2019-2020

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 2019, samples were taken once a month from May to September at 11 historic sites, at Campbell Creek (sampling started in 2017), and at two sites at Nashwaak Valley Farms (related to a restoration project). 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 (1980 – 2005) data to infer trends in parameters. In general, the urban sites closer to the mouth of the river had inferior water quality compared to the uninhabited headwaters sites.

Although water quality in 2019 was generally good throughout the watershed, some measured parameters different from levels that would be considered optimal. We have attributed exceedances in water quality guidelines to an increase in sedimentation of the streams due to a few different activities including soil mining, agriculture, and removal of riparian vegetation. There was only one exceedance of *E. coli* (in June in Gorby Gulch), which was likely due to wildlife as there are no camps directly upstream from that site. Conversely, several water quality parameters, particularly ammonia and pH, were optimal and appeared to be improving when compared to historic levels. This year we purchased a dissolved oxygen (DO) probe and resumed measuring this parameter. DO was below the recommended CCME guideline of 9.5 for the protection of early life at all sites below Ryan Brook.

In 2019 we deployed 37 temperature loggers in both tributaries and along main stem to measure water temperature every six hours between May and October. We retrieved 36 loggers and analysed the recorded temperatures. Meteorological conditions were more moderate in summer of 2019 compared to the last two years and water levels remained normal (compared to 2017 when water levels were very low). Temperatures over the summer of 2019 averaged around 1-2°C lower than in the previous two summers.

Despite relatively lower air temperatures, many sites on the main stem exceeded 28°C. Four tributaries: Nixon Brook, McGiveney Brook, McLean Brook, and McBean Brook remained below 20°C all summer, indicating that they are very important thermal refuges for fish (two additional tributaries only slightly exceeded 20°C: McPherson Brook and Sands Brook). Nixon Brook remained below 11.5°C all summer, indicating that is most certainly ground water 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.

Through our other projects, including our Landover Conservation Program, we have focused on educating watershed residents about the importance of native riparian vegetation and promoting environmentally friendly land-uses on retired agricultural properties in order to keep our streams cool and clean. 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.

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Introduction and background

There are large temporal gaps in monitoring the Nashwaak watershed's health. Long-term monitoring can support the use of statistical trend assessment to help evaluate the influences of human activities & 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 fish populations. Water quality and temperature were noted as data deficient areas in our 2017-2020 Action Plan.

Maintaining the quality of the surface water is extremely important for ensuring a healthy watershed. Due to a broad range of natural & anthropogenic influences, the quality & temperature of a river's water can vary substantially over time & space. Much has changed in the watershed over the last 15 years, including urbanization, putting stress on the river due to an increased human population, which has led to 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 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 Brook Mine will soon begin construction. Having a knowledge of what the water quality is before it begins operating will allow us to calculate its effects. Therefore, in 2017 NWAI resumed monitoring water quality at 11 historic sampling sites and also added one new site. In 2019 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 increases with riparian zone alteration and water extraction (Caissie, 2006). The removal of forests requires road networks, which typically lead to an increase in 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, sedimentation, and input from water treatment plants. Though most present-day industrial and municipal operations are regulated to protect aquatic ecosystems, the persistent impacts from historical forestry operations remain unknown.

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 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" occur in areas where there are deep deposits of coarse soils that infiltrate a large portion of rain or snowmelt and where water tables are large and steeply sloped. Spring-fed creeks have more uniform and stable flows and temperatures. They can be extremely productive habitat for cold-water fish and can provide a refuge for fish from high summer water temperatures. Major upwelling or groundwater discharge areas are also critical locations for spawning and egg incubation. Areas of coarse gravel or sand with upwelling groundwater are the most sensitive and rare environments in a salmonid stream. Spring-fed streams are ecologically important as, being fed by groundwater, they are less susceptible to variations in air temperature & can buffer changes in climate. They support animals that don't occur in the main stem & maintain the base flow of the river.

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) 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).

Determining the location of, & protecting, cold-water tributaries were 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 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 (as recommended by DFO's Ecological Restoration of Degraded Habitats document);
- 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.

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:

- Storm water 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 to the 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 BOD.
- Former army encampment at McGiveney
    - Used as an ammunitions 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 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 streams and rivers by culverts and ditching;
    - Construction can lead to sediment runoff;
    - Hard surfacing of land can lead to run off 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's 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 soils leading to suspended solids loading and altered discharge pattern changes;
    - Culverts can impact fish passage if not properly installed; and
    - Increases salt, chemical, and nutrient runoff.
- Forestry
    - Exposes soils over a large land mass, 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, etc.
- 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

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 high concentrations of metals such as aluminum and iron. The bedrock is covered by moraine blankets deposited by glaciers between 85,000 and 11,000 years ago. Most soils are well-drained to moderately well-drained but are highly erodible (Parish Aquatic Services, 2016).

