2020-2021

Report on the health of the Nashwaak Watershed

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Executive Summary

The Nashwaak Watershed Association Inc. (NWAI) restarted sampling water quality to monitor various parameters in 2017 after a 14-year hiatus. In 2020, samples were taken once a month from May to October at 11 historic sites and at Campbell Creek (sampling started in 2017). We also sampled limited parameters with our field probe and took grab samples for nutrients at two sites related to a cyanobacteria project (Neil's Flats and Nashwaak Valley Farm). Samples were analyzed by the RPC lab in Fredericton using their surface water package and for *Escherichia coli.* Results were compared to the Canadian Councils of the Ministers of the Environment (CCME) guidelines and to historic (pre-2010) data to infer trends in parameters. In general, sites closer to the mouth of the river, had inferior water quality compared to the sites in the headwaters.

Although water quality in 2020 was generally very good throughout the watershed, some measured parameters differed from levels that would be considered optimal. Exceedances of some parameters such as aluminum, iron, and fluoride 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 a few different anthropogenic activities including soil mining, agriculture, and removal of riparian vegetation.

On October 15th, there were several exceedances of *E. coli* and elevated levels of turbidity, nutrients, and some metals recorded at some sites as the samples were taken within 36 hours of a heavy rainfall event. Many water quality parameters, particularly dissolved oxygen (DO) and pH, were optimal and appeared to be improving when compared to historic levels. The Water Quality Index (WQI) score for 2020 was 89.72, which is very good. This value has remained relatively stable over the last four years of sampling.

From May to October this year we deployed 36 temperature loggers in both tributaries and along the main stem of the Nashwaak to measure water temperature in six hours intervals. We retrieved 32 loggers and analysed the recorded temperatures. Meteorological conditions were very warm and dry in summer compared to 2019, and water levels were extremely low (similar to 2017). Temperatures over the summer of 2020 were the warmest measured in the last four years at many sites.

Due to the warm air temperatures this summer, almost all sites on the main stem exceeded 28°C. However, two tributaries: Nixon Brook and East Ryan Brook remained below 20°C all summer, indicating that they are very important thermal refuges for fish (three additional tributaries remained below 21°C: McBean Brook, McGivney, and Sands Brook). Nixon Brook remained below 9.8°C all summer, indicating that is most certainly groundwater fed. Over time, the increased monitoring of temperature on our ecologically important tributaries will help us to understand the source of thermal inputs and the location of more thermal refuges within the watershed.

In order to keep our streams cool and clean, we have focused on educating watershed residents about the importance of native riparian vegetation and promoting environmentally friendly land-uses, through our other projects, including our Landover Conservation Program, and on retired agricultural properties. We will continue to develop and expand our Education and Outreach programs to increase awareness and understanding of watershed processes and promote landowner stewardship. We will also continue to work with the City of Fredericton to improve their floodplain properties and encourage the development of green infrastructure. We have also focused future aquatic connectivity projects on cold water tributaries as it is incredibly important that these streams and brooks are connected to the watershed as they provide spawning, rearing, and feeding habitat in additional to thermal refugia.

Contents

Introduction and background

Historically, there are large temporal gaps in monitoring the Nashwaak watershed's health. Water quality and temperature were noted as data deficient areas in our 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 extremely 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. Our 2016 geomorphic survey of the lower Nashwaak recognized large areas of stream bank erosion, especially downriver from 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. Additionally, the Sisson Mine Project will soon begin construction in the watershed headwaters. Having a knowledge of what the water quality is before it begins operating will allow us to calculate its effects. These factors motivated the NWAI to resume monitoring water quality in 2017, at 11 historic sampling sites, and one new site in Campbell Creek. In 2020 we continued to monitor water quality at these 12 sites and monitored two additional sites related to a restoration project.

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 the last decade and a half;
- Define and approach private landowners in problem areas and discuss management options with them;
- Determine how the changes in water quality are affecting wildlife and habitat, particularly Atlantic salmon;
- Make decisions on the management of the river's health; and
- Promote community stewardship of the Nashwaak River by making the information public.

The risk of extreme temperature events in a river can arise from 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 fishes (Curry &

Gautreau, 2010). Other factors that 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, and agriculture practices that fail to follow best management practices remain.

Warmer water 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).

"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 do not 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.

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 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 threshold minimum 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 our 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.

Historical water quality data

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. In 2019, a dissolved oxygen probe was purchased and sampling for this parameter resumed. A site map of sampled locations can be found in Figure 1.

Sources of pollution in the Nashwaak Watershed

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 McLaggon Bridge (closed?), and veneer mill in Napadogan
    - Potential contamination by hydrocarbons, suspended solids, metals, and biochemical BOD.
- Former army encampment at McGiveney
    - Used as a munitions depot between the late 1930s and mid-1950s, and
    - Potential continued contamination from ammonium, nitrate, hydrocarbons, and explosives.

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 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, 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.

Historical Temperature Data

Limited 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 exactly 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 our 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 particular 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:

Water quality monitoring

Monthly sampling for water quality was carried out at 11 historic sampling sites and at Campbell Creek throughout the watershed between May and September (Fig. 1). We chose these sites (out of 18 historic sites) based on our budget, ease of access (it appeared as if some historic locations were no longer accessible without an ATV), and location (i.e., evenly spread throughout the watershed). We also sampled two sites at Nashwaak Valley Farms, upstream and downstream of a restored bank before and after the restoration occurred. An additional site, NASH-B in Marysville, was sampled regularly by DELG staff. Sites were chosen to capture the water quality from the headwaters to the mouth.

Grab samples were taken according to DELG instructions in sterilized bottles provided by RPC Fredericton. A field sheet, provided by DELG, was completed that included information such as: weather, rainfall, bank stability, presence of garbage, and presence of people swimming or fishing. Physical parameters (DO, pH, conductivity, temperature, and TDS) were measured with handheld probes and recorded on the field sheet. The probes were calibrated for monthly. The DO probe malfunctioned during the July sampling run in the upper watershed. Therefore, those results were not included in the analyses. All field sheets were scanned and emailed to DELG. Blank DELG and RPC field sheets can be found in Appendix A.

Samples were stored in a cooler containing ice packs until they could be delivered to the lab (RPC Fredericton). 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 the next morning.

Samples were analyzed for *E. Coli* and the surface water package by RPC. Data were entered into a central database and graphically compared to historic (1980-2005) data. Parameters were 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 over the CCME limits were highlighted in our database.

Study Area and Land-use

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

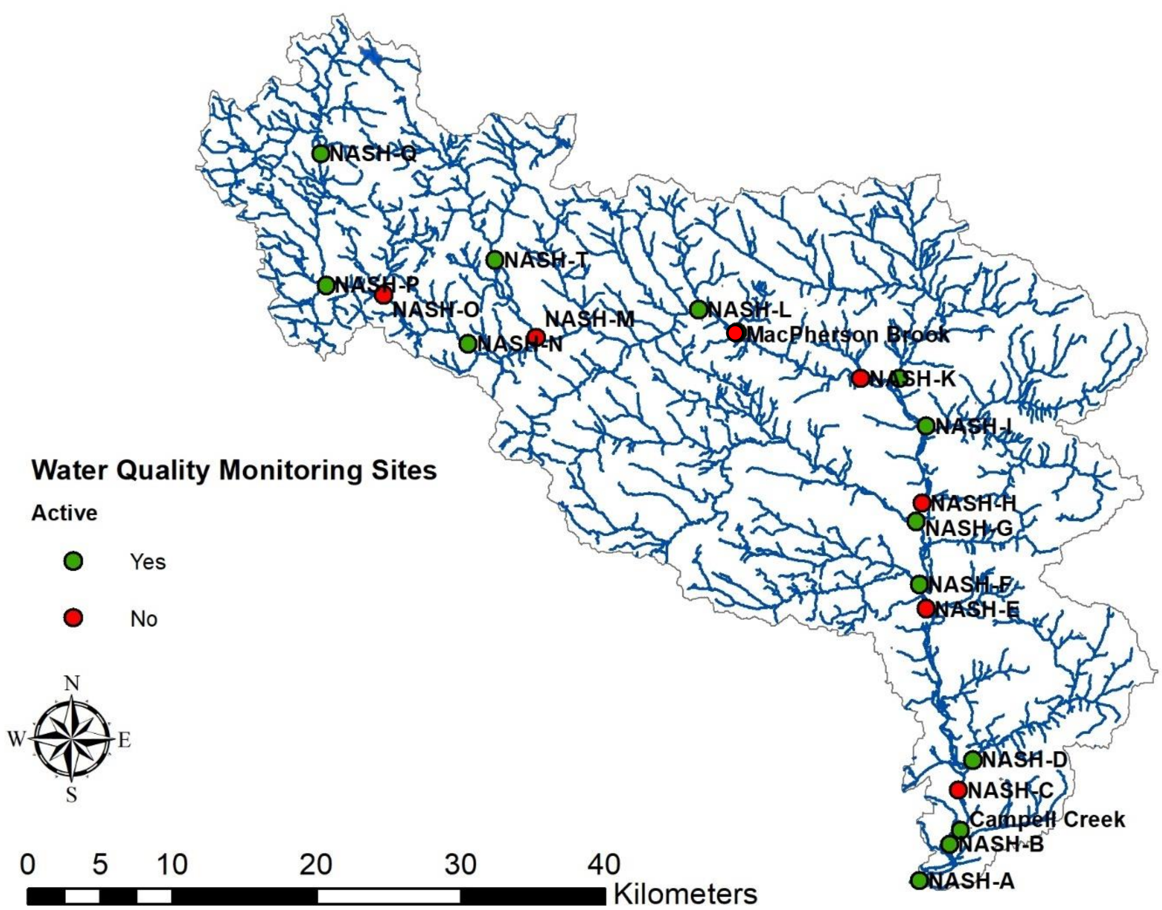

Figure 1 Map of the water quality sampling sites. Active sites (those sampled in 2020) are denoted in green while inactive sites are denoted in red. Sites sampled for the cyanobacteria project are not indicated on this map.

Stations sampled in 2020 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 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.

NASH-B: Marysville (DELG Station 10536)
This station is located just above the bridge in Marysville. Additive drainage from Campbell Creek and McConaghy 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.

This site is sampled by DELG not by NWAI.

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 is a 100-year old dam above the station that is impeding water flow and preventing fish passage. The dam drained in 2016 but it was blocked again by landowner in the fall of 2017. In the summer of 2020, the headpond was began slowly draining again and was drained using gravity syphons in late September. Pollution sources include stagnation from the headpond, road salt, and forestry practices.

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: 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 walking 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 source 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.

Neil'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.

Temperature monitoring

We did not purchase any new temperature loggers this year but were given two to install as part of an AEI project headed up by ACAP Saint John. In total, we had 39 loggers at the start of the season. We chose not to deploy four of those loggers as they had low batteries. Key tributaries were selected for monitoring based on locations (spread throughout the watershed), size (a mixture of larger and smaller tributaries), and ease of access.

HOBOware software was used to set up and launch the loggers. A delayed start was chosen so that the loggers did not record the temperature of the office or vehicle before they were deployed. The loggers were set to record water temperature every six hours (00:00, 4:00, 12:00, and 16:00). The AEI loggers logged every hour. 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 by students at the Canadian Rivers Institute (CRI) and by NWAI staff at previous jobs.

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

The loggers were deployed throughout the watershed between 4 and 12 June (Fig. 3). The AEI loggers were installed on 16 June. We placed 25 loggers in tributaries and 12 in the main stem. We chose locations where water was at least knee deep and there was appropriate substrate. Sand, gravel, and cobble substrates were the easiest; silty substrate and bedrock provided challenges. The rebar was hammered into the substrate at least 30 cm 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.

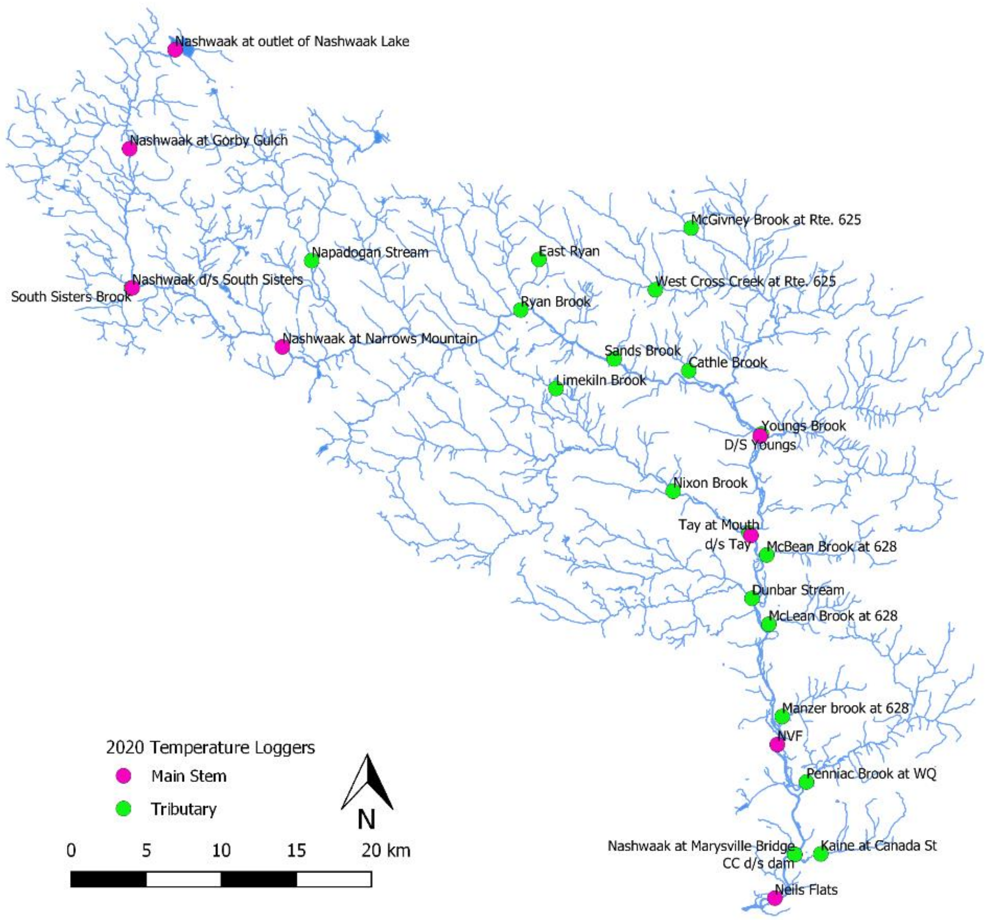

Figure 3. A map of the location of the 34 loggers installed in 2020. Pink denotes the loggers placed in the main stem of the river and green denotes the loggers placed in the tributaries.

We tried to check on the loggers at least monthly but some of the more remotely located loggers were only checked on once after placing them (at the end of July when water levels were lowest). A few loggers needed to be relocated due to dropping water levels. This usually involved moving them a few metres away from their original position.

The loggers were collected between 9 and 16 October. Loggers were read out as soon as possible upon returning to the office if possible, though some continued recording for a day or two 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.

Results

Water Quality Monitoring

Complete water quality data tables are available in the attached database. Selected parameters are presented in the tables and figures below. 2020 data compared to historic data (pre-2010) and new data (2010-2019) at each site to look at changes over time or between sites. Not all sites had data for a specific parameter or date. In addition, reporting limits have changed over time for certain parameters, which makes comparisons, 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. The field sheet was provided by DELG. Observations included bank conditions, weather, presence of swimmers, etc. A blank field sheet can be found in Appendix A.

Temperature, total dissolved solids, conductivity, and pH were measured with an Oakton PCTS Testr 50 probe at the same site where grab samples were taken. The probe was calibrated before each sampling run. DO was measured with an Exton handheld probe that was calibrated regularly.

Total Dissolved Solids

Total dissolved solids (TDS) is a measure of the combined organic and inorganic substances suspended in water. It is measured in mg/L. TDS comprise 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.

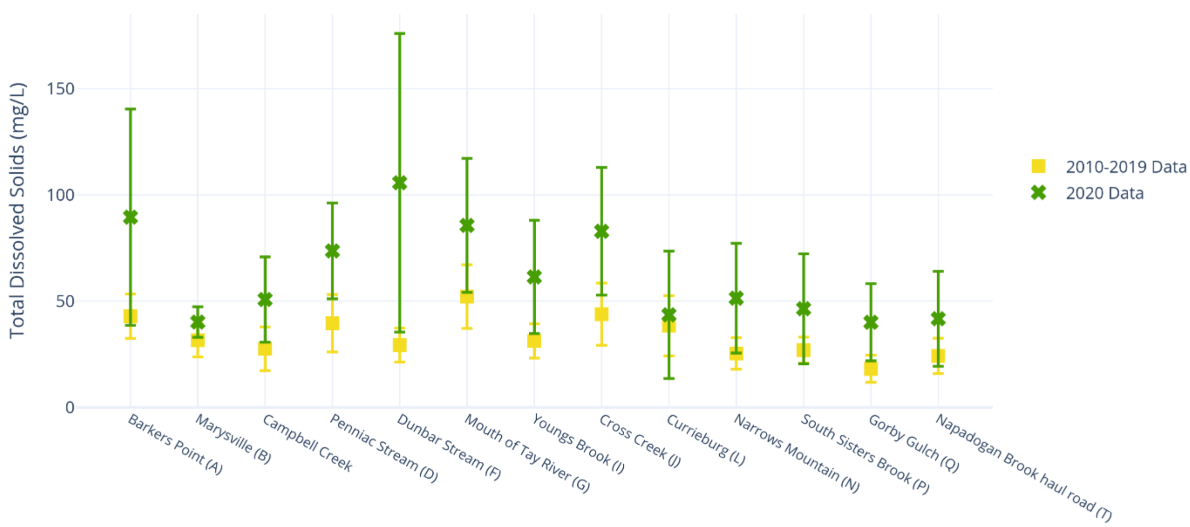

Figure 4 Mean total dissolved solid contents (mg/L) per site for the Nashwaak watershed. Error bars represent standard deviation.

Field measurements of TDS contents were not available prior to 2017 (Fig. 4). TDS concentrations were, in general, higher in 2020 compared to 2010-2019 data, which was likely related to the warm weather and therefore warmer water temperatures in 2020. As water temperature increases, the conductivity of water also increases as TDS in water is directly related to conductivity. Ions move faster in warmer water. In general, TDS was highest in July and August in 2020.

Most results from the previous decade were within the 25 to 60 mg/L range for the lower watershed with the headwater sites having slightly lower values (15 -30 mg/L). Mean values in 2020 ranged between 60-110 mg/L for the lower watershed sites and 40-55 mg/L at the headwater sites. Dunbar stream had particularly high TDS levels in 2020. A source has not been identified but significant bank scour has occurred along the lower part of the stream in the last few years.

As TDS may arise from weathering of rocks and erosion of soils, this could explain the elevated levels at the mouth of the Tay where soil mining is occurring; in Campbell Creek, because the headpond was draining in 2020; and in Penniac Brook, where significant bank erosion is visible.

