Taymouth. Bank erosion increases siltation of rivers and leads to increased levels of metals and suspended sediments. Erosion was particularly noticeable in areas where riparian vegetation had been removed. Existing areas of concern are coupled with the prospect of further development in the riparian area of the watershed. Most notably, a proposed mine in the headwaters near Sisson brook necessitated an increase in baseline monitoring. This data will be used to confirm further degradation from new development and industry moving into the area over time. The NWAI resumed monitoring in 2017, at 11 historic sampling sites, and 1 new site. In 2023, we continued to monitor water quality at a total of 16 sites.

Going forward, the regular monitoring of water quality will allow us to:

- Identify problem areas or industries;
- Assess the condition of the river and how it has changed over time;
- Define and approach private landowners in problem areas and discuss management options with them to improve water quality;
- Determine how the changes in water quality are affecting wildlife and habitat, particularly species-at-risk;
- Make decisions on the management of the river's health; and
- Promote community stewardship of the Nashwaak River by making the information available to the public.

In addition to challenges with water quality, the risk of extreme temperature events in a river system can also impact the health, function, and ecosystem services in the river. Extreme thermal events can be influenced by multiple factors including riparian zone degradation and decreased discharge due to water extraction for irrigation (Caissie, 2006). The removal of forest cover and the associated road networks for forestry operations typically lead to an increase in surface runoff, increasing water temperatures and sediment in rivers. Both factors impact the distribution of cool and cold-water fish species (Curry & Gautreau, 2010). Other external factors that can increase river temperatures include higher air temperatures, increased runoff on impermeable surfaces in urban areas, and input from water treatment plants. Though most present-day industrial and municipal operations are regulated to protect aquatic ecosystems, the persistent impacts from urbanization, current and historical forestry operations, and agriculture practices that fail to follow best management practices remain.

As temperatures increase, they can drastically alter the chemistry and conditions in a freshwater system. Warmer water often contains less oxygen than colder water, so as river temperatures rise and dissolved oxygen decreases fish begin to experience stress, particularly salmonids (salmon, charr, and trout species). To escape warm waters in the mid-summer, many fish species will move to smaller, cooler tributaries or pools near cold groundwater seeps to survive. High temperatures can delay migration, exhaust energy reserves, which can result in reproductive failure, reduce egg survival, slow growth of fry and smolts, and decrease resistance to disease (McCollough, 1999).

As climate change and development increase, so will the frequency of extreme heat events, highlighting the importance of cold-water refuge for heat-sensitive aquatic species. “Spring-fed creeks” or seeps occur in areas where there are deep deposits of coarse soils or fractures in the bedrock that intersect the water table. These sites capture, cool, filter and conduct a large portion of rain or snowmelt to streams. As such, spring-fed creeks have more uniform and stable flows and temperatures and can buffer seasonal temperature extremes. They also contribute to more stable baseflow in downstream reaches of the river system. These sites support animals that don’t occur in the main stem. They can be extremely productive habitat for cold-water fish and can provide a refuge from high summer water temperatures. Major upwelling or groundwater discharge seeps in streams comprising coarse sands and gravels are also critical locations for spawning and egg incubation. However, these areas are also the rarest, and most sensitive to environmental degradation in salmonid-bearing streams. Functional spring-fed streams are ecologically important for resilient aquatic systems and can buffer changes in climate.

A species of specific concern is the remnant outer Bay of Fundy Atlantic salmon population that was COSEWIC listed as endangered in 2010. Adult Atlantic salmon are less tolerant to high temperatures than juveniles. A DFO (2012) report determined that incipient lethal temperature (or the temperature that a fish can tolerate for at least seven days before dying) was 27.8°C for juveniles, while for adults it was around 25°C. The report also noted that juvenile and adult salmon begin aggregating near cool water sources and stopped feeding when minimum nighttime temperatures remained above 20°C for two consecutive nights. Therefore, 20°C is considered the recommended threshold temperature for assessing physiological stress in Atlantic salmon (DFO, 2012).

As recommended by DFO’s Ecological Restoration of Degraded Habitats, determining the location of and protecting cold-water tributaries are noted as High Priority action items in the

NWAI management plan. Monitoring the temperature of our ecologically important tributaries will help us to:

- Better understand the sources of thermal inputs in the river network, and where the cold-water refuges (streams that remain under < 20°C over the summer, which are so important to species such as the Endangered Atlantic salmon and other salmonids, are located within the watershed;
- Communicate the importance of cold-water refuges to the public; and
- Protect, manage, and restore those areas in the future.

<u>Historical Water Quality Data</u>

In 1996, and from 1999 to 2002, NWAI conducted monthly water quality monitoring at 18 sites. Additional data (1980, 1988, 2005) for some of those sites were obtained from the Department of Environment and Local Government (DELG). Only one site in the watershed (NASH-B at the Marysville Bridge) was monitored between 2005 and 2016. These data are available in our 2017 State of the Nashwaak Report. The NWAI resumed water quality and temperature monitoring in 2017 after a 15-year hiatus.

<u>Sources of Pollution in the Nashwaak Watershed</u>

Point Source Inputs

Point source pollution can be traced back to a specific source, such as a discharge pipe. Point source inputs in the Nashwaak Watershed include:

- Stormwater outfalls in Marysville, Barkers Point, and Stanley
    - Carry materials such as petroleum hydrocarbons, metals, road salt, pathogens, and silt.
    - May alter discharge (flow) regimes.
- Municipal wastewater treatment plants in Barkers Point and Stanley
    - Can introduce suspended solids, bacteria, chlorine, ammonia, biochemical oxygen demand (BOD), phosphorus, and nitrate.
    - Wastewater can alter the temperature and oxygen levels of the receiving waters.
    - All wastewater outfalls in the watershed are required to be licensed by the NB DELG and when facilities are operating in accordance with permit limits, the discharge should not result in a violation of the water quality criteria.
- Lumber mill in Devon, sawmill at McLaggan Bridge (closed?), and veneer mill in Napadogan
    - Potential contamination by hydrocarbons, suspended solids, metals, and biochemical BOD.
- Former army encampment at McGivney
    - Used as a munitions depot between the late 1930s and mid-1950s, and

    - Potential continued contamination from ammonium, nitrate, hydrocarbons, and explosives.
- Envirem Organics compost facility on Killarney road

Non-Point Source Inputs

Non-point source pollution comes from many diffuse sources or areas and cannot be pinpointed to a specific location. Non-point source pollution poses a significant threat to New Brunswick's rivers. Carried by snowmelt, rainwater, and ground water, non-point source pollution contributes sediments, nutrients, toxins, and pathogens to watercourses (Maine Rivers, 2005). Non-point source pollution in the Nashwaak Watershed includes:

- Urbanization in Marysville and Fredericton
    - Can alter stream- and river-courses by culverts and ditching;
    - Construction can lead to sediment runoff;
    - Hard surfacing of land can lead to increased runoff, decreased infiltration and altered discharge patterns that cause erosion downstream;
    - Increased flashiness of streams; and
    - Increased human populations lead to increased releases of contaminants to the environment (metals, fuels, oils, pesticides, etc.).
- Active and closed domestic and industrial dump sites at Ryan Brook, Cross Creek Station, Durham Bridge, and Tay River
    - A wide array of potential contaminants not easily quantified due to the lack of knowledge about what is buried there. Possibilities include chloride, hydrocarbons, metals, and BOD.
- Agriculture
    - Removal of riparian vegetation and introduction of bacteria, nitrate, phosphorus, and suspended solids through surface run-off and erosion; and
    - Spreading of manure can introduce pathogens and decrease oxygen content of water.
- Topsoil mining below Durham Bridge, at the lower Taymouth and aggregate (gravel) mining operations on the Penniac Stream
    - Increases suspended solids in run-off as well as nutrient and bacteriological loading when manure is spread of re-seeding; and
    - Leads to eroded banks and widening of the river.
- Industrial/commercial activities in Marysville and Barkers Point
    - A wide array of potential contaminant issues including hydrocarbon, metals, etc.
- Public and logging road construction and maintenance
    - Exposes, compacts and erodes soils leading to suspended solids loading and altered discharge patterns;

    - Culverts can impact fish passage if not properly installed or maintained; and
    - Increases salt, chemical, and nutrient runoff.
- Forestry
    - Exposes soils over large areas, decreases infiltration of precipitation, and increases runoff leading to suspended solids loading, metal leaching, reduction of shading, herbicide spraying that can contaminate waters, and road construction that can impact fish passage and change drainage patterns; and
    - Clear cutting can alter the timing of snow melt and reduce biodiversity.
- Camp development in the headwaters and septic leaks
    - Introduction of nutrients and bacteria.
- Bank erosion, especially near Taymouth
    - Introduction of metals and suspended solids loading.
- Future mine development at Sisson Brook
    - Potential for contamination by metals and hydrocarbons;
    - Increased road construction will alter drainage patterns; and
    - Diversion of water for the mine may lower local water table levels.

The underlying bedrock of the Nashwaak watershed consists of metamorphic and igneous rocks near the headwaters and of sandstone in the central and lower watershed. These sediments contribute to naturally high background concentrations of metals such as aluminum and iron in the water. The bedrock is covered by morainal blankets deposited by glaciers between 85,000 and 11,000 years ago. Most soils in the watershed are well-drained to moderately well-drained but are highly erodible (Parish Aquatic Services, 2016).

Alluvial (river-associated) deposits along the riverbanks of the Tay and Nashwaak River valleys consist of recently deposited gravel and sandy gravel (DNR, 2007). These deposits tend to be capped with a 0.5 to 1 m thick band of more fertile fine-grained silts and sands.

Ultimately, the characteristics of the bedrock and soils play major roles in the movement of water over and through the watershed. Where and how the water moves provide opportunities for some plants and animals and constraints for others.

<u>Historical Temperature Data</u>

Limited and inconsistent historical temperature data exist for the Nashwaak Watershed. Temperatures loggers were placed by the NWAI in at least seven locations in 2002 and several locations in 1999 however, the whereabouts of the raw data is unknown. Information was pulled from a NWAI's Water Classification report (NWAI, 2004). For the logger data from reports, measurements ranged from 0.3 to 25°C for the main stem of the river. Temperatures peaked from the last week of June to first week of August and then dropped off quickly in September. NWAI's Water Classification report (NWAI, 2004) noted that overall results for the watershed were within acceptable range for salmonids and two tributaries (Messer's Brook and an unnamed tributary to the Tay River near its mouth) displayed temperatures of 8 - 11°C throughout the year, which are exceptional temperature regimes. Mean summer temperatures from the 2002 logger data ranged from a low of 14.38 ± 2.48°C for Cathle Brook to a high of 17.05 ± 3.81°C for Cross Creek Stream; however, data was not taken over the same time period and it's unclear if erroneous data (the loggers being in a vehicle, for example) were included in the calculations.

Temperature was also measured for some water quality grab samples taken between 1999 and 2015. Measurements of these samples ranged from a low of 0.03°C in February 2011 to a high of 28.3°C in August 2015 (both extremes were measured at station NASH-B, Marysville Bridge).

Objectives

The overarching objective of the monitoring project was to increase the NWAI's knowledge of the health of the watershed, to grow our capacity to make restoration and management decisions based on sound science. Evaluation of trends will allow the NWAI to better develop and evaluate watershed and habitat management initiatives, assess the effects of industries on water quality and temperature, predict future river conditions, communicate the health of the watershed to public, and assess the effects of our habitat restoration activities.

Methods

<u>Water Quality Monitoring</u>

In 2023 monthly sampling for water quality was carried out at 11 historic (pre-2010) sampling sites and at four other sites related to restoration projects (Campbell Creek, Porter's Brook, Neill's Flats and downstream of Nashwaak Valley Farm) throughout the watershed between May and September (Fig. 1). Additionally, 2 sites were sampled in August 2023 based on concerns of point source pollution from the adjacent composting facility. NWAI chose the 11 historical sites (out of a total of 18) based on budget, ease of access via vehicle and location (i.e., evenly spread throughout the watershed). A further site, NASH-B in Marysville, is sampled regularly by DELG staff and results are available to the public through the Government of New Brunswick (GNB) portal.

Grab samples were taken according to DELG guidance, in sterilized bottles provided by RPC. RPC is a certified laboratory in Fredericton, NB that analyzes water samples. A field sheet, provided by DELG, was completed for each sampling site that included site conditions such as weather, erosion, recreational activity, and garbage. Additionally, field parameters (DO, pH, conductivity, temperature, and TDS) were measured with handheld probes and recorded on the field sheet. In 2022 & 2023, NWAI began using a YSI multimeter to measure the field parameters. The probes and YSI were calibrated monthly according to the manufacturer's guidance. All field sheets were scanned and emailed to DELG. A blank template of the DELG and RPC field sheets can be found in Appendix A.

Samples were stored in a cooler containing ice packs during transport to the RPC laboratory. If the samples could not be delivered to the lab on the same day that they were taken, samples were stored in the refrigerator overnight and delivered to the lab early the next morning.

Samples were analyzed for *E. Coli* and the surface water package by RPC. The results were entered into a central database and graphically compared to historic (1980-2005) data. Parameter results were also compared to standards developed by the Canadian Council of Ministers of the Environments (CCME). These standards depend on the uses for which that water is intended. We considered the standards for the protection of aquatic life and those for recreational waters that were relevant to our analytical package. Results that exceeded CCME recommendations were highlighted, along with relevant information on land-use, and geology.

<u>Study Area and Land-Use</u>

The Nashwaak Watershed is located in central New Brunswick and has a drainage area of ~1,700 km^2. The watershed is sparsely populated (~15,000 people) except for the lower 5 km and remains relatively undeveloped, with 92% of the land covered by forest. Ecologically, the Nashwaak Watershed contributes significantly to the biodiversity of the province, containing rare and unique species and habitat, including at least 31 species of rare or endangered animals and 13 species of rare or endangered plants.

A variety of activities take place throughout the watershed ranging from commercial forestry, soil mining, agriculture, and residential development near the river's mouth. Each land-use creates a different impact on the rivers and streams. Although there has been a marked improvement from the past decades, the Nashwaak River is still affected by several point and non-point source types of pollution including chemical, toxic, and deoxygenating wastes from industry, forest spraying, agricultural and urban runoff, etc.

Station Descriptions

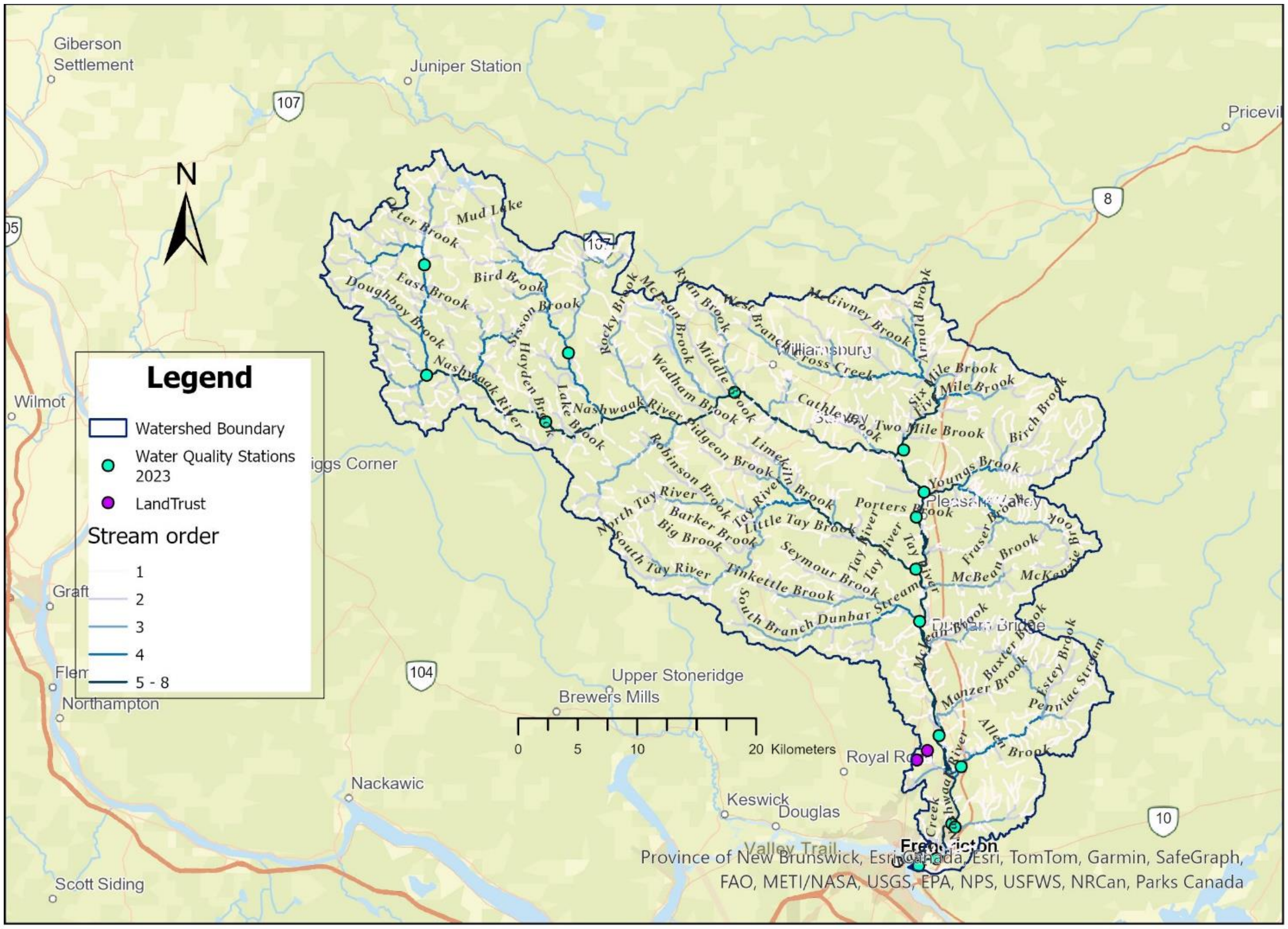


Figure 1. Water quality sampling locations for 2023. Consistent monitoring locations sampled between May-October are in green. Potential contamination site is highlighted in purple which was sampled once in August.

Stations sampled in 2023 are described below:

NASH-A: Barker's Point (DELG Station 10535)

This station is on the main stem of the Nashwaak near the mouth of the river, with approximately 1,627 km^2 of drainage area above. Additive drainage from Fisher and Kaine's Brooks (14 km^2) is comprised of 46% forested land, 10% agricultural land, 40% urban development, and 4% roadways. Pollution sources of note at this station include a major lumber mill in Devon, urban storm water inputs, industrial and commercial activities, and dense human occupation. This area is used extensively for hiking, fishing, canoeing, and cycling.

NASH-B: Marysville (DELG Station 10536)

This station is located just above the bridge in Marysville. Additive drainage from Campbell Creek and McConaughy and Second Gore Brooks is comprised of 87.4% forested land, 6% urban development, and minor wetland, agricultural land, roadways, and gravel pits. There is significant development along both sides of the river near this station. Pollution sources of note include urban development, storm water inputs, and dense human occupation. This area is used extensively for fishing and recreation.

Note: This site is sampled and monitored by DELG.

Campbell Creek

This station is located just below the bridge over Campbell Creek on River Street. This station also receives water from First and Second Gore Brooks, and some unnamed tributaries. The 28 km^2 land drainage is almost 100% forested. There was a 100-year-old dam above the station that impeded water flow and prevented fish passage. In the summer of 2020, the head pond was drained using gravity syphons in late September. In 2021 the dam was removed, and flow was restored to the creek. Pollution sources could include road salt and forestry practices.

Campbell Creek- CC Head Pond

This station is located above the former dam on the Goodine property. The land was forested, but since the removal of the dam and receding of the former head pond, is mostly open grassy field with upland forest.

NASH-D: Penniac Stream (DELG Station 10539)

This station is located on the Penniac Stream just above the new bridge on Rte. 628. Several tributaries drain to this station: the North Branch of the Penniac Stream, as well as Gilmore, Whitlock, Allen, Jakes, Moore, Baxter, Moosehole, and Estey Brooks. Additive drainage is comprised of 92.6% forested land, 4% agriculture, 2% wetland and minor human occupation, gravel pits, and roadways. Pollution sources of note include forestry practices, topsoil mining, and significant cattle grazing. This area is used for hunting, fishing, and recreation.

NASH-F Dunbar Stream (Station ID 10541)

This station is on Dunbar Stream about 30 m upstream from the confluence with the Nashwaak and downstream from Dunbar Falls. The station also receives water from Thomas Lake (2 Ha), Stickles Lake (1.5 Ha), North and South Dunbar Brooks, Tinkettle Brook, and Seymour Brook. Pollution sources of note include forestry and agriculture. A major waterfall (Dunbar Falls) prevents fish from ascending the stream but provides recreational opportunities for residents.

NASH-G Tay River (Station ID 10542)

This station is on the Tay River approximately 50 m upstream from its confluence with the Nashwaak River. This station also receives water from the North Tay River, the South Tay River, Robinson, Pidgeon, Limekiln, Big, Barker, and Little Tay Brooks. Additive drainage is 93% forested and 5% agricultural land. Pollution sources of note include camp lot development, forestry, and major bank erosion in the lower 3 – 5 km of this river. The Tay River is popular for swimming and angling.

NASH-I2 Young's Brook/ Nashwaak Bridge (DELG Station 10544)

NASH-I is located on the mainstem of the Nashwaak above the confluence with Young's Brook near the community of Nashwaak Bridge while NASH-I2 is located at the mouth of Young's Brook. As they are so close the data were analyzed together and called NASH-I. Station NASH-I2 was sampled in after 2017. The station also receives water from Schoolhouse, Cathle, and Falls Brooks. Additive drainage is small (25 km^2) and 98% forested land with minor agriculture and human occupation. Important pollution sources include a former sawmill at Cathle Brook, camp development, and minor agriculture near Ward Settlement. This area is popular for swimming and angling.

NASH-J2 Cross Creek Stream (DELG Station 16938)

Station NASH-J is located on Cross Creek stream approximately 400 m upstream from the walking bridge near the mouth of the stream. Station NASH-J2, sampled in after 2017, is located approximately 50 m above the walking bridge. As they are so close the data were analyzed together and called NASH-J. This station receives water from Arnold, McGivney, Six Mile, Five Mile, Four Mile, and Two Mile Brooks as well as from the North and West Branches of Cross Creek Stream and from Arnold Brook Lake (<0.5 Ha). Additive drainage is 81.3% forested land, 7% agriculture, and minor human occupation and wetlands. Pollution sources of note include agriculture near Williamsburg, Centreville, and Greenhill, a small sawmill, a former army encampment at Five Mile Brook, and a closed landfill. Cross Creek has traditionally been the second most productive salmon producing tributary to the Nashwaak River. There is a heavily used ATV trail along the stream, and it is a popular place to swim. Just upstream from the mouth there is a double waterfall.

NASH-L: Currieburg (DELG Station 10547)

This station is located on the Nashwaak River downstream of Currieburg. It receives water from Grand John Lake (12 Ha), Rocky Brook Lake (4 Ha), Fleetwood Lakes (2 Ha), and Mountain, Rocky, Grand John, Wadham, McLean, Middle, Meadow, and Ryan Brooks. The 232 km^2 drainage to this site is comprised of 93% forested land and 6% wetland. There is little human occupation in this area aside from hunting camps. Pollution sources of note include a closed landfill on Ryan Brook, gravel pits at the headwaters of McLean and Rocky Brooks, a cluster of camps near Grand John Brook, and forestry. There are a series of waterfalls at Rocky Brook known as the Rocky Brook Stairs.

NASH-T: Napadogan Stream (DELG 15449)

This station is located on the Napadogan Stream about 8 km above the confluence with the Nashwaak River at the intersection with the Saint Anne Nackawic Haul Road. This station also receives water from Mud Lake (7 Ha), Napadogan Lake (20 Ha), Martha Lake (1.5 Ha), East, Bird, and Sisson Brooks. The 71 km^2 drainage to this location is comprised of 98% forested land and 2% wetland. The major source of pollution minor camp development, forestry, and road construction. The Sisson Brook Mine could cause future pollution issues.

NASH-N: Narrows Mountain (DELG Station 10549)

This station is located on the Nashwaak River at Valley Road Bridge near Narrows Mountain. Elevations in this region are around 185 m. The station receives water from Hayden Brook and several unnamed tributaries. The 218 km^2 drainage area is 100% forested land with minor logging road development. Sources of pollution are minor camp development and forestry practices.

NASH-P2: South Sisters Brook (DELG Station 10551)

NASH-P2 is located on the Nashwaak River ~ 100 m downstream of South Sisters Brook in front of a camp and just downstream of an ATV crossing of the river. This station receives water from Doughboy Lake (3 Ha), Little Doughboy Lakes, Silver Lake (3 Ha), Cedar Lake (3 Ha), East, Doughboy, Little Doughboy, North Sisters, and South Sisters Brooks, as well as several unnamed tributaries. Land use draining to this site (147 km^2) is ~ 100% forested. Sources of pollution include minor camp development, forestry, and road construction.

NASH-Q: Gorby Gulch (DELG Station 10552)

This station is located on the mainstem of the Nashwaak approximately 20 m upstream from the Gorby Gulch Road Bridge. This is the uppermost monitored location on the mainstem and is at an elevation of 275 m. This station receives water from Upper Nashwaak Lake (93 Ha), Governor's, Otter, and Welch Brooks, and the East and West Branches of the Nashwaak River. The 87 km^2 of land drainage above the station is 100% forested. Pollution sources include minor camp development, forestry, and road construction.

NVF-Down

This site was also sampled for an AEI cyanobacteria project. Limited parameters were measured. This site was previously sampled in 2019 as it was related to a bank restoration project carried out that year. NVF-Down is located ~ 50 m downstream of the restored section of bank. The landowner usually had horses grazing in the field adjacent to the restoration site in the summer of 2020. This site also receives water from Manzer Brook, McLean Brook, and several unnamed brooks. Pollution sources of note included sediment from the eroding bank, soil mining operations upstream, livestock on the property, and residential development upstream.

Neill's Flats

This site was also sampled for an AEI cyanobacteria project. Limited parameters were measured. The site is located about 2 km upstream from NASH-A with approximately 1,627 km^2 of drainage area above. Additive drainage from Fisher and Kaines Brooks (14 km^2) is comprised of 46% forested land, 10% agricultural land, 40% urban development, and 4% roadways. Pollution sources of note at this station include a major lumber mill in Devon, urban storm water inputs, industrial and commercial activities, and dense human occupation. This area is used extensively for hiking, fishing, canoeing, and cycling.

Porter's Brook

The Porter's Brook sampling location is located just below a culvert that crosses the now closed Nashwaak West Road. The road has been closed for over 15 years and it and the culvert are deteriorating rapidly. Porter's Brook drains directly into a salmon-holding pool downstream in the Nashwaak. If a culvert failure or blow-out were to occur irreparable damage due to erosion and sedimentation might be incurred in the stream and pool downstream. Porter's Brook is a relatively short stream with a functional upstream length of 1.18 km above the culvert. There is a single unnamed stream which feeds into the brook. The brook's drainage area is 2.1 km^2 and the predominant landcover type is natural vegetation (95%), 81 % of which is forest, the remaining landcover types are agricultural (1.5%) and urban (3.2%). Potential pollution risks include those associated with forestry, agricultural and residential activities.

Temperature monitoring

NWAI replaced 3 loggers for monitoring in 2023. In total, we deployed 39 loggers at the start of the season, in late May. We removed a redundant site at Campbell Creek and moved the monitoring location of McConaghy brook for pre-restoration monitoring to a more suitable location. Tributaries were selected for monitoring based on locations (spread throughout the watershed), size (a mixture of larger and smaller tributaries), and ease of access.

The HOBOware software package was used to program and launch the loggers before deployment. A delayed start was chosen so that the loggers would only begin logging after deployment in the water. Each logger was set to record water temperature every hour. This was changed this season from the 6-hour logging duration previously employed. This decision was based on recommendations from a local hydrological engineer familiar with thermal monitoring. Casings were made to protect the loggers from UV radiation, current, and debris. The casings were made from grey PVC pipe cut to 15 cm lengths drilled with 5 mm diameter holes. The PVC was attached to a 60 cm piece of coated rebar with a hose clamp and two zip ties. After launching, the logger was inserted into the PVC pipe and secured with a length of high tensile picture wire and a zip tie. An additional zip tie was secured through the top of the pipe to prevent the logger from floating to the surface (Fig. 2). The design was similar to that used at the Canadian Rivers Institute (CRI) and consistent with other, local watershed groups.

Figure 2. A logger in its casing prior to deployment. Zip ties were added for extra security.

The loggers were deployed throughout the watershed in late May (Fig. 3). 26 loggers were placed in tributaries and 14 in the main stem of the river. Locations were chosen where the water was at least knee deep and there was appropriate substrate to hold the rebar in place throughout the season. Sand, gravel, and cobble substrates were the easiest; silty substrate and bedrock proved challenging. The rebar was hammered into the substrate at least 1 foot so that the bottom of the PVC casing sat flush with the substrate. The pendant logger was pushed down inside the casing to ensure that it was in the deepest water possible. Rocks were piled in a cairn around the logger to prevent it from moving too much and to help us in locating it. A waypoint was taken at each logger location.

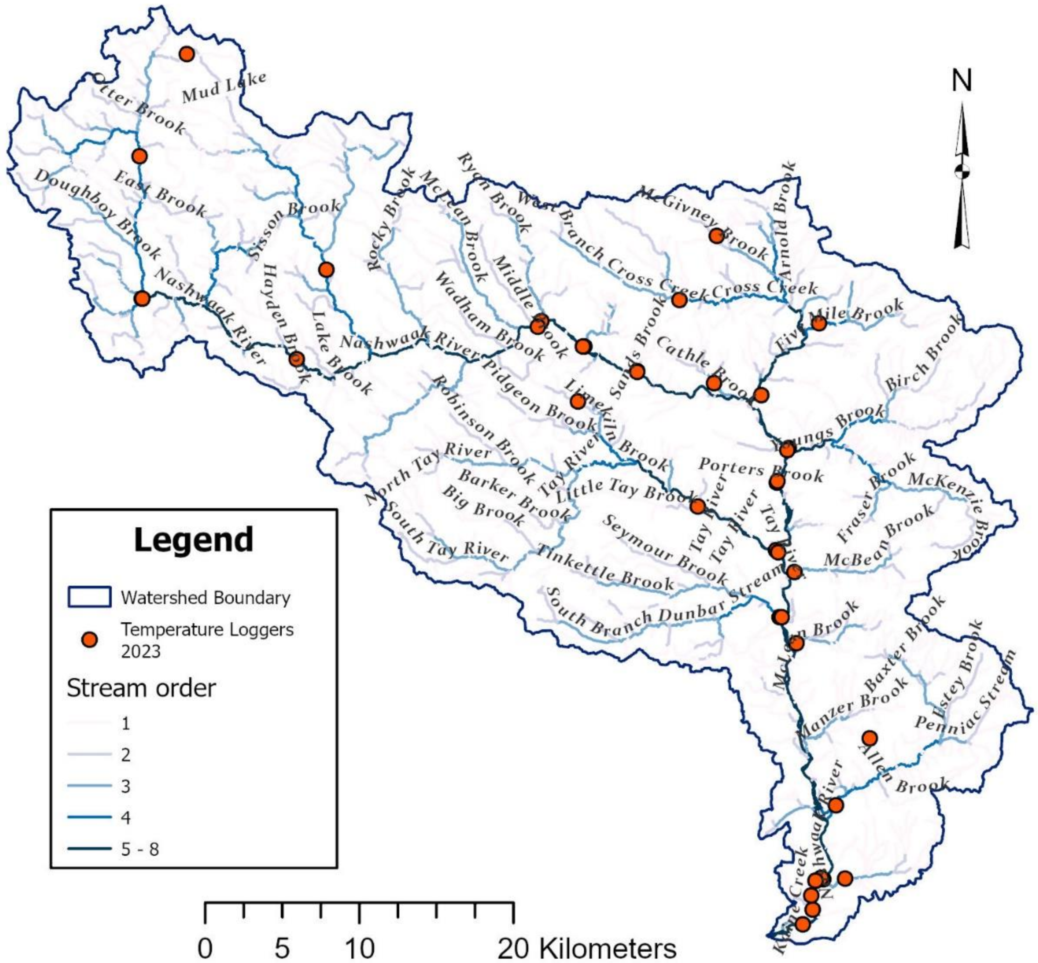


Figure 3. Map of the temperature loggers (red dots) in the Nashwaak watershed, deployed between May-November of 2023.