Alluvial (river-associated) deposits along the riverbanks consist of gravel and sandy gravel. Recent alluvial deposits cover the Tay and Nashwaak River valleys (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 grab 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). Temperature of water quality grab samples exceeded 20°C 23 times. In 2017 and 2019, the NWAI deployed >30 temperature loggers between May and October in the main stem and in tributaries. 2017 was a hot, dry summer with very low water levels while 2018 was a very hot summer but water levels remained normal. The lowest temperatures were recorded in tributaries including McPherson Brook, Nixon Brook, McBean Brook, and McLean Brook. The highest temperatures were observed in the main stem, particularly above McPherson Brook and above Young's Brook. In 2017, the summer average (readings taken between 21 June and 21 September) for main stem loggers was 19.7°C±3.0°C, white in 2018 the summer average in the main stem was 19.7±1.3°C. In 2017, the summer average of the tributaries was 17.9°C±2.7°C, while in 2018 it was 16.6±6.7°C.

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 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

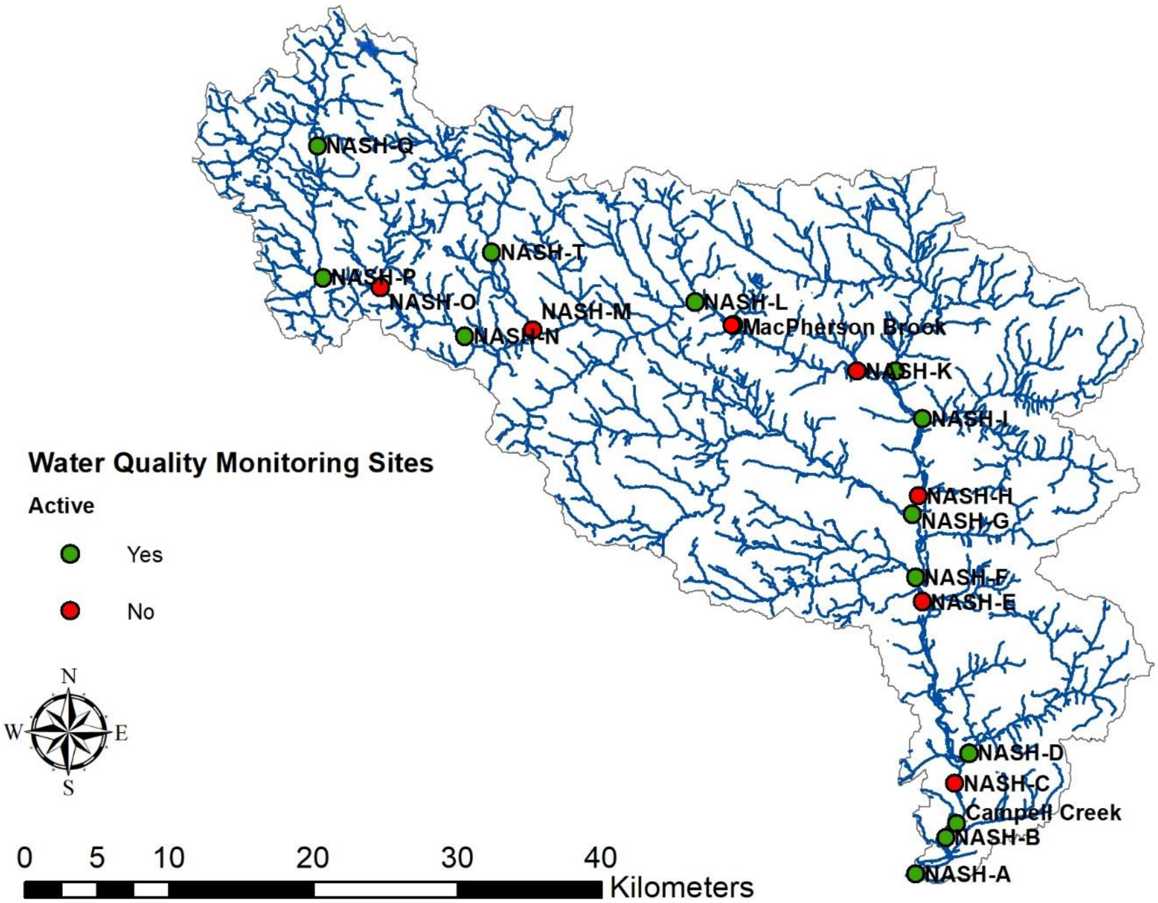

Figure 1 Map of the water quality sampling sites. Active sites (those sampled in 2019) are denoted in green while inactive sites are denoted in red. Nashwaak Valley Farm sites are not included on this map.

Stations sampled in 2019 are described below:

NASH-A: Barker's Point (DELG Station 10535)
This station is on the mainstem 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. Campbell Creek and McConaghy and Second Gore Brooks. Additive drainage 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.