Conductivity

Conductivity is a measure of a stream's ability to carry an electrical current. It is recorded in microsiemens 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.

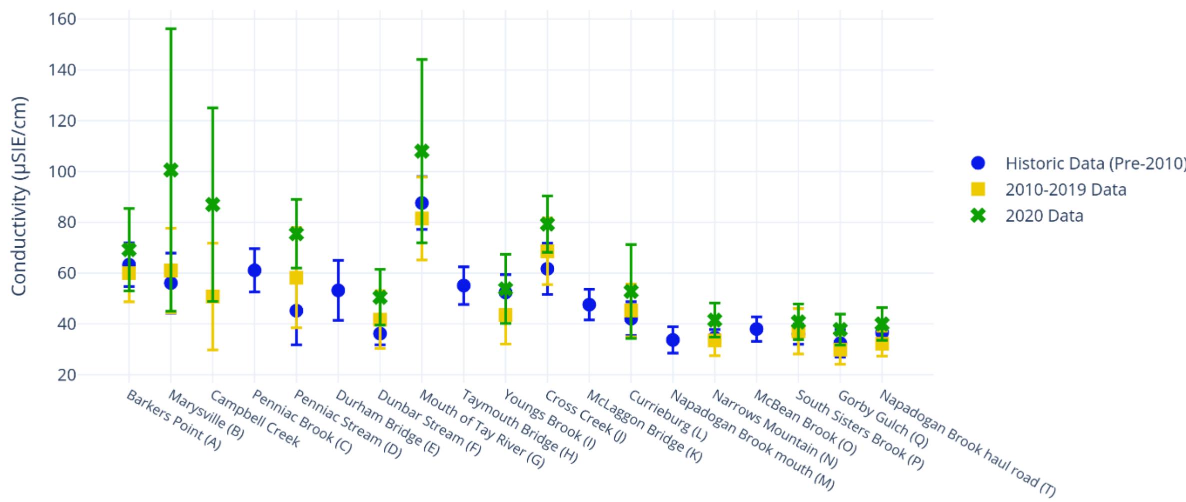

Figure 5. Conductivity measured in µSIE/cm per site across the Nashwaak watershed. Error bars represent standard deviation.

Since 2017, we have measured conductivity in the field as well as was at the lab. Prior to 2017, conductivity was not measured in the field so lab results are compared here (Fig. 5). In the past, our field measurements have been very close to the lab results. However, in 2020 our field measurements were much higher despite our probe being calibrated before every sampling run. 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.

Lab values in 2020 were higher on average at all sites than in the past, likely due to the warmer water temperatures experienced throughout the watershed over the summer. The highest values were sampled at NASH-G (Tay River) and NASH-B (Marysville).

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.

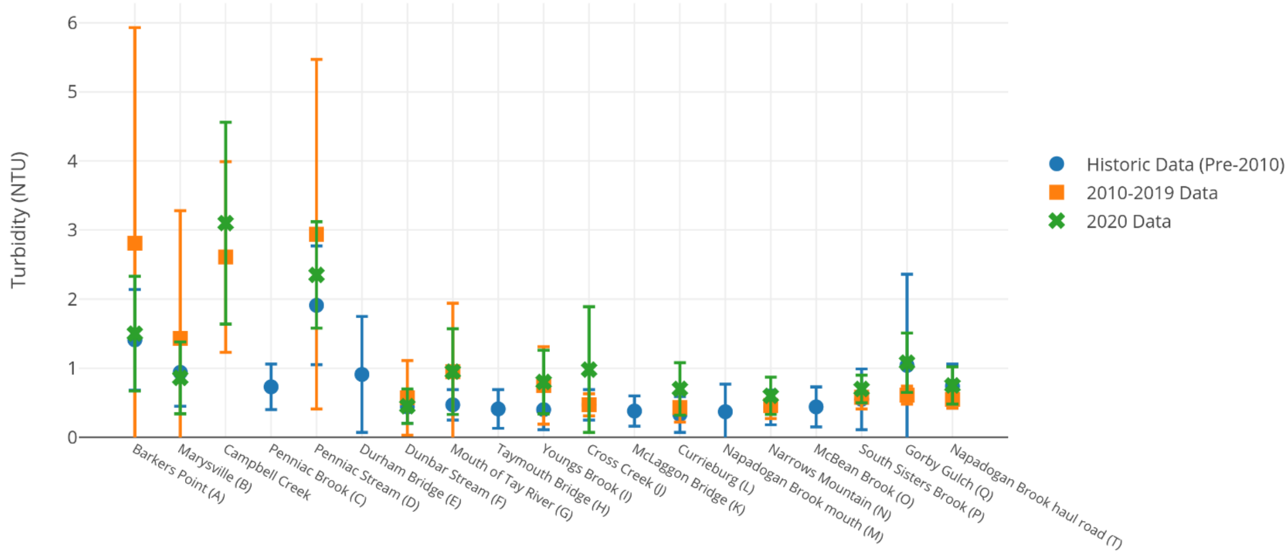

Figure 6 Turbidity (NTU) per site in the watershed. Error bars represent standard deviation.

Values in 2020 were, in general, very low for all sites (median values of 0.4 to 3.1 NTU) (Fig. 6). Values were highest in in the lower watershed, decreasing towards the headwaters. 2020 values were, on average, slightly lower than 2010 - 2019 values in the lower watershed and very similar to historic values in the rest of the watershed. In 2018, increases in background level were observed near Marysville, Campbell Creek, Barker's Point, and Penniac Stream. These increases mostly coincided with a rainfall event on 28 June. Though nine samples were taken in October 2020 after a rainfall event, turbidity values were not significantly higher from those samples compared to other samples from the same sites taken earlier in 2020. Values were slightly elevated at Campbell Creek, likely due to the headpond draining in 2020. It had the highest mean value of all sampled sites in 2020. Values at this site were consistently above 1.9 NTU.

Residents note that streams "run muddy" (i.e., have higher turbidity values) after heavy rainfalls. Topsoil mining, sedimentation due to forestry practices, and road construction were determined to be major sources in NWAI's 2004 report.

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. Increased sediment loads can aggrade channels, which in turn leads to bank erosion and the destruction of habitat. It appears, however, that either detection limits increased or the sampling method changed from the 1980s to the 2000s, making comparisons difficult.

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.

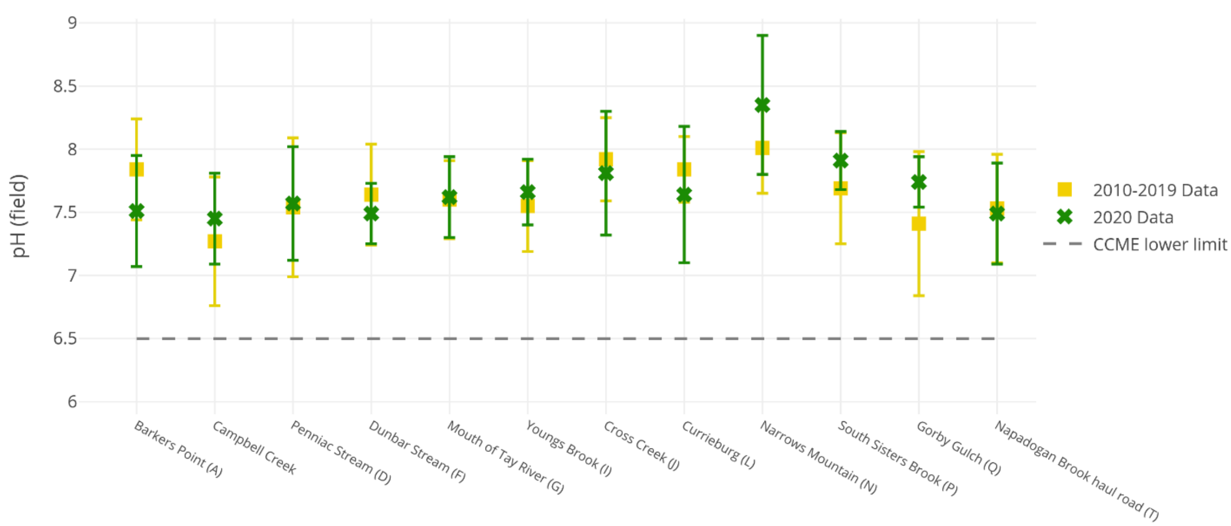

Figure 7. pH (values measured in the field) per site in the watershed (for those sites where data were available). Errors bars represent standard deviation. Historic field measurements were not available for most sites.

For the data available, pH levels for the watershed were within the CCME limits across all sites (Fig. 7). There was no discernable pattern in pH from headwaters to mouth of the river. NASH-N (Narrows Mountain) consistently had the highest (least acidic) pH values while Campbell Creek and NASH-G (Gorby Gulch) had the lowest (most acidic) values. Values measured in 2020 were considered protective of aquatic life. Average values were slightly basic at all 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 amount 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.

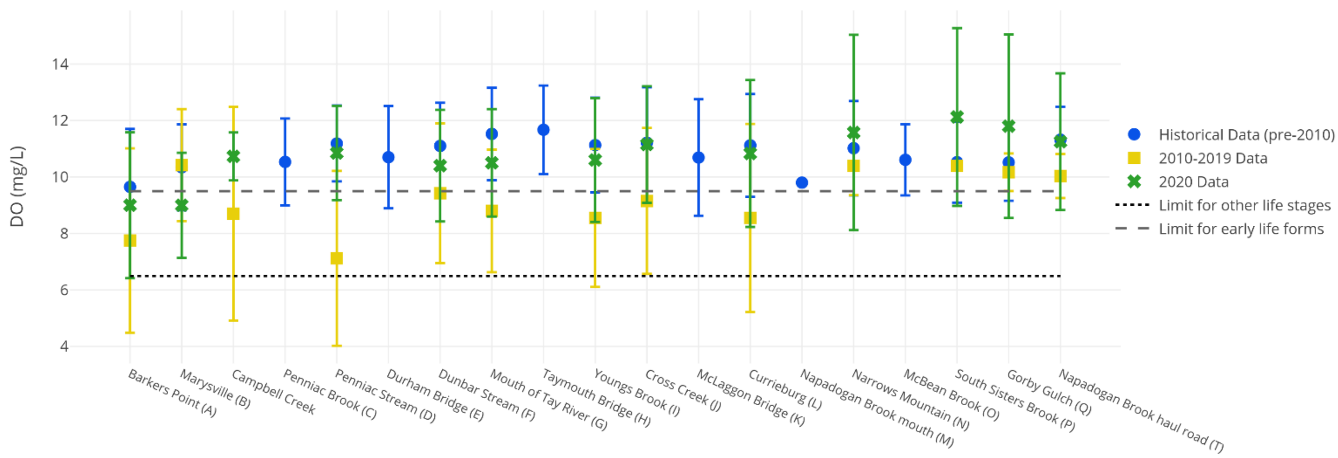

Figure 8 Mean dissolved oxygen content (mg/L) per site. Error bars represent standard deviation. Dashed lines indicate CCME limits for early life forms (9.5 mg/L) and all other life stages (6.5 mg/L).

We resumed measuring DO in 2019 when we purchased a new probe. Dissolved oxygen was on average slightly higher above NASH-L (at the headwaters sites) compared to the lower watershed sites. In 2020, average values at most sites were lower than those measured historically and in 2019 at the lower watershed sites but slightly higher on average at the headwaters sites (Fig. 8). DO contents were above CCME limits for early life forms at almost all sites, which was not expected considering that 2020 was a very hot and dry summer. There were exceedances in 2020 below the limit for early life forms in cool waters but no exceedance below the limit for all life forms in cool waters. As expected, DO was lowest in July when temperatures were the highest and highest in June and October when temperatures were the lowest. The sites with the lowest average value was NASH-B (Marysville) where five out of the seven measurements were below 9.5 mg/L and NASH-A where three out of the four of the measurements were below 9.5 mg/L. The only site with no exceedances below 9.5 mg/L was NASH-P with an average of 12.1 mg/L.

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. 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 lead to increased concentrations of metals in streams. The aluminum is often complexed with organic compounds meaning that it is not harmful to aquatic life (ISCRWB, 2010).

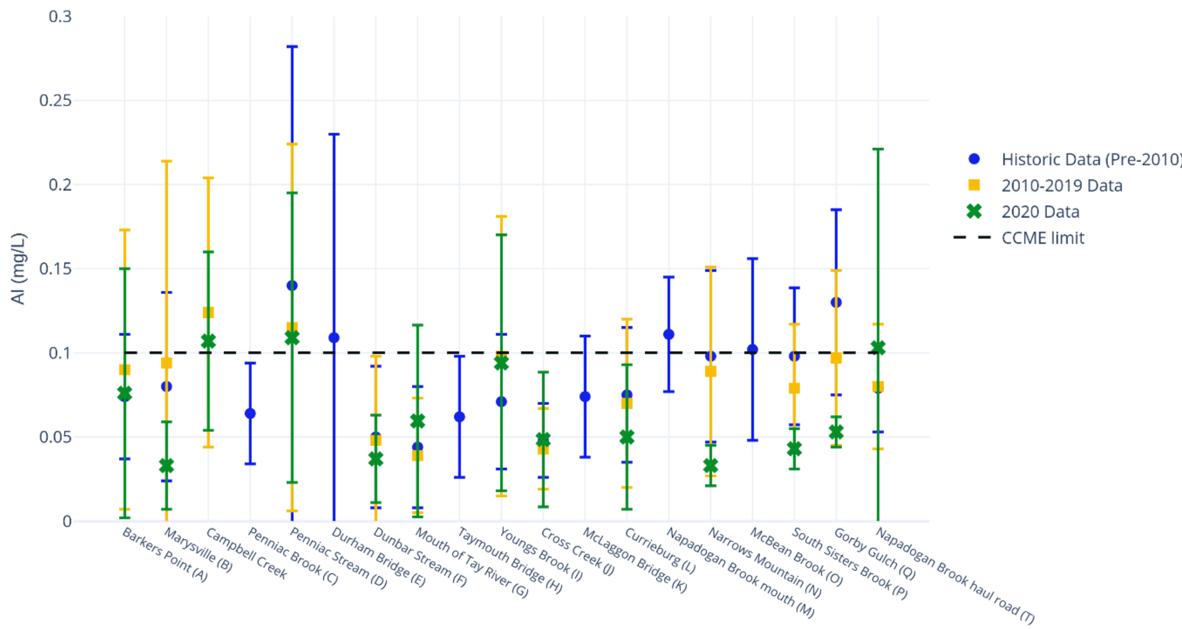

Figure 9 Aluminum content (mg/L) per site. Error bars represent standard deviation. The black dotted line represents the CCME limit of 0.1 mg/L.

Aluminum levels were the highest in the 1990s, especially in Penniac and around Durham Bridge (Fig. 9). Levels were slightly above the CCME limit in the upper reaches of the watershed (Currieburg to Gorby Gulch) in the historical data as well. About half of the Campbell Creek samples taken between 2017 and 2020 exceeded the CCME guideline. This was most likely due to sediment flushing from the headpond. Aluminum levels did not change significantly at any site between 1980 and 2020 though 2020 samples at the headwaters 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. Eight out of the nine samples taken on October 15th, 2020 exceeded the CCME guideline for the October 15th, 2020 sample, which was taken 36 hours after a heavy rainfall. Only NASH-F was below the CCME limit. We have previously noted spikes in Al concentrations after heavy rainfalls, which lead to soil runoff.

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.

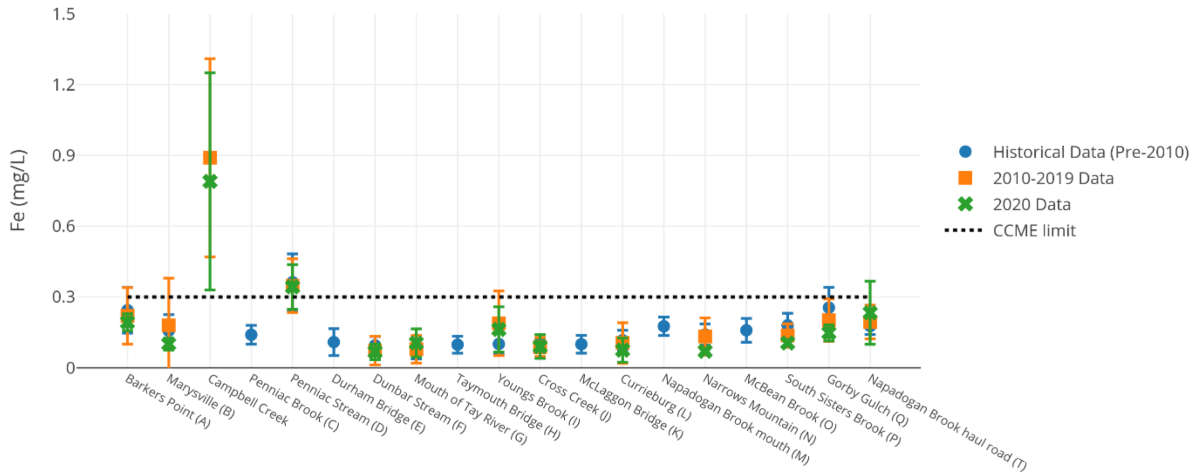

Figure 10 Mean iron content (mg/L) per site in the watershed. Error bars represent standard deviation. The dotted line represents the CCME limit of 0.3 mg/L.

Iron contents 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 two: Penniac Stream, which has consistently just exceeded the limit throughout sampling history; and Campbell Creek, which has exceeded the CCME limit for every sample taken since 2017. (Fig. 10). The only other site to exceed the CCME limit in 2020 was NASH-T in October, after a heavy rainfall. We have previously observed that heavy rainfall leads to spikes iron concentrations at some sites. Exceedances in the historical data may have been due to precipitation-related runoff.

Soil erosion was likely the cause of elevated iron contents. Penniac Stream displayed high levels of both Al and Fe, indicating that soil erosion was likely an issue at or upstream from this site. Iron concentrations were very high at Campbell Creek due to sediment flushing from the headpond.

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 2020.

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.