Due to the unprecedented, high precipitation events during this summer, there was little chance of them being exposed during low water events. The river and tributaries remained at a high/medium level throughout the monitoring season. The loggers at each water quality monitoring site were checked on during each round of sampling and the other, less accessible loggers were checked on at least 1 time. Unfortunately, an intense tropical storm event occurred in September which saw up 150 mm of rain fall over 24 hours in some areas. Several loggers were ripped from their locations and lost during this abnormally high discharge event throughout the watershed.

Temperature loggers that were found, were collected between the 4th and 6th of October 2024. Loggers were read out as soon as possible upon returning to the office. Some loggers continued logging for a couple of days before they were uploaded. Temperatures that were recorded while the loggers were sitting in the truck or office, were removed from the dataset.

Results

Precipitation

The summer between June-September 2023 was unusually wet with total and average summer precipitation the highest in the past 23 years (Figure 4 and 5). A total of 625mm of precipitation fell in Fredericton, NB, Canada between June and September 2023. Notably, July 2023 was the 2nd wettest July on record with a total precipitation amount of 190.1 mm (Figure 5). These high levels of precipitation likely impacted the monitoring results seen in this summer season. Precipitation data was obtained from Environment and Climate Change Canada (ECCC,2024).

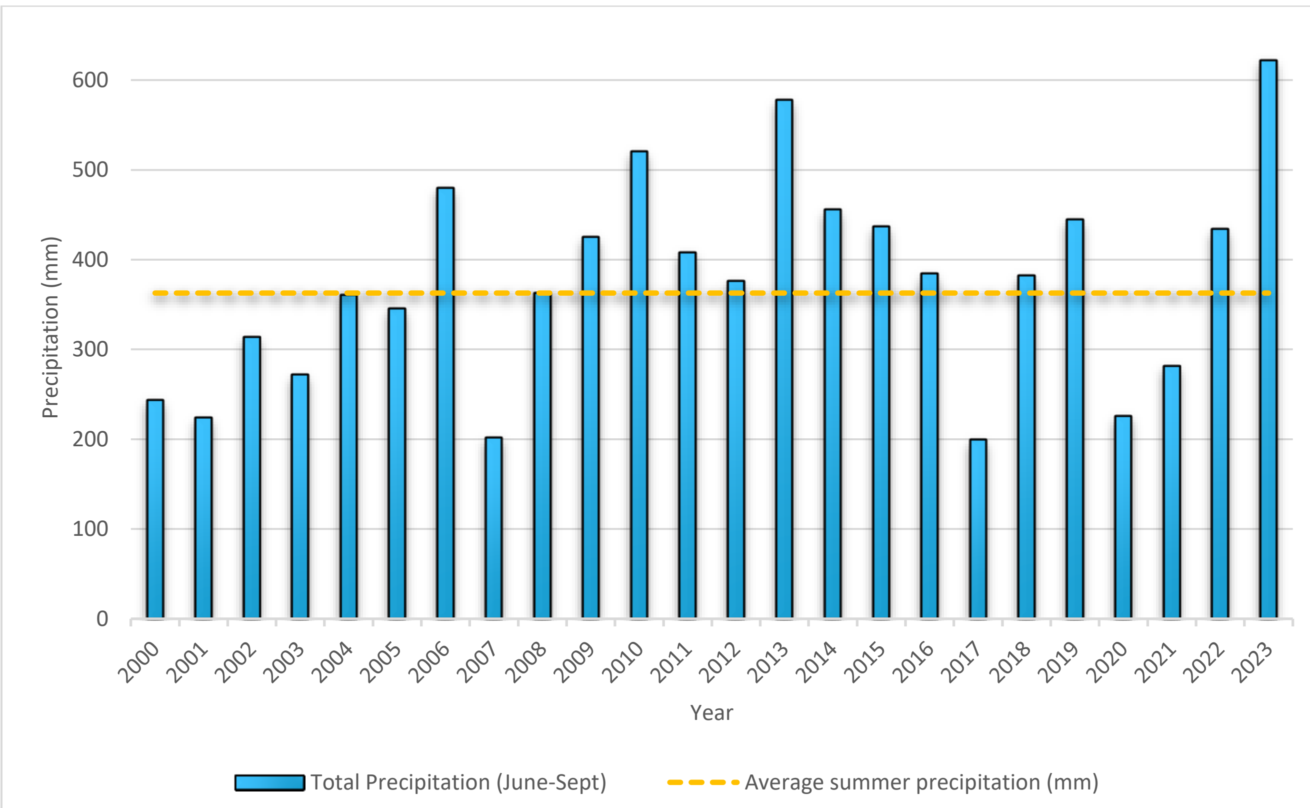


Figure 4. Total precipitation for Fredericton, NB, Canada between June-September, 2000-2023. Orange dotted line indicates the average summer precipitation (June-September) for all years. Data from Environment and Climate Change Canada (ECCC, 2024).

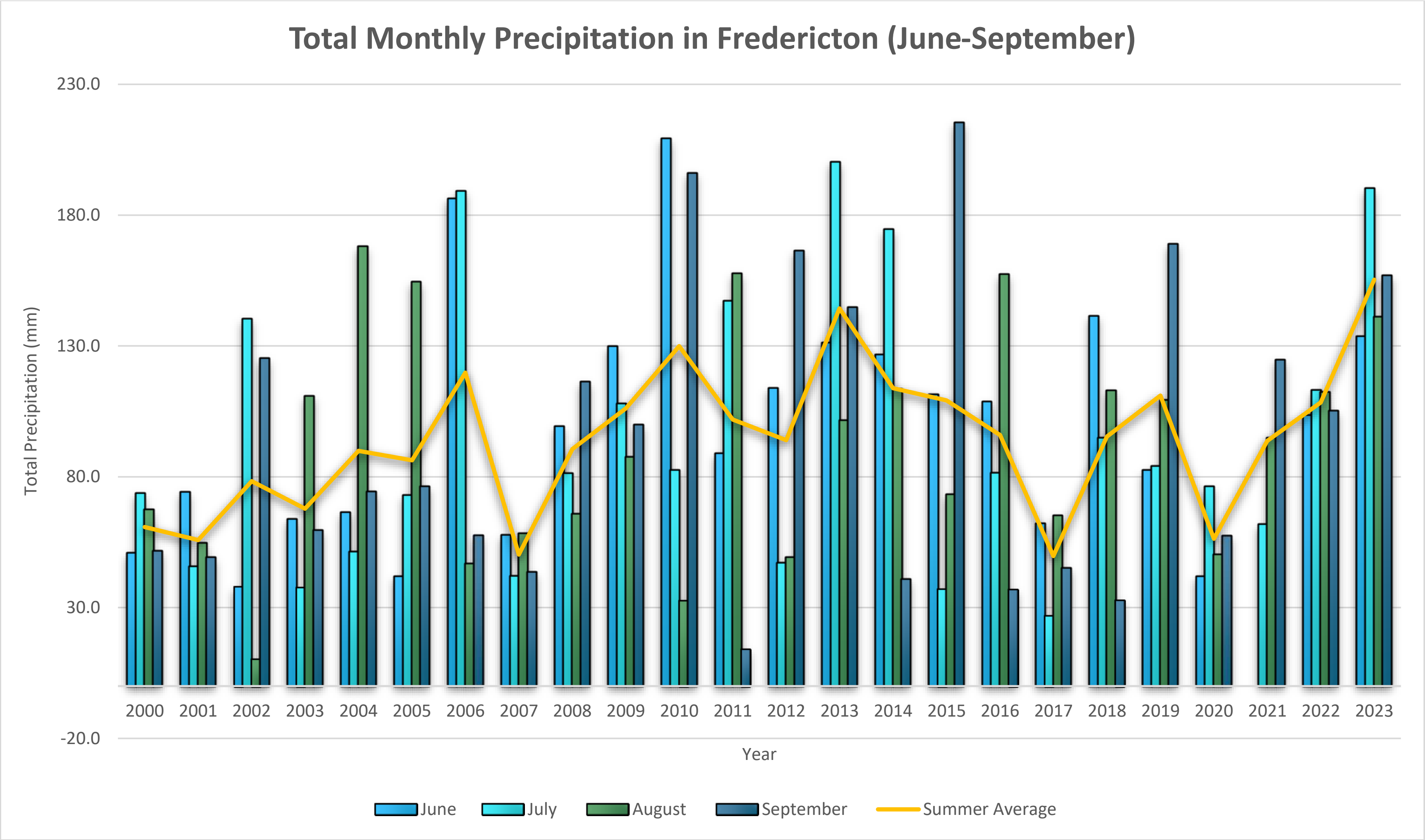


Figure 5. Monthly precipitation total (mm) at Fredericton, NB, Canada between the years 2000-2023. Results were recorded at Fredericton International Airport Station. Orange line represents summer (June-September) average per year. Data from Environment and Climate Change Canada (ECCC, 2024).

Water Quality Monitoring

A complete summary of the water quality results from the entire 2023 season is available in the attached database. Selected parameters are presented in the tables and figures below. 2023 data was compared to historic data (pre-2010) and new data (2010-2021) at each site to look at the temporal trends at several locations. Any exceedances or notable changes in historical norms are highlighted in several graphs and tables below. It should be noted that laboratory testing methods and detection limits have changed over time for certain parameters, which makes comparisons to historical norms, in some cases, difficult. Limits for certain parameters have been developed by the Canadian Council of Environment Minsters (CCME, 1999) and are included on the graphs, where appropriate.

Field Observations

The NWAI recorded field observations at the time of sampling collection. The field sheet was provided by DELG and submitted following field collections. Observations included bank conditions, weather, recreational activities etc. A blank field sheet can be found in Appendix A. Temperature, total dissolved solids, conductivity, and pH were measured with an YSI professional multimeter. These measurements were taken at the same site where grab samples were taken. The probe was calibrated before each sampling run and stored according to the manufacturer. It should be noted that the chord was not functioning properly during the summer months and was giving mixed results for both DO and pH at certain times of use.

Total Dissolved Solids

Total dissolved solids (TDS) are a measure of the combined organic and inorganic substances suspended in water. It is measured in mg/L. TDS is comprised of inorganic salts (mainly calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and a small amount of organic matter dissolved in water. There is no CCME limit for TDS, but 1,000 mg/L is considered brackish. With enough data, a normal range can be determined and fluctuations outside of this range can serve as an indication of a problem. Potential sources of TDS include agricultural and residential run-off, storm-water run-off, and road salts. TDS may also arise from weathering of rocks and erosion of soils.

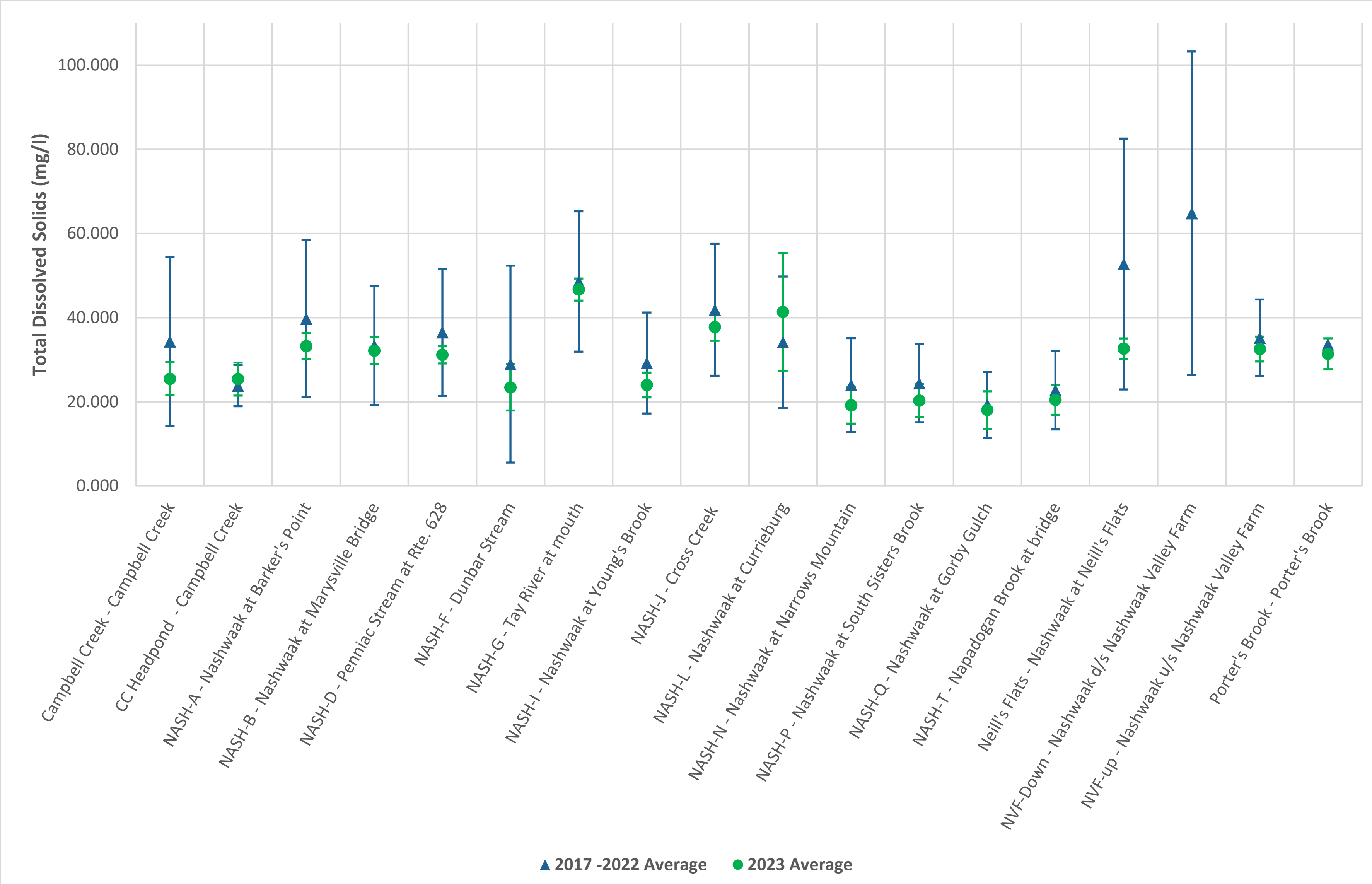


Figure 6. Mean total dissolved solid contents (mg/L) per site for the Nashwaak watershed. Error bars represent standard deviation

Field measurements of TDS content were not available prior to 2017 so there is no historical data for long-term comparison. Short-term historical data shows that the average annual TDS concentrations throughout the watershed have remained somewhat consistent over the year (Figure 4). TDS concentrations were, in general, lower in 2023 compared to the 2010-2022 data (Figure 4). The exception to this trend can be seen in samples taken at Ryan Brook (Nash-L at Currieburg) which saw a mean value of 41.350 mg/L over the 2023 season (Figure 5). While the mean 2023 TDS average was lower than the 2022 average of 47.025 mg/L at this site, the average values are still 17% higher than the 2017-2022 average (Figures 4 & 5). This could be indicative of development upstream from this site which sees both forestry and private development.

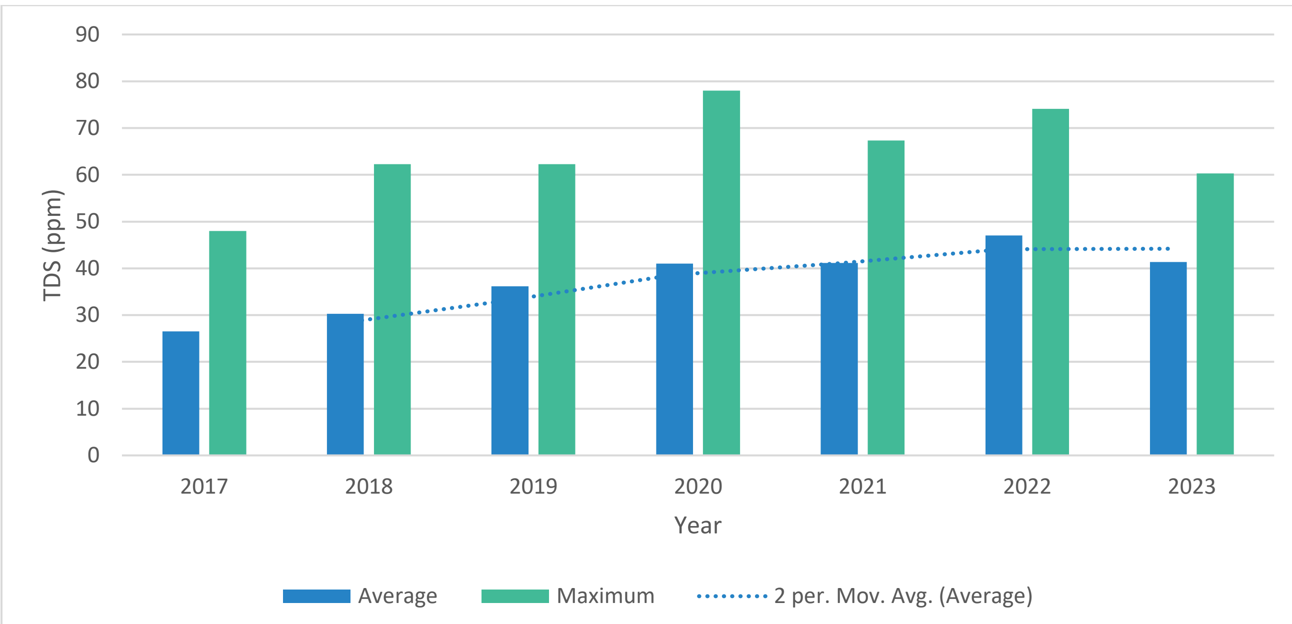


Figure 7. Total dissolved solids (TDS) values in parts per million (ppm) at NASH-L, Nashwaak river at Currieburg sampling site location. Sampling occurred annually between May-October in the years 2017-2023. The blue bar represents the average TDS value for each year. The green bar represents the maximum recorded TDS value per year. Trend line is based on a moving average.

Conductivity

Conductivity is a measure of a stream's ability to carry an electrical current. It is recorded in micro-Siemens per centimetre (µS/cm). Conductivity can be influenced by the presence or absence of inorganic dissolved solids such as chloride, nitrite, sulfate, phosphate, sodium, magnesium, iron, and aluminum. It is also affected by water temperature (higher temperature means higher conductivity). Conductivity is generally determined by geology. The igneous rocks (granite) of the headwaters of the Nashwaak watershed result in lower conductivities while glacial till and clay soils results in higher conductivities because of the presence of materials that ionize when washed into the water. Road salt run off can result in very high conductivity in waters.

There is no CCME limit for conductivity, but most rivers naturally have a conductivity range from 50 µS/cm to 1500 µS/cm but measurements between 150-500 µS/cm are within the desired range. If measurements are recorded outside of a typical range for a stream, it can be an indication of a change in chemistry. Wastewater, agricultural inputs, and failing septic systems can result in higher conductivities due the presence of nitrate, chloride, and phosphates.

Since 2017, conductivity has been measured in the field as well as was at the lab. Prior to 2017, conductivity was not measured in the field so lab results are used for comparative analysis (Figure 5). The field measurements have been very close to the lab results and thus justify a similar comparison. Historically, conductivity values in the lower watershed (below Giant's Glen) were in the range of 50-80 µS/cm while in the upper watershed they were 30-40 µS/cm. These values are likely influenced by the underlying rock types though in urban areas below Taymouth, anthropogenic sources such as wastewater and agricultural inputs are contributing to the higher values.

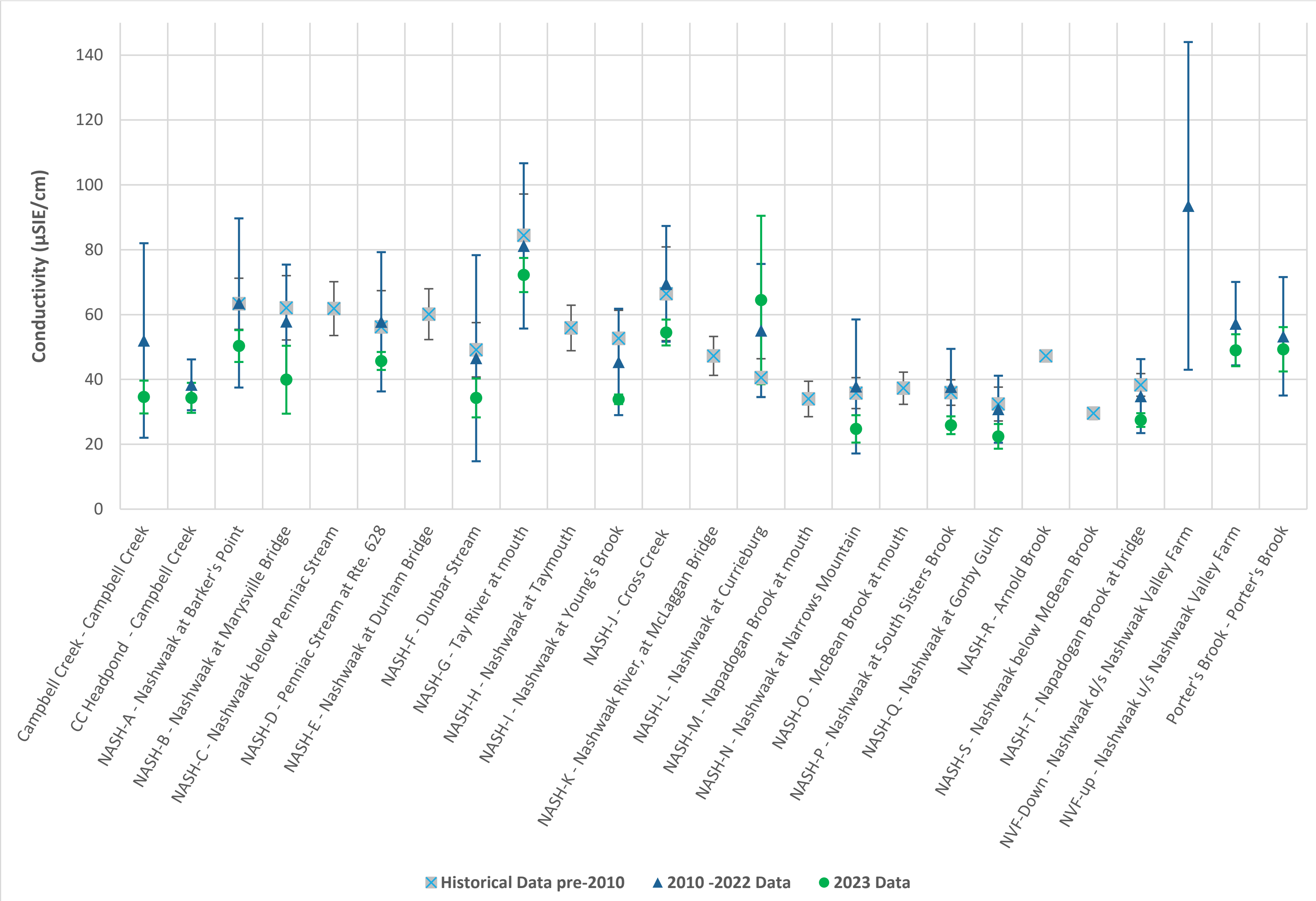


Figure 8. Conductivity measured in µSIE/cm per site across the Nashwaak watershed. Error bars represent standard deviation.

The highest values were consistently sampled in the lower watershed, both historically and in 2023. The exception to this would again, be NASH L-Nashwaak at Currieburg which saw an increase of 17% in average conductivity, when compared to the average results between 2010-2022. It should also be noted that in 2023 Nash-L (Ryan Brook) also saw an 18% increase in mean conductivity readings when compared to the average between 2010-2022. Most notably, this site also had the 2nd and 3rd highest 2023 field measurements in the watershed at 88 and 98 µSIE/cm respectively.

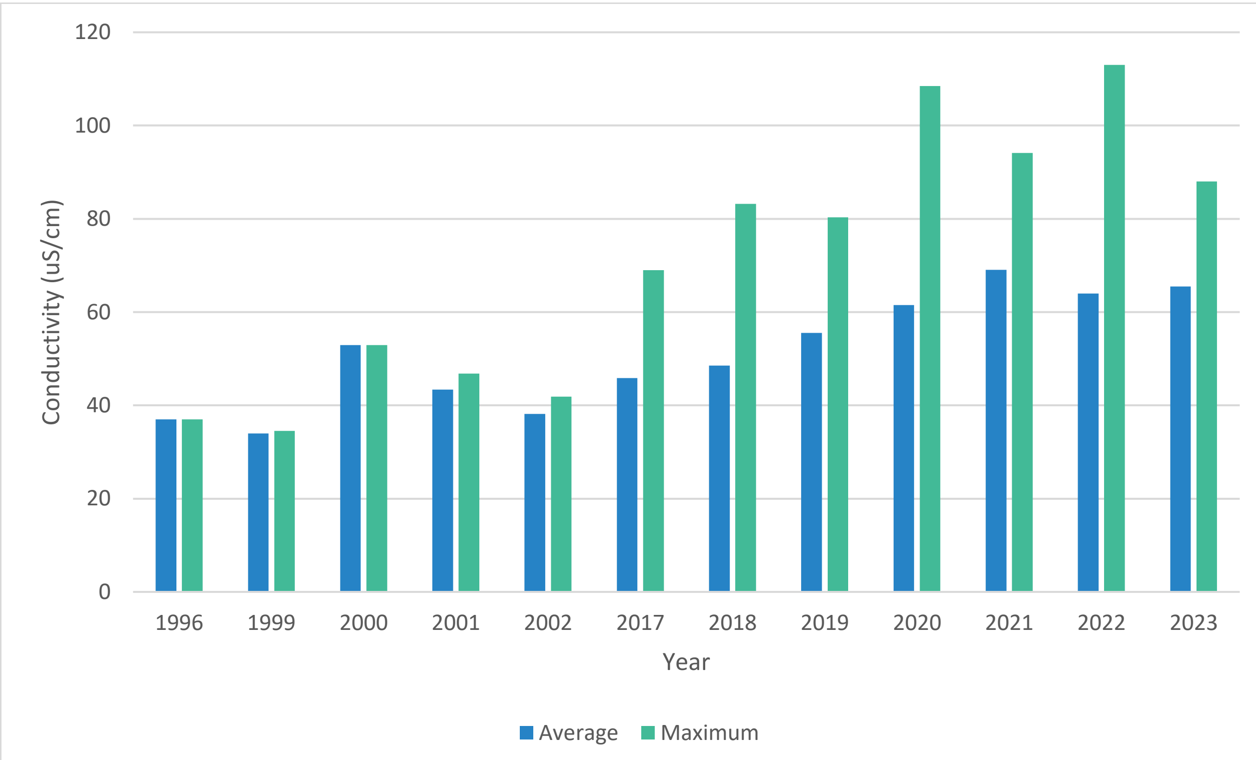


Figure 9. Conductivity values for sampling years between 1996-2023 at site "NASH-L- Nashwaak at Currieburg" on the Nashwaak river, NB, Canada. This site is located at the mouth of Ryan Brook. Samples were collected between May-October annually. The blue bar represents the average annual conductivity value. The green bar represents the maximum annual value.

Turbidity

Turbidity is a measure of the extent to which light penetration in water is reduced due to the amount of sediment suspended in the water column. Generally, values below 10 NTU are acceptable. Values greater than 10 NTU mean that light will be blocked from reaching aquatic plants and feeding of zooplankton will be disrupted. 50 NTUs is the CCME limit for recreational uses while the CCME guideline for the protection of aquatic life is an increase of 8 NTUs from background values for short-term exposure or 2 NTUs for longer exposure. Turbidity normally spikes during and immediately after periods of high rainfall or snowmelt.

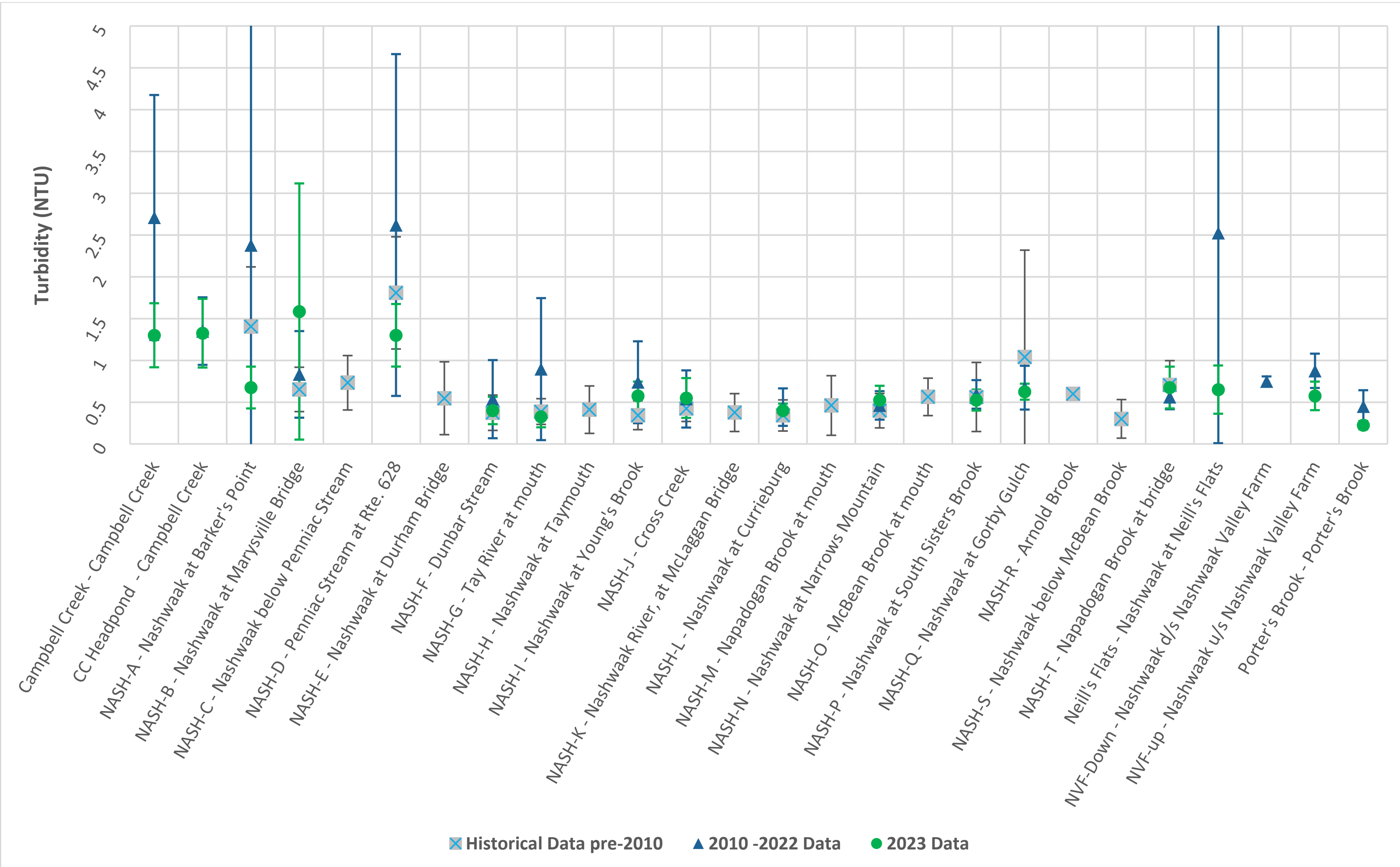


Figure 10. Turbidity (NTU) per site in the watershed. Error bars represent standard deviation.