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 2019, the headpond was full. Prior to 2019 there was a large, active beaver dam at the culvert above the dam, but we observed that it was gone in June 2019. 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: the North Branch of the Penniac Stream, as well as Gilmore, Whitlock, Allen, Jakes, Moore, Baxter, Moosehole, and Estey Brooks. Additive drainage is comprised of 92.6% forested land, 4% agriculture, 2% wetland and minor human occupation, gravel pits, and roadways. Pollution sources of note include forestry practices, topsoil mining, and significant cattle grazing. This area is used for hunting, fishing, and recreation.

NASH-F Dunbar Stream (Station ID 10541)
This station is on Dunbar Stream about 30 m upstream from the confluence with the Nashwaak and downstream from Dunbar Falls. The station also receives water from Thomas Lake (2 Ha), Stickles Lake (1.5 Ha), North and South Dunbar Brooks, Tinkettle Brook, and Seymour Brook. Pollution sources of note include forestry and agriculture. A major waterfall (Dunbar Falls) prevents fish from ascending the stream but provides recreational opportunities for residents.

NASH-G Tay River (Station ID 10542)
This station is on the Tay River approximately 50 m upstream from its confluence with the Nashwaak River. This station also receives water from the North Tay River, the South Tay River, Robinson, Pidgeon, Limekiln, Big, Barker, and Little Tay Brooks. Additive drainage is 93% forested and 5% agricultural land. Pollution sources of note include camp lot development, forestry, and major bank erosion in the lower 3 – 5 km of this river. The Tay River is popular for swimming and angling.

NASH-I2 Young's Brook/ Nashwaak Bridge (DELG Station 10544)
NASH-I is located on the mainstem of the Nashwaak above the confluence with Young's Brook near the community of Nashwaak Bridge while NASH-I2 is located at the mouth of Young's Brook. As they are so close the data were analyzed together and called NASH-I. Station NASH-I2 was sampled in 2017-2019. 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 2017-19, 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-Up and NVF-Down

These sites are related to a bank restoration project carried out in August 2019. NVF-Up is located immediately upstream of the restored section of bank and NVF-Down is located ~50 m downstream of the restored section of bank. The landowner usually has horses and other livestock grazing in the field adjacent to the restoration site, but they were elsewhere in the summer of 2019. Pollution sources of note included sediment from the eroding bank, soil mining operations upstream, livestock on the property, and residential development upstream.

Temperature monitoring

NWAI consulted with PhD candidate Antóin O'Sullivan at Canadian Rivers Institute (CRI) regarding the placement and casings for the loggers. Funding allowed us to purchase six new HOBO 64K Pendant Loggers from Onset to bring our total to 38. 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 recorded water temperature every six hours. 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 7 and 14 June (Fig. 3). 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 1 foot so that the bottom of the PVC casing sat flush with the substrate. The pendant logger was pushed down inside the casing to ensure that it was in the deepest water possible. Rocks were piled in a cairn around the logger to prevent it from moving too much and to help us in locating it. A waypoint was taken at each logger location.