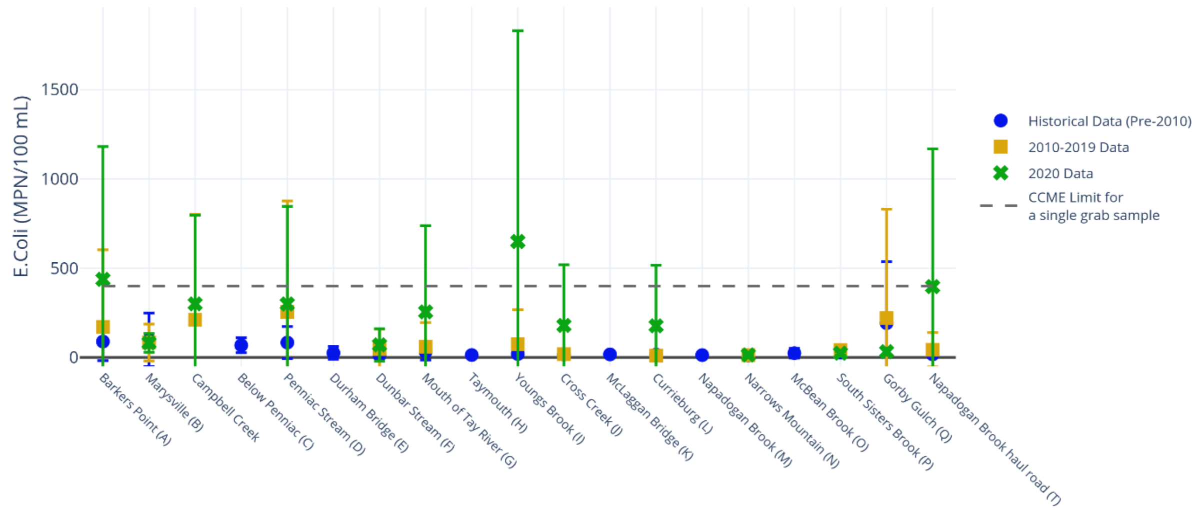

Figure 11 Mean E. coli contents (MPN/100 mL) per site in the watershed. Error bars represent standard deviation. The CCME limit is 400 MPN/ 100 mL for a single grab sample.

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 (Fig. 11). *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.

Exceedances in 2020 were all observed after a rainfall even in October. No site recorded an exceedance in June, July, or August. Historically, grab samples at three sites have exceeded the CCME limit 400 MPN/100 mL for recreational waters unrelated to rain events: NASH-Q (three exceedances not related to rainfall, NASH-B (four exceedances unrelated to rainfall), and NASH-D (one exceedance). Exceedances at Gorby Gulch were likely due to wildlife while exceedances at NASH-B and D are likely from anthropogenic or domestic animal sources.

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. Changing detection limits between historic and newer data made comparisons tricky. Fluoride toxicity results in shifts in migration patterns in salmonids and impaired reproduction in aquatic invertebrates.

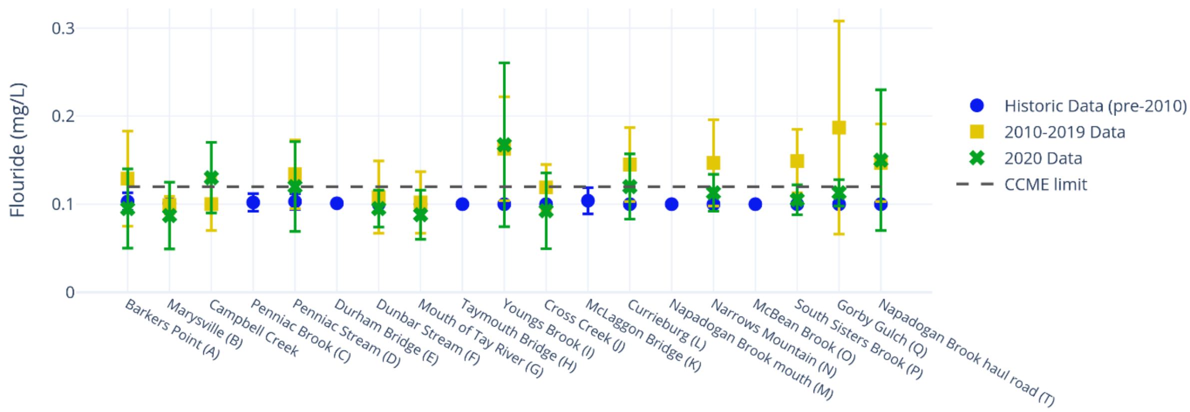

Figure 12. Fluoride concentrations (mg/L) per site in the watershed. Error bars represent standard error. The dashed line represents the CCME guideline of 0.12 mg/L.

Fluoride concentrations have remained relatively unchanged between historic and new data (Fig. 12) except at the headwaters sites, where fluoride concentrations in 2020 were lower than in the previous decade. Unfortunately, detection limits have changed over time (the detection limit in 1990s/2000s was 0.1 mg/L and results were often below detection limits). The increase from historic levels may be related to fertilizer or pesticide run-off or from increased mineral leaching from the bedrock. Mean values at three sites were over the CCME guideline of 0.12 mg/L in 2020: Campbell Creek, NASH-I, and NASH-T.

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 2020, almost all samples taken were below the detection limit of 0.05 mg/L. The highest value was the October 15th, 2020 sample at NASH-F (Dunbar Stream) (0.11 mg/L), which was taken after a heavy rainfall. Higher levels of ammonia are usually indicative of organic pollution.

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 (as N) levels of 3 mg/L are considered acceptable by CCME for the protection of aquatic life. 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. CCME does not set limits for phosphorous, nitrite, or nitrogen as they are not considered toxic to aquatic life. However, guidelines have been developed for Total Phosphorus and Total Nitrogen in terms of ideal, impaired, and concern levels. Elevated nutrients are a bigger problem in lakes than in streams where they can result in blue-green algae blooms, such as the one that happened at Nashwaak Lake this summer.

Nutrient levels in the watershed were generally low in 2020 with nitrate and nitrite levels below the detection limit of 0.05 mg/L at most sites, except after a heavy rainfall in October. The highest levels of nitrate were noted at NASH-G in October (0.59 mg/L). Total nitrogen is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite. Total nitrogen per site is shown in Fig. 13. The CCME limit for total nitrogen is 0.3 for “ideal” and 0.5 mg/L for “concern”.

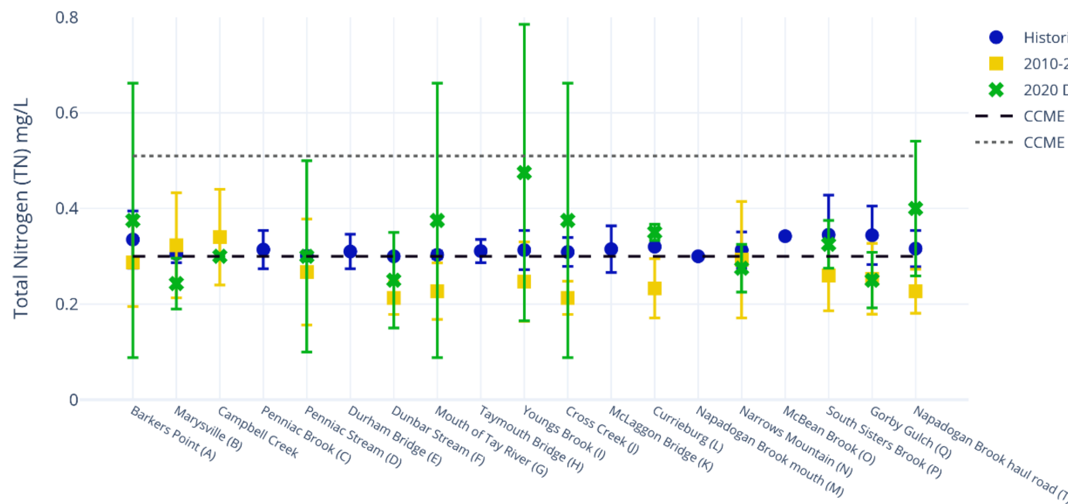

Figure 13. Total Nitrogen concentrations (mg/L) per site across the Nashwaak watershed. Error bars represent standard deviation. Dashed lines represent the limit of ideal levels (0.3 mg/L) and of concern (0.5 mg/L). The limit of detection has changed from 0.3 mg/L in historic samples to 0.2 mg/L after 2017.

In 2020, average total nitrogen levels were higher at most sites, especially the sites in the central watershed, compared to historic and 2010-2019 data. Levels were particularly evelated in the October 15th samples, which were taken after a heavy rainfall. Most samples taken on this date (except NASH-F and Campbell Creek) were above the limit of concern of 0.5 mg/L. Highest levels were observed in October at NASH-I (Young's Brook).

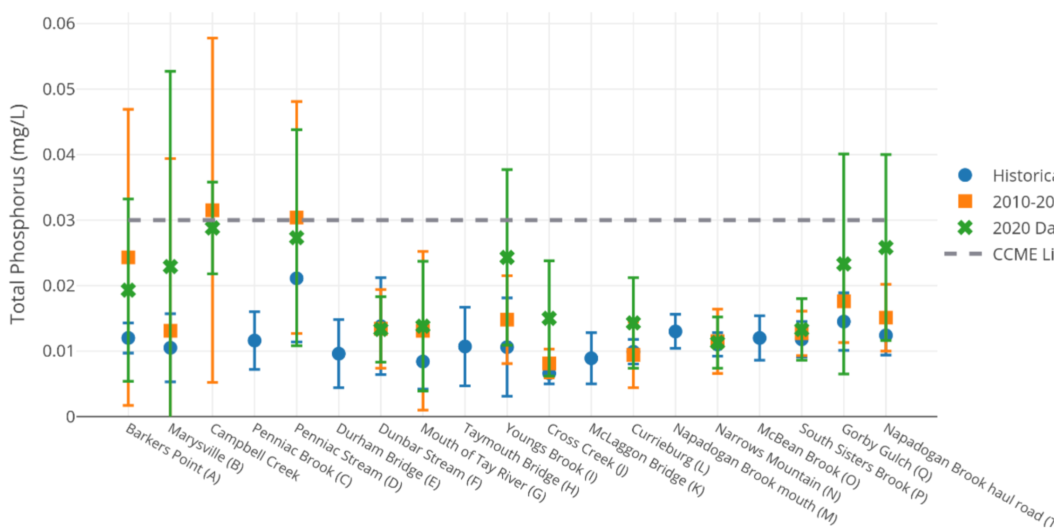

Figure 14. Total phosphorus concentrations (mg/L) per site in the watershed. Error bars represent standard deviation, and the dashed line represents the level of concern (0.031 mg/L).

As with other nutrients, spikes in total phosphorus levels have been recorded after heavy rainfall events. In 2020, the average values were in the 0.01 – 0.03 mg/L range (all below the limit of concern of 0.031 mg/L). Mean values were highest at Campbell Creek (an overall mean of 0.029 mg/L), NASH-D (0.027 mg/L), and NASH-T (0.026 mg/L). It appears that phosphorus concentrations have remained relatively stable over time at most sites (Fig. 14). In general values are highest in the lower watershed though headwater sites showed elevated concentrations in 2020. Agricultural inputs, soil erosion, and the presence of wildlife may be the source(s).

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 instead of TOC was measured. It is used here for comparison purposes.

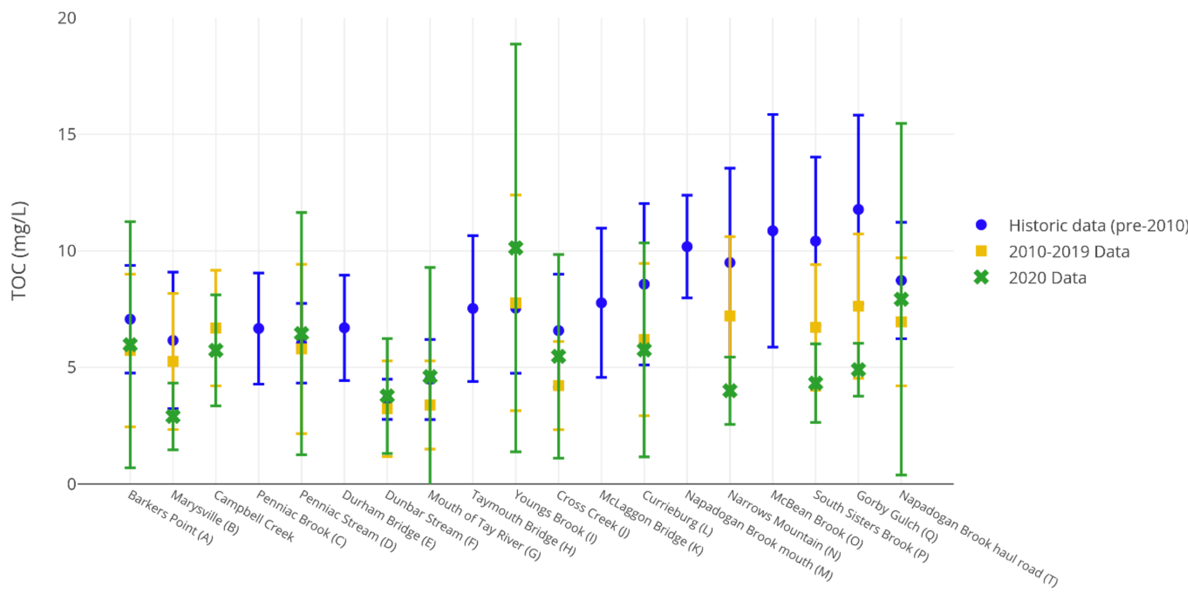

Figure 15. Total Organic Carbon concentrations (mg/L) per site per decade. Error bars represent standard deviation.

Historically, TOC 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 (Fig. 15). In 2020, levels were highest at NASH-I (Young's Brook). The upper watershed values may be influenced by wetlands in the area whereas the lower watershed values are likely influenced by urban or agricultural run-off.

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 general 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 the Atlantic Water Network's WQI Calculator for R. However, comparisons between years were difficult because some important parameters used in the calculations were not 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 number of samples did not meet the minimum in certain years.

Parameters used to calculate the 2020 WQI were: arsenic, cadmium, chloride, dissolved oxygen, E. coli, iron, ammonia, molybdenum, nitrite, nitrate, lead, pH, total dissolved solids, temperature, phosphorus, turbidity, selenium, silver, thallium, and zinc. Results for the 2020 WQI calculations can be found in Figure 16. Water quality was very good overall throughout the watershed.

The poorest WQI results were from Neil's Flats and Nashwaak Valley Farm (though fewer parameters were used to calculate the WQI at those sites), possibly due to soil erosion in both areas leading to high sediment loads. In addition, water temperatures were very warm and dissolved oxygen levels were low this summer, particularly in the lower watershed. For the regularly monitored sites, Campbell Creek and NASH-T (Napadogan Brook) had the lowest WQIs. NASH-T (Napadogan Brook) and NASH-J (Cross Creek) had the largest drop in WQI from 2019 to 2020 (96.0 in 2019 to 85.4 in 2020 for NASH-T and 100 in 2019 to 88.6 in 2020 for

NASH-J) due to elevated nutrients, high metal contents, and E. Coli exceedances in October. NASH-I (Young's Brook) also had a large drop in WQI in 2020.

The highest WQI was again observed at the main stem headwaters sites NASH-N (Narrows Mountain) and NASH-P2 (South Sisters). Several sites had higher WQIs in 2020 compared to 2019: NASH-F (Dunbar Stream), NASH-D (Penniac), NASH-P (South Sisters), and NASH-Q (Gorby Gulch), which had the biggest improvement of 3.0 points.

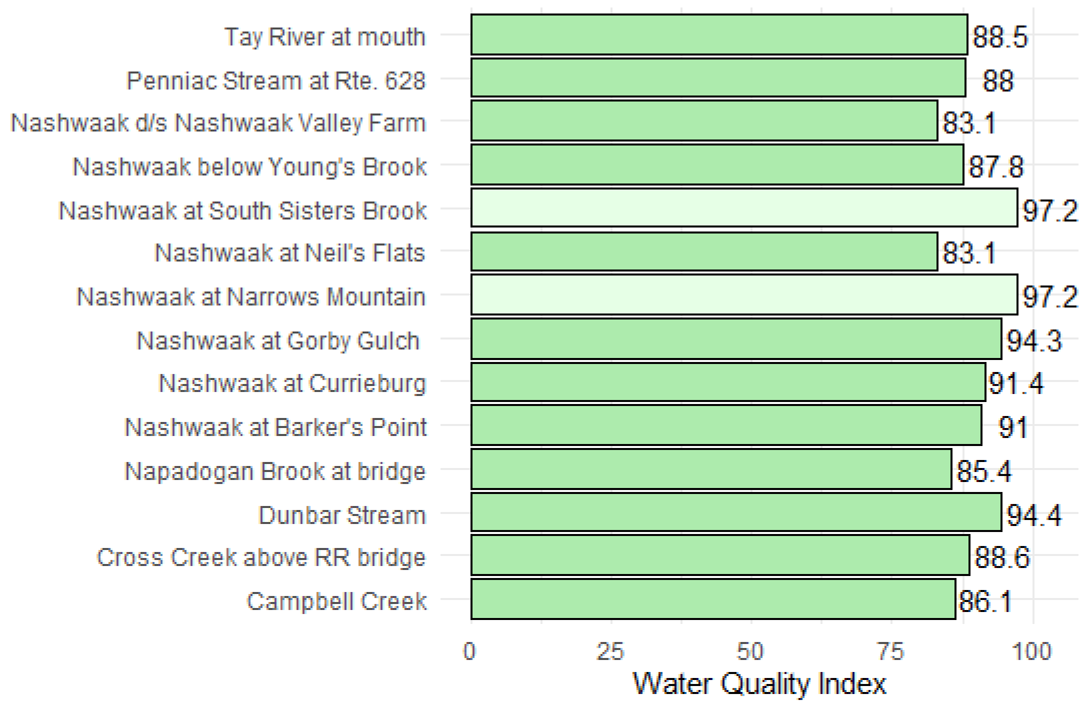

Figure 16. 2020 WQIs. Light green = Excellent, darker green = Very good

Figure 17 compares the 2020 average WQI for the entire watershed to those measured in 2017, 2018, and 2019. Overall, the WQI for the watershed has remained relatively constant over the last four years. 2019 had the healthiest water in the last four years.

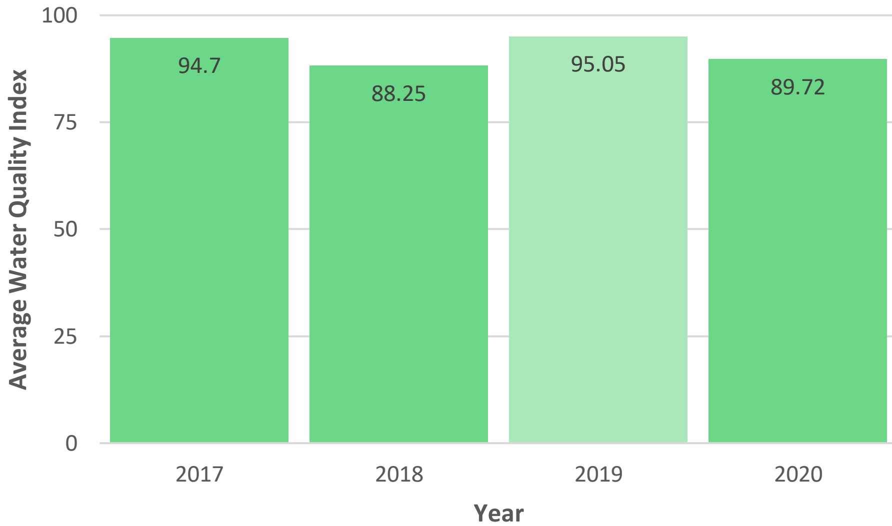

Figure 17. Comparing 2020 WQIs to previous years.