As visible in Figure 10, the average turbidity values in 2023 were, in general, lower for most sites when compared to the recent historical averages seen between 2010-2022. Results showed average site values between 0.33 to 1.5 NTU, with the highest reading being recorded at "NASH B-Nashwaak at Marysville Bridge" (5.6 NTU) in September. It should be noted that measurements taken at this location in October showed that the readings had reduced to 1.3 NTU. This result is within the CCME guidelines for short-term exposure. Long-term trends show that both average and maximum values for turbidity have increased at this site, on average, since monitoring began (Figure 11). This could be due to the increase in urban development in the Marysville community over the past decade.

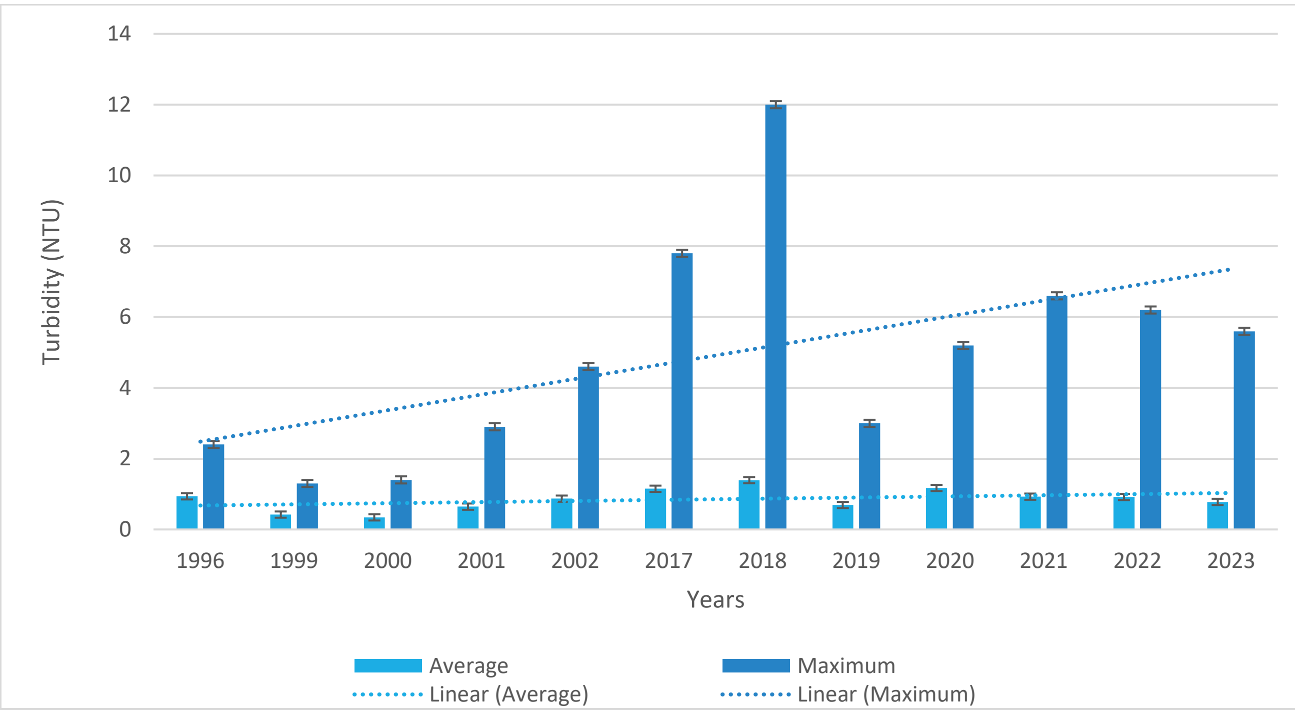


Figure 11. Turbidity measurements taken at site "Nash B- Nashwaak at Marysville Bridge" in the Nashwaak river, NB, Canada between 1996-2023. Blue bar represents annual averages for samples collected between May-October. The dark blue bar represents maximum readings taken each year. Line represents standard deviation of all data.

Suspended Sediments

Suspended sediments consist of clay, silt, fine particles of organic and inorganic matter, plankton, and other microscopic organisms. Suspended sediments naturally vary depending on soil type, shoreline erosion, and surrounding land use.

The CCME guideline for the protection of aquatic life is an increase of no more than 25 mg/L in suspended sediments for short term exposure (<24 hours) and 5 mg/L for longer term exposure. Suspended sediment loads, in general, increased at most sites between the 1980s to the 2000s but were not measured after 2005 as it was no longer part of RPC's surface water package. Turbidity, colour and total dissolved solids are still being measured, which still gives an accurate picture of the sediment loading in the watershed. Increased sediment loads can aggrade channels, which in turn leads to bank erosion and the destruction of habitat. As the laboratory and field measurements changed from the 1980s to the 2000s, long-term, historical comparisons cannot be made. Short-term historical comparisons of sediment loading can be seen by viewing sections dedicated to turbidity (Figure 10) and total dissolved solids (Figure 6).

pH

pH is a measure of the acid/basic nature of the water. It is the logarithmic measurement of free hydrogen ions in a solution. It is measured on a scale from 0-14 with 0 being acidic, 14 being basic, and 7 being neutral. The buffering capacity of a stream is its ability to resist changes in the pH of the water.

pH varies naturally but can be affected by human interference, surficial geology, wastewater run-off, the presence of wetlands, and by acid rain. Low pH levels create stress for fish while high pH can lead to death or damage to eyes and gills. CCME limits for pH are between 6.5 and 9.0. pH must be measured in the field because the value will change and approach 7 as carbon dioxide from the air dissolves in the water. Data comparisons have been challenging because pH was not regularly monitored in the field between 1980 and 2002. Lab measurements were not compared here as they can differ between those collected in the field.

For the data available, pH levels for the watershed were mostly within the CCME limits across all sites (Figure 12). Unfortunately, the YSI probe used during the 2023 sampling period was defective, often detecting values that were lower than the normal range or measuring levels that were out of the norm for freshwater systems. The YSI was confirmed defective in late 2023 by the equipment provider, Hoskin Scientific ltd. It is unclear how many measurements were inaccurate. For this reason, major outliers were removed, and the 2023 pH results will not be used to make any specific inferences on the water quality. The remaining results can still be viewed in Figure 12.

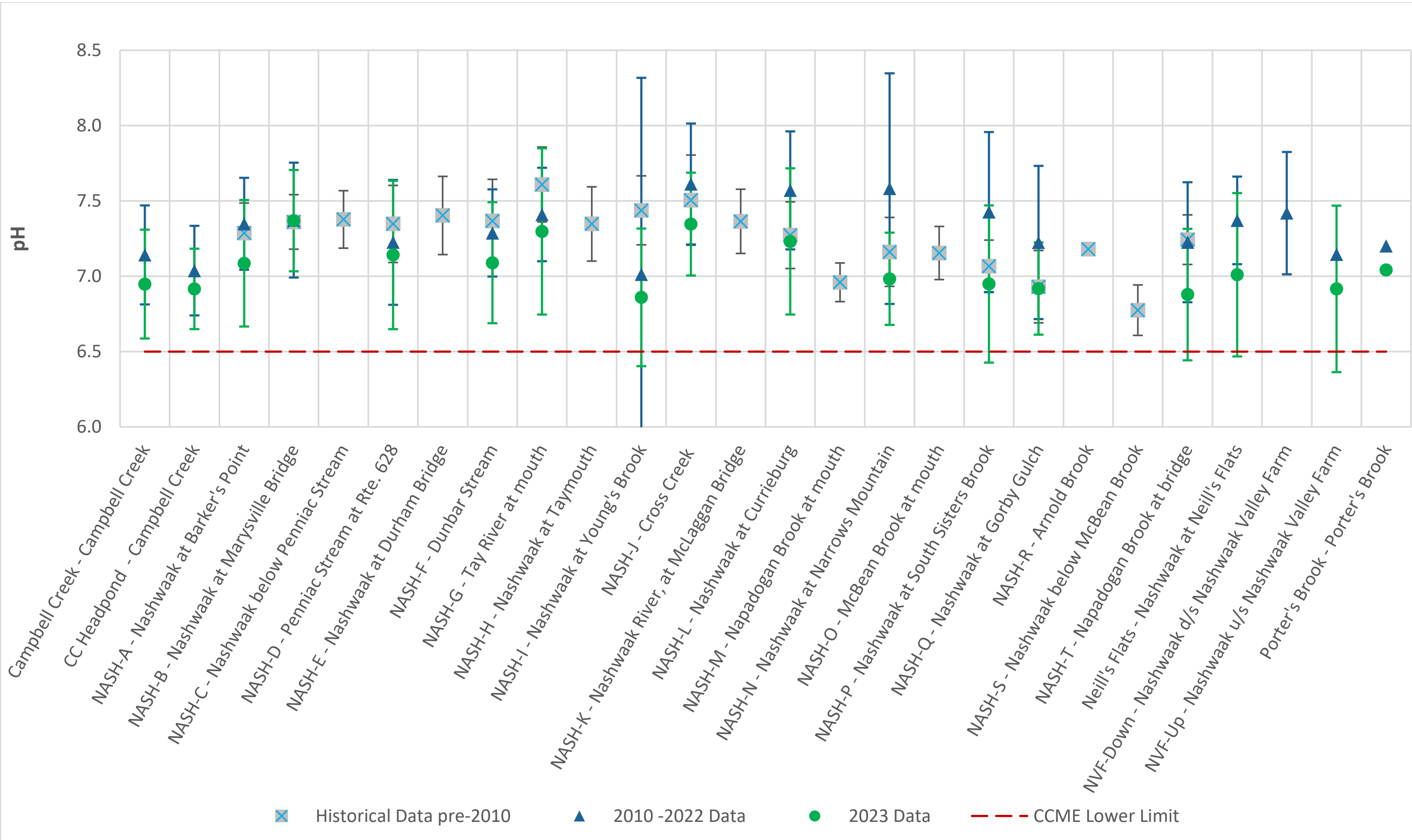


Figure 12. pH (values measured in the field) per site in the watershed (for those sites where data were available). Errors bars represent standard deviation. Historic field measurements were not available for most sites.

Dissolved Oxygen

Dissolved oxygen (DO) is a widely used and important indicator of aquatic health. Organisms require oxygen dissolved in the water to survive. Levels below 6.5 mg/L can cause stress, especially for cold water fish, and levels below 9.5 mg/L can cause stress to early life forms. Dissolved oxygen decreases as water temperature increases (i.e., warm water can hold less oxygen than the same volume of cold water). Sewage or algal blooms resulting from elevated nutrients can lower the DO content by consuming oxygen.

Rivers, in general, can accept and assimilate a certain number of oxygen-demanding wastes. However, if too much organic material is discharged, oxygen can become severely depleted leaving insufficient oxygen for aquatic organisms. Fish under stress from low oxygen levels become more susceptible to the effects of other substances discharged into the river.

We began measuring DO with a YSI professional plus multimeter in 2022. Unfortunately, there were multiple problems with the quality of the DO membrane on the probe and the results we obtained were not reliable. DO concentrations were still recorded within the CCME limits, with the exception being at Cross Creek. Data is available in Figure 13 and 14 but will not be used to make observations on trends.

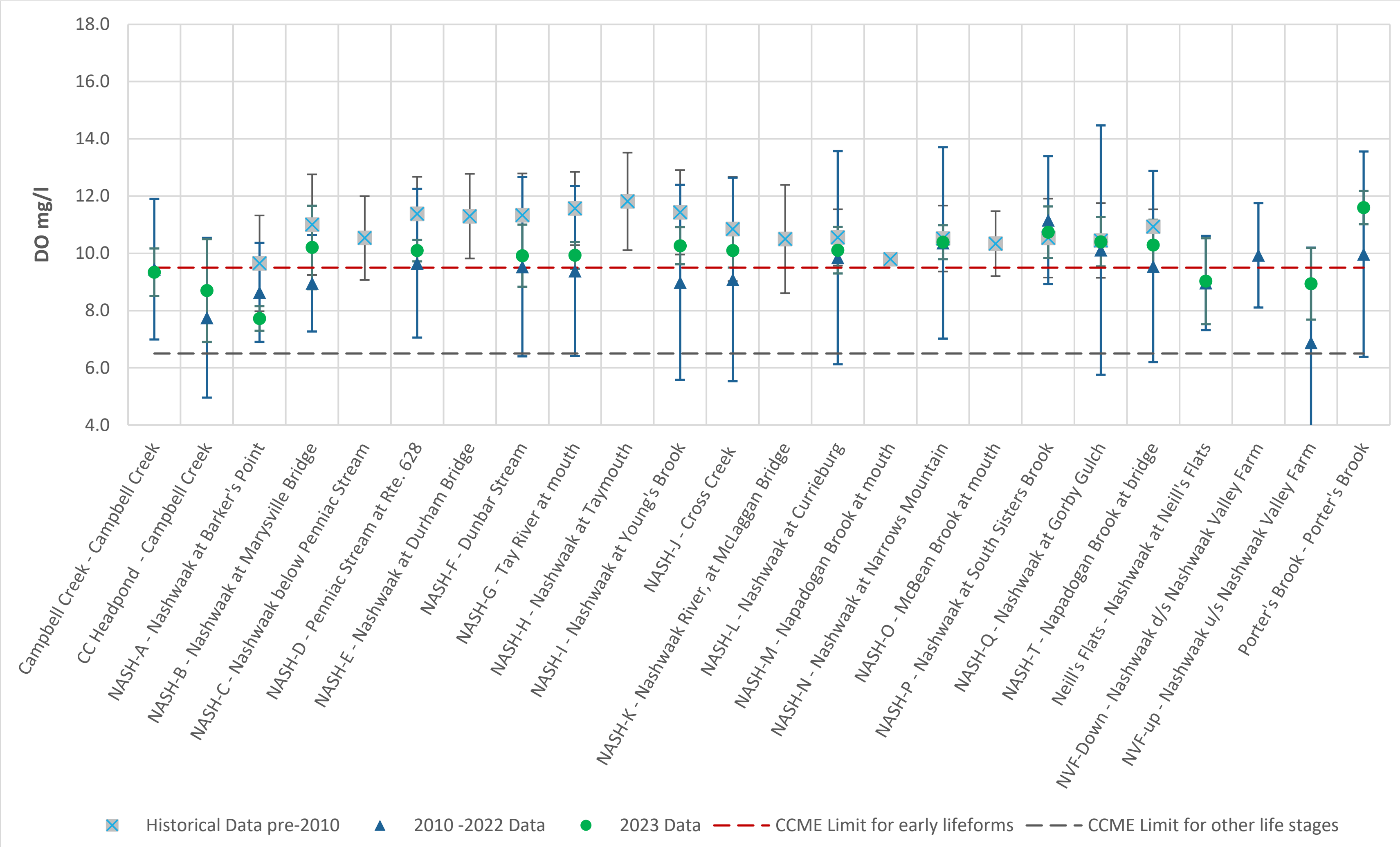


Figure 13. Mean dissolved oxygen content (mg/L) per site. Error bars represent standard deviation. Dashed lines indicate CCME limits for early life forms (9.5 mg/L) and all other life stages (6.5 mg/L).

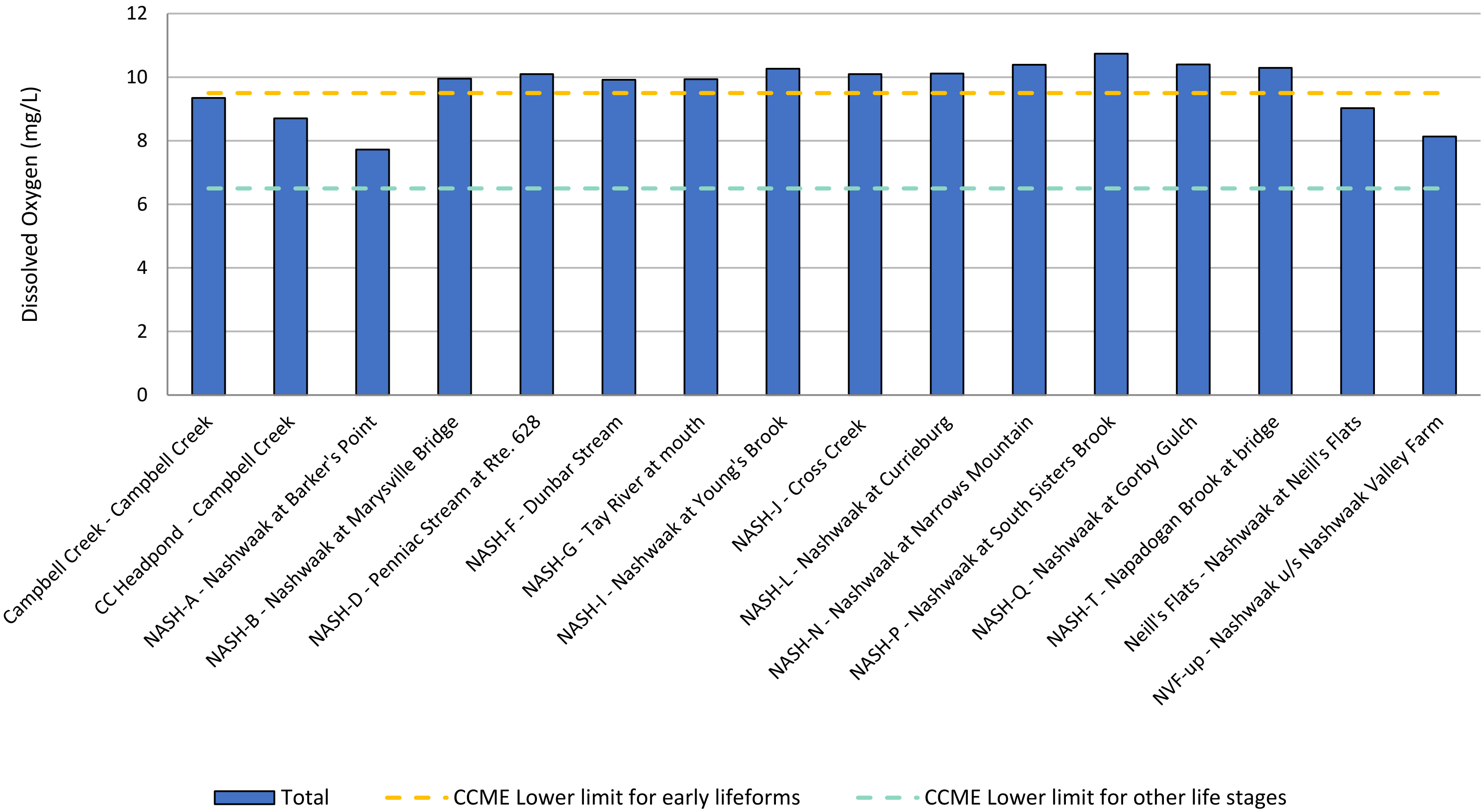


Figure 14. Average Dissolved Oxygen (mg/L) for sampling conducted between May-October 2023 in the Nashwaak watershed, NB, Canada. Orange line represents the CCME recommendation on the lowest DO concentration for early aquatic lifeforms. Green line represents the CCME recommendations for the lowest DO concentration for all other life stages of aquatic lifeforms.

Metals

Aluminum

CCME has set a limit of 0.1 mg/L aluminum at pH of >6.5 for freshwater aquatic life. The limit for drinking water and for aesthetics and recreation is 0.2 mg/L. Aluminum is a naturally occurring element in many rocks and soils and therefore, concentrations are expected to rise with increased erosion. Most Atlantic Canadian rivers have elevated levels of aluminum due to the underlying bedrock geology rather than human activity (Canadian Rivers Institue, 2011). However, increased amounts of bank erosion can lead to increased concentrations of metals in streams. When aluminum is complexed with organic compounds, it is not harmful to aquatic life (ISCRWB, 2010). Several studies have shown a link between aluminum toxicity and fish (Gensemer,1999) which decreases with increasing pH levels. Atlantic salmon are specifically sensitive to aluminum toxicity in acidic waters (Poléo et al., 1997). As the pH has remained relatively stable over the years, small increases in aluminum concentrations should have low impact on the populations of salmonids that reside in the Nashwaak Watershed system.

When looking at the historical (pre-2010) data, average aluminum levels were the highest in the 1990s in the upper watershed. Levels were slightly above the CCME limit in the upper reaches of the watershed (Currieburg to Gorby Gulch). Aluminum levels did not change significantly at any site between 1980 and 2020 though 2020 samples at the headwater's sites were lower on average than historical samples. Exceedances were likely due to the underlying geology as well as sedimentation of streams due to removal of riparian vegetation and subsequent erosion.

In 2023, several sites had aluminum values exceeding the CCME guidelines of 0.10 mg/L for freshwater systems with pH values >6.5. Average summer concentrations of aluminum exceeded CCME limits at both Campbell Creek sites throughout the summer months (Figure 16). Levels were only below the CCME threshold in June and the creek maintained elevated levels throughout the remaining summer months. Similarly, NASH B-Marysville Bridge had levels, on average, above CCME thresholds throughout the summer, with concentrations hovering just below the threshold in June (0.07 mg/L) and July (0.099 mg/L). July showed the highest concentrations of aluminum across all sites, except for NASH B and Porters Brook (Figure 16). As aluminum concentrations can be directly linked to increases in sedimentation, this is likely due to the heavy rain events that peaked in July with 190.1 mm of rain falling in the area

(Figures 4 and 5).

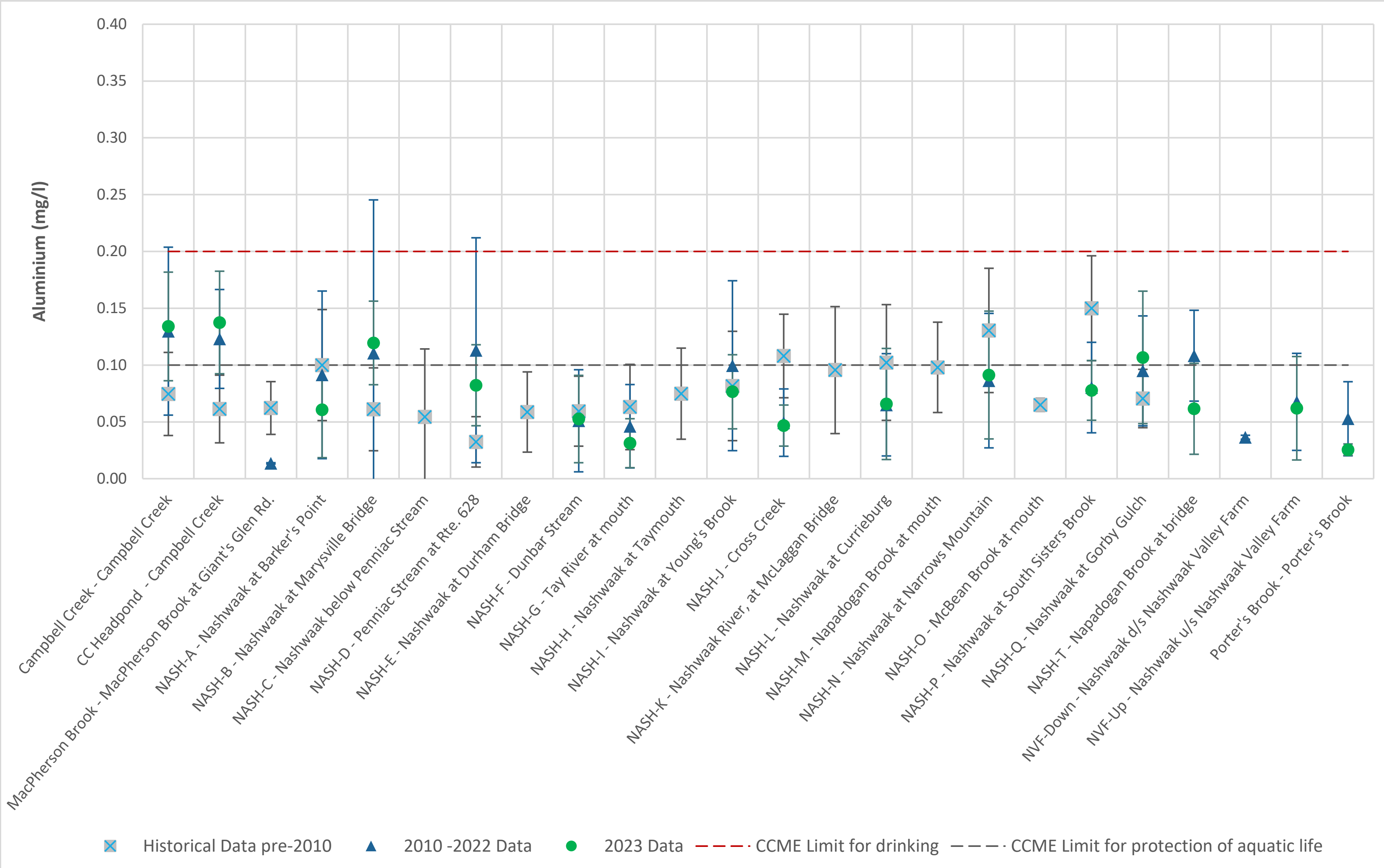


Figure 15. Aluminum content (mg/L) per site. Error bars represent standard deviation.

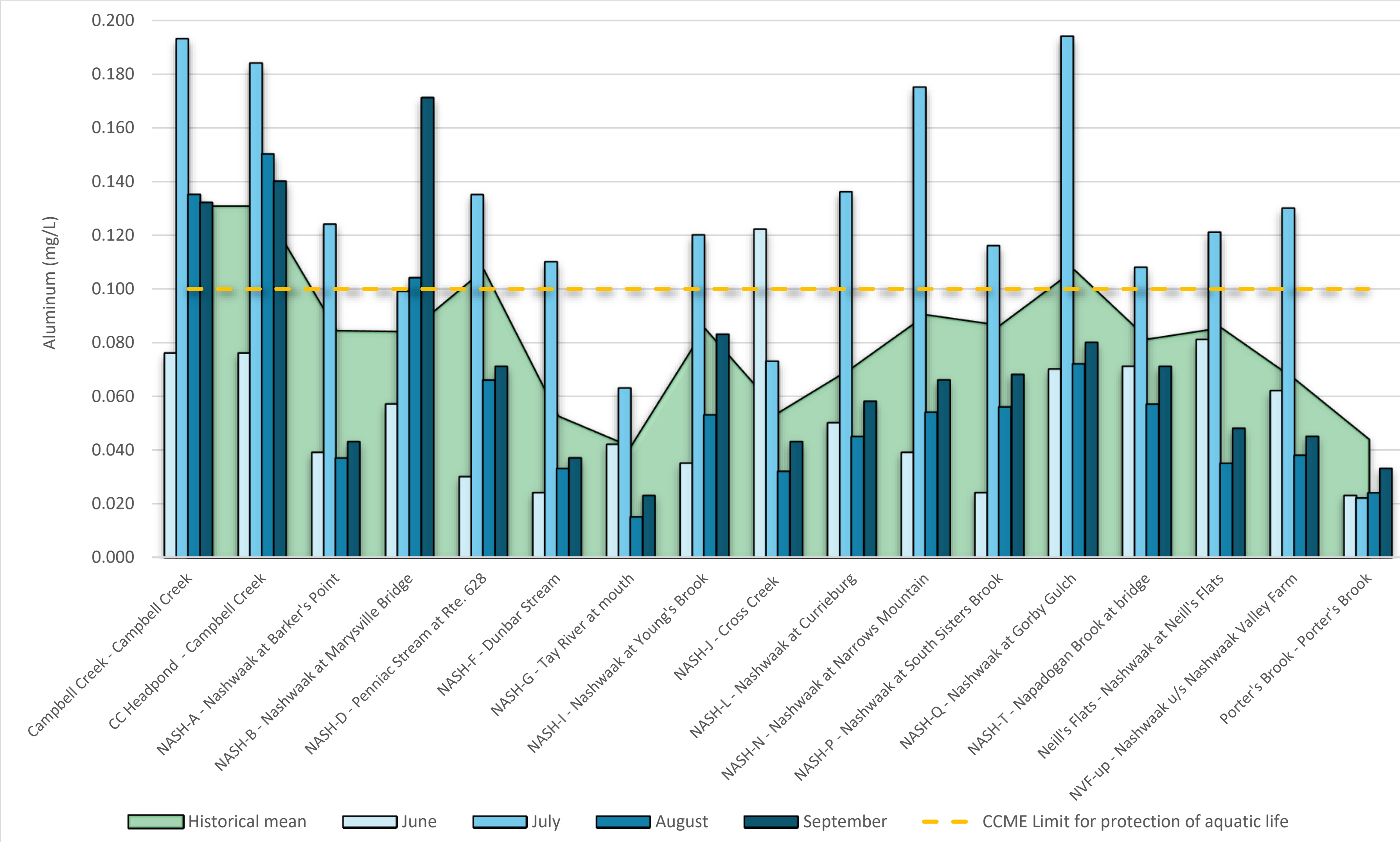


Figure 16. Aluminum concentrations between June-September in the Nashwaak watershed, NB, Canada in 2023. Orange line represents the CCME recommended guideline for the protection of aquatic life in neutral pH environments. Green fill represents the historical mean from 1996-2023.

Iron

Iron is another metal that occurs naturally in rocks and sediments. Bank erosion leads to increased levels of metals in streams due to run-off of those iron-rich sediments. However, it may also be derived from industrial waste or corroding metal pipes.