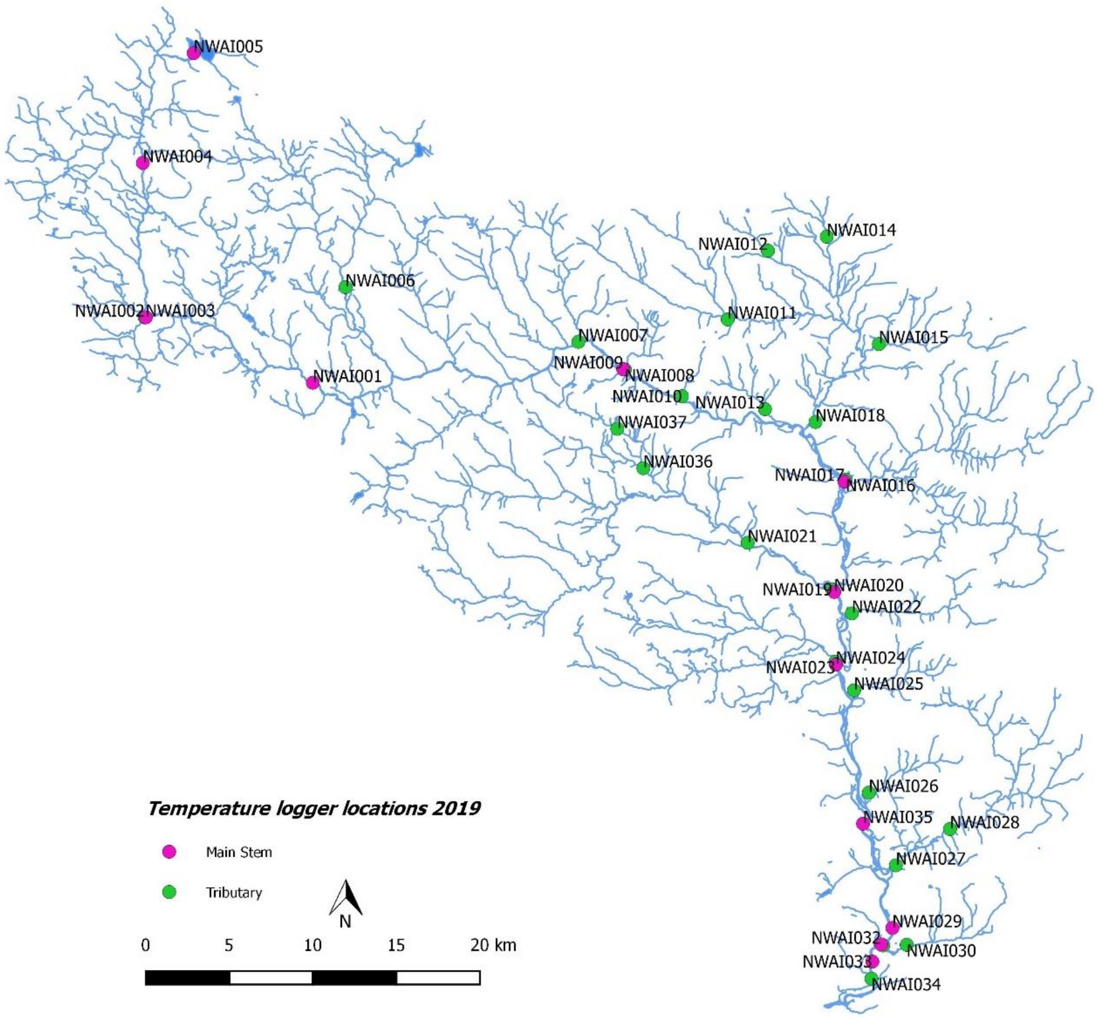

Figure 3. A map of the location of the 37 loggers installed in 2019. Pink denotes the loggers placed in the main stem of the river and green denotes the loggers placed in the tributaries.

We tried to check on the loggers at least monthly but some of the more remotely placed 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 slightly relocated due to dropping water levels. This usually involved moving them a few metres away from their original position.

The loggers were collected between the 3rd and the 17th October. One logger could not be found despite searching for over 30 mins: the one downstream from Route 8 on Campbell Creek. This tributary is popular with anglers, so it is possible that someone took it. We did manage to find a logger that we thought lost in 2018: the logger at the outlet of Nashwaak Lake. It had successfully logged all winter and was recovered in June and read out. One logger (at Five Mile Brook) stopped logging early (September 26th) due to a battery malfunction. 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. Data were grouped per decade (1980s, 1990s, etc.) and analysed graphically per site to look at changes over time or between sites. Not all sites have data for a specific parameter or date, which makes comparisons, in some cases, very difficult. Limits for certain contaminants have been developed by the Canadian Council of Environment Minsters (CCME, 1999).

Overall water quality improves moving upstream in the watershed. Patterns of water quality parameters were as expected based on land use patters. Areas of concern are from the Penniac Stream downstream to the mouth of the river.

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. Unfortunately, the probe malfunction on our July sampling run and was recording levels of 0.1-0.5 mg/l DO. We did not include these results in our analyses.

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.

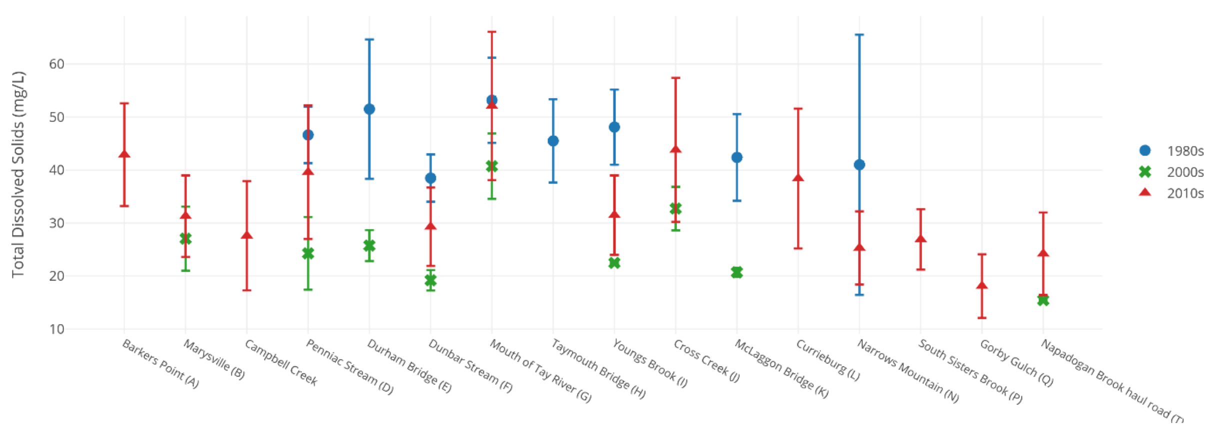

Figure 4 Mean total dissolved solid contents (mg/L) per site per decade for the Nashwaak watershed. Error bars represent standard deviation.