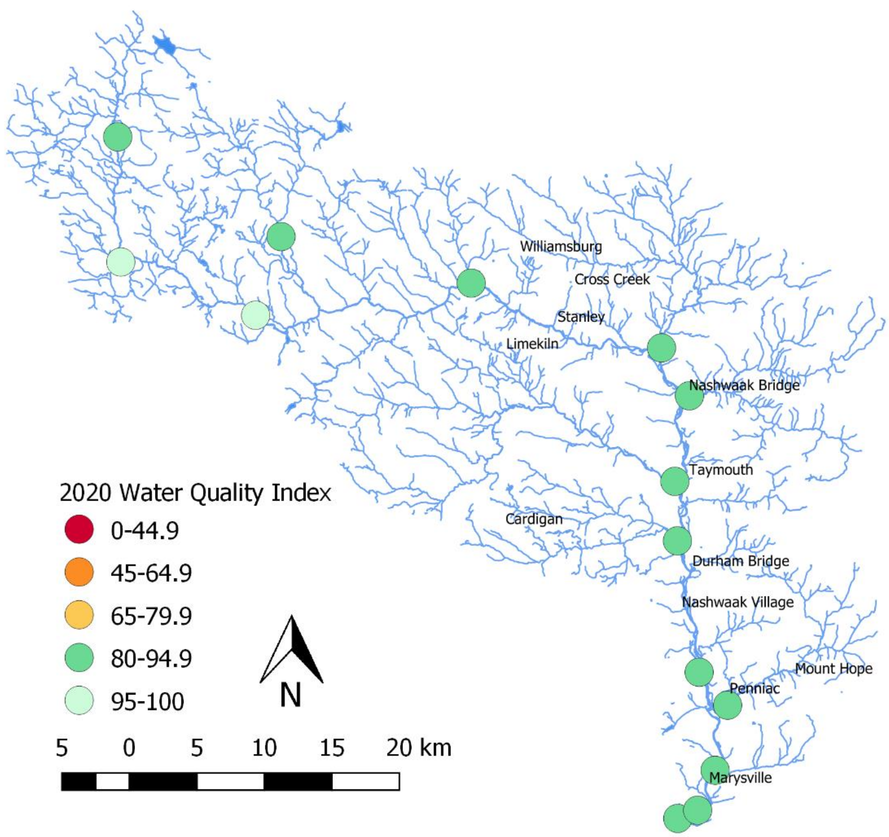

Figure 18. Map of WQIs in 2020 in the watershed.

Water Quality Discussion

Overall water quality in the Nashwaak watershed is very good and no significant change was noted in the water quality in the last four years. Patterns of water quality parameters were as expected based on land use patters. Water quality generally improves moving upstream in the watershed. The headwaters sites (NASH-N, P, Q, and T) are generally healthier as they are less affected by urbanization and other anthropogenic impacts though the WQI at NASH-T had the largest drop between 2019 and 2020. Clear-cut logging in the headwaters remains a concern and a potential source of contaminants and run-off.

Most parameter exceedances in 2020 were noted in the October 15th sample, which was taken less than 36 hours after a heavy rainfall event. Elevated E. Coli, turbidity, nutrients, and some metals were measured due to run-off and erosion in the Nashwaak and its tributaries. Despite 2020 being a hot summer which resulted in very low water throughout the watershed, dissolved oxygen contents were higher on average than 2017-2019 samples. Total dissolved solids and conductivity were higher in 2020 than in previous years likely due to the warm weather. The lack of rain in the summer of 2020 contributed to low turbidity values across the watershed. Nutrient levels were higher at some sites in the central watershed in 2020 and levels exceeded “levels of concern” in the October samples that was taken after a heavy rainfall.

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. Values of iron, total phosphorus, and turbidity were higher at Campbell Creek than at any other site measured. The dam was drained as part of the removal process in 2020. We are excited to see how the water quality changes after the dam is removed in 2021.

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 BMPs 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 commission to ensure that proper riparian setbacks are adhered to and BMPs are being followed,
- Reporting any dumping or abuse of the river to DELG or DNRED, and
- Riverbank stabilization and problem area assessment.

Temperature Monitoring

32 out of 35 installed loggers installed this year were recovered. A map of the logger placement can be found in Figure 3. The loggers were collected between 9 and 16 October.

Two loggers were left in place due to high water and strong currents: the logger upstream from McPherson Brook and the logger downstream of Dunbar Stream. One logger could not be found despite searching for over 30 mins on two separate occasions: the one downstream from Campbell Creek in the Nashwaak. It is possible that someone took it. Unfortunately, four loggers had battery errors, which meant that they did not collect data. These were: the logger in McPherson Brook, Cross Creek at water quality site, Campbell Creek downstream of Rte. 8., and Five Mile Brook. In addition, one logger (at downstream of the Campbell Creek dam) stopped logging early (August 9^{th}) due to a battery malfunction. We will be switching out all the batteries before deploying the loggers next summer. All of the loggers had over 50% battery charge before they were deployed, which should have been sufficient to log for the summer, so we are not sure why the errors occurred.

Loggers were read out as soon as possible upon returning to the office if possible, 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.

For the calculations below, we used data from 20 loggers in tributaries and 8 loggers in the main stem of the Nashwaak river. Table 2 summarises the maximum, minimum, average, and summer average temperatures along with the number of days when the minimum was above 20°C and number of days when the maximum was over 23°C for 2017 - 2020.

Peak temperatures ranged from a low 9.7°C in Nixon Brook to 29.9°C in the Nashwaak at Neil's Flats (Figure 19, Fig. 20). Average maximum temperature was 22.9°C in the tributaries (compared to 26.1°C in 2017, 22.7°C in 2018, and 22.8°C in 2019) and 28.3°C in the main stem of the river (compared to 29.2°C in 2017 and 27.6°C in 2018, and 27.5°C in 2019). Most peak temperatures were recorded on August 11^{th} at 16:00 or the following day on the 12^{th}. According to Environment and Climate Change Canada (ECCC), annual air temperatures in Fredericton peaked at 32.4°C on August 11^{th} (the hottest day of the year).

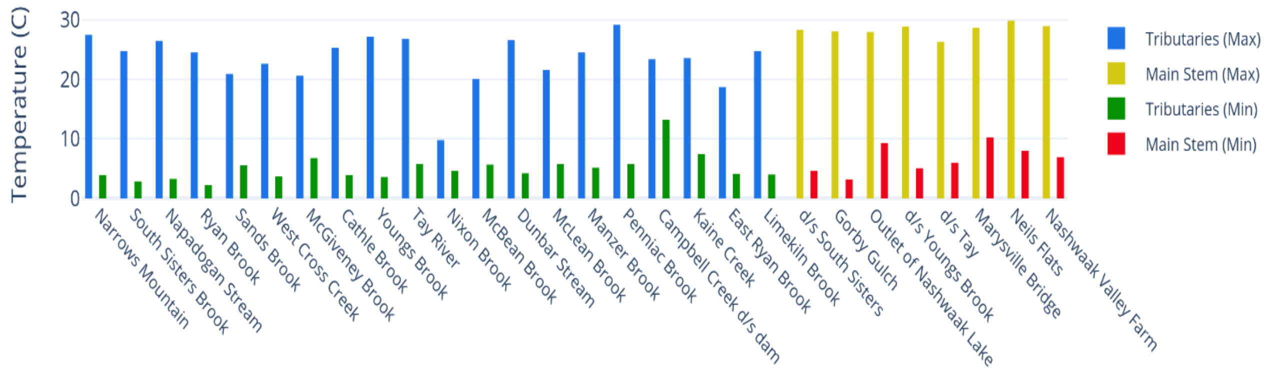

Figure 19. Maximum and minimum temperatures recorded for each logger, grouped by tributaries and main stem.

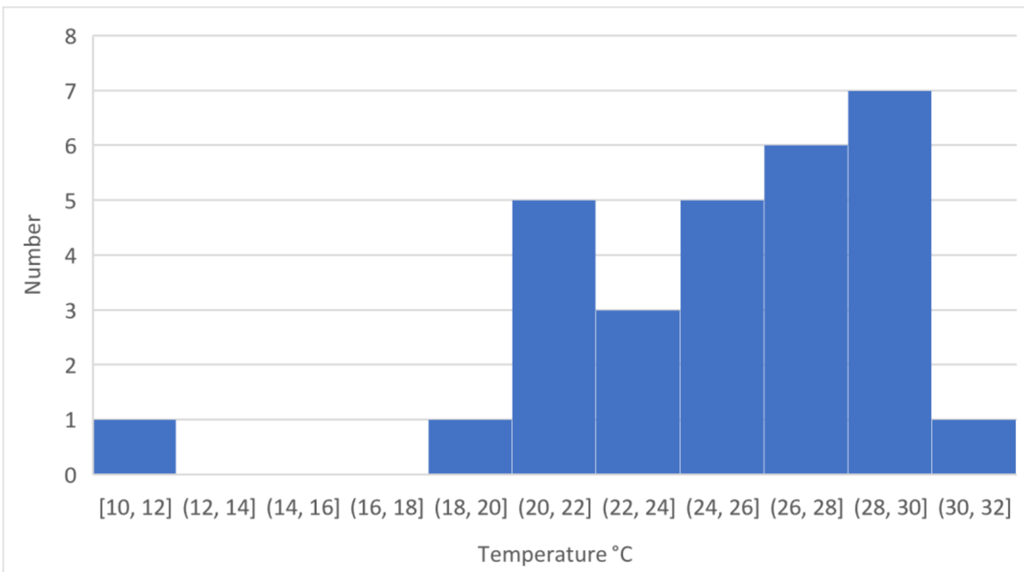

Figure 20 Histogram of maximum daily water temperatures from all loggers.

Minimum temperatures ranged from 2.1°C in Ryan Brook to 13.1°C downstream of Campbell Creek dam (Figure 19). Minimum temperatures were mostly recorded just before most of the loggers were pulled out in October. Average minimum temperatures were 5.1°C for the tributaries and 6.3°C the main stem.

The overall corrected average temperature (removing any readings logged in the office or truck after the logger had been pulled from the water) for all 28 loggers was 16.8 ± 4.1°C, approximately one degree higher than last year's average of 15.7 ± 3.4°C. The overall average for the main stem loggers was 19.1 ± 4.7°C (compared to 18.4 ± 3.9°C in 2017, 17.6 ± 1.4°C in 2018, and 17.6 ± 4.0°C in 2019), while the tributaries averaged 15.6 ± 3.8°C over the entire period they recorded (compared to 15.1 ± 2.2°C in 2018 and 14.7 ± 3.1°C in 2019).

The summer average (readings taken between 21 June and 21 September) for all loggers was 16.5 ± 3.0°C. The summer average for main stem loggers was 18.8 ± 3.4°C (compared to 19.7 ± 1.3°C 2017 and 2018), while the tributaries remained a few degrees cooler with an overall average for those 23 loggers of 15.5 ± 2.77°C (compared to 16.6 ± 6.7°C in 2018) (Fig. 21). Compared to the last two summers, this was the coolest year recorded.

Average temperatures in both July and August 2020 were the warmest recorded in the last four years in the main stem but both July and August recorded cooler average temperatures in the tributaries in both July and August when compared to 2018 and 2017 (though fewer tributaries were measured in 2017).

As with last year, the coolest site was Nixon Brook (NWAI021), which averaged 7.4 ± 0.5°C over the summer, indicating that is likely fed by ground water. The temperature at this site only deviated by 4.9°C across the entire recorded period! The warmest site was Nashwaak River at Neil's Flats (NWAI038), which averaged 22.5 ± 3.4°C. Seven sites averaged over 20°C in the summer (compared to one site last year, four sites in 2018, and eight sites in 2017) indicating that the summer of 2020 was very warm but not as warm as 2017 when eight sites surpassed 30°C.

Table 2. Summary of temperature logger data for the main stem and tributaries of the Nashwaak for 2017-2020

	Max (°C)	**Min (°C)**	**July Avg**	**Aug Avg**	**Summer avg (°C)**	**SD**	**# days min ≥20°C**	**# days max ≥23°C**
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
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

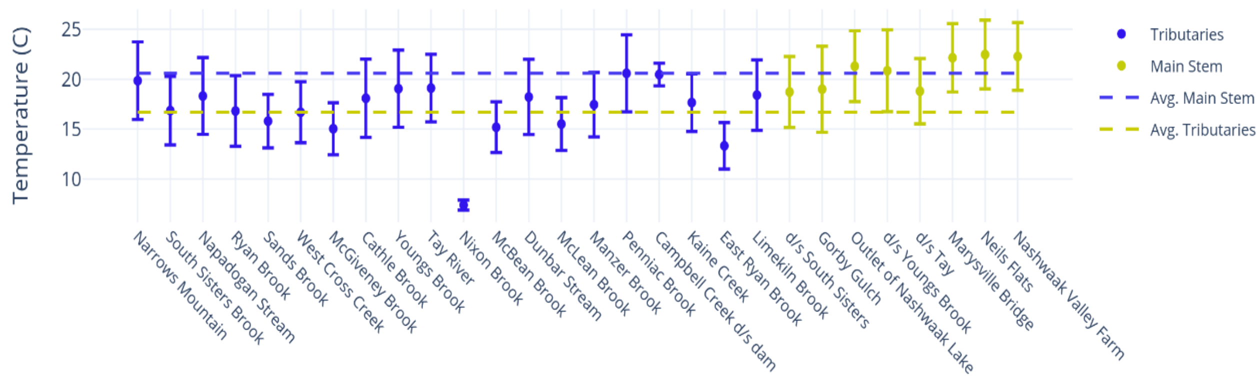

Figure 21. Average summer water temperatures (21 June to 21 September) separated by tributaries and main stem.

We calculated the number of days when maximum daily water temperatures exceeded 23°C and when minimum daily water temperatures exceeded 20°C (Fig. 21). 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).

On average, the number of days when the minimum daily water temperature was above 20°C (i.e., it remained over 20°C all day) was 40 days in the main stem (compared to 12 days in 2017 and 24 days in 2018, and 21 days in 2019) and seven days in the tributaries (compared to 3 days in 2017, four days in 2018, and one day in 2019). The number of days when the maximum temperature exceeded 23°C was 23 days for the main stem (down from 50 in 2017, 31 in 2018, and 23 for 2019) and 13 days for the tributaries (compared to 21 days in 2017, seven in 2018, and five days in 2019) (Figure 22).

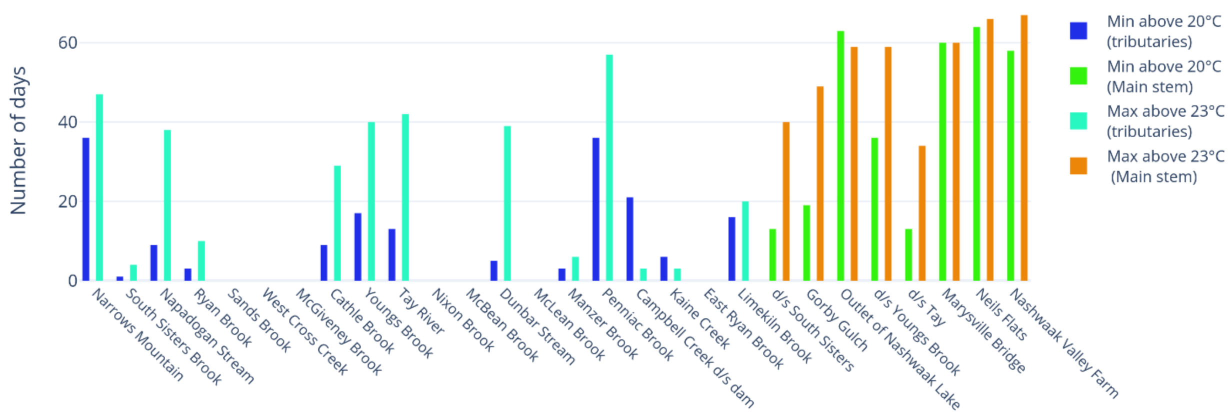

Figure 22. Number of days when minimum water temperatures exceeded 20°C and number of days when maximum daily water temperatures exceeded 23°C.

Based on comparisons of the main stem last year, there were almost twice as many days when the minimum temperature remained above 20°C compared to the last three years. There were also significantly more days when the peak temperature in the main stem was over 23°C compared to 2019 and 2018 but a similar number to 2017. Similarly, in the tributaries there were almost twice as many days when the minimum temperature remained about 20°C compared to the last three years. There were also significantly more days when the peak temperature in the tributaries was over 23°C compared to 2019 and 2018 but fewer days than in 2017.

We calculated the total sustained heatwave duration (in days), that is the number of consecutive sets of seven or more days where the minimum temperature was above 20°C and the maximum temperature was above 23°C. Heatwave events were only recorded at main stem sites (loggers at Narrows Mountain, at Nashwaak Lake, downstream of Young's Brook, and downstream of Marysville Bridge). The number of heatwave events was one at Narrows Mountain and Marysville and two at Nashwaak Lake and Young's Brook. The dates of the heatwaves are outlined in Table 3. Heatwaves last between seven and 32 days.

Finally, we calculated the number of events of prolonged physiological stress (the number of events lasting at least two days where the minimum temperature was above 20°C). These events occurred in 68% of rivers or streams monitored, 41% of which were tributaries, and 59% of which were in the main stem. The four loggers that recorded heatwaves also recorded the highest number of events of prolonged physiological stress. Nashwaak Lake recorded the highest number at 61.

Table 3. Heatwave duration, date range, and number of events of prolonged physiological stress.

Site	Sustained Heatwave Duration (Days)	Number of heatwaves	Event 1 Duration (Days)	Date range	Event 2 Duration (Days)	Date range	No. events of prolonged physiological stress
NWAI 001 Nashwaak @ Narrows Mountain	19	1	19	27 July - 16 August	N/A	N/A	30
NWAI005 Nashwaak @ Nashwaak Lake	51	2	19	19 June - 7 July	32	20 July - 20 August	61
NWAI019 Nashwaak downstream Young's Brook	22	2	15	29 July - 6 August	7	9 August - 15 August	28
NWAI030 Nashwaak downstream Marysville	37	1	31	19 July - 18 August	N/A	N/A	55

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. The summer of 2020 was both very hot and very dry. Temperatures in the main stem over the summer were ~0.8°C warmer on average than in 2017 and 2018 and 1.9°C warmer than in 2019 (the coolest year that we have recorded with our loggers). In the tributaries, the average summer temperature was 1.3°C warmer than in 2019, 0.2°C warmer than in 2018 and 1.1°C cooler than in 2017.

Only two tributaries remained below 20°C all summer compared to four last summer: Nixon Brook peaked at 9.8°C on September 20th after a rainfall and averaged 7.4°C over the summer; East Ryan Brook peaked at 18.7°C on August 8th and averaged 13.3°C over the summer. This was the first year that we monitored this brook. In previous years McLean, McBean, McGivney and MacPherson Brook all remained under 20°C. Unfortunately, the logger in MacPherson Brook could not be read our due to a battery error. McLean brook peaked at 21.5°C this year and averaged 15.5°C (1.8°C warmer on average than last year), McBean Brook peaked at 20.0°C and averaged 15.1°C over the summer (1.6°C warmer on average than last year), and McGivney Brook peaked at 20.6°C and averaged 15.0°C over the summer (1.1°C warmer on average than last year). Sands Brook is another brook that remains relatively cool. This year it peaked at 20.9°C and averaged 15.8°C. Analyses of specific tributaries are discussed below.