Iron content in the Nashwaak have not changed significantly at any site since the 1980s. Mean iron contents for the Nashwaak watershed were well below the CCME limit of 0.3 mg/L at all sites except for three: Penniac Stream, which has consistently just exceeded the limit throughout sampling history; and 2 at Campbell Creek, which has exceeded the CCME limit for every sample taken since 2017 (Figure 17). Although mean concentrations were mostly higher than the pre-2010 average, they were still within the normal range. Soil erosion and water sedimentation due high precipitation (Figure 4 and 5) are the likely causes of elevated iron contents observed at Penniac and Campbell Creek. Both watercourses saw a spike in both Iron and Aluminum concentrations in the wetter month of July (Figure 16 and 18).

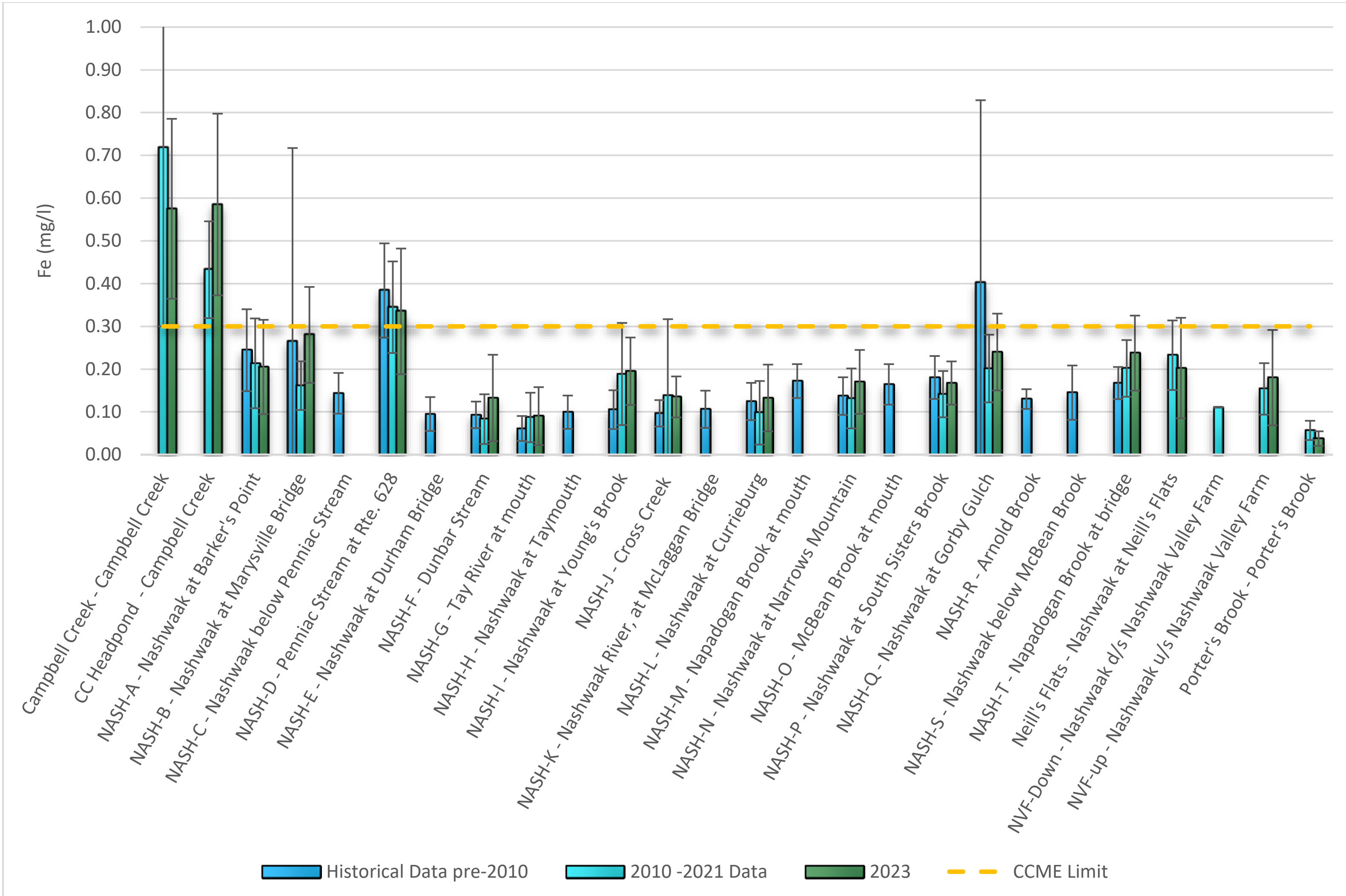


Figure 17. Mean iron content (mg/L) per site in the watershed. Error bars represent standard deviation. The dotted line represents the CCME limit of 0.3 mg/L.

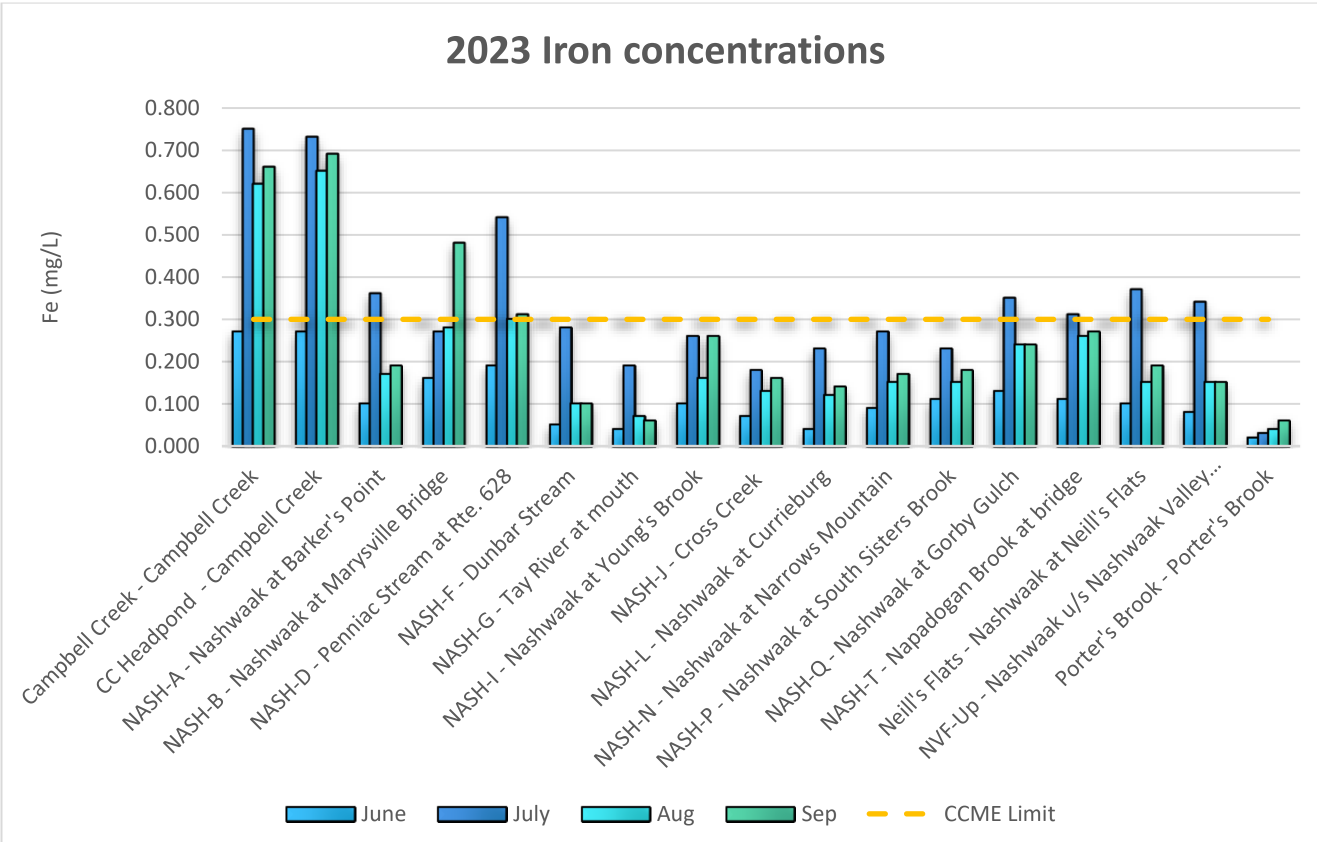


Figure 18. Monthly iron (Fe) concentrations (mg/L) for sites sampled in the Nashwaak Watershed in 2023. The dotted line represents the CCME limit of 0.3 mg.

Other metals (i.e., nickel, copper, cadmium, lead) can be associated with industrial inputs. Concentrations of these elements were mostly below detection levels and were relatively consistent throughout the watershed. There were no exceedances for heavy metals in 2023.

Escherichia coli

E. coli are bacteria that live in the digestive tract of warm-blooded animals and are used to indicate the potential presence of harmful organisms. Potential sources of contamination include poorly maintained septic systems or sewage treatment plants, farms, domestic animals, aquatic wildlife, and livestock. There is no CCME limit for the protection of aquatic life, so we use the CCME recreational limit as a guideline for human safety.

Historically, *E. coli* contents were generally higher at the downstream sampling sites, particularly downstream from the Tay River, where there is increased human habitation and lowest in the central watershed (Durham Bridge to South Sisters Brook), where there are fewer humans and more undeveloped, forested land (Figure 17). *E. coli* may be contaminating the water from faulty septic systems or sewage treatment plants, or it may be coming from animal waste. Heavy rain usually results in a spike in *E. coli* as it causes runoff of soil as well as animal feces. Very heavy rains can also cause sewer backups.

In 2023, the Health Canada updated their guidance on *E. coli* and fecal contamination levels that are "acceptable" for recreational use. The threshold for risk was reduced from 400 MPN/100 ml to 235 MPN/100 ml (Health Canada, 2023). These new guidelines were developed for primary contact activities such as swimming and boating.

2023 sampling results showed minimal exceedances in *E. coli*. While the summer average remained below the CCME threshold for recreation (Figure 19), there were spikes at both of the Campbell Creek sites in July as well as at NASH B-Marysville Bridge in September (Figure 20). Follow-up sampling in the next month indicated a drop in concentrations to acceptable levels. Both exceedances were likely due to run off from high-rain events in July (Figure 4 and 5). There were no other samples collected that exceeded 235 MPN/100ml throughout the summer months.

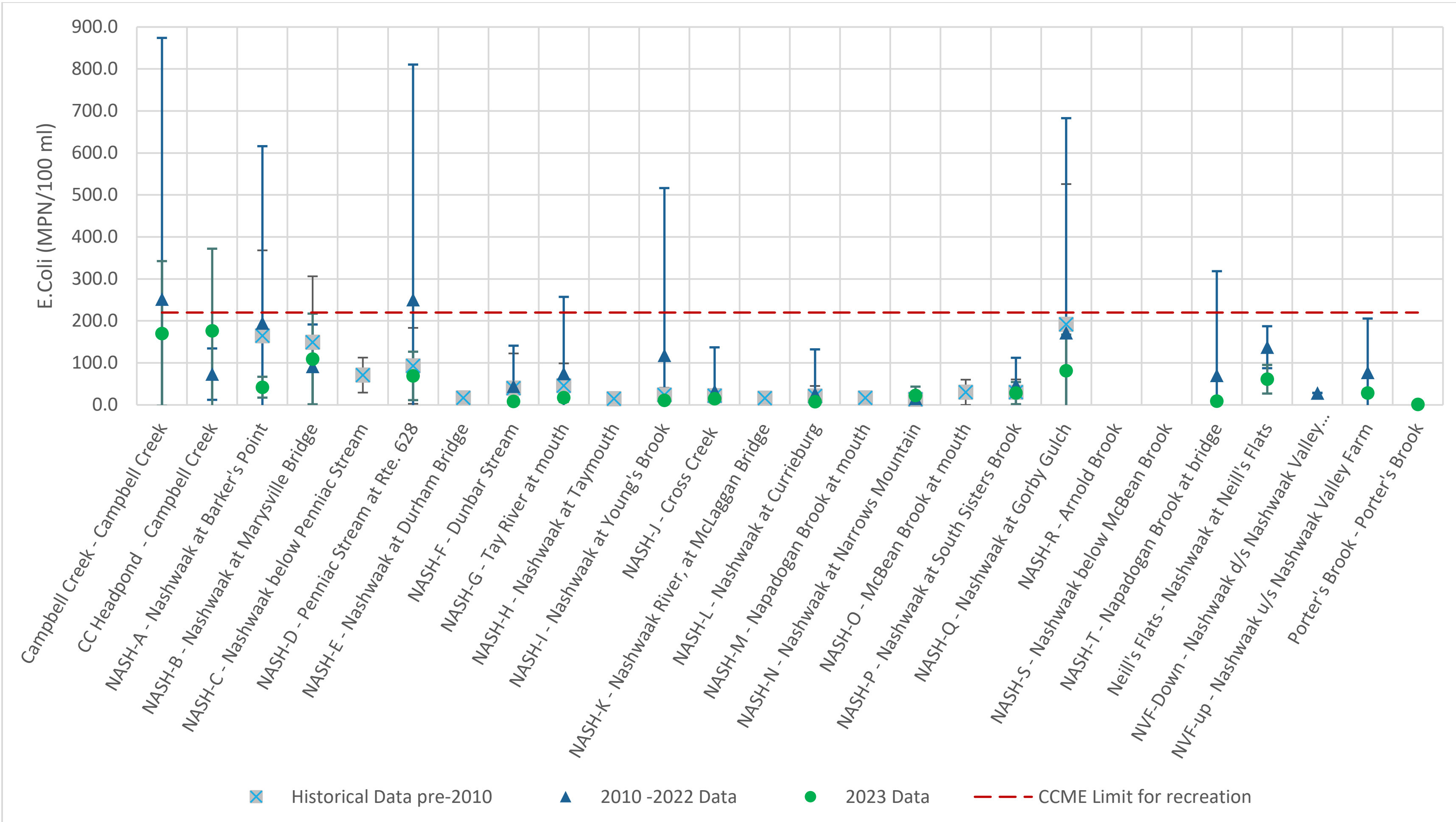


Figure 19. Mean *E. coli* contents (MPN/100 mL) per site in the watershed. Error bars represent standard deviation. The CCME limit is 235 MPN/ 100 mL for a single grab sample.

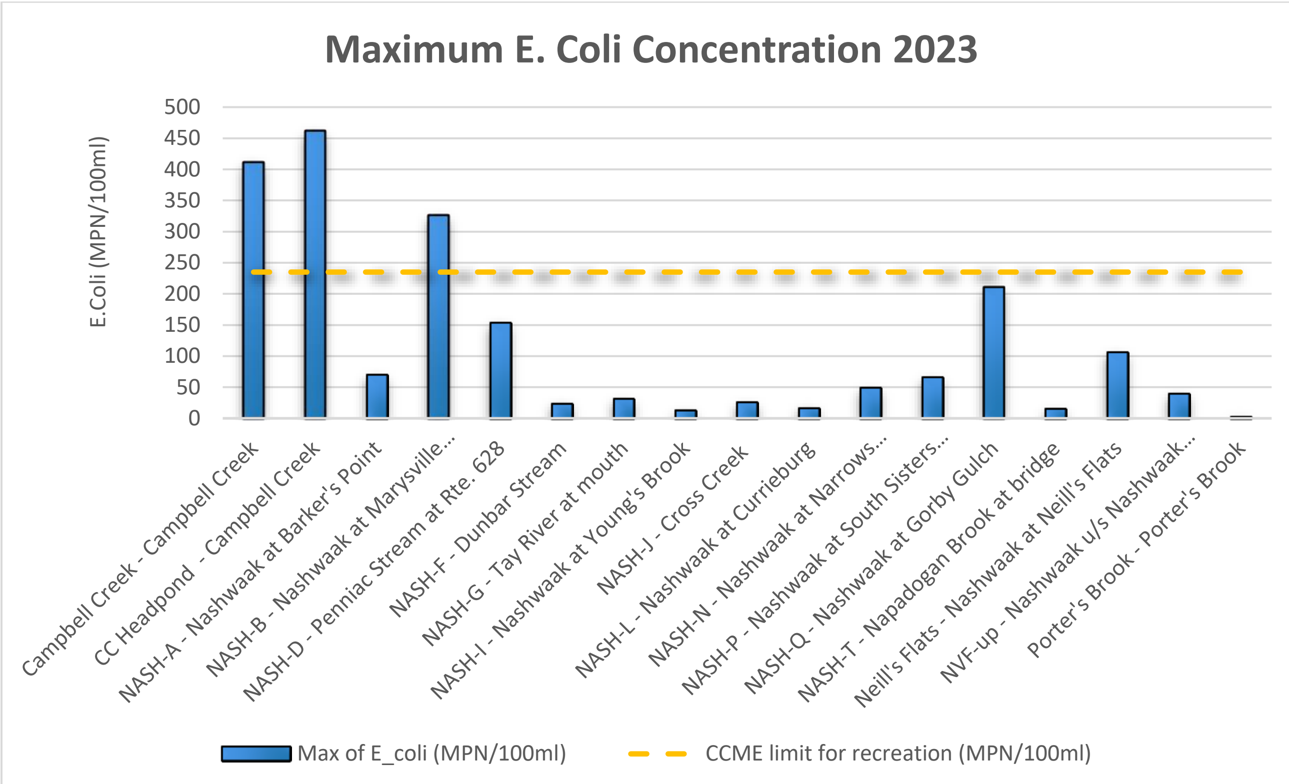


Figure 20. Maximum *E.coli* concentrations across all sampling sites in 2023 for the Nashwaak Watershed, NB, Canada. Orange dotted line indicates CCME safe limits for recreational use.

Fluoride

Fluoride is naturally present in bedrock, particularly in alkalic and silicic igneous and sedimentary rocks (e.g., shales), from which inorganic fluoride-containing minerals are leached by groundwater into surface water. Environmental concentrations in freshwater vary depending on the hydrogeological characteristics and mean fluoride concentration in freshwater across Canada is 0.05 mg/L. Anthropogenic sources include pesticides and fertilizers. The CCME limit for the protection of aquatic life is 0.12 mg/L (CCME, 2002). Changing detection limits between historic and newer data has made comparisons with historical data difficult. Fluoride toxicity results in shifts in migration patterns in salmonids and impaired reproduction in aquatic invertebrates.

Fluoride concentrations have risen in recent years, with samples across the watershed exceeding the CCME limit in 2020, 2021, 2022 and 2023 (Figure 21 and 22). In 2023, the mean concentration at all sites exceeded CCME's guidelines for the protection of aquatic life (Figure 22). Unfortunately, due to detection limits changing over time (the detection limit in 1990s/2000s was 0.1 mg/L and results were often below detection limits) it is difficult to make comparisons to mean concentrations prior to 2010. The increase from historic levels may possibly be related to fertilizer/pesticide run-off or from increased mineral leaching from the bedrock.

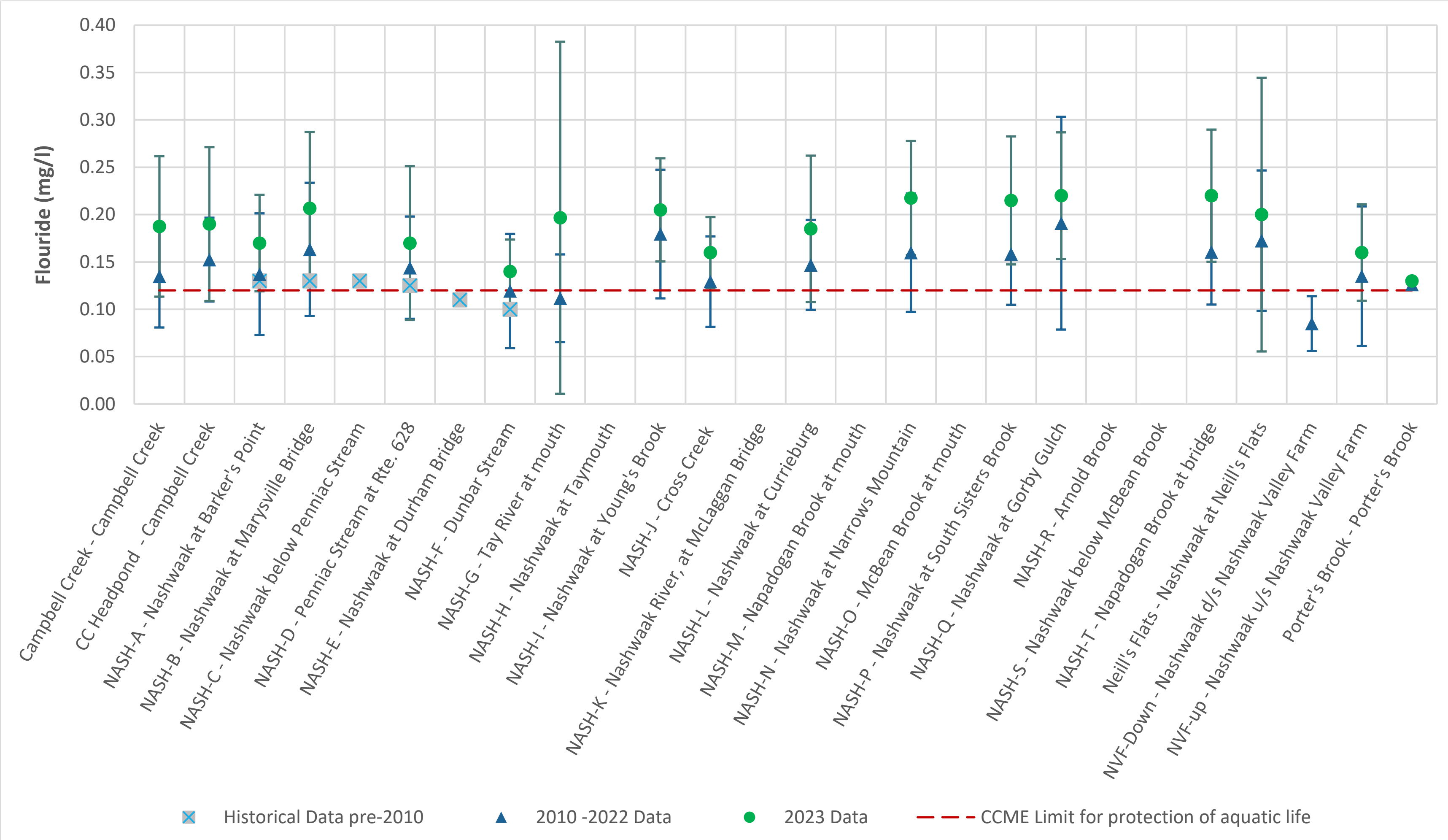


Figure 21. Fluoride concentrations (mg/L) per site in the watershed. Error bars represent standard error. The dashed line represents the CCME guideline of 0.12 mg/L.

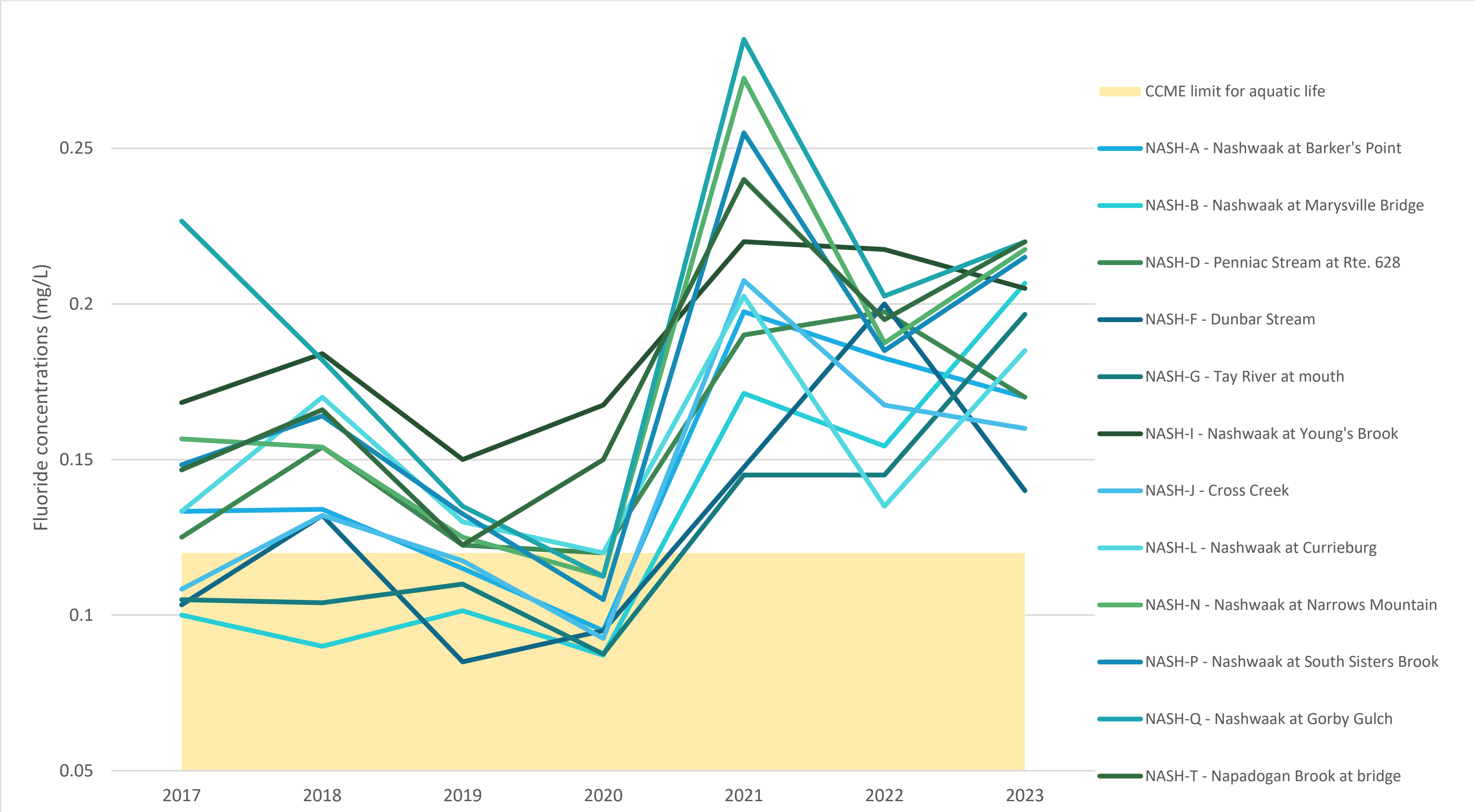


Figure 22. 2023 fluoride concentrations (mg/L) per site in the watershed. The orange block represents the CCME guideline.

Ammonia

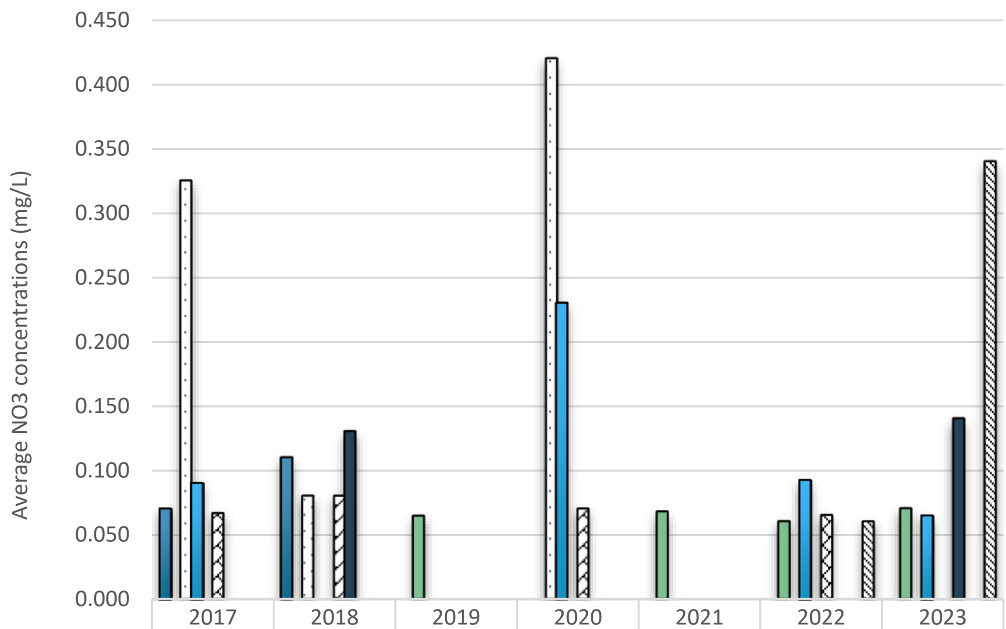
Ammonia is an important component of the nitrogen cycle and, because it is oxidized in the environment by microorganisms (i.e., nitrification), it is a large source of available nitrogen in the environment. Ammonia is highly soluble in water and its speciation is affected by a wide variety of environmental parameters including pH, temperature, and ionic strength. The term total ammonia is used to describe the sum of ammonia (NH_3) and ammonium (NH_4^+) (Environment Canada, 1997). Ammonia commonly enters the environment from municipal, industrial, agricultural, and natural processes. Natural sources of ammonia include the decomposition or breakdown of organic waste matter, gas exchange with the atmosphere, forest fires, animal waste, human breath, the discharge of ammonia by biota, and nitrogen fixation processes. Point sources of ammonia include emissions and effluents from a wide variety of industrial plants such as iron and steel mills, fertilizer plants, oil refineries, and meat processing plants (Environment Canada, 1997). The largest non-industrial point sources are sewage treatment plants. Other non-point sources of ammonia include agricultural, residential, municipal, and atmospheric releases. The CCME guideline for total ammonia for the protection of aquatic life changes depending on pH and temperature. For example, at pH of 8.0 and a temperature of 15°C, the limit is 0.715 mg/L. The limit decreases with increasing pH and temperature. Detection limits have changed over time. Before September 2016, the detection limit for ammonia was 0.01 mg/L but after 2017, RPC's detection limit changed to 0.05 mg/L total ammonia.

It was difficult to visualize the ammonia data or discern a trend in total ammonia concentrations because of the detection limit increase and because most samples were below the detection limit. In 2023, the only site that exceeded the detection limit of 0.05 mg/L was NASH-A- Barkers Point in September, which showed a concentration of 0.11 mg/L.