Field measurements of TDS contents were available for selected sites from the 1980s and 2000s and for all sampled sites in 2017 – 2019 (Fig. 4). TDS contents were, in general, lowest in the 2000s and highest in the 1980s. Most results were within the 25 to 60 mg/L range (now considered the normal range for the Nashwaak Watershed) with the headwater sites having slightly lower values (15 -30 mg/L).

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, which could explain the elevated levels at the mouth of the Tay and near Durham Bridge and Penniac Stream where soils mining is more common. Currieburg, at the mouth of Ryan Brook, may have had high levels in 2019 a large culvert replacement that was completed late fall 2018. This site had slightly elevated levels in 2018 as well.

Suspended Sediments and 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. Suspended sediments are fine particles, primarily clays, silts, and fine sands that require low water velocities to remain in suspension. It naturally varies depending on soil type, shoreline erosion, and surrounding land use. 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.

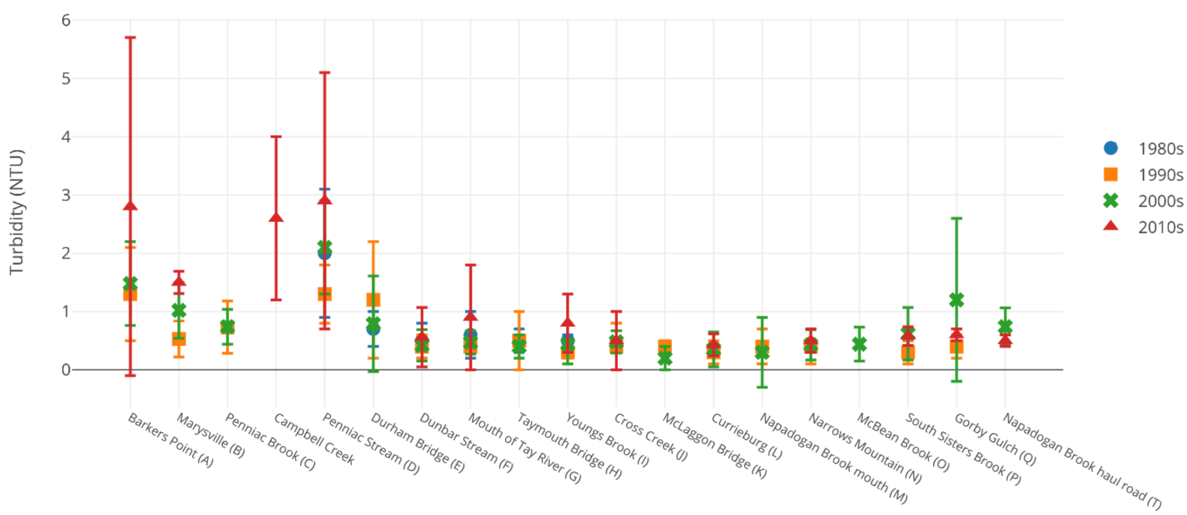

Figure 5 Turbidity (NTU) per site per decade in the watershed. Error bars represent standard deviation.

Values were, in general, very low for all sites (median values of 0.3 to 2.1) (Fig. 5). Values were highest in 2005, 2017 and 2018. In 2019, slight 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. The highest value recorded in 2019 was 13.0 NTU at Marysville, recorded by DELG in February. The remainder of 2019 values at Marysville stayed below 1.2 NTU. The other site with the highest median value in 2019 was Campbell Creek at 2.1 NTU. Values at this site were consistently above 1.5 NTU, similar to previous years. This is likely influenced by the dam above this sampling location.

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. Turbidity at Campbell Creek may be affected by the headpond above the dam.

Suspended sediments consist of clay, silt, fine particles of organic and inorganic matter, plankton and other microscopic organisms. The CCME guideline for the protection of aquatic life is an increase of no more than 25 mg/L for short term exposure (<24 hours) and 5 mg/L for longer term exposure. Suspended sediment loads have, in general, increased at most sites from the 1980s to the 2000s but were not measured in 2018 as it was not 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 detection limits increased 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.

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.