Summary of Key Tributaries

Penniac Stream

In 2020, only one logger was placed in Penniac Stream. It was located near our water quality site. A beaver built a dam just above the logger in late summer and its retrieval was difficult! 2020 recorded a higher peak temperature than the previous three years at 29.2°C. On average throughout the summer, 2020 was warmer than previous year (1.8°C warmer than the average of the previous three years). Compared to previous years, in 2020 there were many more days when the minimum was above 20°C (36 days versus the previous average of four days) and days when the maximum was above 23°C (57 days versus the previous average of 21 days). July was the warmest month recorded at the lower station in the last four years; 0.4°C warmer than August, on average. 2020 was the hottest year on record in Penniac Brook.

Table 4 Summary of the water temperature over the last four 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
2020	29.2	20.6±3.9	22.0	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	**27.4**	**19.2±3.2**	**20.3**	**19.8**	**16**	**32**

Table 5 Summary of the water temperature in the Penniac Stream (higher station). This station was not monitored in 2020.

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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

In 2020, the Tay recorded a peak temperature of 26.8°C and a summer average temperature of 19.1 ± 3.4°C. Peak temperatures were warmer than in 2019 but cooler on average than in 2017 and 2018. Summer average temperature was also warmer in 2019 and in 2017 but cooler than in 2018. In 2020 there were more days when the minimum was above 20°C compared to 2019 and 2017 but slightly fewer than in 2018. However, there were more days than any other year recorded when the maximum was above 23°C. July was the warmest month recorded in the last four years; 1.1°C warmer than August, on average.

Table 6 Summary of the water temperature over the last four 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
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	**26.8**	**18.9±3.1**	**20.5**	**19.4**	**9**	**29**

Cross Creek

Unfortunately, our logger in Cross Creek had a battery error in 2020. In 2019 Cross Creek recorded a similar peak temperature to previous years of 27.6°C. However, summer average in 2019 was 2.2°C and 1.7°C cooler than 2018 and 2017, respectively. There were also many fewer days than the previous two years where the minimum was above 20°C and when the maximum was above 23°C. July was the warmest month recorded in the last four years; 1.2°C warmer than August, on average.

Table 7 Summary of the water temperature over the last four years in Cross Creek

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2020	No data	No data	No data	No data	No data	No data
2019	27.6	17.3±3.7	19.0	18.8	4	18
2018	28.6	19.5±3.7	21.9	20.0	17	39
2017	27.1	19.0±2.7	20.6	19.1	13	29
Avg	**27.7**	**18.6±3.4**	**20.5**	**19.3**	**11**	**29**

Dunbar Stream

In 2020, Dunbar Stream recorded the highest peak temperatures of the last four years at 26.7°C and the summer average was warmer than previous years recorded at 18.2±3.8°C. This was the first year that recorded any days when the minimum was above 20°C (five days recorded). 39 days were recorded when the maximum was above 23°C, much higher than in previous years (previous average was 11 days). July was the warmest month recorded in the last four years; 0.6°C warmer than August, on average. 2020 was the warmest year we have recorded at Dunbar Stream.

Table 8 Summary of the water temperature over the last four 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
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	**25.4**	**17.1±3.2**	**19.0**	**18.4**	**1**	**18**

Youngs Brook

The logger in Youngs Brook was lost in 2018, therefore we have no data from that year, which would have been the most similar to 2020. Youngs Brook recorded the warmest peak temperature and summer average temperature in 2020 compared to 2019 and 2017. Youngs Brook peaked 0.7°C higher than in 2019 and 0.8°C higher than in 2017. The average summer temperature was 2.4°C warmer than in 2019 and 1.1°C warmer than in 2017. Youngs Brook recorded maximum temperatures of over 23°C on 40 days and recorded 17 days where the minimum was above 20°C, many more compared to 2019 and 2017. 2020 was the warmest year on record at Youngs Brook. July was the warmest month recorded in the last four years; 0.7°C warmer than August, on average.

Table 9 Summary of the water temperature over the last four years in Youngs Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	**26.7**	**17.9±3.4**	**19.4**	**18.7**	**7**	**24**

South Sisters Brook

In 2020, peak and average temperatures were warmer than in 2019 and 2017 but similar to 2018 in South Sisters Brook. Peak temperature was recorded to be 24.7°C and the average summer temperature was 16.9 ± 3.4°C. There was one day when the minimum was above 20°C and four days when the maximum was above 23°C. July was the warmest month recorded in the last four years; 1.1°C warmer than August, on average. 2020 was the second warmest year that we have recorded at South Sisters Brook behind 2018.

Table 10 Summary of the water temperature over the last four 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
2020	24.7	16.9±3.4	18.3	17.3	1	4
2019	23.1	15.7±3.0	17.7	16.6	0	1
2018	24.6	17.2±3.1	19.1	18.0	1	6
2017	23.5	16.0±2.5	17.1	16.0	0	1
Avg	**24.0**	**16.4±3.0**	**18.1**	**17.0**	**1**	**3**

Ryan Brook

Ryan Brook recorded a warmer peak temperature (24.6°C) in 2020 compared to 2019 and 2018. The logger was located further down the stream (closer to the mouth) in 2017, which resulted in a warmer peak and average temperature. In 2020, the average summer temperature was 1.7°C warmer than 2019 but very similar to 2018. Compared to 2018 and 2019, there were more days when minimum was above 20°C and more days when the maximum was above 23°C. July was the warmest month recorded in the last four years; 0.9°C warmer than August, on average.

Table 11 Summary of the water temperature over the last four 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
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	**24.8**	**16.2±3.2**	**18.3**	**17.4**	**2**	**5**

Napadogan Stream

Napadogan Stream was not monitored in 2017. Both peak temperature and the summer average temperature were warmer in 2020 compared to 2018 and 2019. There were many more days when minimum was above 20°C and when the maximum was above 23°C. 2020 was the warmest year on record at Napadogan Brook. July was the warmest month recorded in the last four years; 0.9°C warmer than August, on average. 2020 was the warmest year recorded at Napadogan Brook.

Table 12 Summary of the water temperature over the last three years in Napadogan Stream

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	26.0	17.8±3.1	19.6	18.5	4	11
2017	No data	No data	No data	No data	No data	No data
Avg	**25.9**	**17.5±3.4**	**19.2**	**18.3**	**5**	**19**

McBean Brook

McBean Brook was not monitored in 2017. Peak temperature in 2020 was over 1°C warmer than in 2019 and 2018. The average summer temperature was 0.6°C warmer than in 2018 and 1.7°C warmer on average than in 2019. As with previous years, there were no days when minimum was above 20°C and only one day when the maximum was above 23°C. July was the warmest month recorded in the last four years, except in 2018; but only by 0.2°C warmer than August, on average.

Table 13 Summary of the water temperature over the last three years in McBean Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
2020	20.0	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	**19.2**	**14.5±2.2**	**15.4**	**15.2**	**0**	**0**

Kaine Creek

Kaine Creek was not monitored in 2017. As with other small tributaries, 2020 recorded the warmest peak temperature summer average temperature compared to previous years. Kaine Creek peaked 1.7°C higher than in 2019 and 1.3°C higher than in 2018. The average summer temperature was 1.6°C warmer than in 2019 but only 0.3°C warmer than in 2018. For the first time, Kaine Creek recorded maximum temperatures of over 23°C (three days) and recorded six days where the minimum was above 20°C. July was the warmest month recorded in the last four years, except in 2018; but only by 0.4°C warmer than August, on average.

Table 14 Summary of the water temperature over the last three years in Kaine Creek

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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**	**17.1±2.6**	**18.4**	**18.0**	**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 0.6°C (thought 2020 recorded the warmest peak temperature). In 2020, the average summer temperature was 1.5°C warmer than in 2019 but only almost identical to the 2018 average. Like previous years, Sands Brook recorded no days when maximum temperatures were over 23°C and no days where the minimum was above

20°C. July was the warmest month recorded in the last four years; 0.3°C warmer than August, on average.

Table 15 Summary of the water temperature over the last three years in Sands Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	**20.7**	**15.3±2.5**	**16.5**	**16.2**	**0**	**0**

Cathle Brook

Cathle Brook was not monitored in 2017. As with other small tributaries, 2020 recorded the warmest peak temperature and summer average temperature of all recorded years. Cathle Brook peaked at 25.3°C, which was 2.8°C higher than in 2019 and 0.6°C higher than in 2018. The average summer temperature was 2.8°C warmer than in 2019 but only 0.2°C warmer than in 2018. Cathle Brook recorded maximum temperatures of over 23°C on nine days and recorded 29 days where the minimum was above 20°C, many more than in previous years. July was the warmest month recorded in the last four years; 0.3°C warmer than August, on average.

Table 16 Summary of the water temperature over the last three years in Cathle Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	**24.2**	**17.1±3.2**	**18.4**	**18.1**	**6**	**14**

Manzer Brook

Manzer Brook was not monitored in 2017 but was the site of a restoration of fish passage project in 2018. As with other small tributaries, 2020 recorded the warmest peak temperature and summer average temperature compared to previous years. Manzer Brook peaked 1.2°C higher than in 2019 and 1.9°C higher than in 2018. The average summer temperature was 1.8°C warmer than in 2019 but only 0.5°C warmer than in 2018. For the first time, Manzer Brook recorded minimum temperatures of over 20°C (three days) and recorded six days where the maximum was above 23°C (there had previously only been one day in the last two years that reached 23°C). July was the warmest month recorded in the last four years; 0.5°C warmer than August, on average.

Table 17 Summary of the water temperature over the last three years in Manzer Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	0
2017	No data	No data	No data	No data	No data	No data
Avg	**23.6**	**16.7±2.8**	**18.1**	**17.6**	**1**	**2**

McLean Brook

McLean Brook was not monitored in 2017. As with other small tributaries, 2020 recorded the warmest peak temperature and summer average temperature of all recorded years. McLean Brook peaked 1.0°C higher than in 2019 and 2.3°C higher than in 2018. The average summer temperature was 1.8°C warmer than in 2019 and 0.8°C warmer than in 2018. As with previous year, McLean Brook recorded no days with minimum temperatures of over 20°C and no days where the maximum was above 23°C. Opposite to other sites, August was the warmest month recorded in the last four years, except in 2020; 0.2°C warmer than July, on average.

Table 18 Summary of the water temperature over the last three years in McLean Brook

Year	Peak Temp (°C)	Summer Avg. (°C)	July Avg. (°C)	Aug Avg. (°C)	# days min. >20°C	# days max. >23°C
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	15.0	15.8	0	0
2017	No data	No data	No data	No data	No data	No data
Avg	**20.2**	**14.6±2.3**	**15.4**	**15.6**	**0**	**0**

Campbell Creek (downstream from dam)

It is important to note than in 2017 the headpond was drained when the loggers were deployed while in 2018 and 2019 it was full. In 2020, the headpond 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.

Peak temperature in 2020 in Campbell Creek was warmer than in 2017 and 2019 but cooler than in 2018. However, 2020 recorded the warmest summer average from the last four years by almost 2°C. 2019 recorded the lowest summer average from the recorded years (similar to other tributaries). 2020 also recorded the greatest number of days where minimum was above 20°C (tied with 2018) and while 2017 recorded the greatest number of days when the maximum was above 23°C.

Unfortunately, the logger upstream of the dam was lost in 2019 and the battery failed in 2020 so comparisons could not be made. In both previous years, the average temperature was cooler downstream from the dam as opposed to upstream though in 2017, the results were within error. In 2018 the water was ~ 2°C cooler downstream. As the headpond was full in 2018, temperature stratification of the reservoir was likely occurring, and the dam was releasing denser, cooler water from the bottom, which would account for the 2°C difference. Figures 22 and 23 compare the temperatures in Campbell Creek above and below the dam and to the Nashwaak River.

It is apparent that Campbell Creek has a cooling effect on the Nashwaak River (it is ~ 0.8°C cooler downstream from the confluence compared to upstream). In 2017, Campbell Creek was on average 2.5°C cooler than the Nashwaak River (above its confluence), while in 2018 it was an average of 4.5°C cooler. However, in 2019 it was only an average of 1.9°C cooler. The logger downstream from Campbell Creek was lost or taken in 2020.

Table 19 Summary of the water temperature over the last four 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
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	24.0	18.8±2.1	20.1	19.6	21	3
2017	22.3	18.5±2.4	19.4	19.2	3	17
Avg	**24.3**	**18.8±2.1**	**19.7**	**19.8**	**13**	**6**

We can assume that when the headpond is drained the stream will have an average summer temperature similar to the logger that was placed upstream of Rte. 8 in 2018 (18.9°C with maximum temperatures ranging up to 24°C). These temperatures are within the optimal range for adult survival, migration, for feeding parr, and for early fry.

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

Discussion of Water Temperature

2020 was a very hot and dry summer. Peak temperatures were experienced in ate July and early August. Water levels dropped to their lowest levels at the Durham Bridge station (AL002) on September 22nd (17.643 m asl). Historical average water levels in September are 17.979 m asl. The AL002 station recorded its highest level of the year (21.1 m asl) on December 2nd, 2020 after a heavy rainfall.

Water temperatures, in general, became warmer moving downstream from sites at the headwaters to those closer to the mouth of the river (Fig. 23). For the main stem upstream of Giant's Glen, summer averages were 19.7°C and minimum water temperatures exceeded 20°C an average of 33 days and 23°C an average of 49 days. Downstream of Giant's Glen, summer averages were warmer at 21.3°C, minimum water temperatures exceeded 20°C an average of 46 days and maximum water temperatures exceeded 23°C on an average of 57 days.

Despite the very hot and dry summer we experience in 2020, two tributaries remained below 20.0°C all summer (Nixon Brook and East Ryan Brook) and McBean Brook peaked at 20.04°C. A total of seven tributaries recorded no days with minimum temperatures of over 20°C and no days where the maximum was above 23°C. These tributaries provide important thermal refuges for fish during the summer months and cool the main stem of the Nashwaak; therefore, they are extremely important to protect and restore.

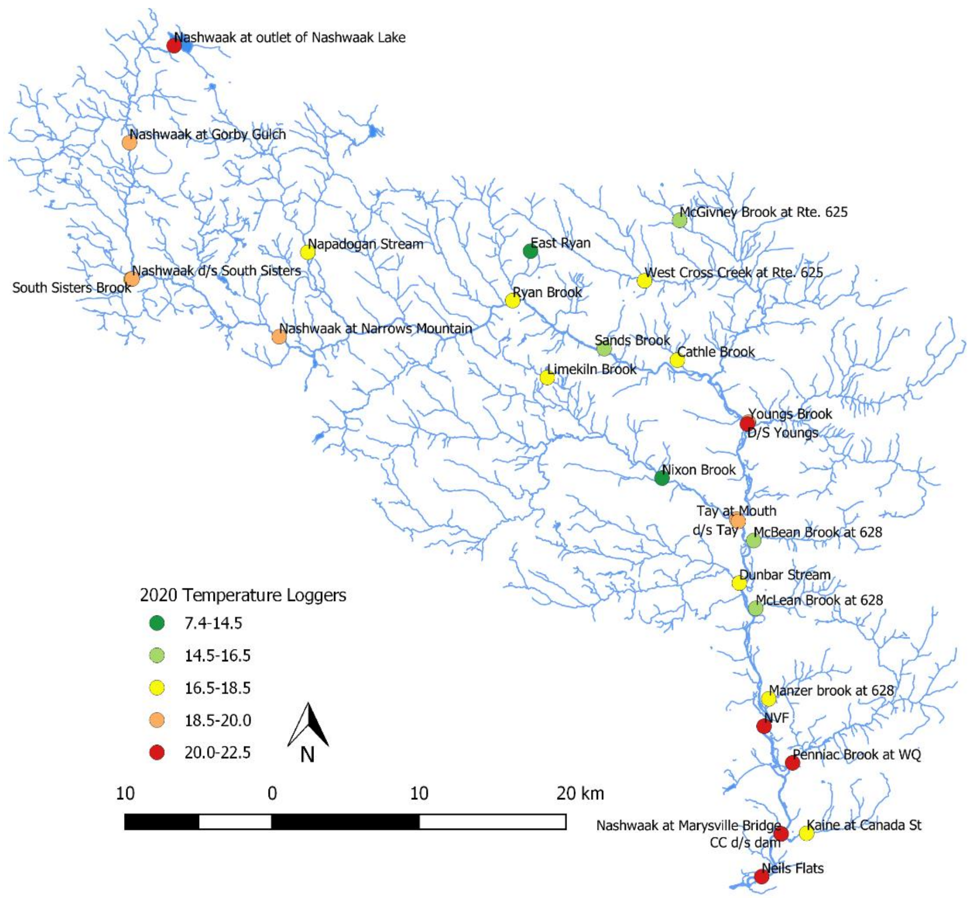

Figure 23. Map of the loggers placed in the watershed in 2020. Coloured symbols show average summer water temperature from green (cooler) to red (warmer).

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, 2017 and 2018 provided a learning curve for the association and 2019 and 2020 continued in that respect. Initially, we were worried that people would remove or tamper with many of our loggers and we expected a loss of 10 - 20%. In fact, only one was taken/lost in 2020 and none appeared to be tampered with. Unfortunately, four of our loggers experienced a battery error in 2020 despite having sufficient battery to log when installed. We will change all the batteries and test the loggers before re-deploying them next season.

In 2017, we had issues with low water levels and had to move almost all our loggers. In 2020 we placed them in deeper water and only a handful had to be moved. However, we are still finding it difficult to find locations that were not too deep in the spring and fall (if the water is too deep, installation and removal is very difficult) but remained underwater in mid-summer. In addition, finding appropriate substrate (gravel substrate is ideal) was challenging in some locations.

Another challenge we faced in 2017 was that the wire used to secure the logger to the casing began to rust very quickly, despite being stainless steel. Therefore, zip ties were added to the casing to prevent the logger from floating to the top and being lost. In 2018 we changed from multistrand wire to solid picture wire and this held up better. We also added a small, thin zip tie to back up the wire. We continued to build loggers this way in 2020 and did not have any problems.