Nitrogen and Phosphorus

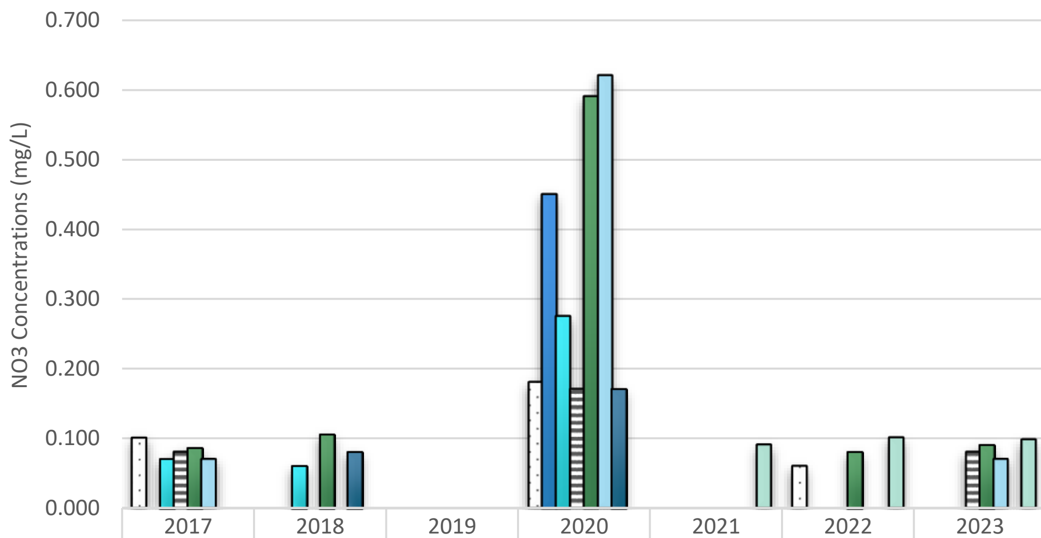
Nitrogen and phosphorus are nutrients essential for all life forms and they occur naturally in rocks and soils. However, when present in elevated concentrations, they can degrade water quality by causing algal blooms, which lower DO contents leading to hypoxic or anoxic conditions. Nitrogen occurs as nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), and organically bound nitrogen. Major sources of nutrients include wastewater discharges, agricultural run-off (chemical fertilizers), faulty septic systems, wastewater treatment plants, manure storage, and erosion.

Nitrate is the most important when determining water quality. Nitrate is released into the water when aquatic plants and animals die, from atmospheric deposition, and from bedrocks. Nitrate, NO3 (as N) levels of 3 mg/L are considered acceptable by CCME for the protection of aquatic life (CCME, 2012). Of the 9 sites with detectable limits, all were well within the CCME 3 mg/L guidelines (Figures 23 and 24). In the main river, NVF-up showed a substantial increase in concentration from 2022 levels, and NASH Q saw the highest recorded concentration of NO3 in the last 7 years of sampling (Figure 23). Results from samples collected in the tributaries showed an increase in the average N03 concentrations at Dunbar, Tay River and Cross Creek sites when compared to results from those sites in 2021 and 2022 (Figure 24).



	2017	2018	2019	2020	2021	2022	2023
NASH-A Barkers Point	0.070	0.110					
NASH-B - Marysville (DELG tests)			0.064		0.068	0.060	0.070
NASH-I2 - Youngs Brook	0.325	0.080		0.420			
NASH-L - Currieburg/ Ryan Brook	0.090			0.230		0.093	0.065
NASH-N - Narrows Mountain							
NASH-P2 - South Sisters	0.067	0.080		0.070		0.065	
NASH-Q - Gorby Gulch		0.130					0.140
Neills Flats							
NVF-Down							
NVF-Up						0.060	0.340

Figure 23. Average Nitrate (NO_3) concentrations (mg/L) in the mainstem Nashwaak river in the years 2017-2023. Samples were collected between May-October in all years.



	2017	2018	2019	2020	2021	2022	2023
Campbell Creek	0.100			0.180		0.060	
Campbell Creek Headpond				0.450			
NASH-D - Penniac Stream	0.070	0.060		0.275			
NASH-F - Dunbar Stream	0.080			0.170			0.080
NASH-G - Tay River	0.085	0.105		0.590		0.080	0.090
NASH-J2 - Cross Creek	0.070			0.620			0.070
NASH-T - Napadogan Brook		0.080		0.170			
Porters Brook					0.090	0.100	0.098

Figure 24. Average Nitrate (NO3) concentrations (mg/L) in select tributaries in the Nashwaak watershed for the years 2017-2023. Samples were collected between May-October in all years.

CCME does not set limits for phosphorous, nitrite, or nitrogen, however guidelines have been developed for Total Phosphorus in terms of ideal, impaired, and concern levels. Elevated nutrients are a bigger problem in lakes than in streams where they can result in harmful algal blooms (HABs) , which are a regular occurrence at Nashwaak Lake.

Total nitrogen is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. Total nitrogen in 2023 per site is shown in Figure 25. While there are no CCME guidelines for Total Nitrogen, this can be looked at over time to indicate nutrient loading in the watershed. The total nitrogen in 2023 was within the normal range for the watershed. It should be noted that there were higher levels of total nitrogen along the mainstem Nashwaak River at NASH Q, NASH L and NASH B for 2023, when compared with previous years (Figure 26).

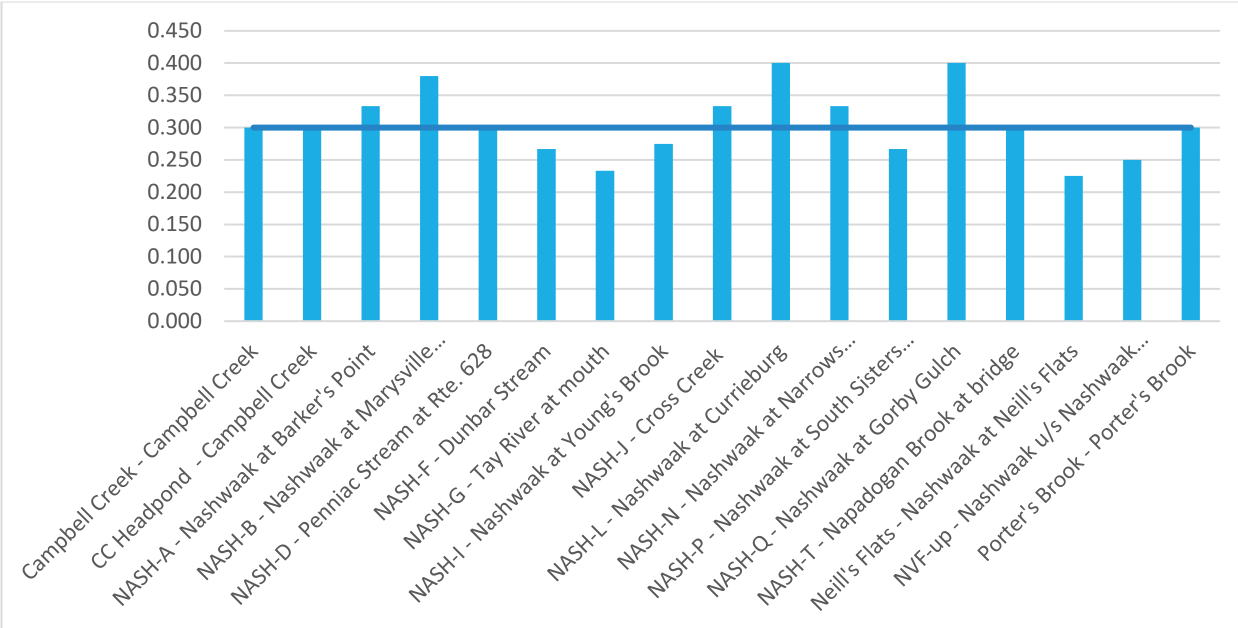


Figure 25. Average Total Nitrogen (TN) for the summer months (May-September) in 2023.

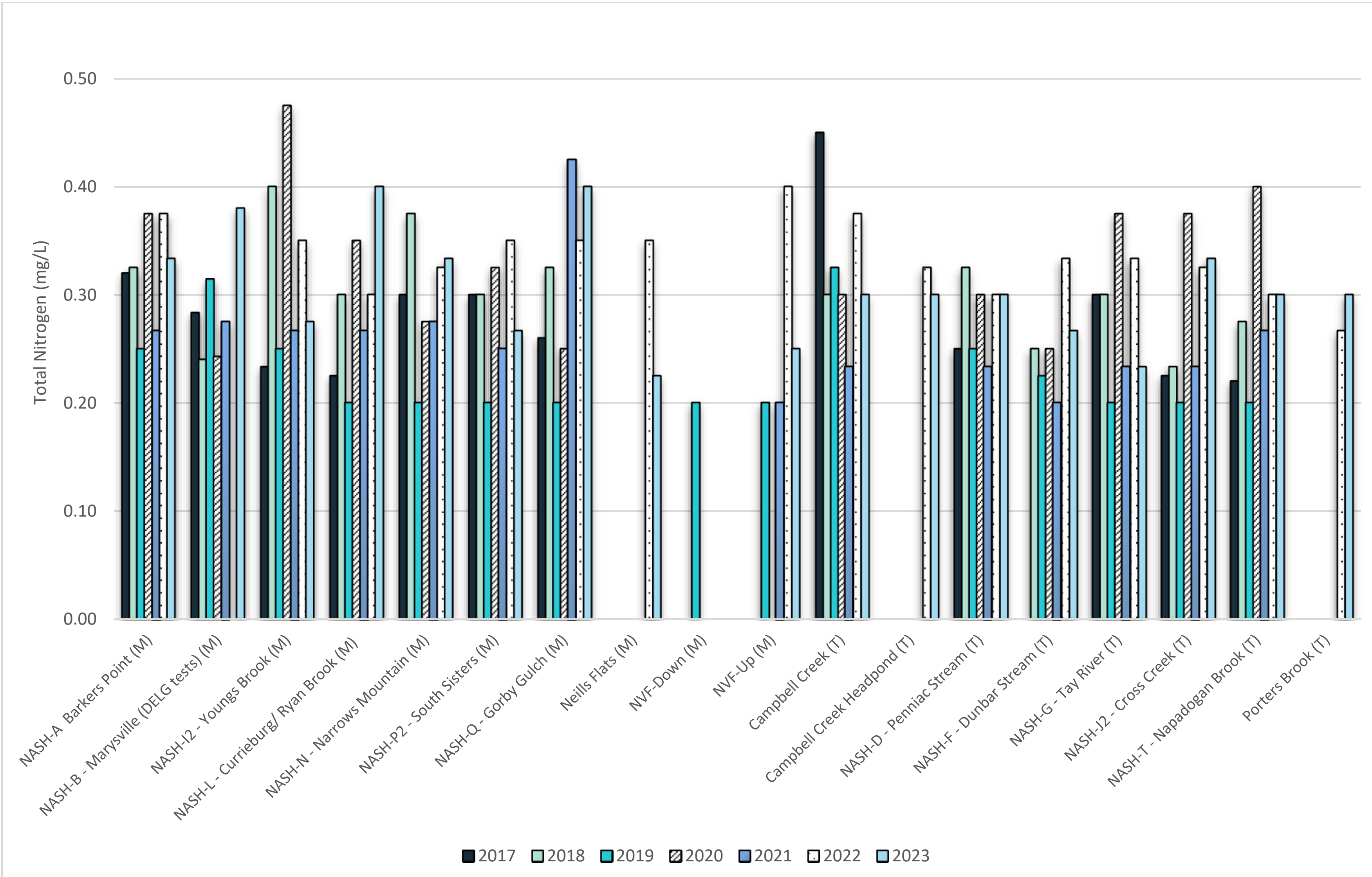


Figure 26. Average TN (Total nitrogen) in mg/L collected in the Nashwaak Watershed, NB, Canada between 2017-2023. Annual average was calculated across samples taken between May-October in a given year.

As with other nutrients, spikes in total phosphorus levels have been recorded after heavy rainfall events. An increase of more than 50% of the baseline can indicate nutrient loading and can signal the possible formation of HABs according to the CCME guidelines. As a baseline has not been established for the Nashwaak Watershed, a maximum threshold of 0.035 mg/L has been chosen to represent “eutrophic” conditions (CCME, 2004). This guideline was chosen in reference to the Department of Environment and Local Government (DELG)’s quantification of the trophic status for several lakes in the New Brunswick, all of which were classified as either oligotrophic or meso-eutrophic (NB DELG,2019). In 2023, there were no changes in the level of phosphorus considered for eutrophic status in the Nashwaak watershed (Figure 27).

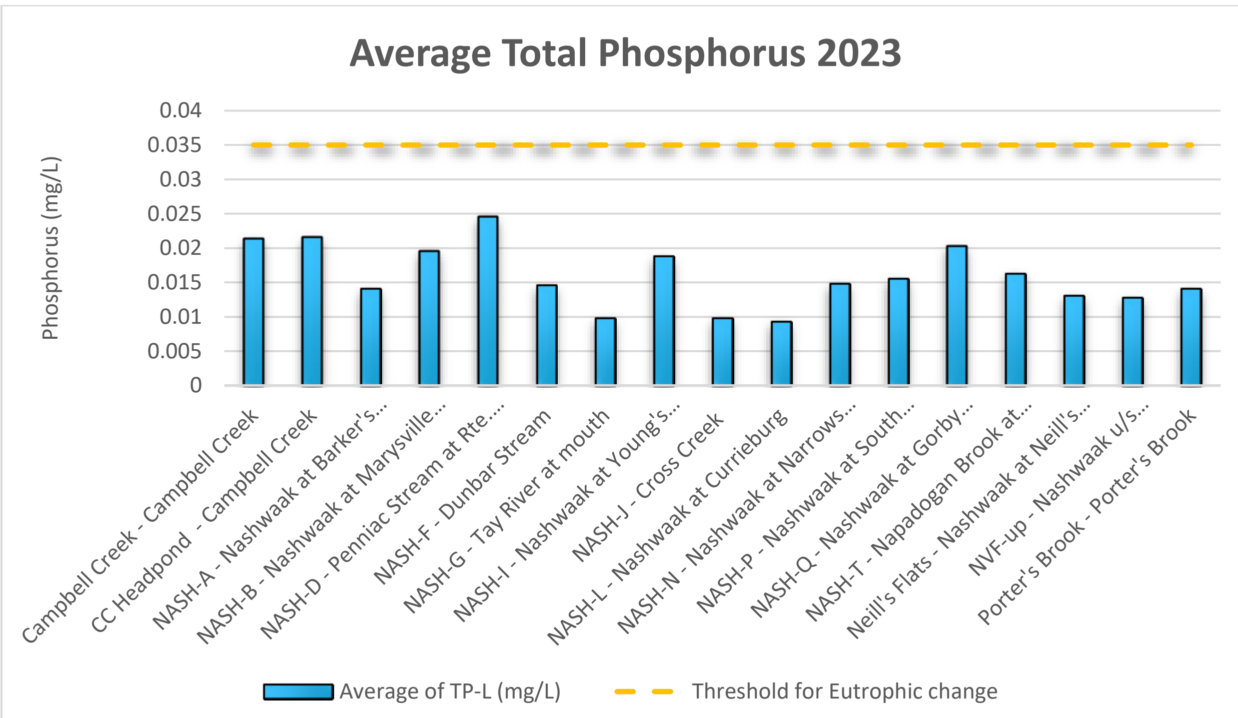


Figure 27. Average total phosphorus for 2023. Calculated for samples collected in May-October 2023. Dotted orange line indicates threshold at while lake/river is considered "eutrophic".

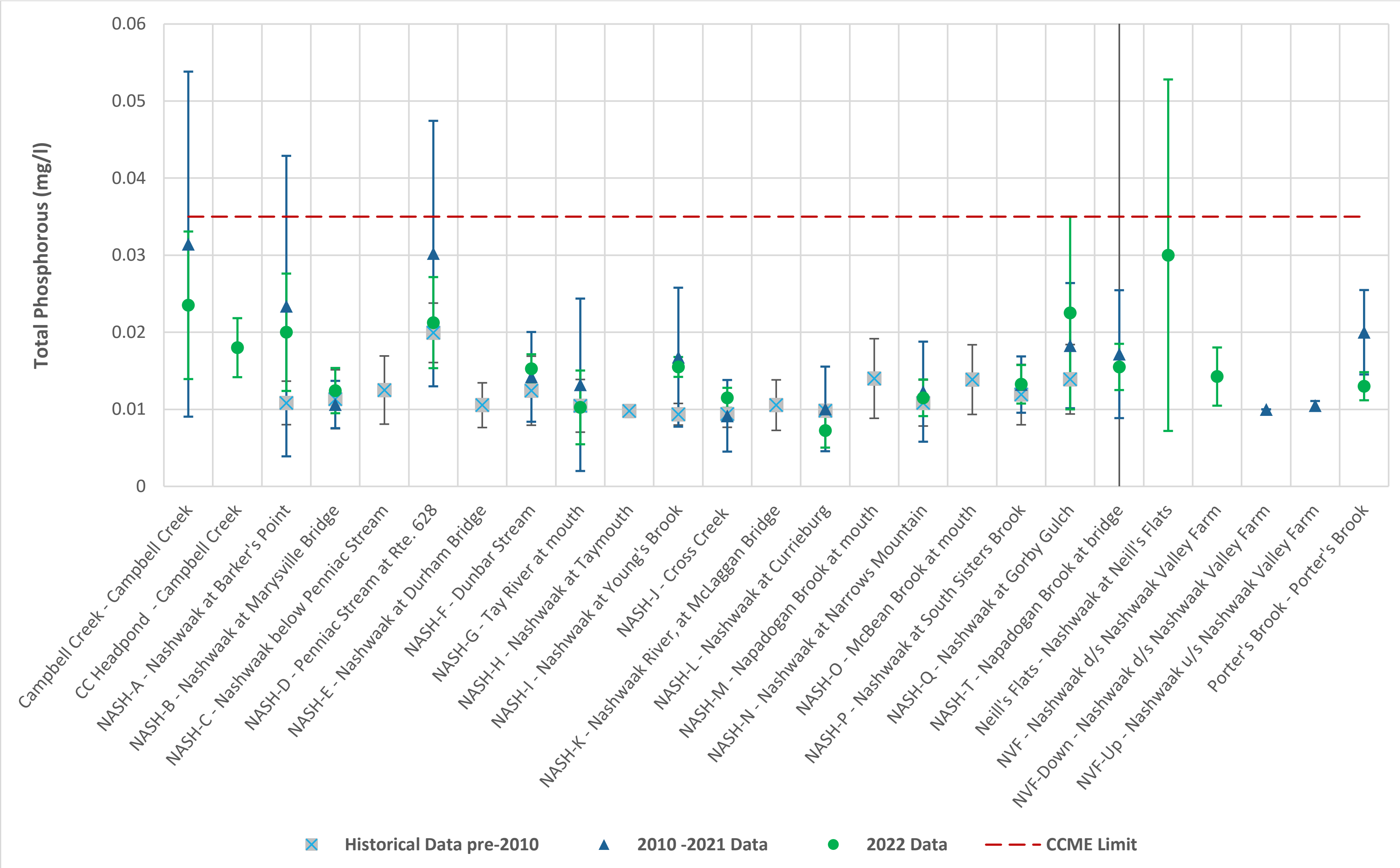


Figure 28. Average total phosphorus concentrations (mg/L) per site in the Nashwaak Watershed. Error bars represent standard error. The dashed line represents the guideline of 0.035 mg/L.

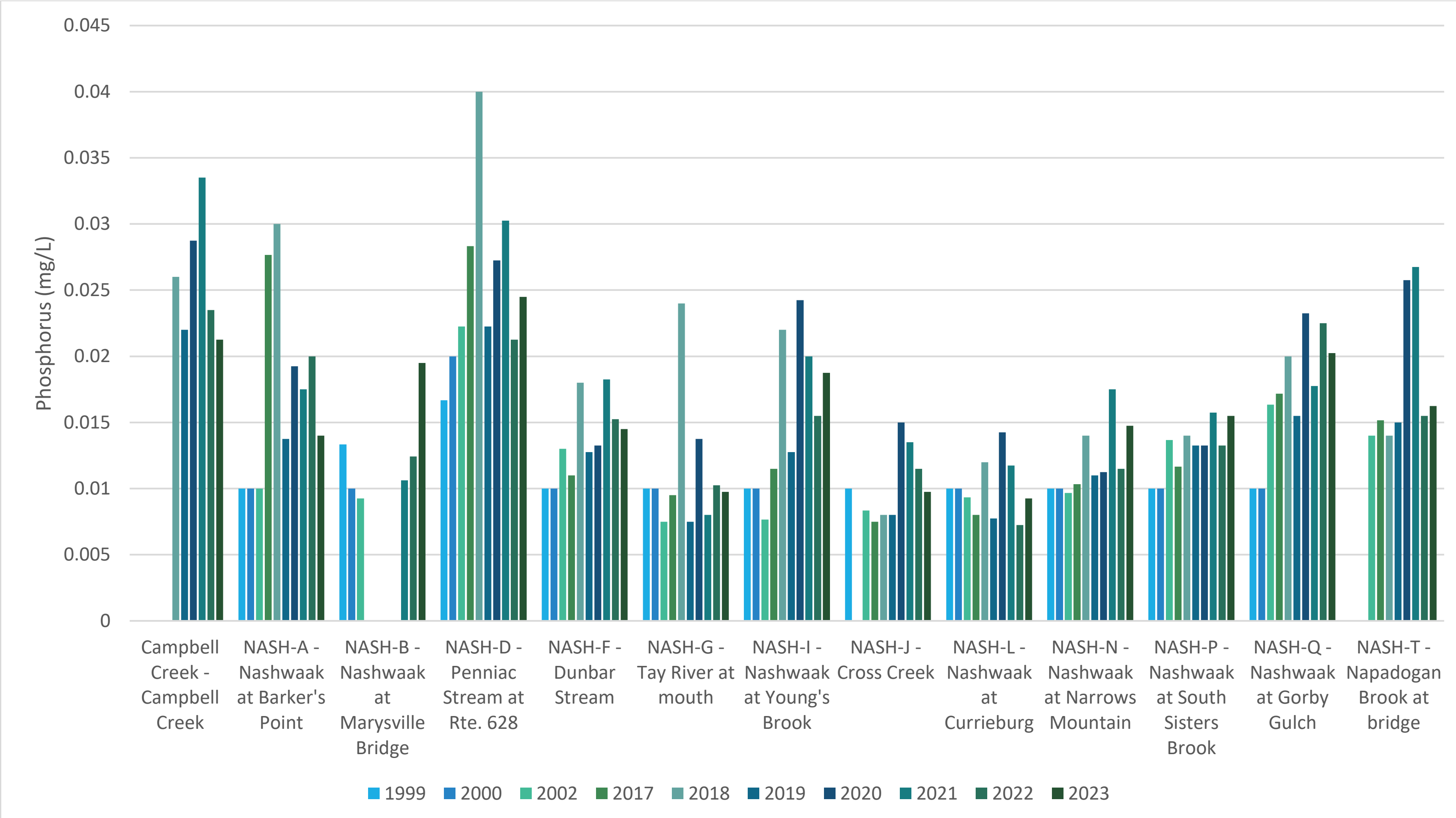


Figure 29. Average total phosphorus, across all sites per year in the Nashwaak Watershed. Averages were calculated for samples collected between May-October each year.

Total Organic Carbon

Total Organic Carbon (TOC) is a combination of humic substances, as well as partly degraded animal and plant material. TOC may enter a watercourse via run-off from agriculture or from urban or industrial areas. It may also enter via wetlands. There is no CCME limit for TOC; however, low levels are important to prevent the consumption of oxygen during decomposition. From 2017 onwards, Dissolved Organic Carbon (DOC) instead of TOC was measured. It is used here for comparison purposes.

Historically, organic carbon levels were highest in the upper watershed above Currieburg and particularly above McBean Brook where average values exceeded 10 mg/L. Levels were particularly high throughout the watershed in 2001. Levels in the lower watershed have remained stable over time while levels in the headwaters have dropped on average over time (pre-2010).

In 2023, mean DOC levels were variable compared to historic averages (Figure 30). When comparing average concentrations to the 2022 results there was a notable increase in several of the mainstem sites in the upper watershed. NASH L, N, P, Q and T all saw between a 6-25% increase in average TOC. Several sites in the lower mainstem (NASH A, Neill's Flats, NVF-up) saw between a 42-44% decrease in average DOC compared to 2022 (Figure 29).

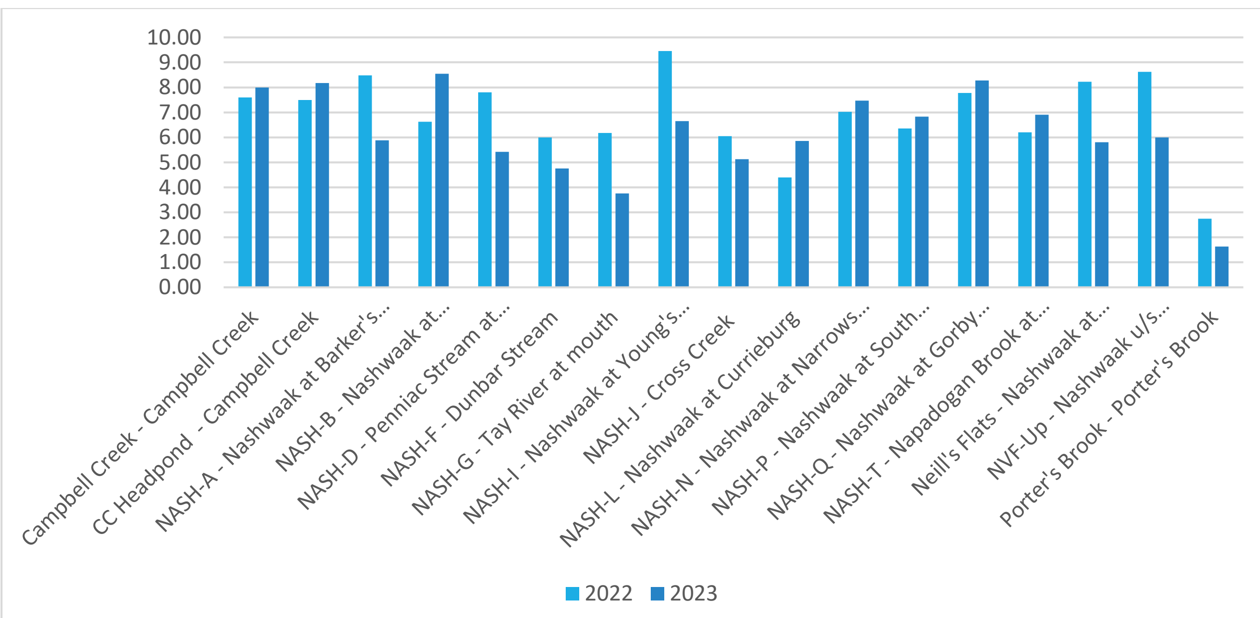


Figure 30. Total Organic Carbon (TOC) in mg/L across the Nashwaak Watershed, NB, Canada in 2022 and 2023.

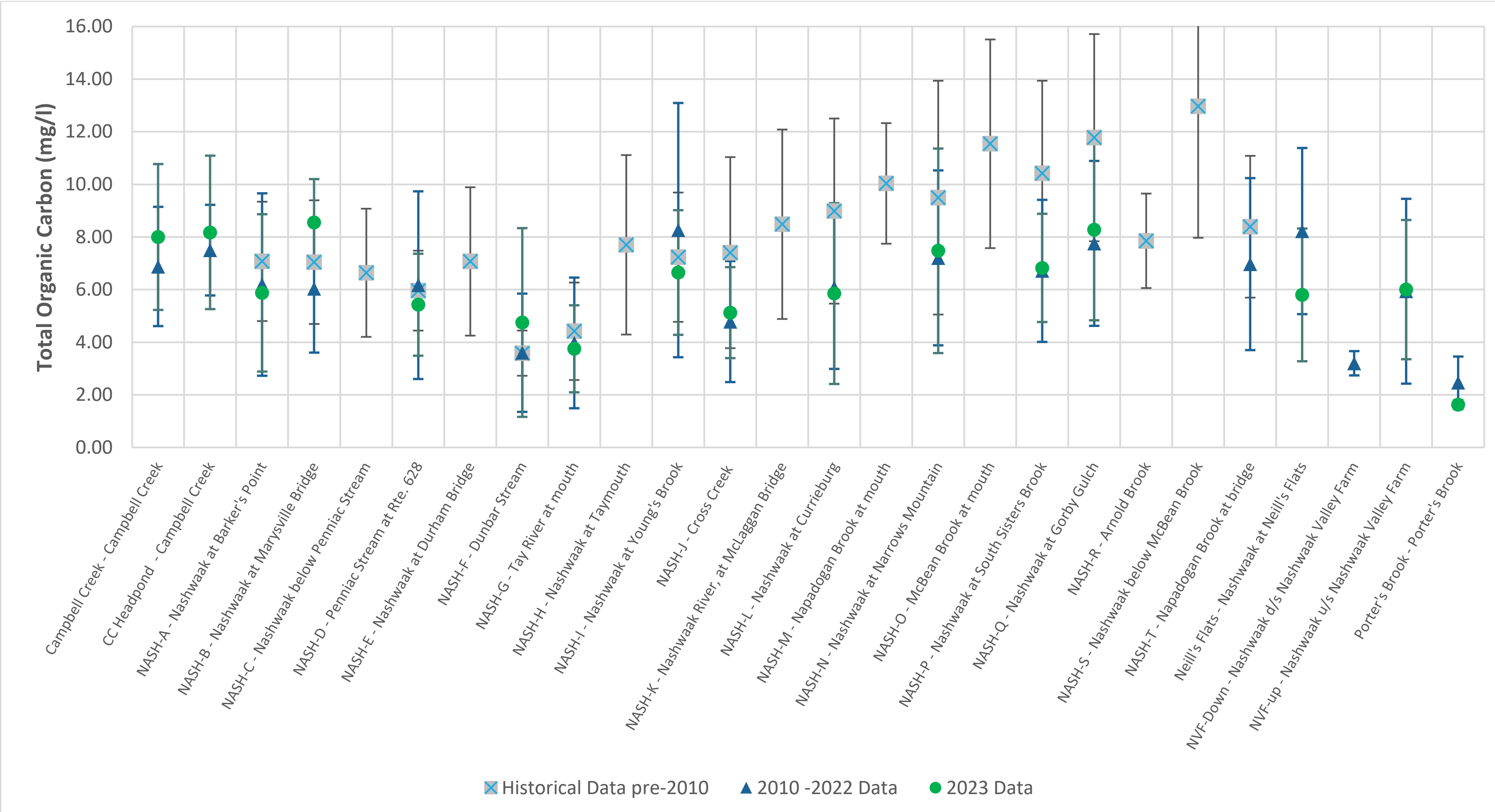


Figure 31. Total Organic Carbon concentrations (mg/L) per site. Data Error bars represent standard deviation.

Water Quality Index

The Water Quality Index, or WQI, is a means to provide a consistent way to report water quality information and communicate it to the public. The Canadian WQI was developed by the CCME and it provides a single number that expresses the overall water quality at a certain time and location based on selected parameters. Ratings are follows:

Table 1. Water Quality Index rating based on CCME guidelines.

95-100	Absence of threat Almost pristine
80-94	Minor degree of threat Usually desirable levels
65-79	Occasional threat Sometimes desirable
45-64	Frequent threat Often not desirable
0-44	Almost constant threat Usually not desirable

WQI is calculated based on:

- the number of parameters that exceed guidelines,
- the number of times guidelines are exceeded,
- and the amount by which they are exceeded.

For an accurate WQI, a site is required to have four samples per year with at least four variables measured.

WQIs for each site and year were calculated using CCME's WQI Calculator. However, comparisons between years were difficult because some important parameters used in the calculations weren't measured in certain years (e.g., Al wasn't measured in 1980, DO and temperature were not consistently measured, and nitrate and nitrite were measured in the 1990s). In addition, detection limits have changed over time and a number of samples did not meet the minimum in certain years.