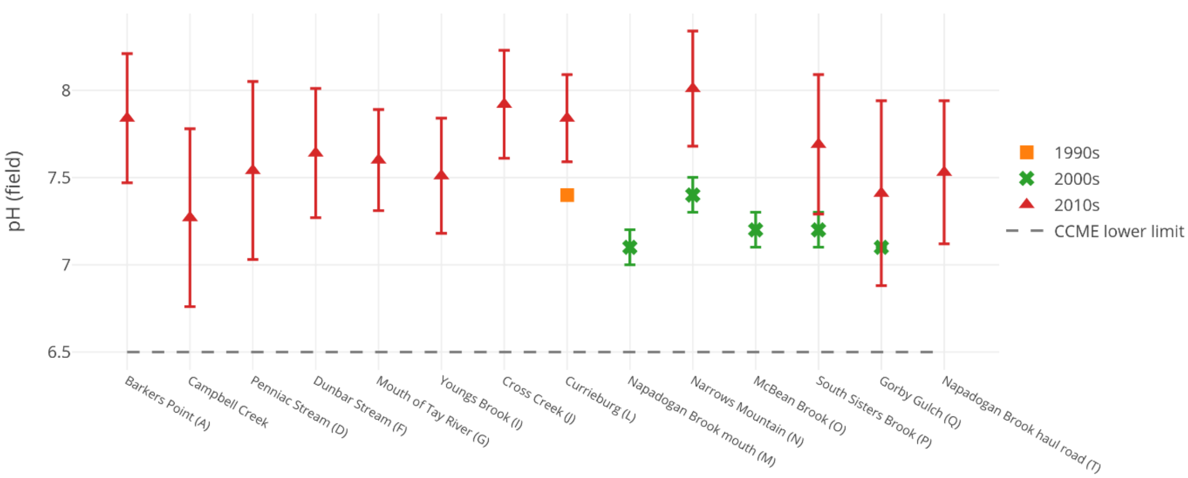

Figure 6. pH (values measured in the field) per site per decade in the watershed (for those sites where data were available). Errors bars represent standard deviation. Historic field measurements were not available for most sites.

For the data available, pH levels for the watershed were within the CCME limits (Fig. 6). There is no discernable pattern in pH from headwaters to mouth. Data show that pH has increased (become less acidic) at every site from the 1990s/2000s to the 2010s, but, as mentioned above, little historic data are available for field measurements. Values measured in 2019 are considered protective of aquatic life.

Average values were slightly higher throughout the watershed in 2019 compared to 2018 and average 7.6 over all monitored 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.

We resumed measuring DO in 2019 as we purchased a new probe. Dissolved oxygen was on average higher above Currieburg. Average values at most sites were lower than of those measured in the 2000s except for Marysville, which was only slightly higher and includes the most data points. There were several exceedances in 2019: 22% of measurements were below 6.5 mg/l and 41% were below 9.5 mg/l. As was expected, DO was lowest in July when temperatures were the highest and highest in June and September when temperatures were the lowest. The site with the lowest average value was NASH-D (Penniac) where 3 out of the 4 measurements were below 9.5 mg/l.

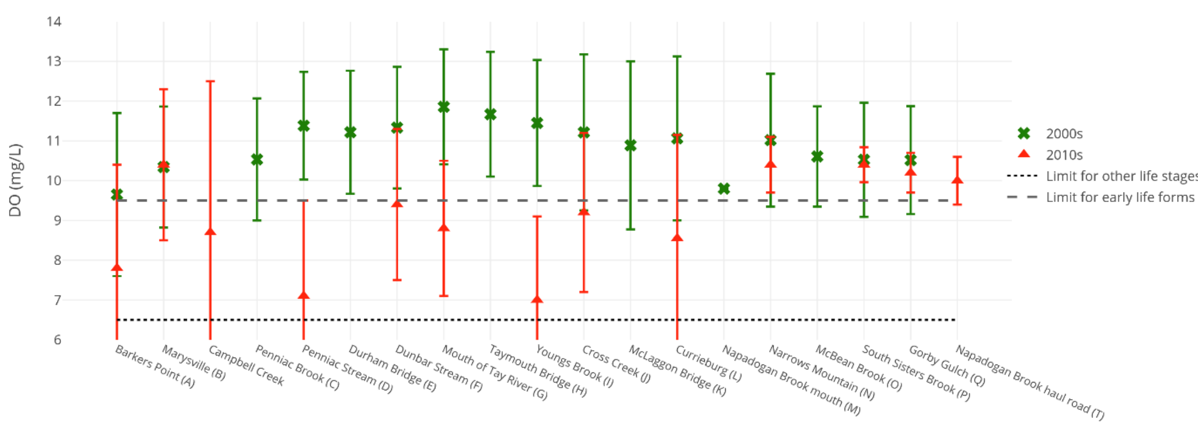

Figure 7 Mean dissolved oxygen content (mg/L) per site per decade. Error bars represent standard deviation. Dashed lines indicate CCME limits for early life forms (9.5 mg/L) and all other life stages (6.5 mg/L).

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).