The final challenge face was that in some locations with fine sediment, the loggers because buried or the casings filled with sediment. When we checked on them, we would pull them, clean them, and reinstall them. 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. 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: ____

Station name: ____

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

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

Sample collected by: ____

Weather: ____

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), aquatic insects? ____

____

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: ____

____

____

____

____

____

Water Temperature (°C): ______________   Dissolved Oxygen: ________ (mg/L)

pH: __________   Conductivity: _______ (µs/cm) 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**
Company:	Company:	Site Location:
Address:	Address:	Project Number:
		Submission Date:
Contact:	Contact:	Sampled by (print):
Telephone:	Telephone:	Sampler's Initials:
Fax:	Fax:	Purchase Order #:
E-mail:	E-mail:	**RPC Quotation #:**

Turnaround Time

Routine:
- ☐ Varies by analysis

Rush (surcharge applies):
- ☐ 24 Hours ☐ 48 Hours
- ☐ 3 Days ☐ 4 Days

Specific Date Required
(do not use ASAP):

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 Containers
- ☐ Sample Temperature
- ☐ Sample Volume
- ☐ Hold Time

Temperature = ________________ °C

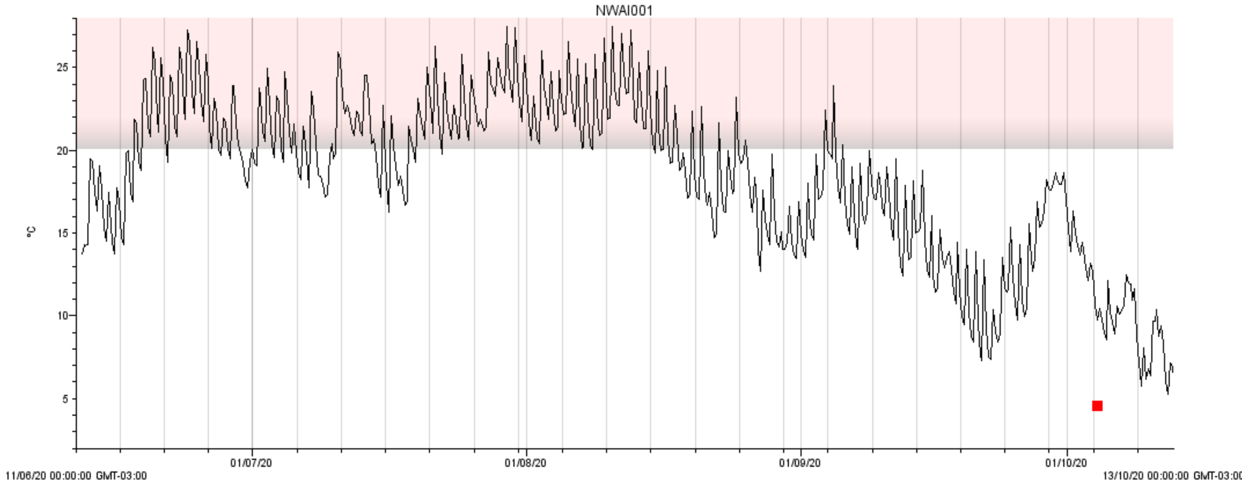
Comments:

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:

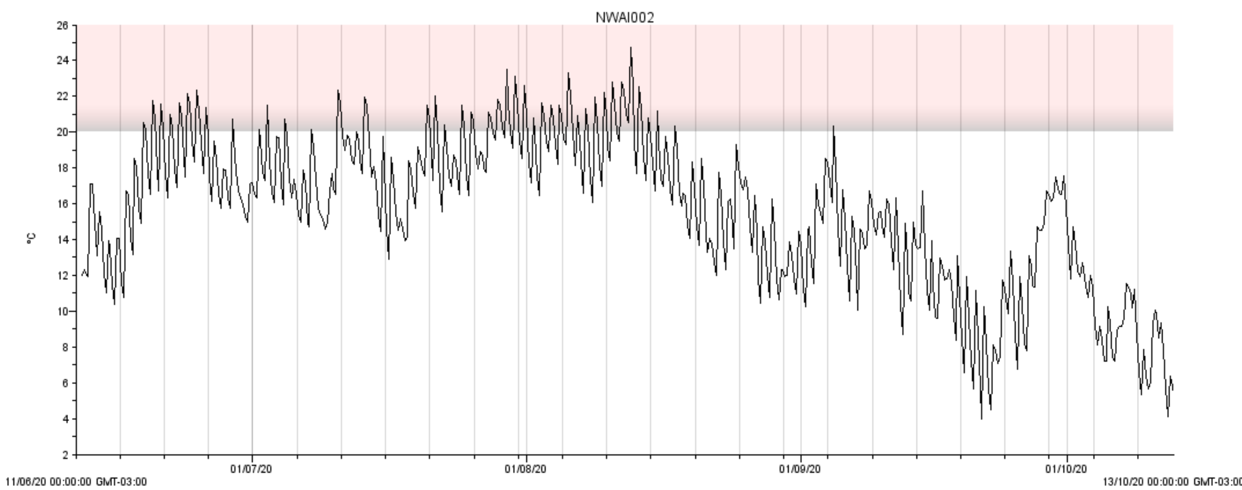
Original: File Copy Yellow: Customer Copy Page ________ of ________

Appendix B: Logger data

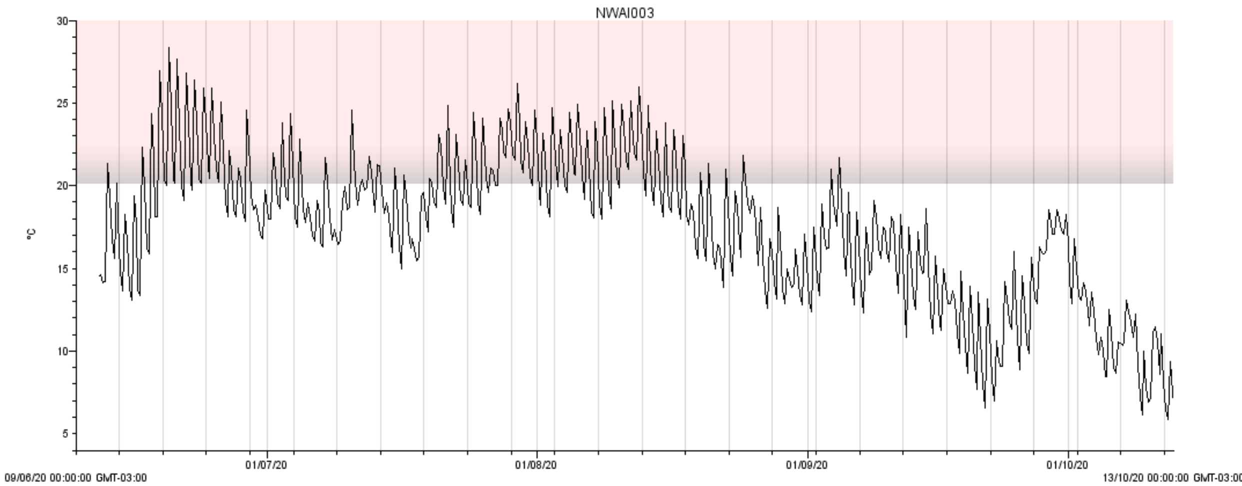


NWAI001. Located in Nashwaak River ~100 m upstream from the Narrows Mountain Bridge [46.2904, -67.02534]
Max temp: 27.47°C
Average summer temp*: 19.8°C ± 3.9°C
The logger recorded a bad battery a few days before it was removed

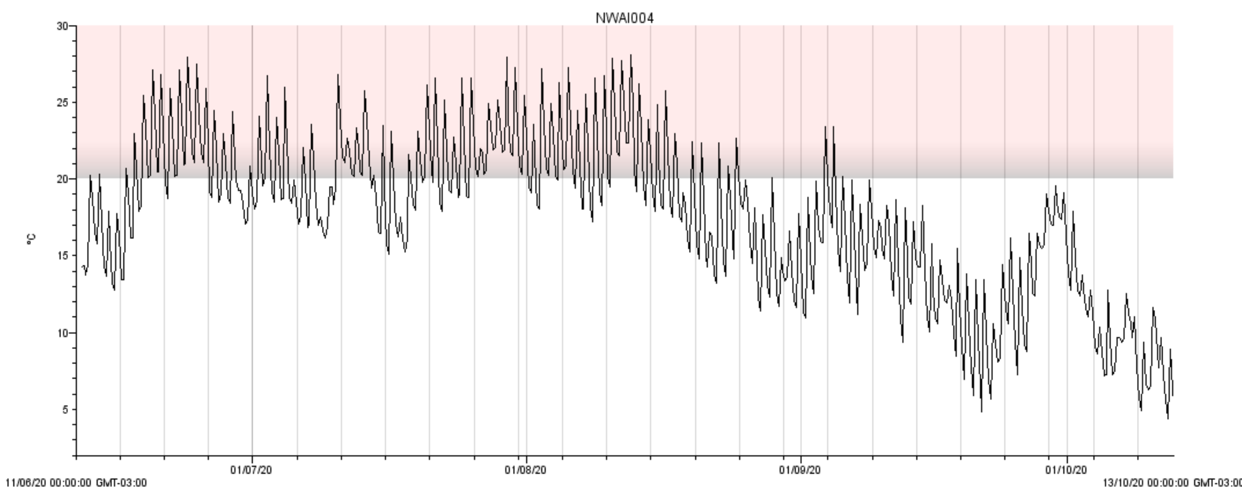
**Average summer temperature is the mean of all readings taken between 00:00 on 21 June to 22:00 on 21 September.*



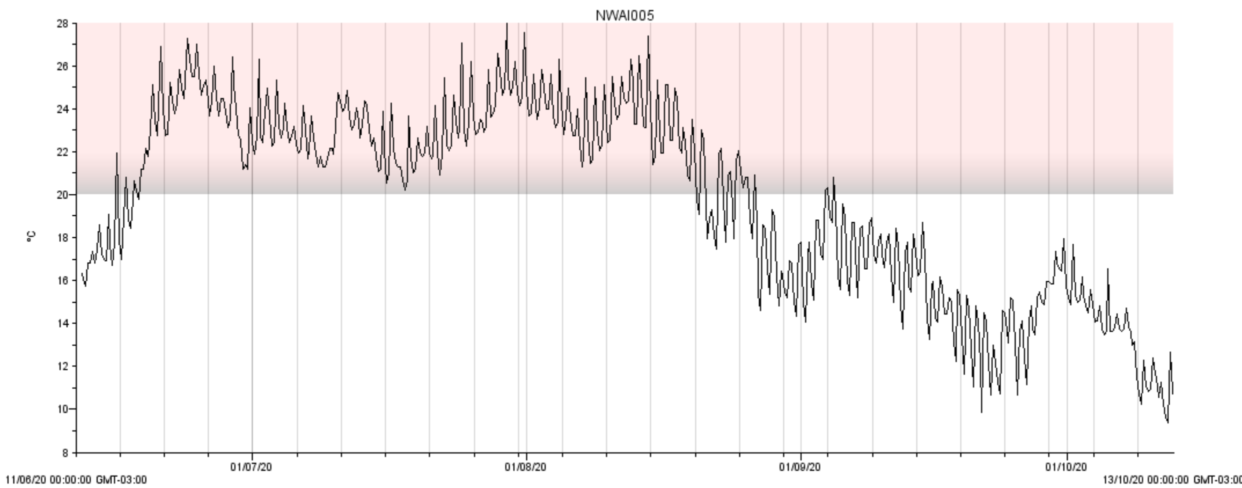
NWAI002. Located in the mouth of South Sisters Brook [46.32531, -67.1564].
Max temp: 24.7°C
Average summer temp: 16.9°C ± 3.4°C



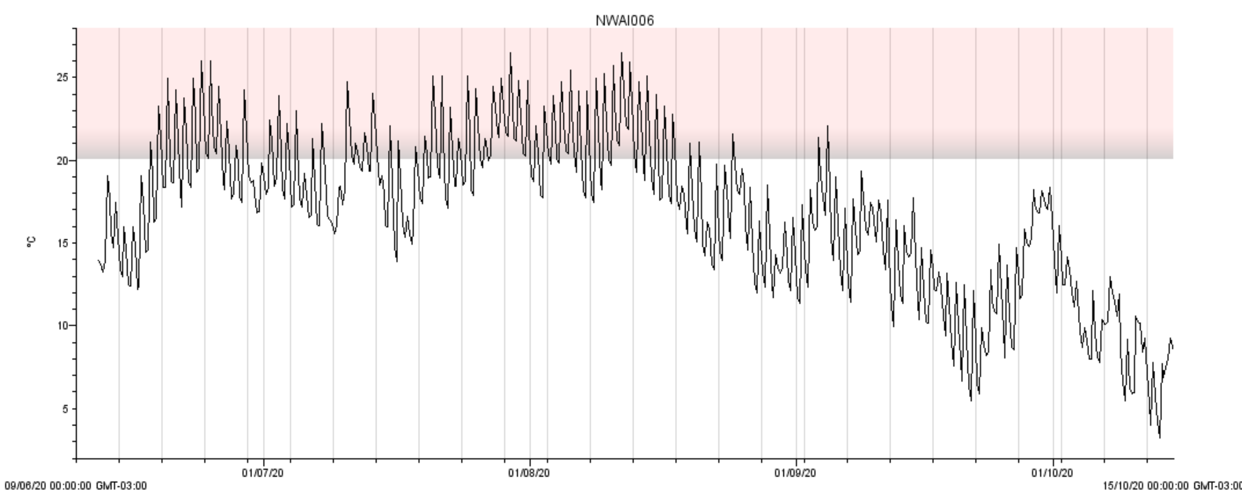
NWAI003. Located in Nashwaak River ~100 m downstream from South Sisters Brook [46.32539, -67.15559]
Max temp: 28.4°C
Average summer temp: 18.7°C ± 3.6°C



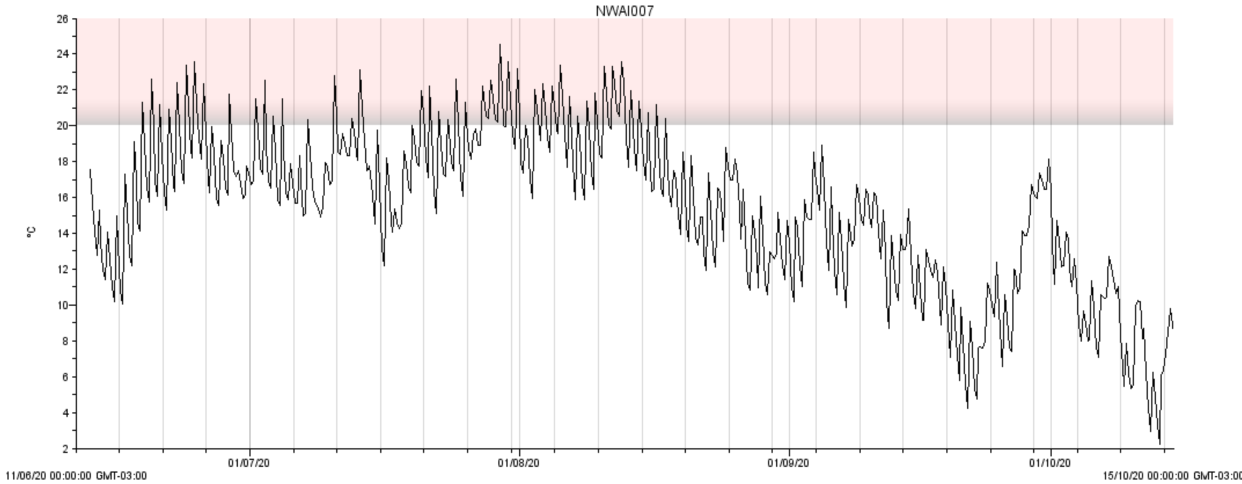
NWAI004. Located in Nashwaak River ~50 m upstream of the Bridge at Gorby Gulch [46.40867, -67.15884]
Max temp: 28.1°C
Average summer temp: 19.0°C ± 4.3°C



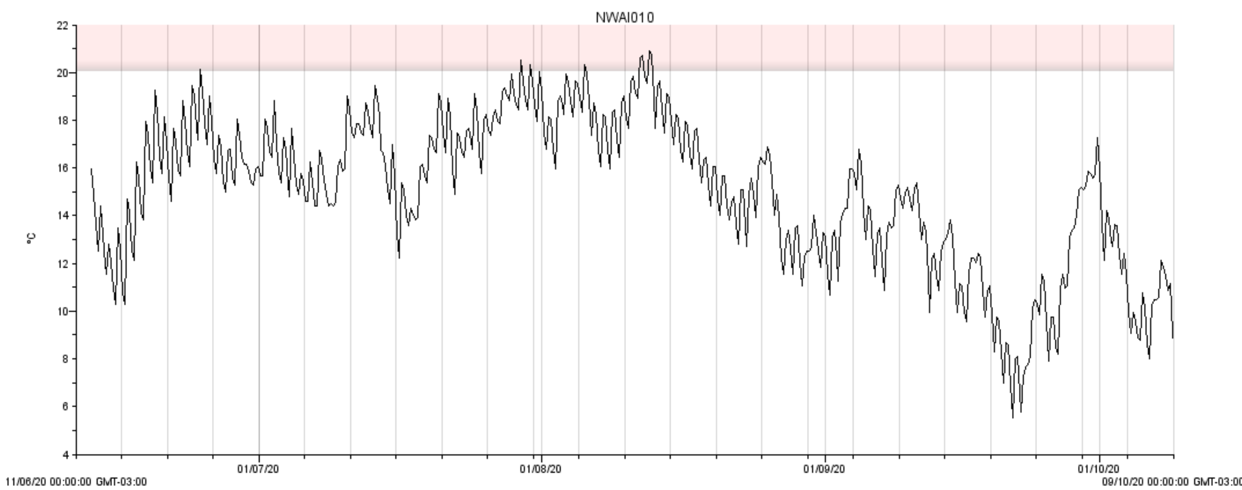
NWAI005. Located at Outlet of Nashwaak Lake [46.4070, -67.2173]
Max temp: 28.0°C
Average summer temp: 21.3°C ± 3.6°C



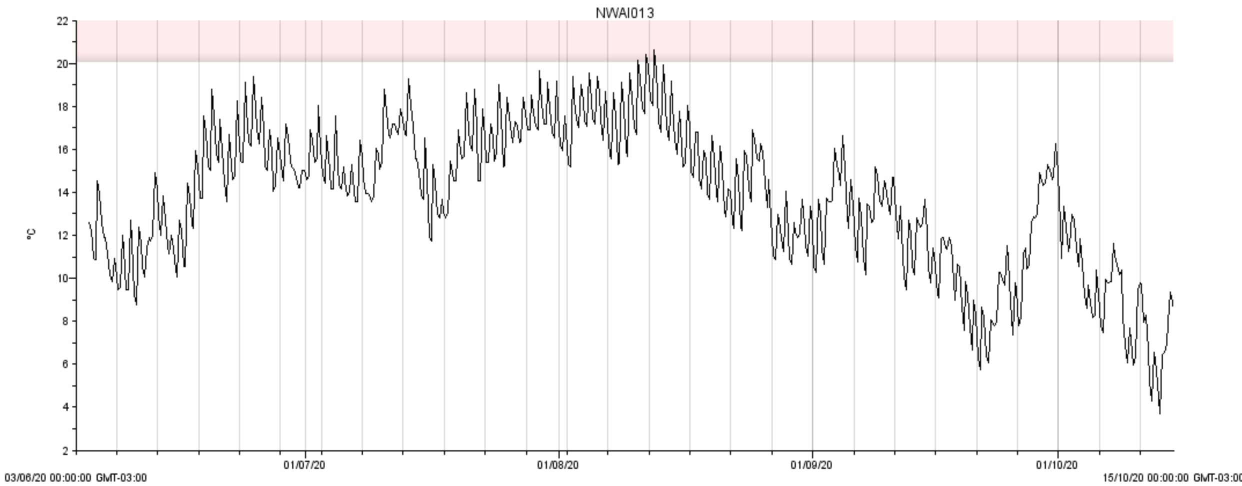
NWAI006. Located in Napadogan Stream at water quality site [46.34243, -67.0004]
Max temp: 26.5°C
Average summer temp: 18.3°C ± 3.9°C