Parameters used to calculate 2023 WQI were: ammonia, arsenic, cadmium, chloride, chromium, conductivity, copper, *E. coli*, fluoride, iron, lead, manganese, molybdenum, organic carbon, turbidity, zinc and aluminum. Water quality was very good overall throughout the watershed. The best water quality according to the index was found at Porters Brook (Figure 31). Unsurprisingly, the poorest water quality was found in Campbell Creek. The water quality will hopefully improve at this site as the system restores over time. Most water quality was better in the upper watershed and degraded when moving towards the more urban areas near the Wolastoq River.

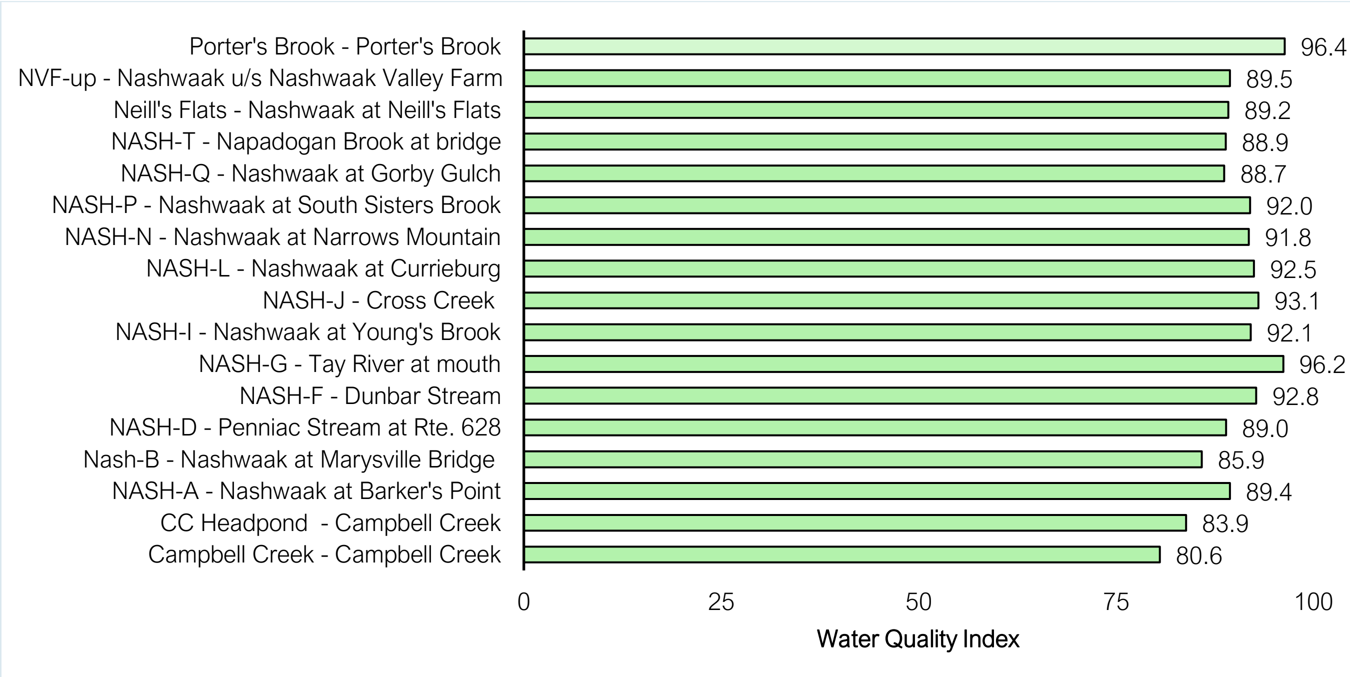


Figure 32. 2023 WQIs by site. Light green = Very good (80-94)

Figure 33 compares the 2023 average WQI for the entire watershed to those measured from 2017 to 2022. Overall, the WQI for the watershed has remained relatively constant over the last seven years. Notable, 2019 had the “healthiest” water quality rating in the last 7 years.

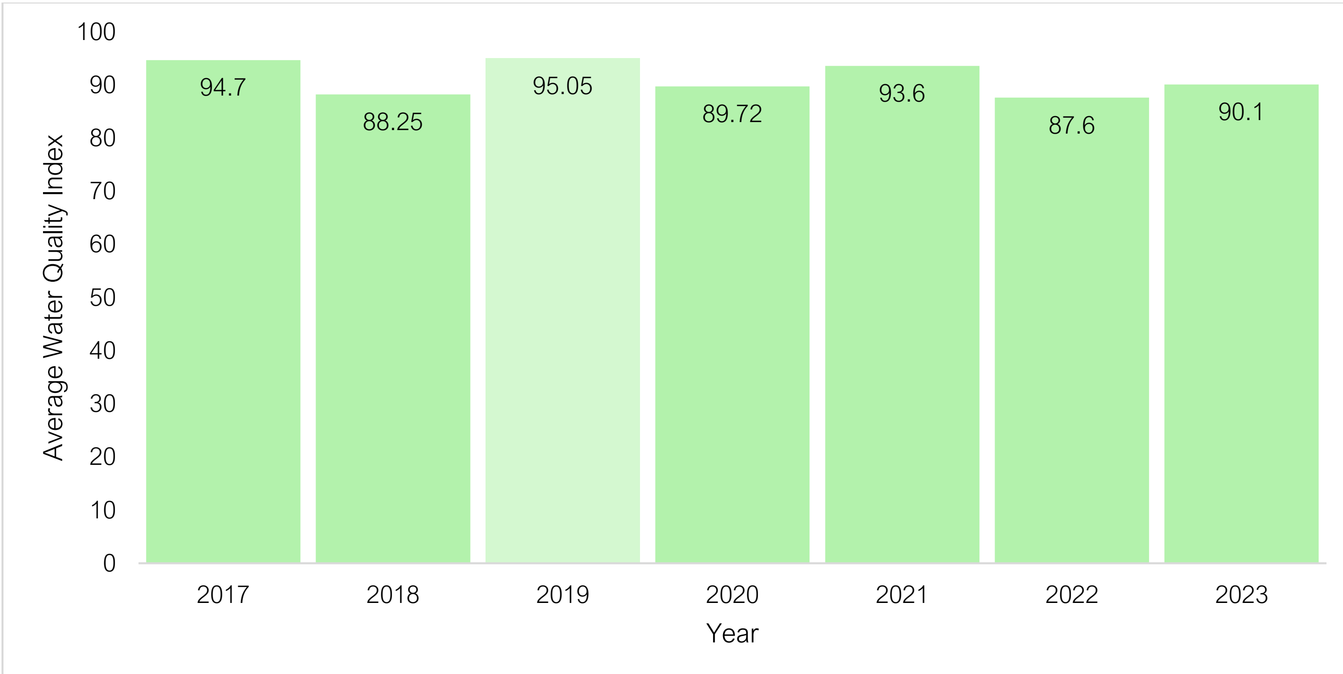


Figure 33. Average WQIs between 2017-2023 in the Nashwaak Watershed, NB Canada . Light green = excellent (95-100), darker green = very good (80-94).

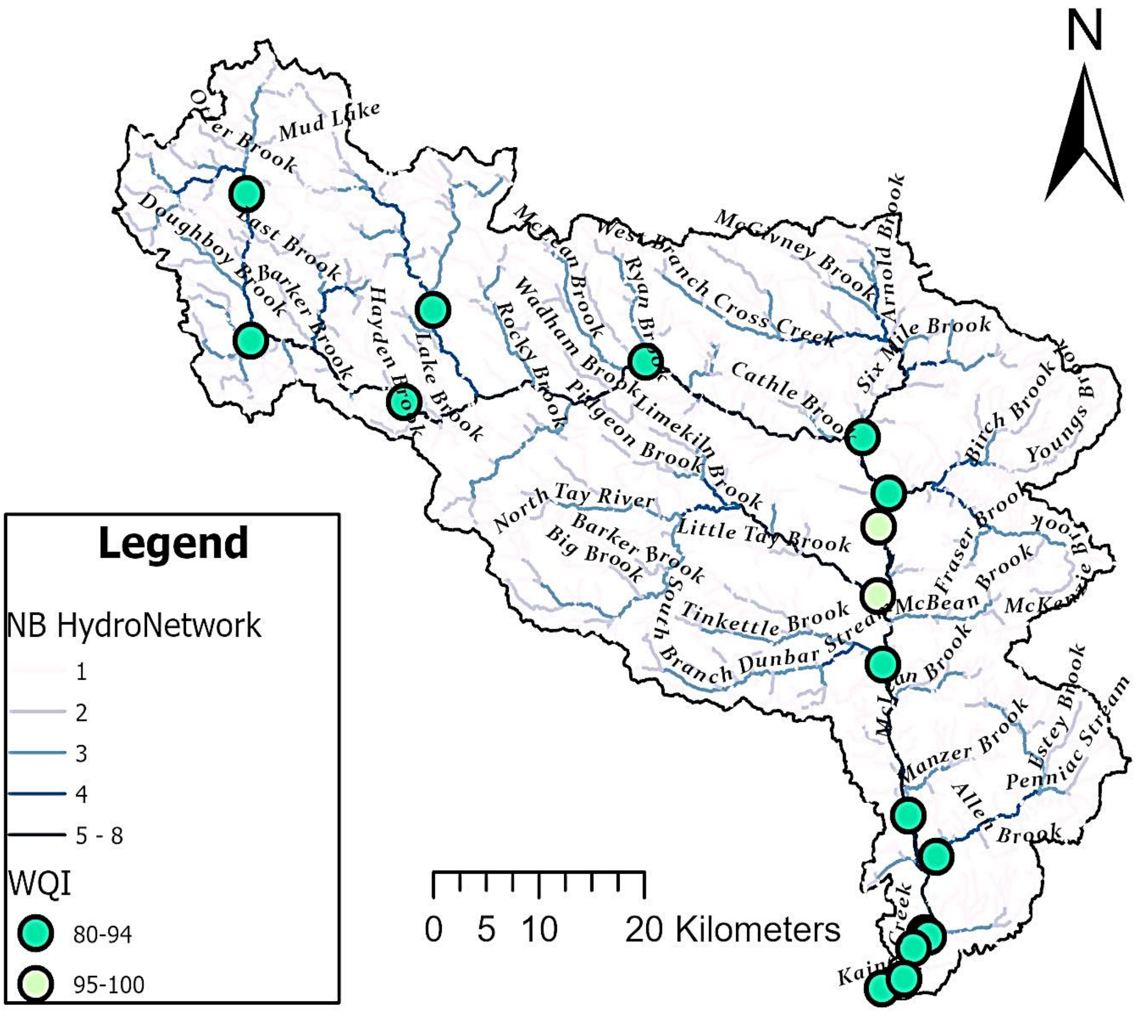


Figure 34. Map of average WQIs in the Nashwaak watershed, NB, Canada for 2023.

Discussion

Water Quality

Overall water quality in the Nashwaak Watershed is good according to the CCME water quality index and no significant change was noted in the water quality in the last five years. Patterns of water quality parameters were as expected based on land use patterns. Water quality generally improves moving upstream in the watershed. The headwaters sites are generally healthier as they are less affected by urbanization and other anthropogenic impacts. However, elevated iron, aluminium, suspended sediment and fluoride are indicative of increasing erosion and sediment loading in the headwaters and clear-cut logging in the headwaters remains a concern and a potential source of contaminants and run-off.

Areas of most concern in the watershed are from the Penniac Stream downstream to the mouth of the river where there is the most human impact. Campbell Creek's water quality is affected by the dam and impounded sediments which are predicted to improve with the removal of the dam. Values of iron, total phosphorus, and *E. coli* were higher at Campbell Creek than at any other site measured. The dam was removed in 2021 and much sediment was flushed downstream during the sampling period. We are already seeing changes to the water quality at Campbell Creek in 2023, 2-years post-removal.

Overall Improvement of the Nashwaak Watershed's Water Quality

In addition to continuing to monitor water quality and improve riparian buffer zones, several action items are suggested for the entire watershed:

- Addressing the practice of topsoil mining by ensuring that existing legislation is adhered to, and force fining or permit cancellation of operators who do not comply with regulations;
- Ensuring that best management practices are followed by logging companies and that any environmental infractions are communicated to DELG or DNRED;
- Working with landowners to ensure proper road construction and maintenance including road-stream crossings;
- Working with farmers on fencing projects and buffer planting to limit or restrict cattle access to the river and tributaries;
- Partnering with wastewater treatment facilities to improve current practices;
- Working with local and rural planning commissions to ensure that proper riparian setbacks are adhered to and best management practices are being followed;
- Reporting any dumping or abuse of the river to DELG or DNRED; and
- Riverbank stabilization and problem area assessment.

Temperature Monitoring

In 2023, 39 temperature loggers were deployed throughout the mainstem and several key tributaries. The loggers recorded hourly temperatures between May to October. Increased temperature monitoring of ecologically significant tributaries will help us to understand the source of thermal inputs and location of thermal refugia within the watershed. 20°C is considered the threshold minimum temperature for assessing physiological stress in salmonids and at 23°C, it has been shown that salmonids will seek refuge in cooler temperatures.

Unfortunately, due to unprecedented high flows and precipitation amounts, only 26 loggers were able to be retrieved in 2023. Several sites were checked on monthly, but in September, there was a tropical storm with high precipitation amounts that fell over 24 hours (>100mm in some areas). The high discharge caused several loggers to be ripped out and swept away. Of the 26 loggers retrieved, several loggers were unable to be read off due to logger recording failure. A representative from the manufacturer (Onset) confirmed this was likely due to the age and long-term use of many of the loggers. There were partial/full datasets for 19 logger locations. A full summary of individual loggers can be found in Table 2.

Table 2. Summary of loggers deployed in 2023 in the Nashwaak Watershed Association. Green background denotes a full data set. Blue denotes the logger was retrieved but there was missing or no data. Orange denotes that the logger was unable to be retrieved from the water.

Field_Name	Long_dec	Lat_Dec	Location	Date_removed	Notes
NWAI001	-67.02530	46.29074	Nashwaak at Narrows Mountain	2023-10-05	
NWAI002	-67.15642	46.32533	South sisters Brook	2023-10-05	
NWAI003	-67.15560	46.32542	Nashwaak ds south sisters	2023-10-05	DATA CORRUPT
NWAI004	-67.15891	46.40850	Nashwaak at Gorby Gulch	2023-10-05	
NWAI005	-67.12010	46.46815	Nashwaak at Nashwaak Lake	2023-10-05	
NWAI006	-67.00069	46.34275	Napadogan	2023-10-05	
NWAI007	-66.81944	46.31371	Ryan Brook	2023-10-05	DATA CORRUPT
NWAI008	-66.78294	46.29877	McPherson Brook	2023-10-05	DATA CORRUPT
NWAI009	-66.78410	46.29886	Nashwaak us McPherson		LOST
NWAI011	-66.67384	46.27759	Cathle Brook	2023-10-06	
NWAI012	-66.78857	46.26669	Limekiln	2023-10-06	PARTIAL-found 2022 logger. Stopped logging July 31/23
NWAI013	-66.67162	46.36348	McGivney Brook		LOST
NWAI014	-66.62080	46.21990	Porters Brook		LOST
NWAI015	-66.62063	46.22036	Nashwaak ds Porters Brook	2023-10-06	
NWAI016	-66.61091	46.23969	Youngs Brook	2023-10-04	
NWAI017	-66.61195	46.23858	Nashwaak ds Youngs		LOST
NWAI018	-66.63445	46.27061	Nashwaak Cross Creek	2023-10-06	PARTIAL-Stopped logging July 17th
NWAI019	-66.58533	46.31280	5 mile Brook		LOST
NWAI020	-66.62131	46.18041	Tay at mouth		LOST
NWAI021	-66.61993	46.17913	Nashwaak ds Tay		LOST
NWAI022	-66.68710	46.20551	Nixon Brook		LOST
NWAI023	-66.61842	46.14117	Nashwaak ds Dunbar		LOST
NWAI024	-66.60623	46.16739	McBean at 628	2023-10-04	Data from 2021-2023
NWAI025	-66.57112	46.03117	Penniac Stream	2023-10-04	Stopped logging Sept 12/23
NWAI026	-66.54294	46.07062	Manzer Brook	2023-10-04	
NWAI027	-66.60433	46.12589	McLean Brook	2023-10-04	DATA CORRUPT
NWAI028	-66.61685	46.14135	Dunbar Stream		LOST
NWAI029	-66.59059	45.97027	Kaine Creek	2023-10-04	Found Downstream _ DATA Corrupted
NWAI030	-66.59153	45.97871	Nashwaak at Marysville	2023-10-06	
NWAI031	-66.56337	45.98855	Campbell Creek	2023-10-04	

NWAI032	-66.58169	45.98811	Campbell Creek ds dam (off bridge)		LOST
NWAI033	-66.58306	45.98887	Nashwaak ds Campbell Creek	2023-10-06	DATA corrupt
NWAI034	-66.70293	46.32596	West Cross Creek at Rte. 625	2023-10-05	
NWAI035	-66.82241	46.31014	East Ryan Brook	2023-10-05	Stopped logging Sept 1st
NWAI036	-66.73845	46.28413	Nashwaak ds Sands Brook	2023-10-05	DATA CORRUPT
NWAI037	-66.57112	46.03117	Fisher Brook	2023-10-04	
NWAI038	-66.59863	45.96191	Neill's Flats		DO NOT DEPLOY here -LOST
NWAI040	-66.58784	45.98723	McConaghy Brook		LOST

Loggers were read out as soon as possible upon returning to the office, though some continued recording for a few days before they were shut off. Temperatures that were recorded while the loggers were sitting in the truck or office were not included in the dataset. Unreliable temperatures due to potential exposed loggers or lost loggers, were also not included in the dataset. Data was used from 14 loggers in tributaries and 5 loggers in the main stem of the Nashwaak River and run through a program in r. Temperatures in both the main stem and the tributaries varied depending on air temperature throughout the summer, though those fed by ground water showed less variability.

Maximum summer temperatures ranged from 18.2 °C in Fisher Brook to 27.2 °C in Nashwaak Lake (Figure 35). The average maximum temperature was 24.9°C in the mainstem and 22.5°C in the tributaries. Average water temperatures were the warmest in July across all sites. Table 4 summarises the average maximum, minimum, and summer average temperatures along with the average number of days when the minimum was above 20°C and number of days when the maximum was over 23°C for 2017 - 2023.

As less than half of the loggers had a full dataset to disseminate data, it is difficult to make comparisons across the watershed in its entirety. Averages in the mainstem were generally consistent with historical norms but there were several cold-water tributaries missing from the tributary calculations which likely skewed the average results for this year (Table 4). The warmest site in the watershed in terms of maximum temperature, average summer temp and minimum temperature was at Nashwaak Lake outlet (Figure 35 & Table 3). This is a similar outcome to the data collected in 2022.

The number of days when maximum daily water temperatures exceeded 23°C and when minimum daily water temperatures sustained exceedances of 20°C is displayed in Table 3 (20°C is considered the threshold minimum temperature for assessing physiological stress in Atlantic salmon, (DFO, 2012). Additionally, it has been shown that when maximum daily water temperature exceeds 23°C, salmonids will seek cooler water refugia (Breau, 2013). It is important to understand the long-term temperature regime for both tributaries and the mainstem river to guide conservation and protection priorities for cold-water refugia. As climate change continues to alter the temperature of our river systems, access to cold water refuge during high-heat conditions will be a necessity for survival for many species.

Table 3. Summar of all logger statistics from 2023, collected in the Nashwaak Watershed.

Mainstem (M) or Tributary (T)	LoggerID	Location	Average Summer Temp (°C)	Max summer temp (°C)	Min summer temp (°C)	Standard deviation of results	# of days where minimum was >20°C	# of days where maximum was >23°C
M	NWAI015	Nashwaak ds Porters Brook	16.6	24.9	11.1	2.1	0	4
M	NWAI004	Nashwaak at Gorby Gulch	17.0	23.1	11.3	2.3	0	4
M	NWAI001	Nashwaak at Narrows Mountain	17.9	24.4	12.1	2.5	2	10
M	NWAI030	Nashwaak at Marysville	19.2	24.7	13.7	2.4	23	19
M	NWAI005	Nashwaak at outlet of Nashwaak Lake	21.3	27.2	15.5	2.5	49	40
T	NWAI024	McBean at 628	14.3	19.0	10.0	1.6	0	0
T	NWAI037	Fisher Brook	15.2	18.2	10.3	1.3	0	0
T	NWAI011	Cathle Brook	15.2	21.1	9.7	1.8	0	0
T	NWAI010	Sands Brook	15.3	19.5	9.9	1.5	0	0
T	NWAI034	West Cross Creek at Rte. 625	15.8	21.8	10.5	1.8	0	0
T	NWAI016	Youngs Brook	16.1	23.9	10.1	2.2	0	4
T	NWAI002	South Sisters Brook	16.1	22.7	10.2	2.4	0	0
T	NWAI006	Napadogan Stream	16.7	23.3	10.7	2.3	0	1

T	NWAI031	Campbell Creek u/s	16.8	21.3	10.7	1.7	0	0
T	NWAI026	Manzer Brook	16.9	22.7	10.9	1.9	0	0
T	NWAI025	Penniac Stream	17.8	24.3	11.1	2.4	0	8
T	NWAI035	East Ryan Brook	18.6	26.1	11.7	2.6	2	16
T	NWAI018	Cross Creek at WQ	18.8	26.4	10.7	2.7	0	7
T	NWAI012	Limekiln Brook	19.8	25.1	13.1	2.2	9	6

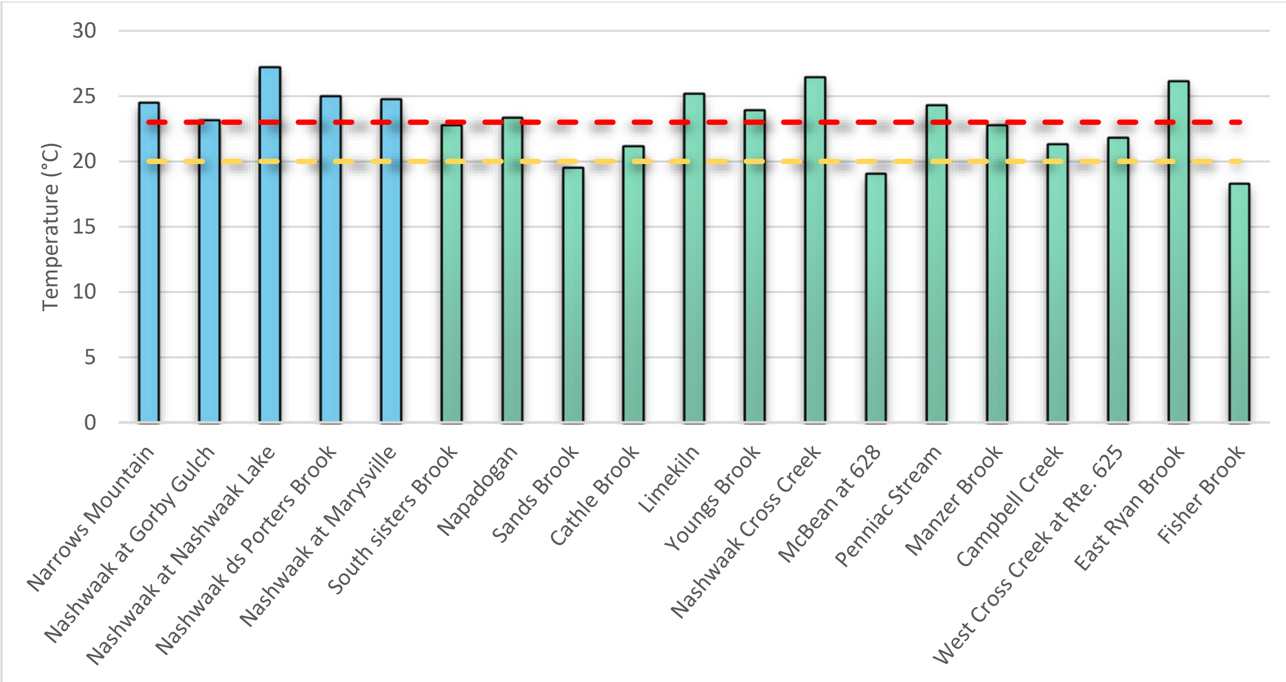


Figure 35. Maximum summer (June 21st-September 21st) temperatures for the Nashwaak river (blue) and tributaries (green) in 2023. Red dotted line represents the 23°C short-term temperature threshold for salmonids. Orange dotted line represents the 20°C long-term temperature threshold for salmonids.

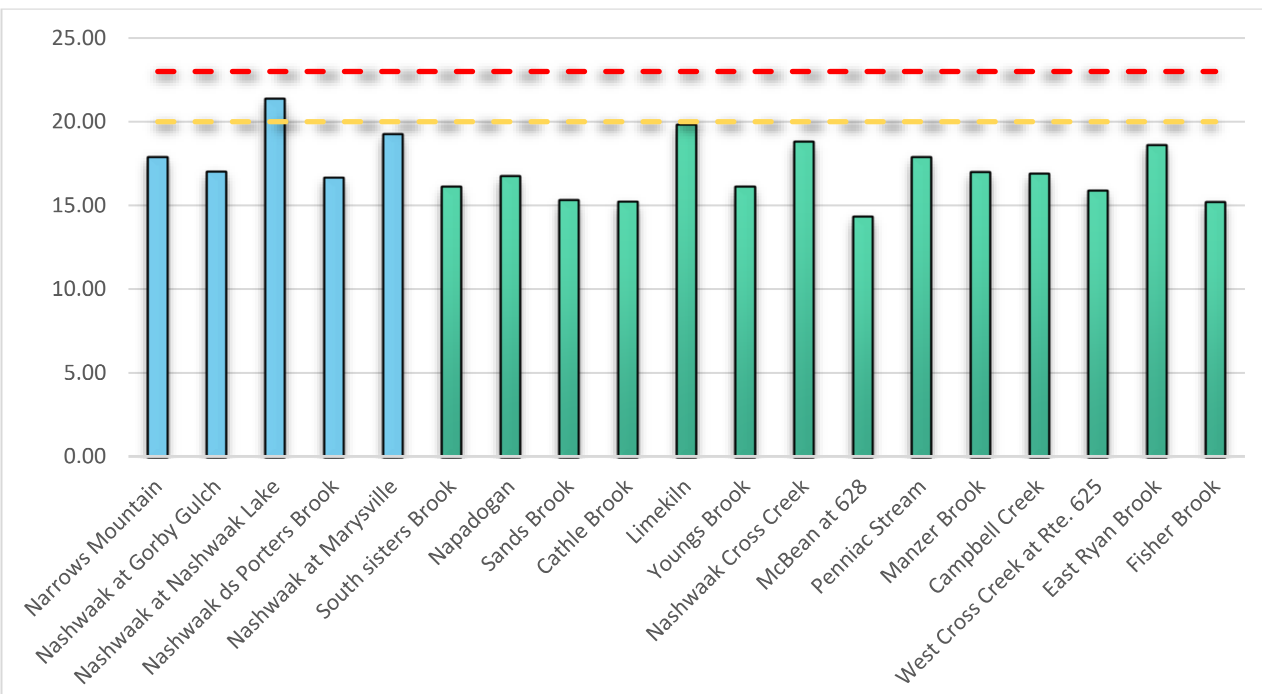


Figure 36. Average summer (June 21st-September 21st) temperatures for the Nashwaak river (blue) and tributaries (green) in 2023. Red dotted line represents the 23°C short-term temperature threshold for salmonids. Orange dotted line represents the 20°C long-term temperature threshold for salmonids.

Table 4. Summary of temperature logger data for the main stem and tributaries of the Nashwaak for 2017-2023

	Max (°C)	Min (°C)	July Avg (°C)	August Avg. (°C)	Summer avg. (°C)	Standard Deviation	# days min ≥20°C	# days max ≥23°C
2023 Main Stem (Avg)	27.2	11.1	19.63	17.22	18.4	3.16	15	15
2022 Main Stem (Avg)	33.0	3.3	17.7		17.2	2.7	7	10
2021 Main Stem (Avg)	27.95	9.7	18.99	20.91	18.93	3.37	25	27
2020 Main Stem (Avg)	28.27	6.34	22.06	21.09	20.60	3.66	40	53
2019 Main Stem (Avg)	27.53	7.28	20.71	20.23	18.78	3.44	21	24
2018 Main Stem (Avg)	27.58	6.67	21.69	20.18	19.74	1.30	24	31
2017 Main Stem (Avg)	29.19	6.53	20.46	19.50	19.78	3.04	12	50
2023 Tributaries (Avg)	24.3	9.7	18.21	15.27	16.67		1	3
2022 Tributaries (Avg)	30.0	6.4	16.6	16.7	15.8	2.4	2	5
2021 Tributaries (Avg)	21.52	7.58	15.06	16.47	15.16	2.17	1	2
2020 Tributaries (Avg)	22.95	5.18	17.87	17.34	16.77	2.94	7	13
2019 Tributaries (Avg)	22.82	6.06	17.04	16.57	15.49	2.77	1	5
2018 Tributaries (Avg)	22.68	6.13	17.88	17.45	16.59	6.69	4	7
2017 Tributaries (Avg)	26.11	6.51	19.15	20.15	17.86	2.68	3	21

Summary of Key Tributaries

Penniac Stream

2023 saw all temperatures below average at the Penniac Stream site (Table 5).

Table 5. Summary of the water temperature over the last six years in the Penniac Stream (lower station)

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	24.3	17.8±2.4	18.2	16.42	0	8
2022	27.7	18.6±3.0	19.6	19.4	6	19
2021	26.7	17.5±2.8	17.5	19.3	6	16
2020	29.2	20.6±3.9	22	21.2	36	57
2019	28.1	18.1±3.6	19.9	19.7	4	22
2018	24.5	19.1±2.9	19.2	18.6	2	12
2017	27.7	19.1±2.6	20.2	19.7	7	29
Average	**26.9**	**18.7±3.0**	**19.5**	**19.2**	**8.7**	**23.3**

Table 6. Summary of the water temperature in the Penniac Stream (higher station). This station was not monitored in 2022/23.

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	No data	No data	No data	No data	No data	No data
2021	No data	No data	No data	No data	No data	No data
2020	No data	No data	No data	No data	No data	No data
2019	26.1	16.5±3.3	18.3	17.6	0	11
2018	25.9	19.1±3.1	18.6	21.2	15	19
2017	No data	No data	No data	No data	No data	No data
Average	**26.0**	**17.8±3.2**	**18.4**	**19.4**	**8**	**15**

Tay River

There is no accurate data for this logger as it was lost in 2023.

Table 7. Summary of the water temperature over the last five years in the Tay River

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	N/A	N/A	N/A	17.6	0	0
2021	25.3	17.5±2.8	16.7	19.4	4	9
2020	26.8	19.1±3.4	20.5	19.5	13	42
2019	25.8	17.7±3.1	19.5	18.9	2	11
2018	27.5	19.7±3.2	21.9	19.9	18	29
2017	27.1	19.0±2.7	20.2	19.4	4	32
Average	**26.5**	**18.6±3.7**	**19.7**	**19.4**	**8**	**25**

Cross Creek

Unfortunately, the logger at this station stopped logging on July 17, 2023. The calculations for the summer average, peak temperature and days of heat waves will not be reflective of the entire summer. The temperatures recorded at the station in Cross Creek in 2023 were warmer, on average than 2022 and higher than the average historical temperatures at this site. Peak temperatures were recorded at 26.4°C.