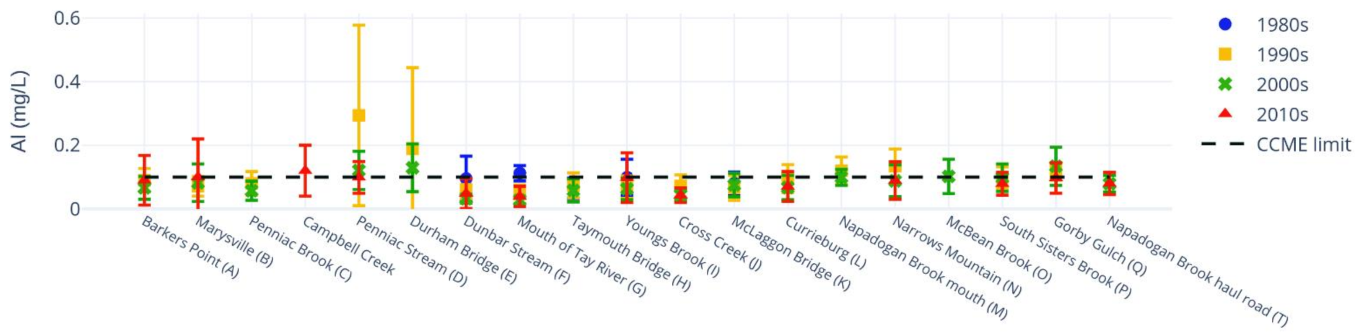

Figure 8 Aluminum content (mg/L) per site per decade. Error bars represent standard deviation. The black dotted line represents the CCME limit of 0.1 mg/L.

Aluminum levels were the highest in the 1990s, especially in Penniac and around Durham Bridge where soil mining is more common (Fig. 8). Levels were slightly above the limit in the upper reaches of the watershed (Curriburg to Gorby Gulch) in the 1990s and 2000s as well. Aluminum levels at most sites did not change significantly at any site between 1980 and 2019. The exceedances are likely due to the underlying geology as well as sedimentation of streams due to removal of riparian vegetation and subsequent erosion. 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.

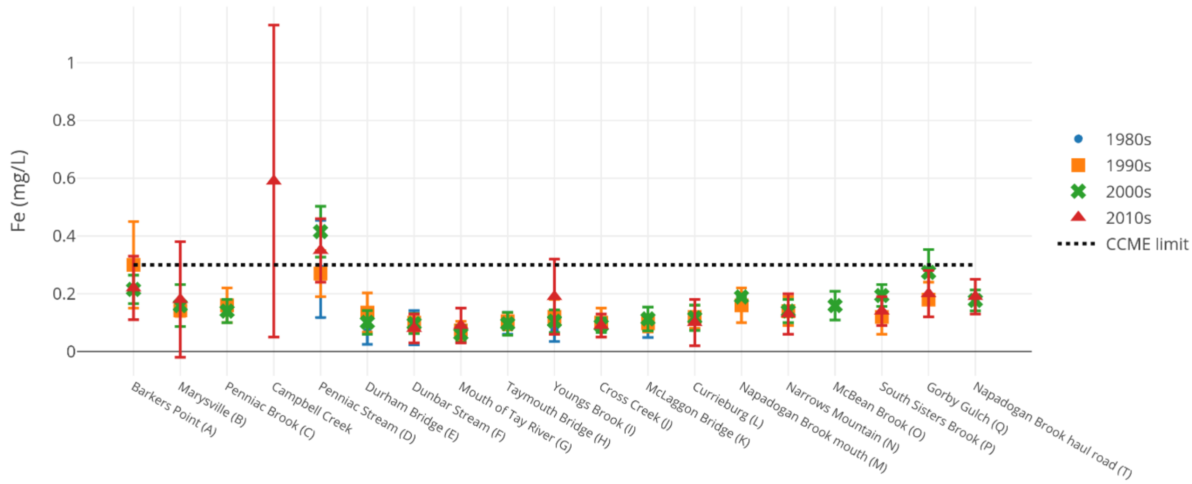

Figure 9 Mean iron content (mg/L) per site per decade in the watershed. Error bars represent standard deviation. The dotted line represents the CCME limit of 0.3 mg/L.

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 five: Barker's Point, which exceeded the limit in the 1990s; Penniac Stream, which has consistently exceeded the limit throughout sampling history; Young's Brook, which has two exceedances in 2018; Gorby Gulch, which had exceedances in 2011, 2002, and 2018; and Campbell Creek, which was way above the CCME limit with a mean value of 0.79 mg/L at Campbell Creek. (Fig. 9). We have previously observed that heavy rainfall leads to spikes iron concentrations. Exceedances in the historical data may have been due to precipitation-related runoff.

Soil erosion is likely the cause of elevated iron contents. Penniac Stream displayed high levels of both Al and Fe, particularly in the 1980s, indicating that soil erosion was likely an issue at this time. We are unsure why iron concentrations are very high at Campbell Creek. It may be due to the amount of sediment being held behind headpond, though aluminum levels are below CCME guidelines.