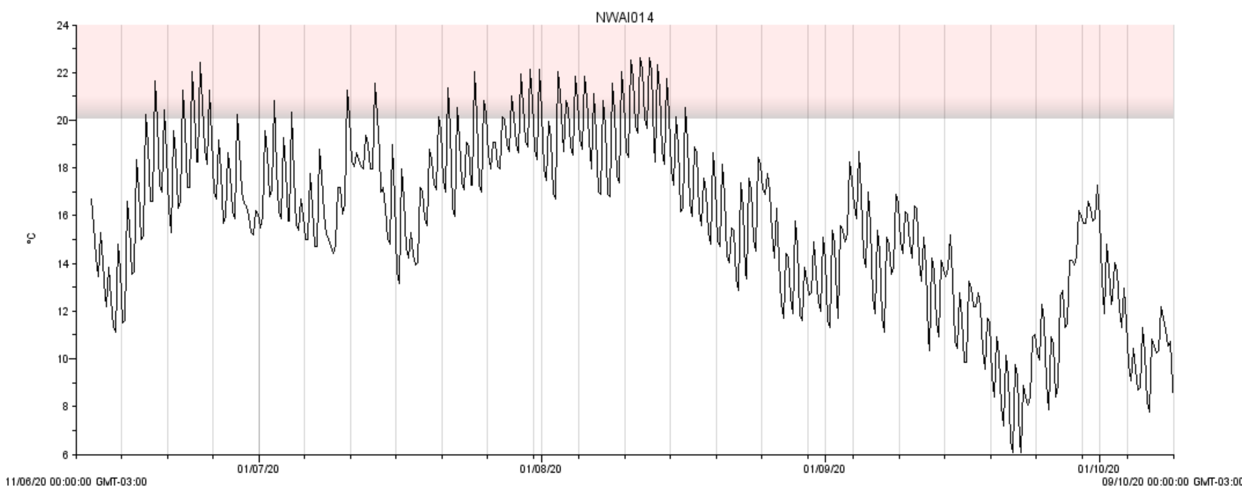
NWAI007. Located in Ryan Brook upstream from the trail bridge [46.31358, -66.81908]
Max temp: 24.5°C
Average summer temp: 16.8°C ± 3.5°C



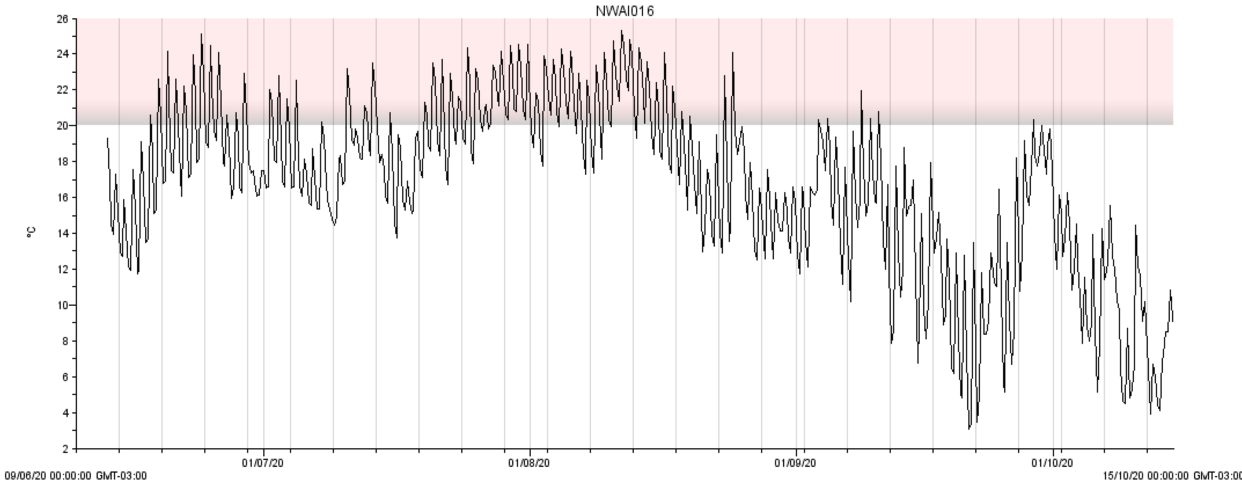
NWAI010. Located in Sands Brook [46.29439, -66.73838]
Max temp: 20.9°C
Average summer temp: 15.8°C ± 2.7°C



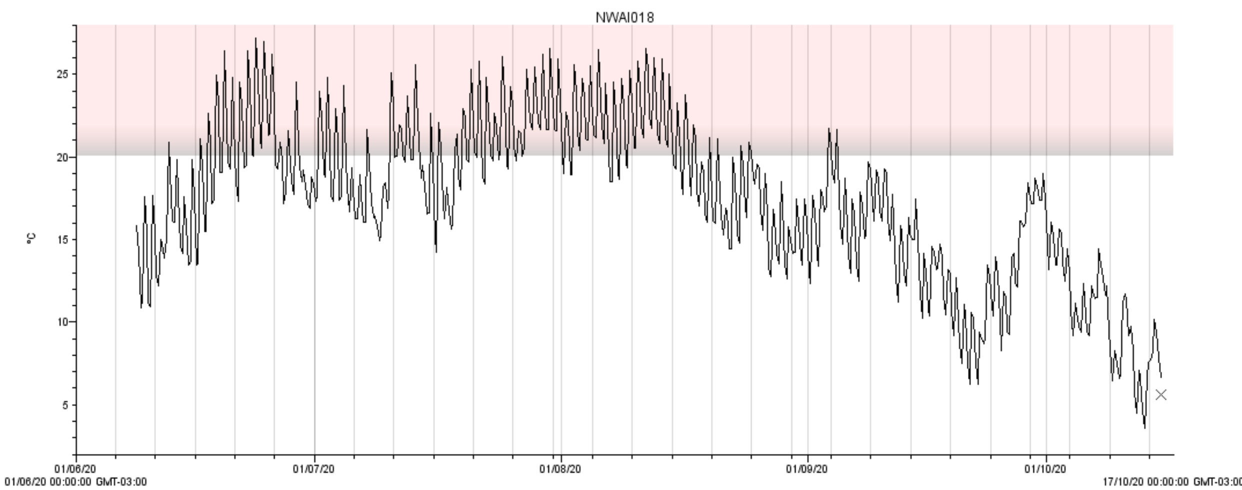
NWAI013. Located in McGiveney Brook at Rte. 625 [46.36309, -66.67183]
Max temp: 20.6°C
Average summer temp: 15.0°C ± 2.6°C



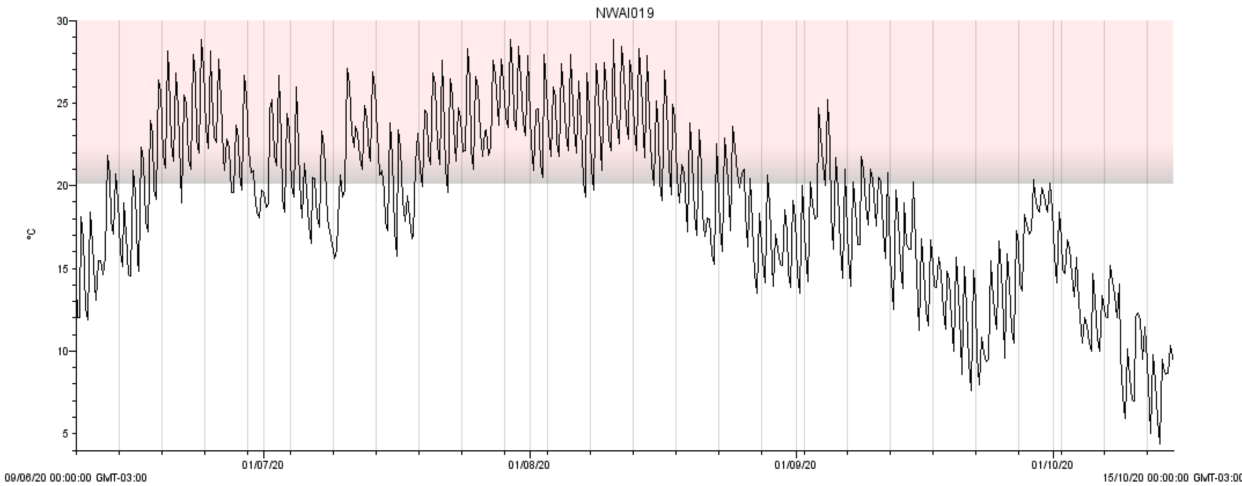
NWAI014. Located in West Cross Creek at Rte. 625 [46.32594, -66.70299]
Max temp: 22.6°C
Average summer temp: 16.7°C ± 3.1°C



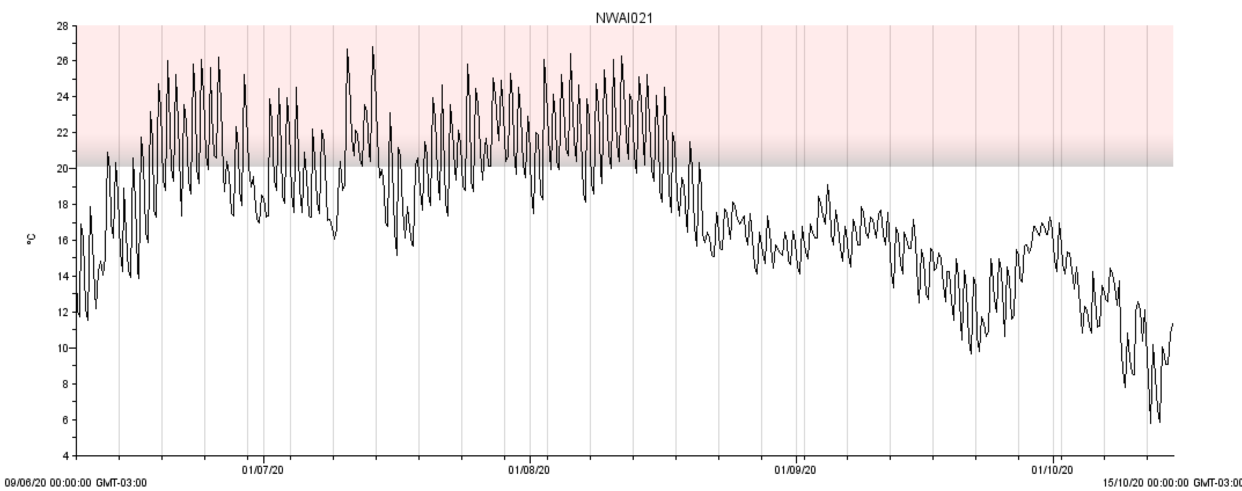
NWAI016. Located in Cathle Brook [46.27755, -66.67384]
Max temp: 25.3°C
Average summer temp: 18.1°C ± 3.9°C



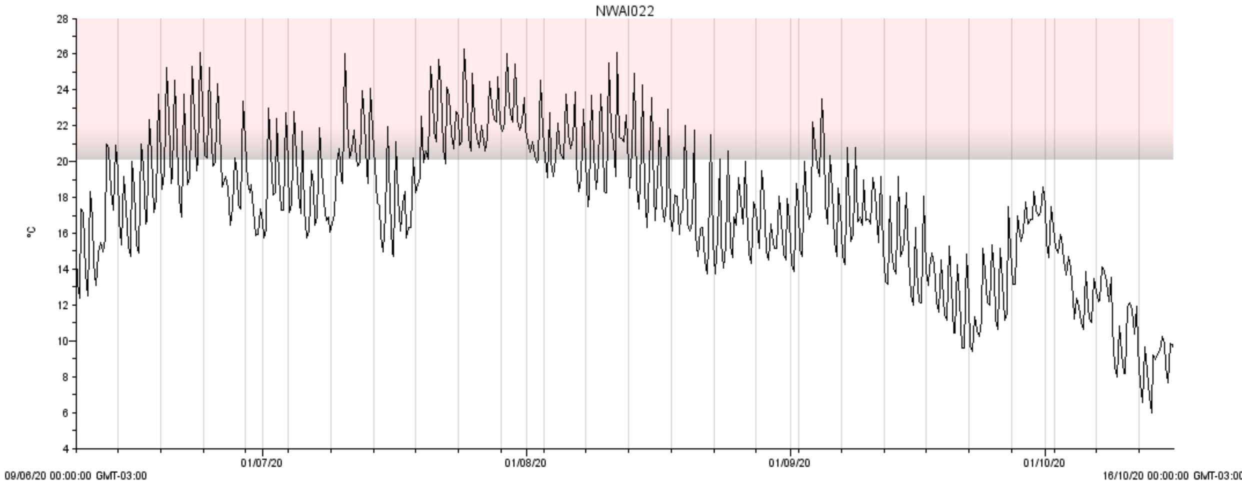
NWAI018. Located in Young's Brook [46.23964, -66.61092]
Max temp: 27.2°C
Average summer temp: 19.1°C ± 3.9°C



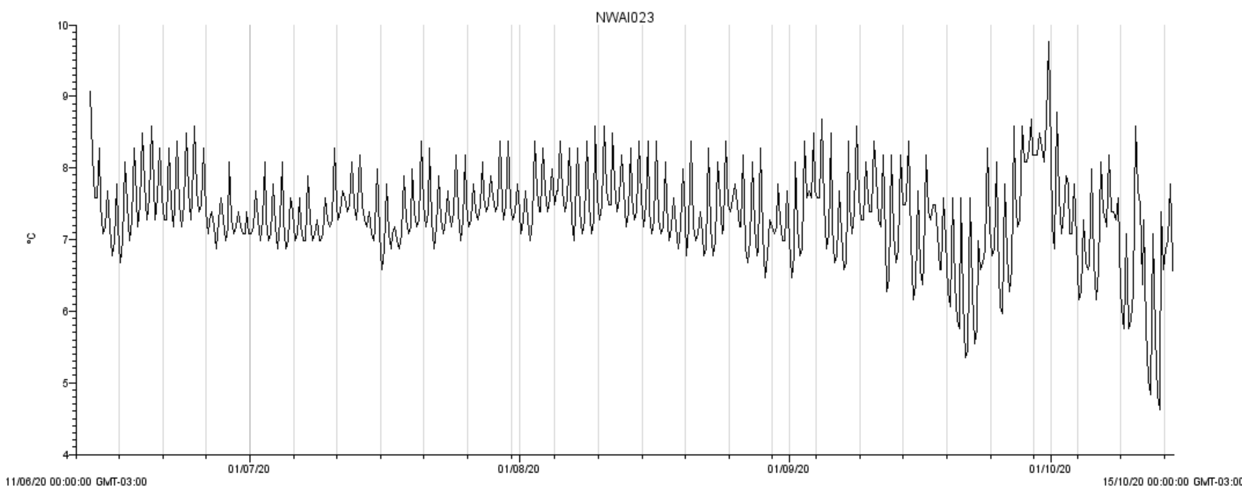
NWAI019. Located in Nashwaak River ~150 m downstream of Young's Brook [46.23853, -66.61196]
Max temp: 28.9°C
Average summer temp: 20.9°C ± 4.1°C



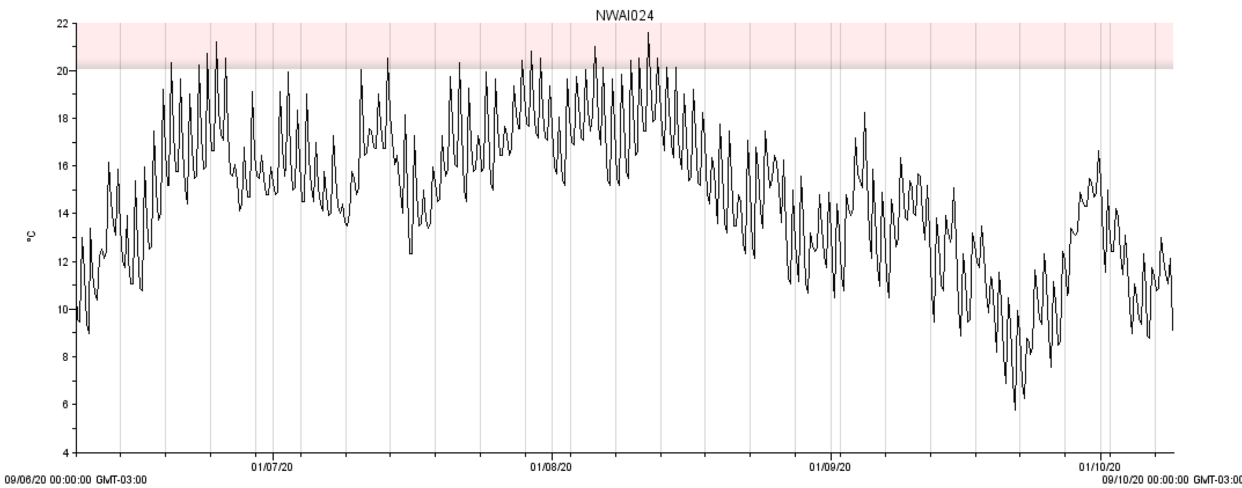
NWAI021. Located in Tay River at the mouth [46.18039, -66.62136]
Max temp: 26.8°C
Average summer temp: 19.1°C ± 3.4°C