Table 8. Summary of the water temperature over the last five years in Cross Creek. 2023 calculations only reflect partial data between June 21st-July 17th.

Year	Peak Temp (°C)	Summer Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	26.4	18.8±2.7	N/A	0	7
2022	26.6	18.2±3.1	18.3	2	18
2021	21.3	15.4±2.3	16.7	0	0
2020	No data	No data	No data	No data	No data
2019	27.6	17.3±3.7	18.8	4	18
2018	28.6	19.5±3.7	20	17	39
2017	27.1	19.0±2.7	19.1	13	29
Avg	**26.3**	**18.0±3.0**	**18.58**	**7**	**21**

Dunbar Stream

In 2023, the data logger was lost.

Table 9. Summary of the water temperature statistics over the last seven years in Dunbar Stream

Year	Peak Temp (°C)	Summer Avg (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	25.0	15.8±2.7	17	16.5	0	2
2021	24.2	15.6±2.5	15.4	17.3	0	1
2020	26.7	18.2±3.8	22.0	21.2	5	39
2019	25.4	16.0±3.3	17.6	17.5	0	9
2018	24.4	16.8±2.9	18.4	17.3	0	10
2017	25.1	17.2±2.7	18.2	17.7	0	14
Avg	**25.13**	**16.45±3.1**	**18.1**	**17.92**	**1**	**15**

Youngs Brook

The average summer temperature was similar to 2022 (a difference of -0.1°C) but saw a much warmer July, on average (Table 10). The average August temperatures in Youngs Brook were 2.1°C cooler than in 2022 and 2.8°C cooler when compared to the historic average for this month (17.9). It is unsurprising then, that the # of days with minimum temperatures >20°C was 0 and the 3 of days where the maximum temperature was >23°C was 4.

Table 10. Summary of the water temperature and statistics between the year 2017-2023 in Youngs Brook.

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	23.9	16.1±2.2	17.8	15.1	**0**	**4**
2022	25.6	16.2±2.8	13.8	17.2	0	4
2021	24.6	16.5±3	16.2	18.5	1	10
2020	27.2	19.1±3.9	20.4	19.7	17	40
2019	26.5	16.7±3.5	18.4	18.2	2	12
2018	No data	No data	No data	No data	No data	No data
2017	26.4	18.0±2.9	19.2	18.4	1	21
Avg	**25.7**	**17.1±3.1**	**17.6**	**17.9**	**3.5**	**15.2**

South Sisters Brook

In 2023, the peak temperatures and South Sisters Brook was slightly (+0.1°C) warmer than the 2022 Peak but lower than the historical (2017-2023) average for peak temperature (Table 11). As with many of the other tributaries, July was warmer, on average in 2023 than 2022 (18.4°C vs 17.3°C respectively). Similarly, the average August temperatures were 2.8°C cooler when compared to 2022 and 2.1°C cooler than what is historically seen, on average, at this site in August. There were no days with minimum temperatures >20°C, or with maximum temperatures >23 °C.

Table 11. Summary of the water temperature over the last six years in South Sisters Brook.

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	22.7	16.1±2.4	18.4	14.8	0.0	0.0
2022	22.6	16.4±2.6	17.3	17.6	0.0	0.0
2021	23.7	16.0±2.9	16.0	17.8	0.0	1.0
2020	24.7	16.9±3.4	18.3	17.3	1.0	4.0
2019	23.1	15.7±3.0	17.7	16.6	0.0	1.0
2018	24.6	17.2±3.1	19.1	18.0	1.0	6.0
2017	23.5	16.0±2.5	17.1	16.0	0.0	1.0
Avg	**23.6**	**16.4±2.8**	**17.7**	**16.9**	**0.29**	**1.86**

Ryan Brook

2023 has no data for Ryan brook due to the logger being lost.

Table 12. Summary of the water temperature over the last six years in Ryan Brook.

Year	**Peak Temp (°C)**	**Summer Avg. (°C)**	**July Avg. (°C)**	**Aug Avg. (°C)**	**# days min. >20°C**	**# days max. >23°C**
2023	No data	No data	No data	No data	No data	No data
2022	29.1	19.0±3.4	20.1	20	12	30
2021	22.4	15.4±2.6	15	17	0	0
2020	24.6	16.8±3.5	18.4	17.3	3	10
2019	23.6	15.1±3.0	16.9	16.3	0	1
2018	24.1	16.7±3.1	18.5	17.5	2	3
2017	26.9	17.9±2.7	19.3	18.4	2	16
Avg	**25.1**	**16.8±3.0**	**18.1**	**18**	**3**	**10**

Napadogan Stream

Napadogan Stream was not monitored in 2017 and data is missing from 2021. In 2023, the stream reached a peak temperature that was 1.3°C cooler than in 2022 (Table 13). While the average July temperatures were 1.2°C warmer than in 2022, they were in line with the historic July average seen in this tributary. August was 2.2 °C cooler than 2022 and 2.1 °C than the historic average for the month of August. There was only 1 day with maximum temperatures > 23°C.

Table 13. Summary of the water temperature statistics in Napadogan Stream between 2017-2023.

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	23.3	16.7±2.3	18.9	15.5	0	1
2022	24.6	16.7±2.8	17.7	17.7	0	2
2021	No data	No data	No data	No data	No data	No data
2020	26.4	18.3±3.9	19.8	18.8	9	38
2019	25.2	16.4±3.3	18.3	17.6	2	7
2018	26	17.8±3.1	19.6	18.5	4	11
2017	No data	No data	No data	No data	No data	No data
Avg	**25.1**	**17.2±3.1**	**18.9**	**17.6**	**3**	**12**

McBean Brook

McBean Brook saw the second highest peak temperature recorded between 2018-2023. The summer average was 0.3 °C warmer than in the previous year but was still in line with the average summer temperatures over time (Table 14). July was 0.9°C warmer than 2022 and 0.3°C than the historic average for this month. Keeping in line with other tributaries, August was, on average, cooler by 1°C when compared to the 2022 average for that month. There were no days with minimum temperatures >20°C or maximum temperatures >23°C.

Table 14. Summary of the historical water temperature statistics for McBean Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	19.0	14.3±1.6	15.6	13.7	0	0
2022	18.8	14.0±1.9	14.7	14.7	0	0
2021	No data	No data	No data	No data	No data	No data
2020	20	15.2±2.5	16.3	15.7	0	0
2019	18.8	13.5±2.1	14.6	14.4	0	0
2018	18.6	14.6±2.1	15.3	15.6	0	0
2017	No data	No data	No data	No data	No data	No data
Avg	**19.0**	**14.3±2.0**	**15.3**	**14.8**	**0**	**0**

Kaine Creek

There is no trends to report at Kaine Creek in 2023 due to the logger being lost (Table 15).

Table 15. Summary of the water temperature statistics over time in Kaine Creek

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	23.7	17.1±2.3	17.7	18.4	3	1
2021	21.4	16.7±1.8	16.4	17.8	1	0
2020	23.6	17.7±2.9	18.9	18.2	6	3
2019	21.9	16.1±2.5	17.7	17.3	0	0
2018	22.3	17.4±2.4	18.6	18.6	1	0
2017	No data	No data	No data	No data	No data	No data
Avg	**22.6**	**17.0±2.3**	**17.9**	**18.1**	**2**	**1**

Sands Brook

Sands Brook was not monitored in 2017. Peak temperatures in Sands Brook have been very similar over the last years, only differing by ± 0.9 °C from the historic average. Notably, the peak temperatures and the August average temperatures were the coldest on record. Specifically, the August temperatures were 1.3 °C than the historic average for this month.

Table 16. Summary of the water temperatures in Sands Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	19.5	15.3±1.5	16.5	14.7	0	0
2022	20.7	15.0±2.2	15.7	16.1	0	0
2021	20	15.0±2	14.7	16.3	0	0
2020	20.9	15.8±2.7	16.7	16.5	0	0
2019	20.3	14.3±2.3	15.5	15.3	0	0
2018	20.8	15.9±2.5	17.2	16.9	0	0
2017	No data	No data	No data	No data	No data	No data
Avg	**20.4**	**15.2±2.3**	**16.0**	**16.0**	**0**	**0**

Cathle Brook

Monitoring for Cathle Brook began in 2018. In 2023, the peak temperature was the 2nd lowest on record and 1.7 °C cooler than the average peak temperatures over time (Table 17). The average temperature for July was the exact same as 2022 (16.6°C). August was significantly cooler than 2022 (-1.9°C) and the historic average (-2.6°C). There were no high heat events recorded in the stream for the summer of 2023.

Table 17. Summary of the water temperatures in Cathle Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	21.1	15.2±1.8	16.6	14.4	0	0
2022	22.2	15.5±2.6	16.6	16.3	0	0
2021	20.8	15.2±2.4	15.1	16.6	0	0
2020	25.3	18.1±3.9	19.3	19.1	9	29
2019	22.5	15.3±2.7	16.3	16.7	0	0
2018	24.7	17.9±2.9	19.6	18.6	3	13
2017	No data	No data	No data	No data	No data	No data
Avg	**22.8**	**16.4±2.8**	**17.2**	**17.0**	**2**	**7**

Manzer Brook

Manzer Brook was not monitored in 2017 but was the site a fish passage restoration project in 2018. In 2023, the summer peak temperature was only slightly lower than the average over time (-0.3°C) (Table 18). 2023 saw the warmest average temperature on record for the month of July, 1°C above the historic average. This was followed by the coldest average temperatures for the month of August, which were 1.3°C cooler than the historic average for this month.

Table 18. Summary table of the water temperature statistics over time in Manzer Brook.

Year	**Peak Temp (°C)**	**Summer Avg. (°C)**	**July Avg. (°C)**	**Aug Avg. (°C)**	**# days min. >20°C**	**# days max. >23°C**
2023	22.7	16.9±1.9	18.8	16.0	**0**	0
2022	22.4	16.5±2.3	17.3	17.5	0	0
2021	22	16.1±2.1	16.2	17.4	0	0
2020	24.6	17.5±3.2	18.6	18.2	3	6
2019	23.4	15.7±2.7	17.4	16.7	0	1
2018	22.7	17.0±2.6	18.2	18	0	0
2017	No data	No data	No data	No data	No data	No data
Avg	**23.0**	**16.6±2.5**	**17.8**	**17.3**	**0.5**	**1.2**

McLean Brook

McLean Brook was not monitored in 2017 but was the site of a restoration of fish passage project in 2018. There is no statistic data available for 2023 due to the logger being lost.

Table 19. Summary of the water temperatures in McLean Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	18.7	14.1±1.7	14.7	14.7	0	0
2021	16.6	13.8±1.7	13.9	14.8	0	0
2020	21.6	15.5±2.7	16.4	16.1	0	0
2019	19.7	13.7±2.2	14.7	14.8	0	0
2018	19.3	14.7±2.0	15	15.8	0	0
2017	No data	No data	No data	No data	No data	No data
Avg	19.2	14.4±2.1	14.9	15.2	0	0

Campbell Creek (upstream and downstream from dam)

It is important to note than in 2017 the head pond was drained when the loggers were deployed while in 2018 and 2019 it was full. In 2020, the head pond drained slowly throughout the summer and then was drained using gravity syphons in September. 2017 and 2020 were drier years with record low water levels and low precipitation compared to 2018 and 2019. In 2021 the dam was removed, and flow was restored to the creek.

Unfortunately, the logger downstream of the dam was lost in 2023 (Table 20). The logger upstream from the former dam saw lower peak temperatures (Table 21) when compared to 2022 (-3.3 °C) and the historic average peak temperature (-3.1°C). Average August temperatures were 0.9 °C warmer than in 2022. Average August temperatures were the coldest on record at 3.3°C cooler than the average for that month.

Table 20. Summary of the water temperature over the last six years in Campbell Creek (downstream of dam)

Year	Peak Temp (°C)	Summer Avg. Temp (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	No data	No data	No data	No data	No data	No data
2022	28.4	19.3±2.7	17.3	20.2	5	4
2021	23.1	16.6±2.6	16.4	18	0	1
2020	23.4	20.5±1.1	20.3	21.2	21	3

2019	22.2	17.7±2.6	18.9	19.3	5	0
2018	24	18.8±2.1	20.1	19.6	21	3
2017	22.3	18.5±2.4	19.4	19.2	3	17
Avg	**23.9**	**18.6±2.2**	**18.7**	**19.6**	**9**	**5**

Table 21. Water temperature over 4 years in Campbell Creek (upstream of dam) and Headpond.

Year	Peak Temp (°C)	Summer Avg. Temp (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2023	21.3	16.8±1.7	18.4	15.1	0	0
2022	24.6	17.7±2.1	17.5	18	1	1
2021	23.6	16.7±2.5	16.2	17.5	0	1
2020	No data	No data	No data	No data	No data	No data
2019	No data	No data	No data	No data	No data	No data
2018	21.76	17.2±2.4	21.8	21.2	1	0
2017	30.6	19.3±9	20.3	20.1	46	3
Avg	**24.4**	**17.5±3.5**	**18.8**	**18.4**	**9.6**	**1.0**

Porter's Brook

Porter's Brook is a potential fish passage restoration site that NWAI began monitoring in 2021. Unfortunately, the logger was lost in 2023 in the brook.

Table 21. Summary of water temperature over 2 years in Porter's Brook

Year	**Peak Temp (°C)**	**Summer Avg. Temp (°C)**	**July Avg. (°C)**	**Aug Avg. (°C)**	**# days min. >20°C**	**# days max. >23°C**
2023	No data	No data	No data	No data	No data	No data
2022	15.2	10.5±1.3	10.8	11.3	0	0
2021						
Avg						

Data and graphs for all loggers found are available in Appendix B.

Water Temperature

2023 was an unusually wet summer with temperatures that were warmer in July and significantly cooler in the tributaries in August when compared against historic August temperatures.

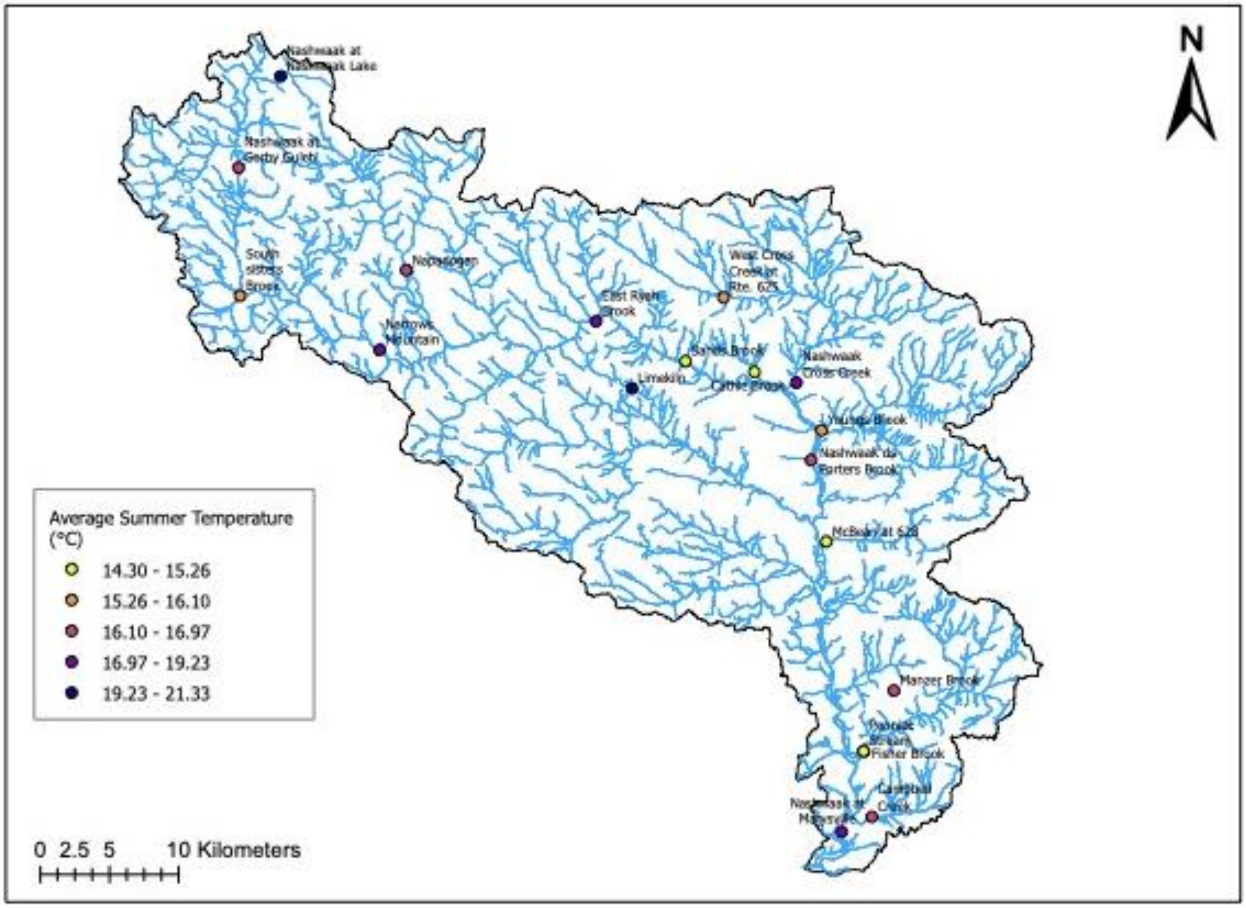


Figure 37. Map of the loggers placed in the watershed in 2023. Coloured symbols show average summer water temperature from yellow (cooler) to dark blue (warmer).

Challenges

Though temperature loggers were deployed by the NWAI previously in 2002 and 2005, the details of how and where they were deployed were not recorded. Therefore, the past seven years have provided a learning curve for the association, and 2023 continued in that respect.

2023 was the worst year on record for temperature data collection success. 12 loggers out of 39 were lost after several high discharge events (including a devastating tropical storm). While the loggers had all the batteries changed before deployment, several loggers failed to log after the set time once deployed. Similarly, 2 loggers stopped logging prior to retrieval, which resulted in data gaps. Of the 27 loggers that were retrieved, only 19 loggers contained viable data. The final challenge faced was that in some locations with fine sediment, the loggers became buried, or the casings filled with sediment. When checked on, the loggers were removed, cleaned, and promptly reinstalled. A solution might be to cover the top of the casing with fine mesh the inhibits sediment build-up but still allows water flow through the casing.

Conclusions

Despite the hiatus, the reintroduction of water quality and temperature monitoring in 2017 and its continuation in subsequent years has and will contribute to our understanding of the natural state of the water network as well as evaluating the impacts of human activities. We are already starting to see trends in the data collected. The NWAI strives to continue to monitor watershed health and improve our understanding of both the natural variability of the system and the impacts that anthropogenic land-use have on the quality of the water. We hope that continued data collection will help us determine and address the greatest water quality concerns.

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Appendix A: Field Data Sheets

NAME OF GROUP/COMPANY: ____

Monitoring Site Name: ____

Site Coordinates:

DELG field number: ____________________ (unique number for this station for this day)

Date: ___________________________Time (00:00-24:00): _____________________

Sample collected by: ____

Weather/Air Temperature:____

Rainfall in the last 24 hours: _______ None _______ Light _______ Heavy

Water level: _______ Low _______ Normal _______ High

Water clarity/colour? ____

Algae? ____

Oil/film/foam on water? ____

Garbage (in water or on shore)? ____

Fish (dead or alive)?____

Bank erosion / state of bank vegetation? _______________________________________

ATV crossings / cattle crossings? ____

Construction (e.g., road, bridge) upstream of sample site? __________________________

People fishing/swimming upstream? ____

____

Natural/man-made barriers, beaver dams upstream/downstream? ___________________

____

Other general comments: ____

____

DO (mg/L)	Temperature (°C)	pH	Conductivity (µs/cm)	Salinity (ppt)	TDS (ppm)

rpc

Sample Submission Form

Chain of Custody Record - SS01.10

Shaded Areas for Laboratory Use Only
Submission #:

Fredericton: 921 College Hill Rd., Fredericton NB E3B 6Z9 T: 506.452.1212 F: 506.452.0594 Toll Free: 800.563.0844
Moncton: 150 Lutz St., Moncton NB E1C 5E9 T: 506.855.6472 F: 506.855.8294

Report To Customer	**Bill To Customer (if different)**	**Project/Submission Information**	**Turnaround Time**
Company:	Company:	Site Location:	**Routine:** ☐ Varies by analysis
Address:	Address:	Project Number:	**Rush (surcharge applies):**
		Submission Date:	☐ 24 Hours ☐ 48 Hours
Contact:	Contact:	Sampled by (print):	☐ 3 Days ☐ 4 Days
Telephone:	Telephone:	Sampler's Initials:	**Specific Date Required**
Fax:	Fax:	Purchase Order #:	(do not use ASAP):
E-mail:	E-mail:	**RPC Quotation #:**	

LIMS #:	Sample Matrix	Client Sample Identification	Sample Date/Time	Analysis Required I	II	III	IV	V	Other Analyses/Comments Special Instructions/Hazards

	Analysis Required (Description)	Preservatives
I		
II		
III		
IV		
V		

Please see reverse side for more information.
Label samples carefully and complete all parts of the form.

Sample Receiving Checklist

☐ Documentation ☐ Sample Volume
☐ Sample Containers ☐ Hold Time
☐ Sample Temperature Temperature = ________________ °C

Comments:

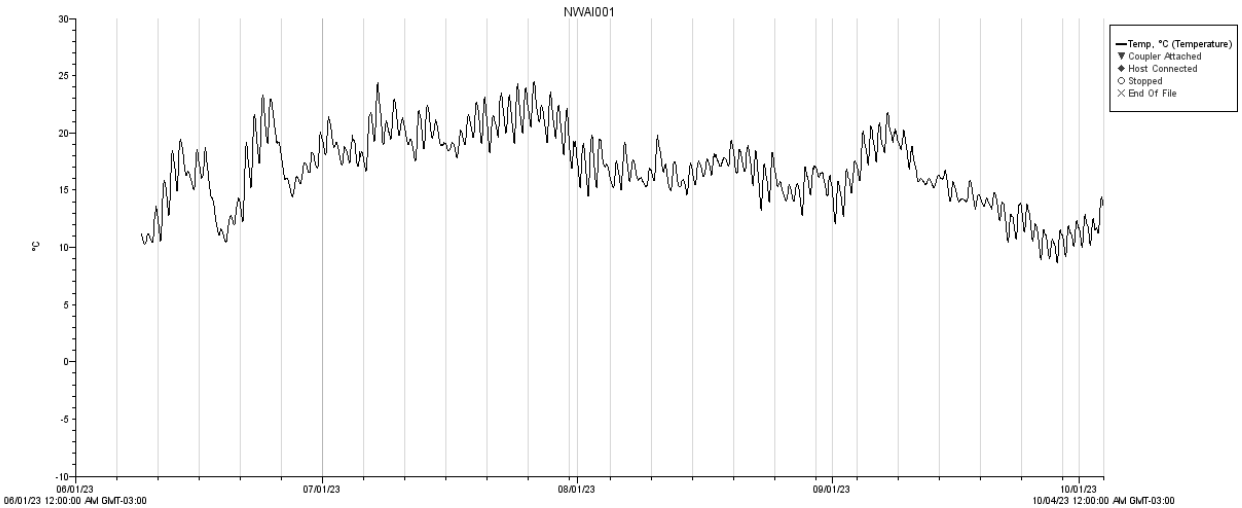
Chain of Custody

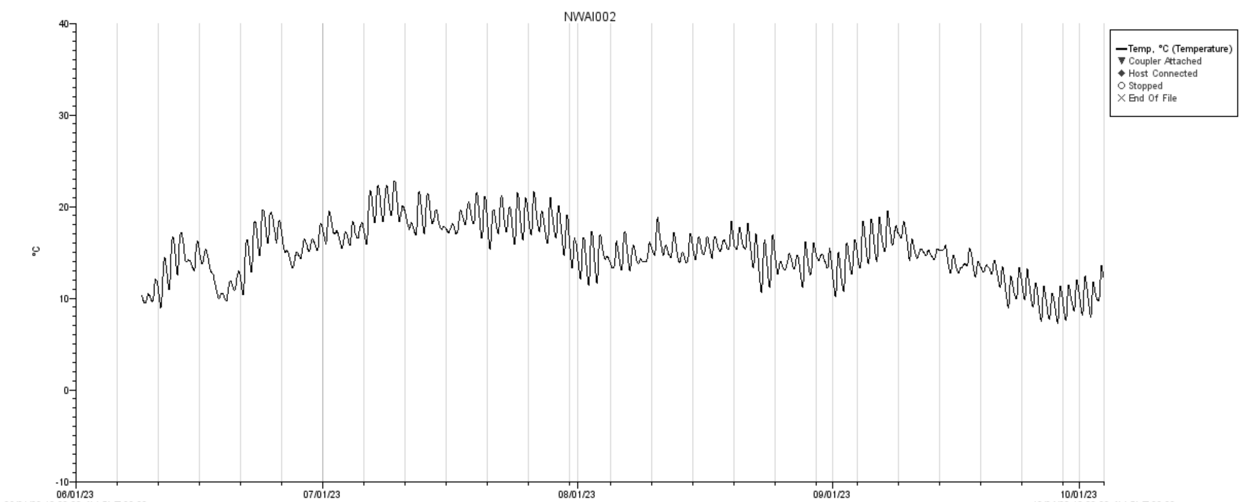
(1) Relinquished by:	Date:	(1) Received by:	Date:
Company:	Time	Company:	Time:
(2) Relinquished by:	Date:	(2) Received by:	Date:
Company:	Time	Company:	Time:

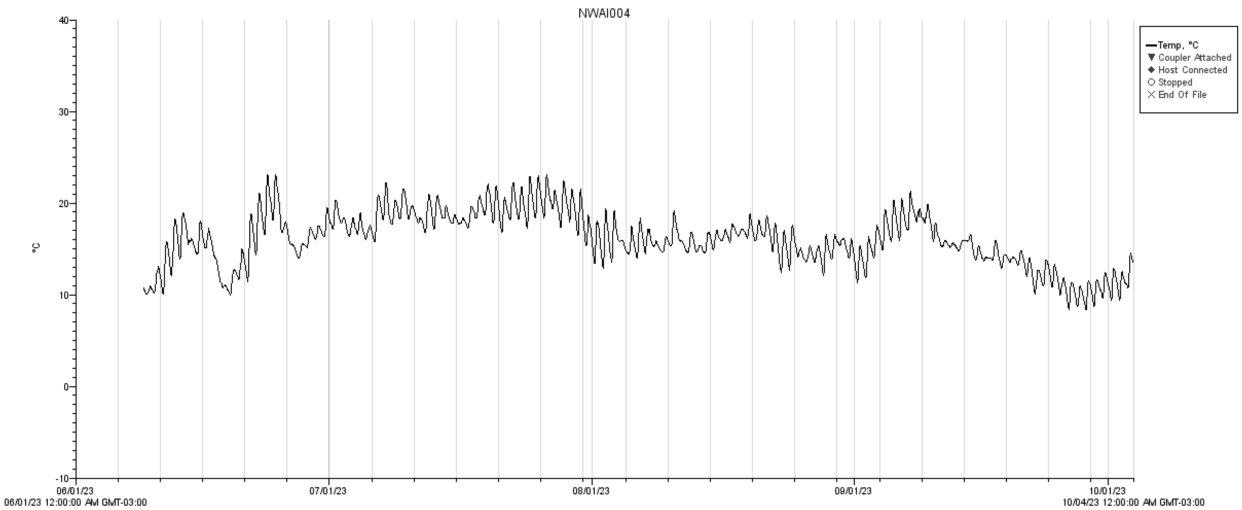
Original: File Copy Yellow: Customer Copy Page ________ of ________

Appendix B: Data

Historical water quality and temperature data is available on our website: https://www.nashwaakwatershed.ca/reports/



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Coupler Attached
Host Connected
Stopped
End Of File
°C
06/01/23
06/01/23 12:00:00 AM GMT-03:00
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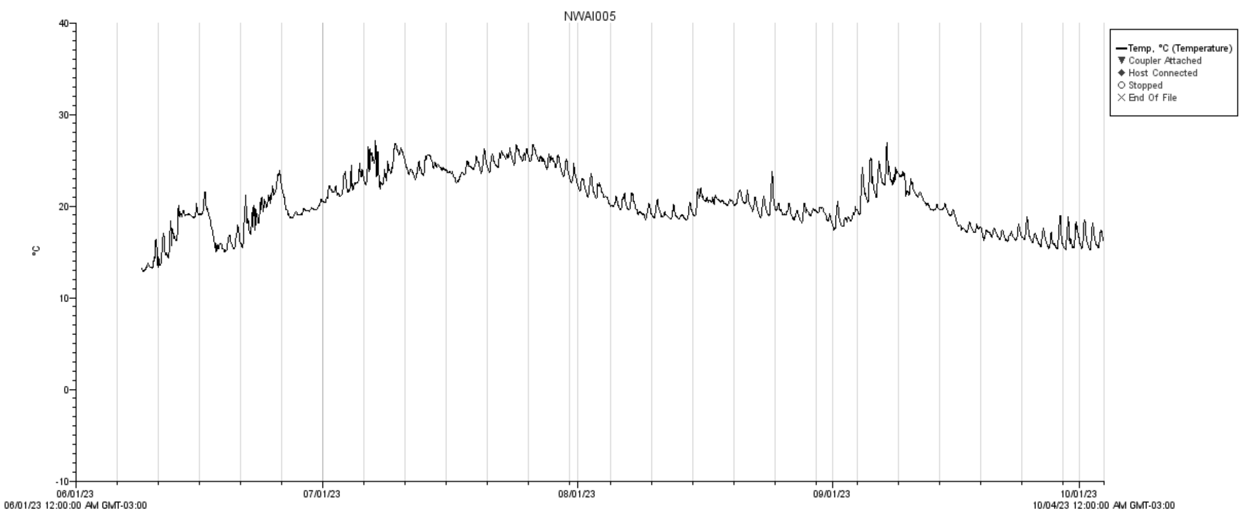
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°C
06/01/23
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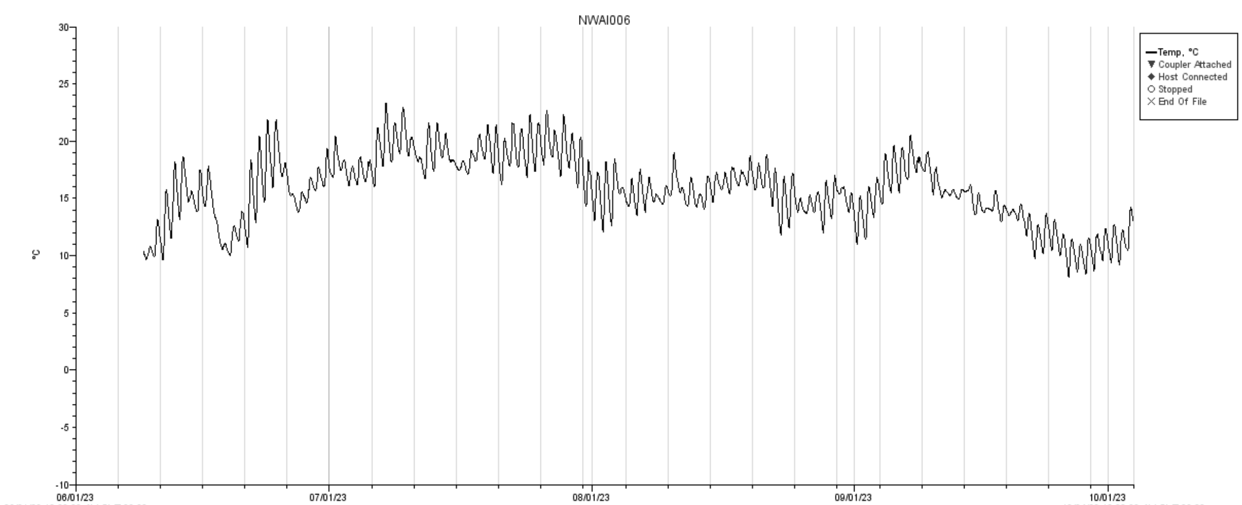
07/01/23
08/01/23
09/01/23
10/01/23
10/04/23 12:00:00 AM GMT-03:00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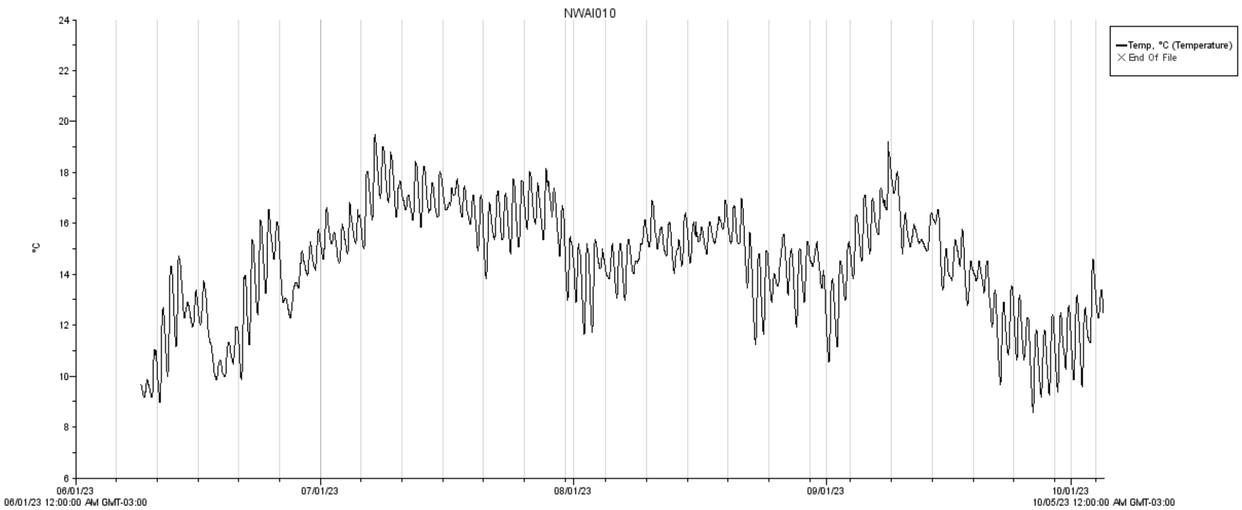
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°C
24
22
20
18
16
14
12
10
8
6
06/01/23
06/01/23 12:00:00 AM GMT-03:00
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Temp, °C (Temperature)
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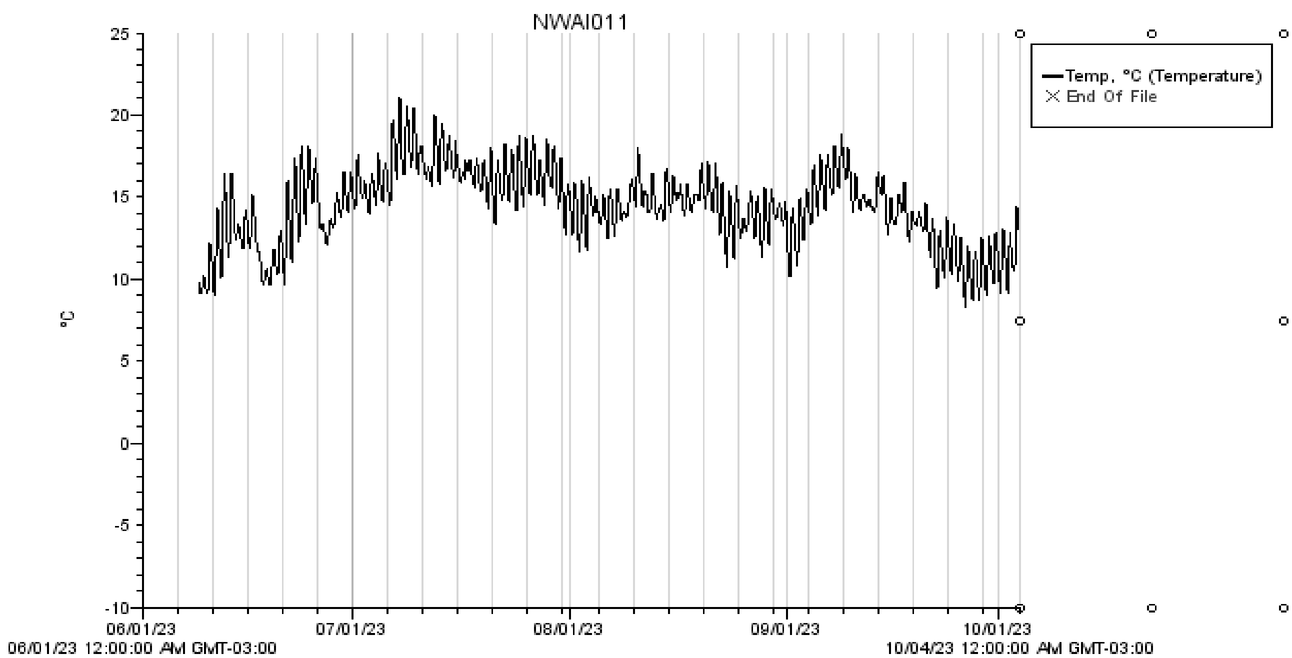
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°C
25
20
15
10
5
0
-5
-10
06/01/23
06/01/23 12:00:00 AM GMT-03:00
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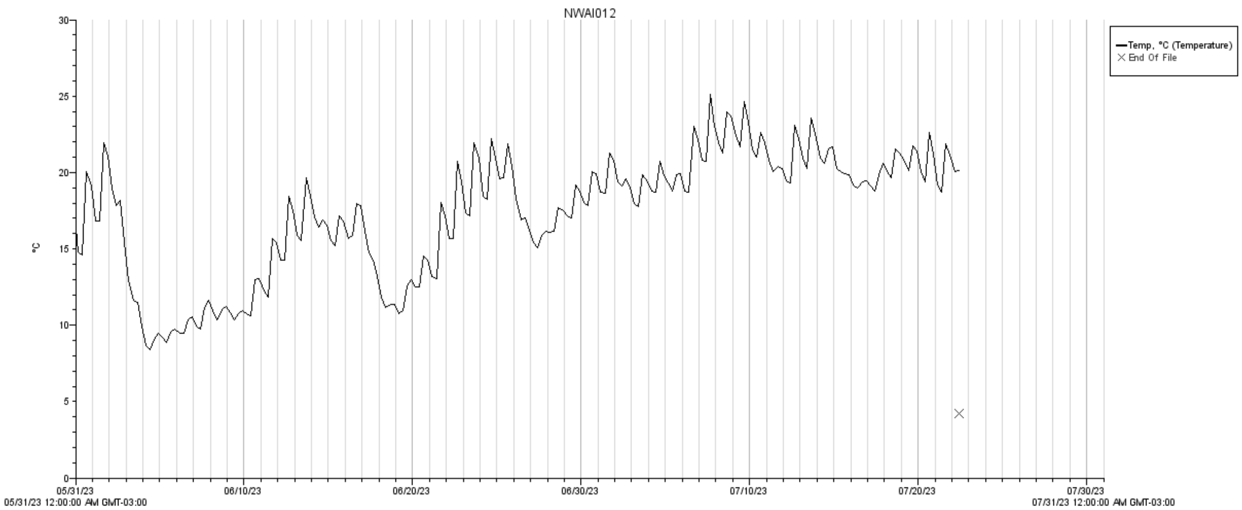
End Of File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°C
05/31/23
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06/20/23
06/30/23
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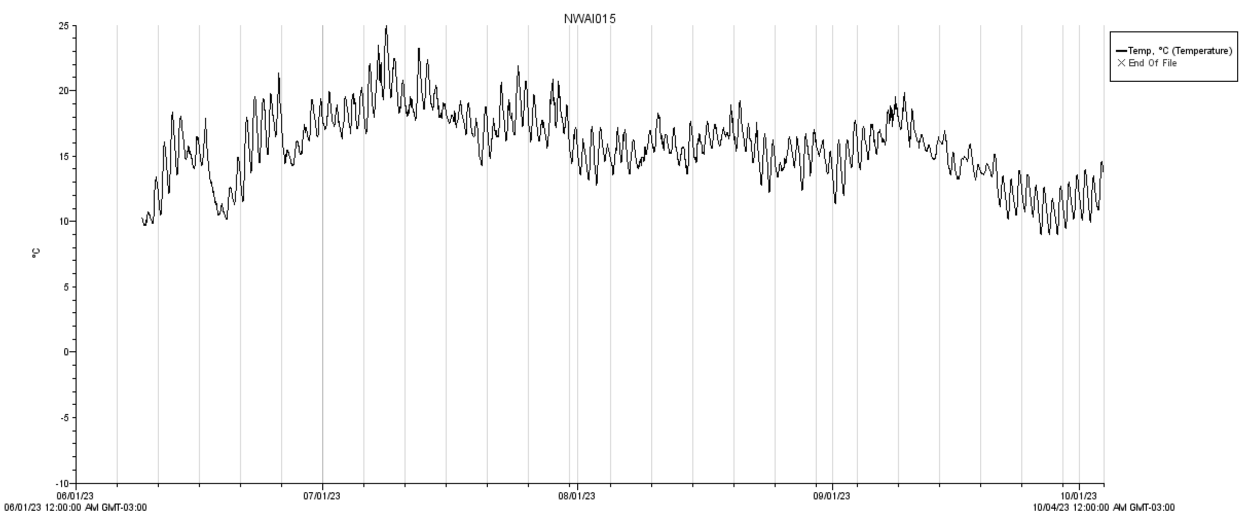
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°C
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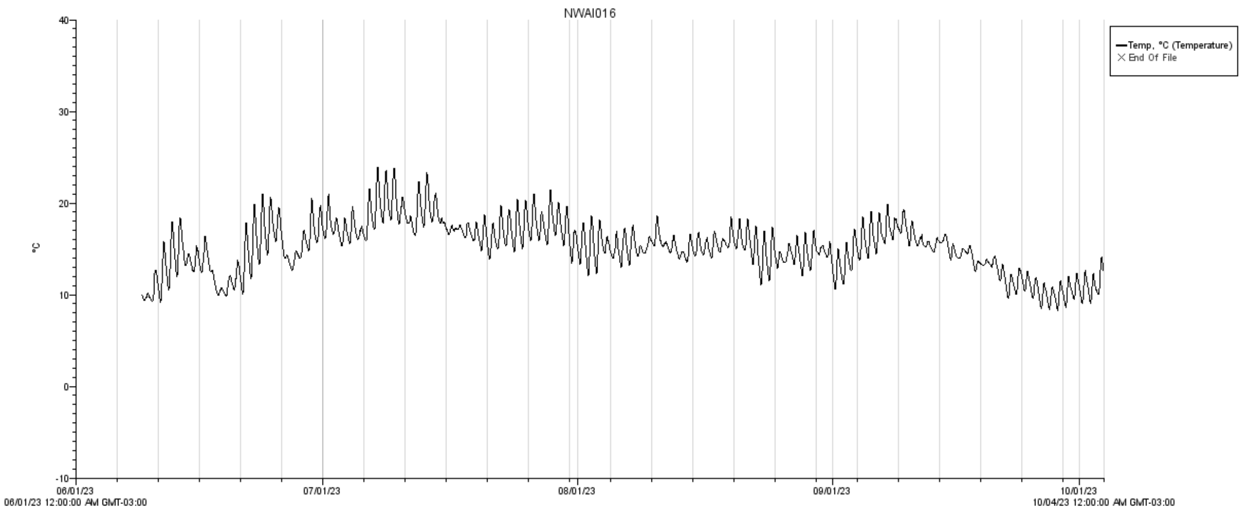
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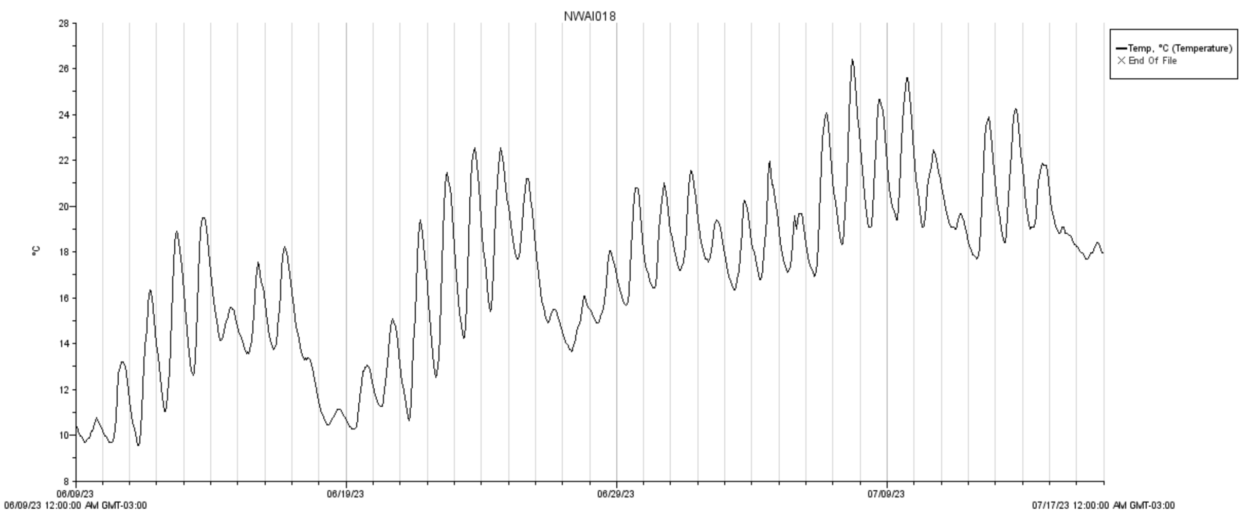
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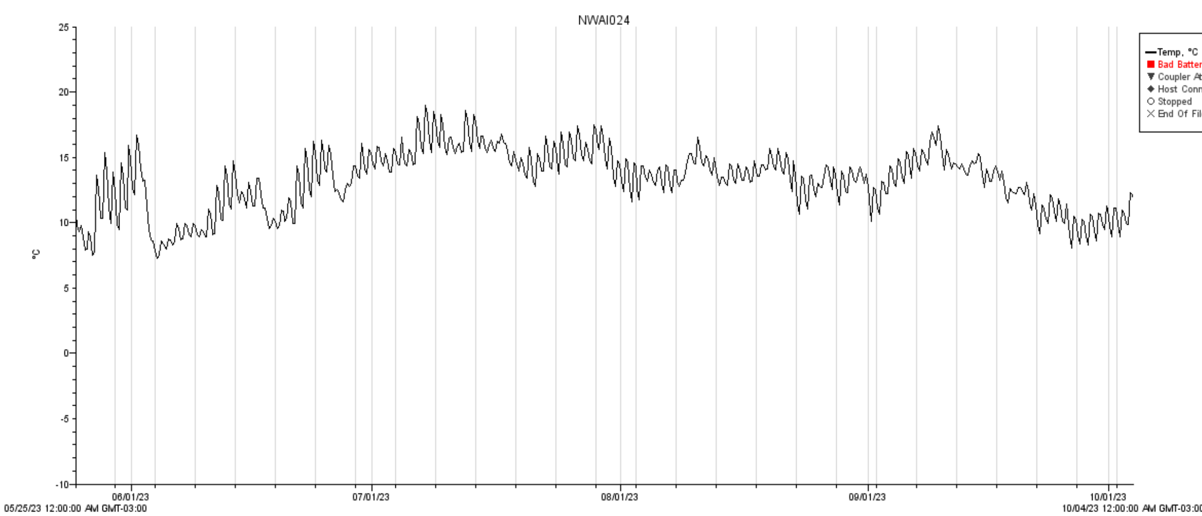
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Temp, °C
Bad Battery
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End Of File
°C
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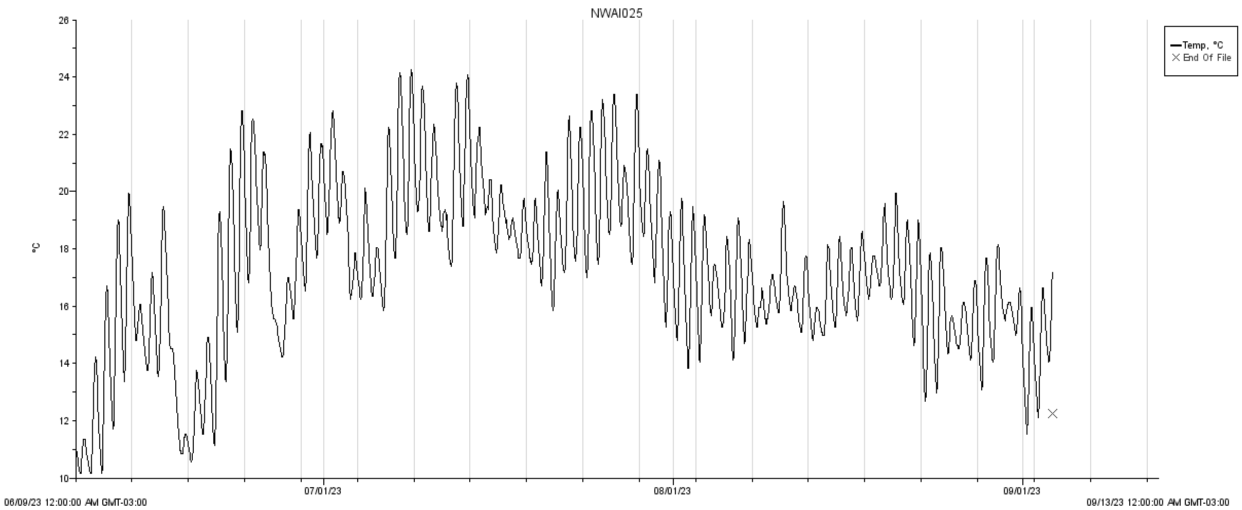
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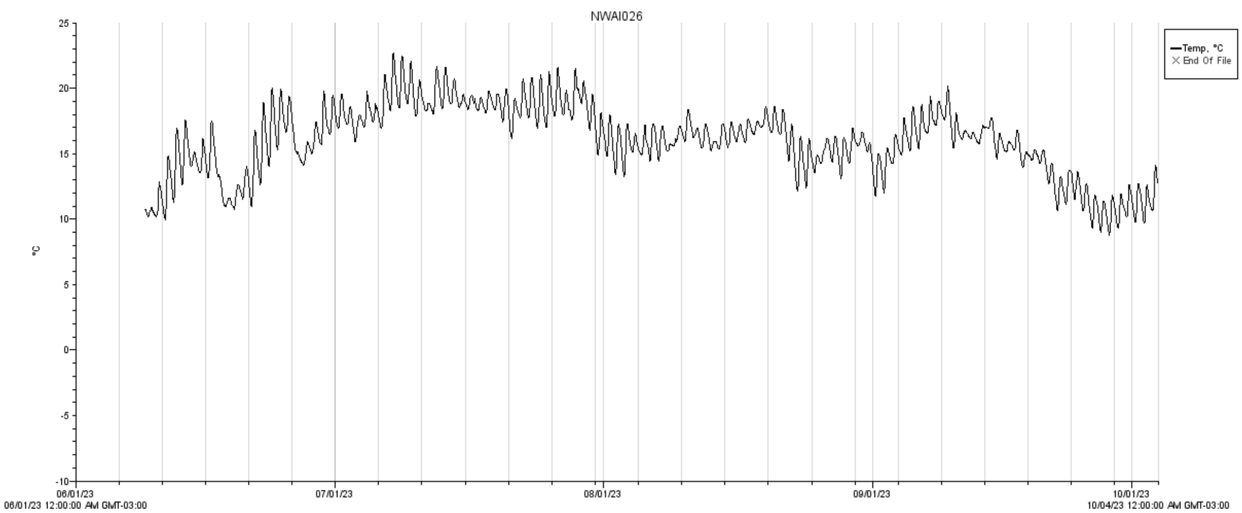
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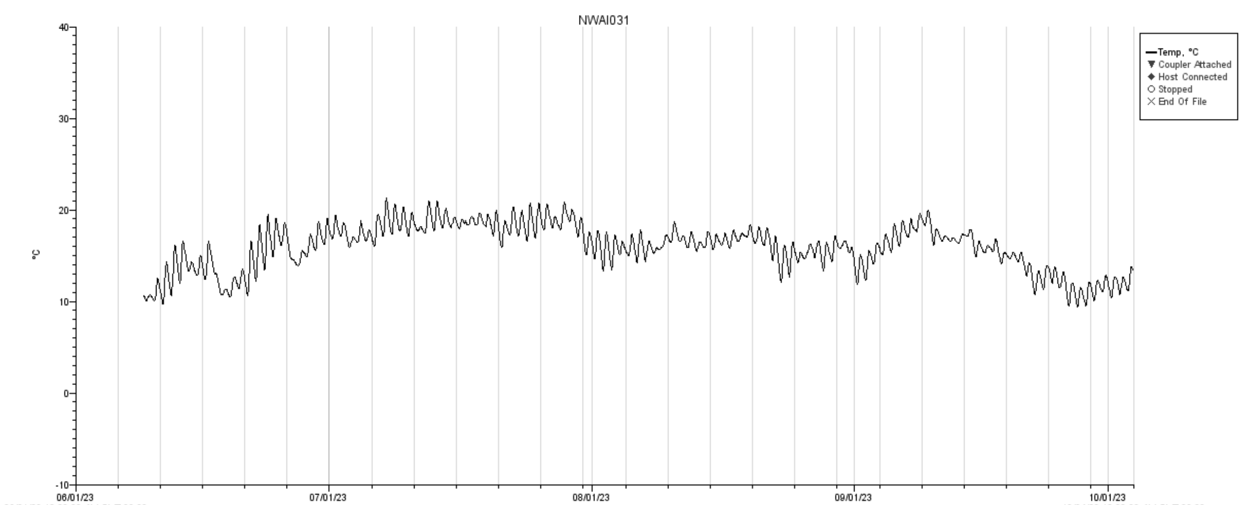
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End Of File
°C
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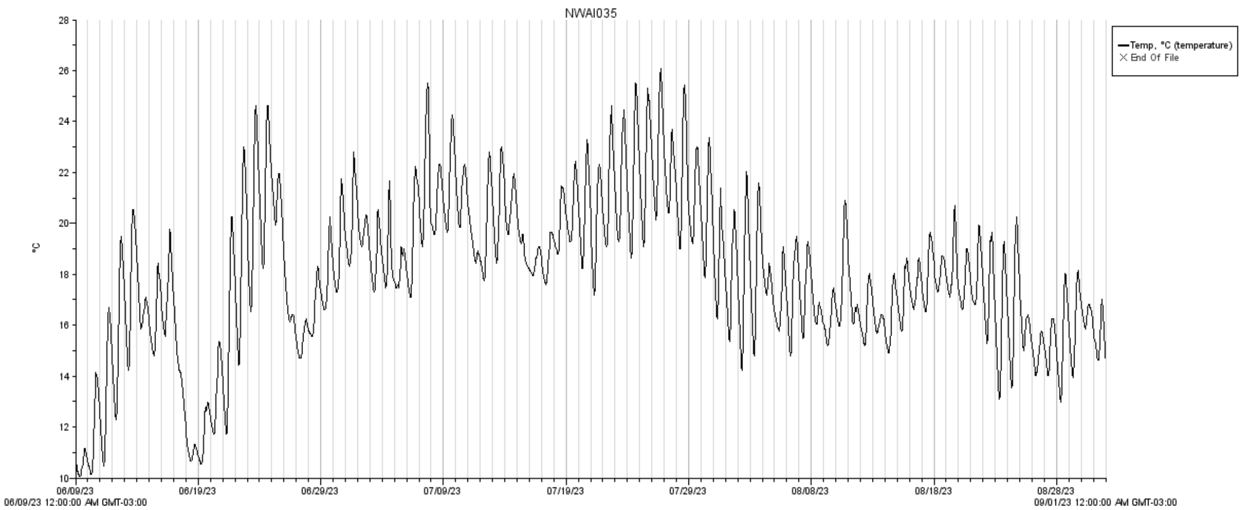
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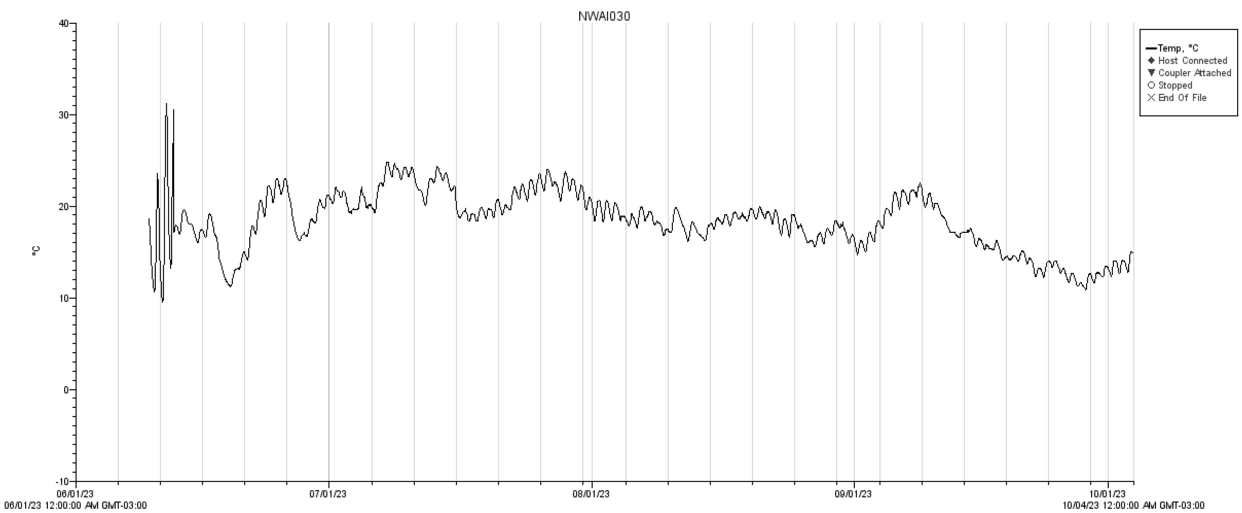
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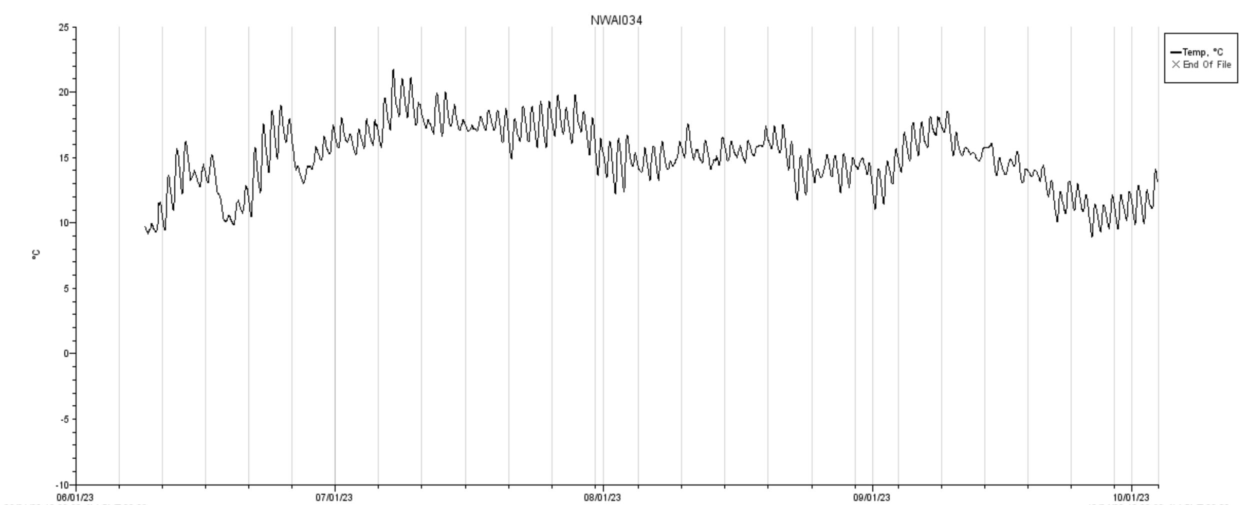
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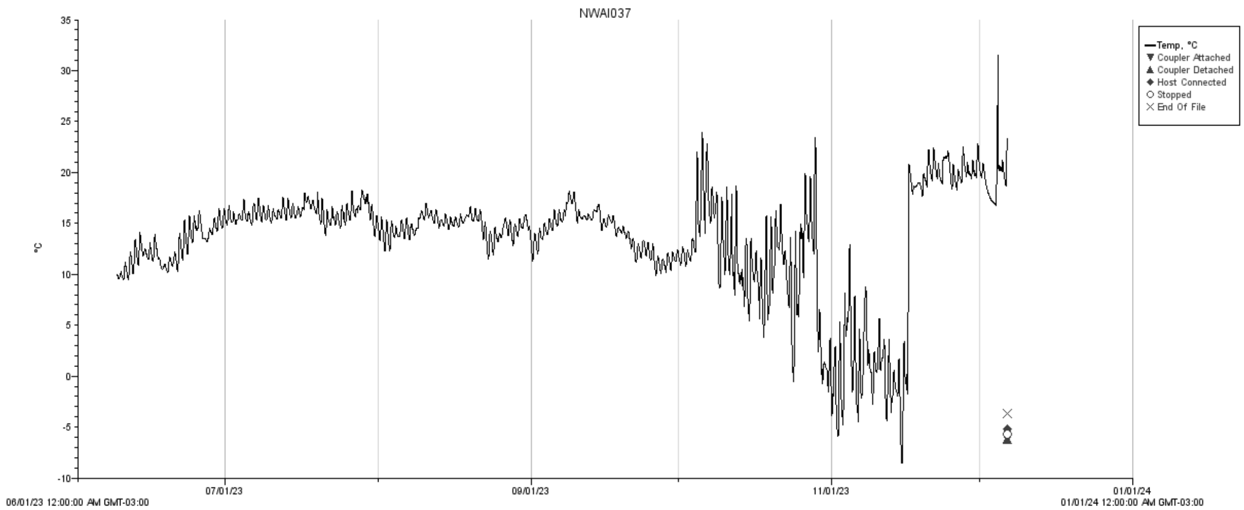
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End Of File