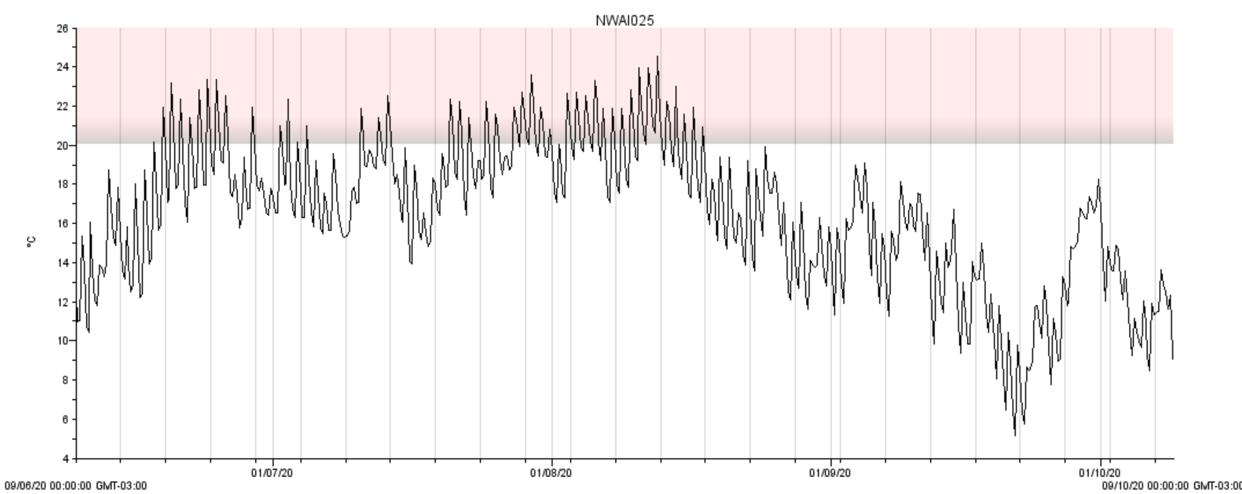
NWAI022. Located in Nashwaak River ~150 m downstream of Tay River [46.17903, -66.61982]
Max temp: 26.3°C
Average summer temp: 18.8°C ± 3.3°C



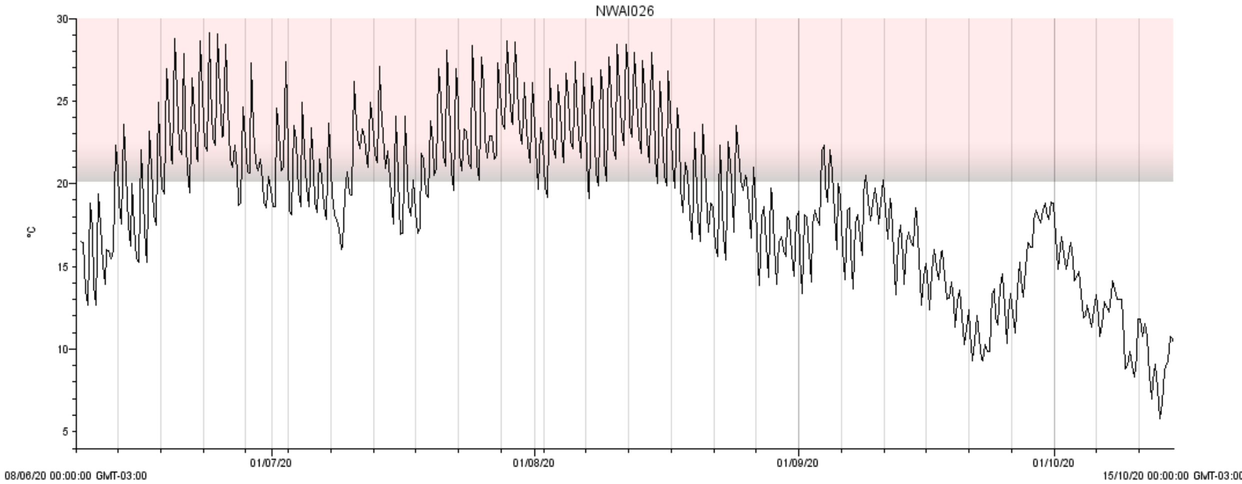
NWAI023. Located in Nixon Brook [46.20545, -66.68704]
Max temp: 9.8°C
Average summer temp: 7.4°C ± 0.5°C



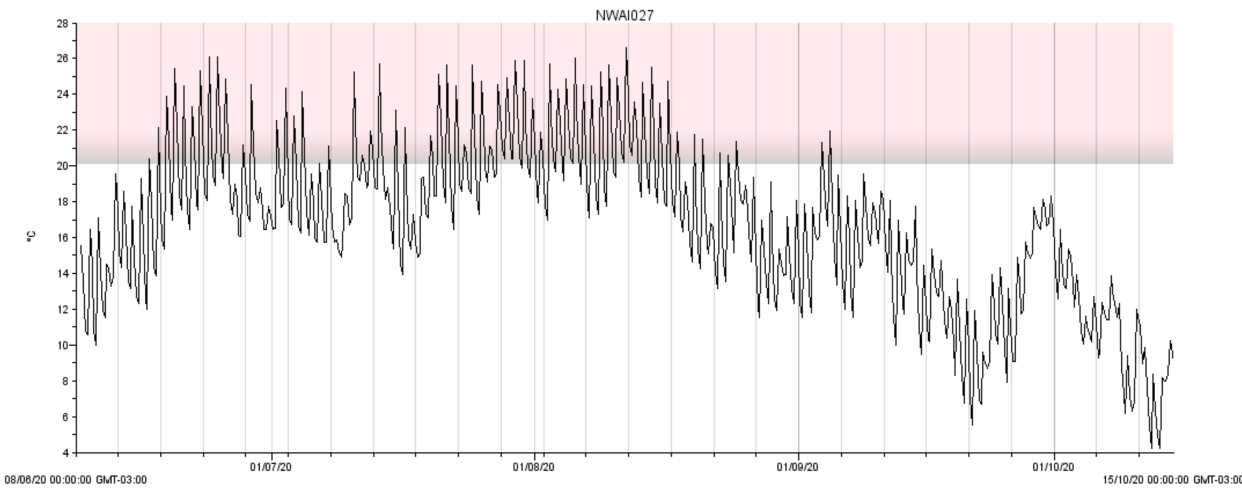
NWAI024. Located in McLean Brook downstream of the Rte. 628 bridge [46.12589, -66.6044]
Max temp: 21.6°C
Average summer temp: 15.5°C ± 2.7°C



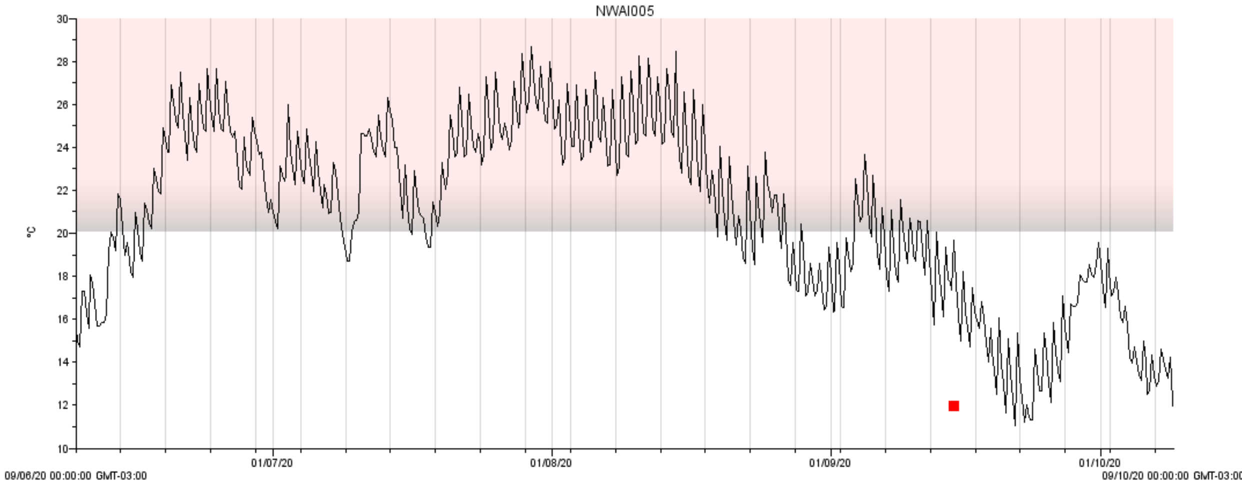
NWAI025. Located in Manzer Brook downstream from the Rte. 628 culvert [46.07066, -66.59277]
Max temp: 24.5°C
Average summer temp: 17.5°C ± 3.2°C



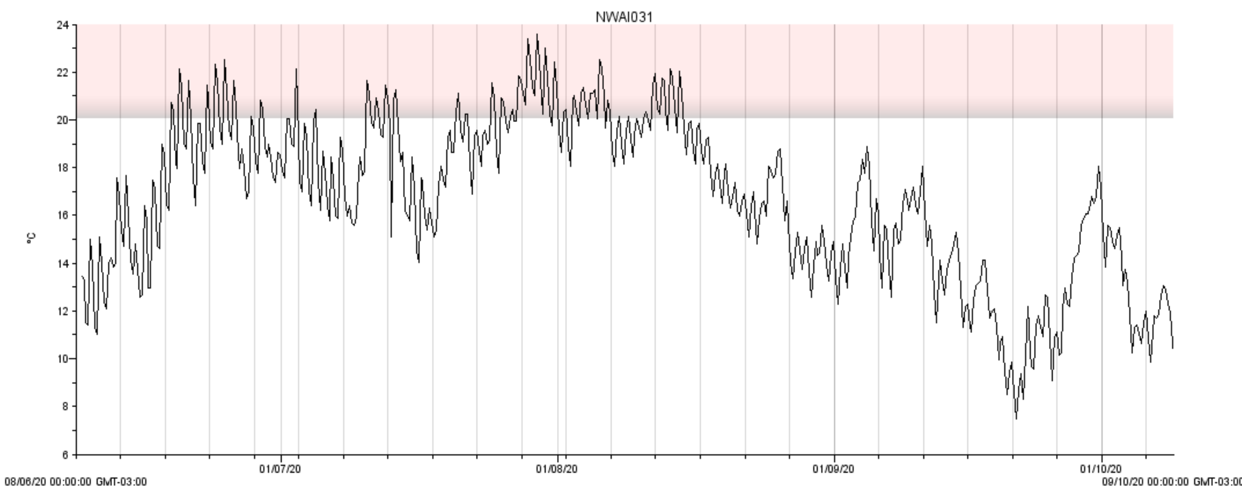
NWAI026. Located in Penniac Stream at our water quality site [46.03155, -66.57180]
Max temp: 29.2°C
Average summer temp: 20.6°C ± 3.9°C



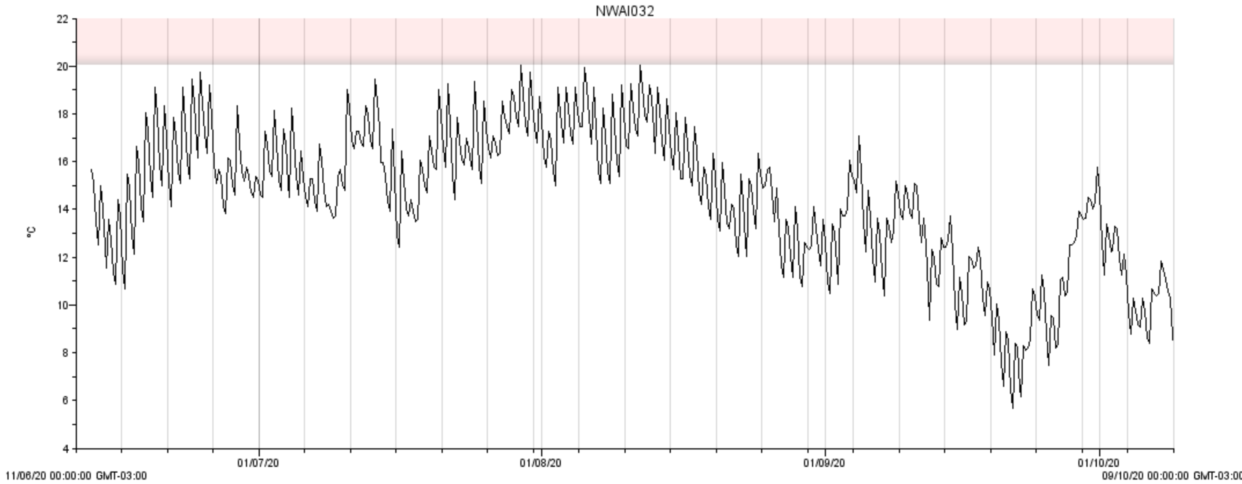
NWAI027. Located in Dunbar Stream at our water quality site [46.14139, -66.61873]
Max temp: 26.6°C
Average summer temp: 18.2°C ± 3.8°C



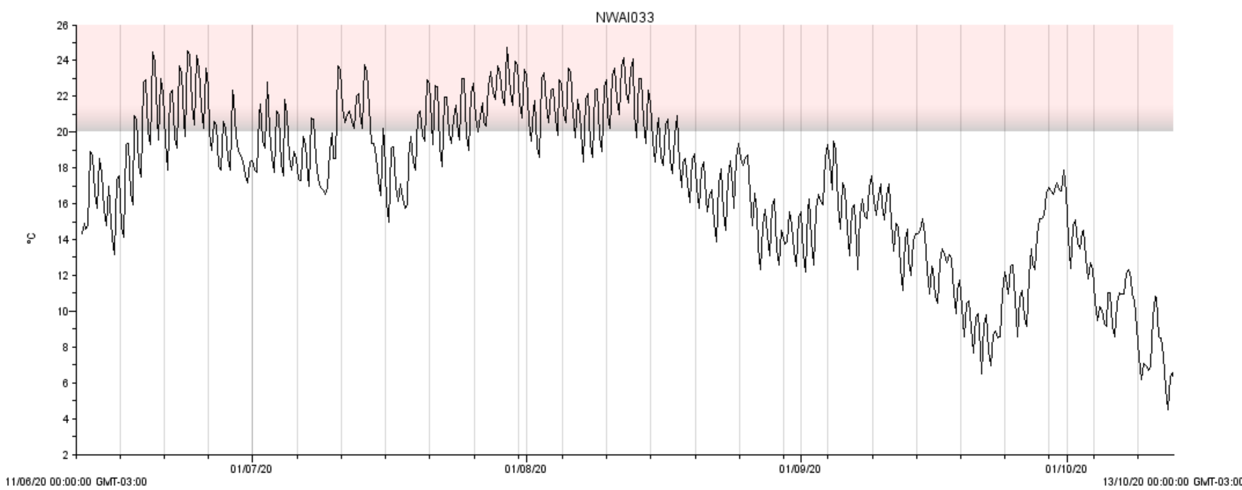
NWAI030. Located in Nashwaak River above Marysville Bridge [45.97952, -66.58989]
Max temp: 28.7°C
Average summer temp: 22.2°C ± 3.4°C
**the logger recorded a bad battery towards the end of September, which did not seem to affect the results*



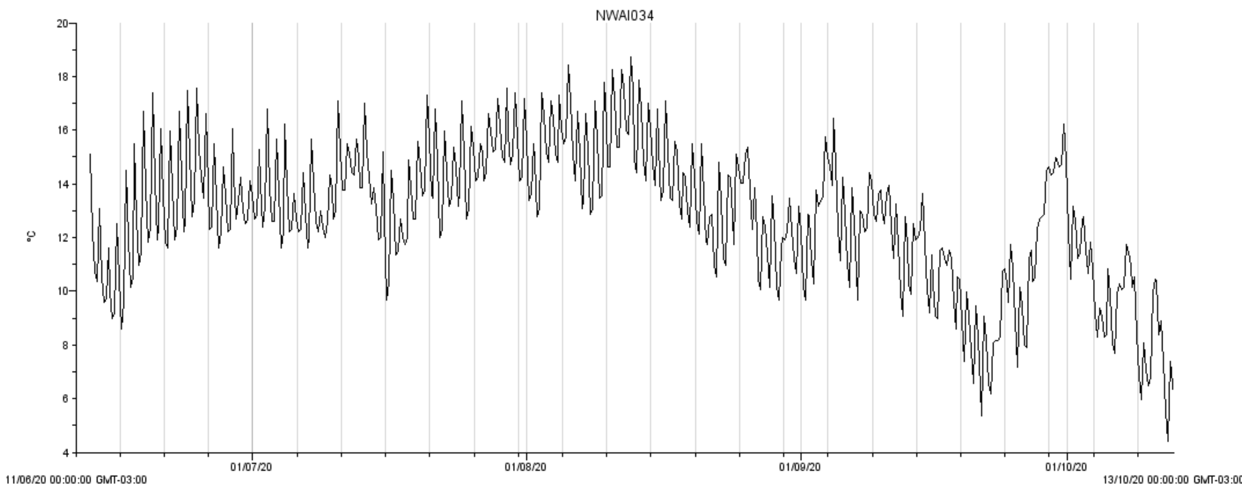
NWAI031. Located in Kaine Creek downstream from Canada Street [45.9703, -66.59058]
Max temp: 23.6°C
Average summer temp: 17.7°C ± 2.9°C



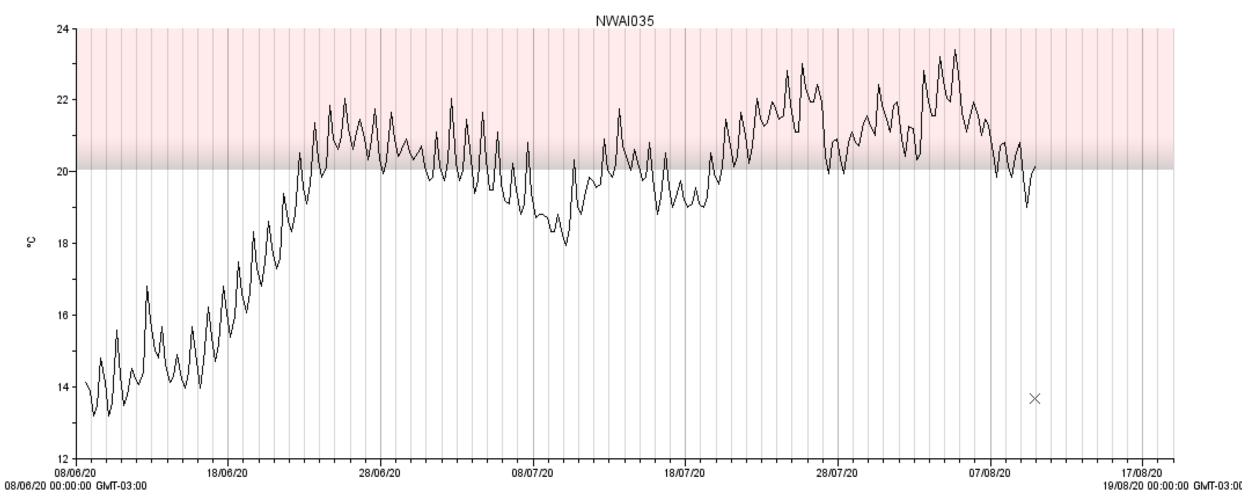
NWAI032. Located in McBean Brook downstream of Rte. 628 [46.16738, -66.6062]
Max temp: 20.0°C
Average summer temp: 15.2°C ± 2.5°C



NWAI033. Located in Limekiln Brook at Rte. 620 [46.26669, -6678860]
Max temp: 24.7°C
Average summer temp: 18.4°C ± 3.5°C



NWAI034. Located in East Ryan Brook [46.34387, -66.8038]
Max temp: 18.7°C
Average summer temp: 13.3°C ± 2.3°C



NWAI035. Located in Campbell Creek ~100 m downstream of dam [45.98825, -66.58157]
Max temp: 23.4°C
Average summer temp: 20.5°C ± 1.1°C
The logger stopped logging in early August for unknown reasons (the battery had enough charge