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 2019.

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.

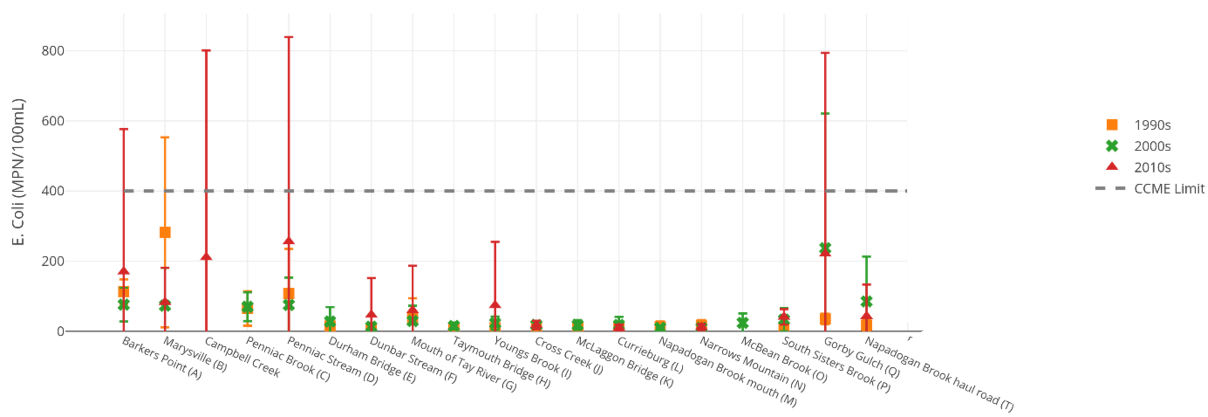

Figure 10 Mean E. coli contents (MPN/100 mL) per site per decade in the watershed. Error bars represent standard deviation. The CCME limit is 400 MPN/ 100 mL for a single grab sample.

E. coli contents were generally higher in the downstream sampling sites, particularly downstream from Penniac, where there is increased human habitation, and especially in the 1990s (Fig. 10). However, both Gorby Gulch and Napadogan had high concentrations of *E. coli* in the 2000s. Gorby Gulch also had exceedances in 2018 and 2019, likely due to wildlife. Historically, grab samples at two sites have exceeded the CCME limit 400 MPN/100 mL for recreational waters: NASH-Q (in 2001 (n=1), and 2002 (n=1)), NASH-B (in 1998 (n=1), 1999 (n=1), 2005 (n=1), and 2010 (n=1)). There is no CCME limit for the protection of aquatic life. *E. coli* is lowest in the central watershed (Durham Bridge to South Sisters Brook), where there are fewer humans and more undeveloped, forested land. *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.

There was only one exceedance for *E. Coli* in 2019 – at Gorby Gulch in June, which was likely due to wildlife.

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 made comparisons tricky. Fluoride toxicity results in shifts in migration patterns in salmonids and impaired reproduction in aquatic invertebrates.

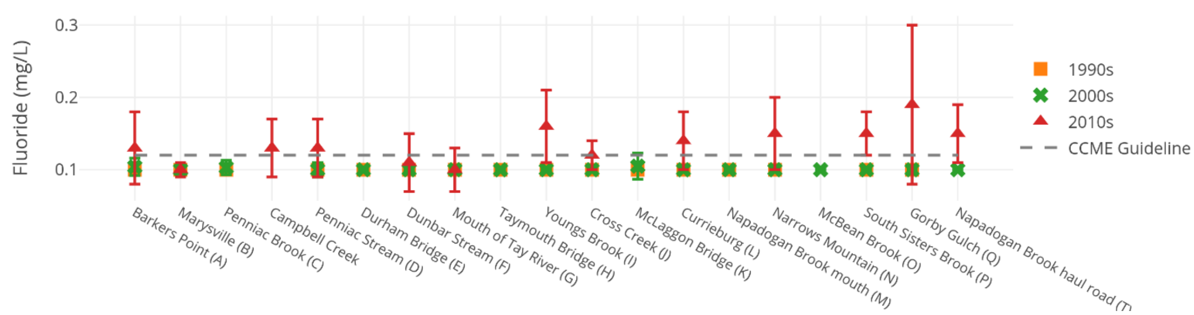

Figure 11. Fluoride concentrations (mg/L) per site per decade in the watershed. Error bars represent standard error. The dashed line represents the CCME guideline of 0.12 mg/L.

Fluoride concentrations have risen slightly from the 1990s/2000s to 2019 (Fig. 11). However, detection limits have also changed (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. Several sites were over the CCME guideline of 0.12 mg/L in 2019, particularly in the upper watershed.

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. Previously (before September 2016), the detection limit was 0.01 mg/L but after 2017 RPC's detection limit was 0.05 mg/L total ammonia.

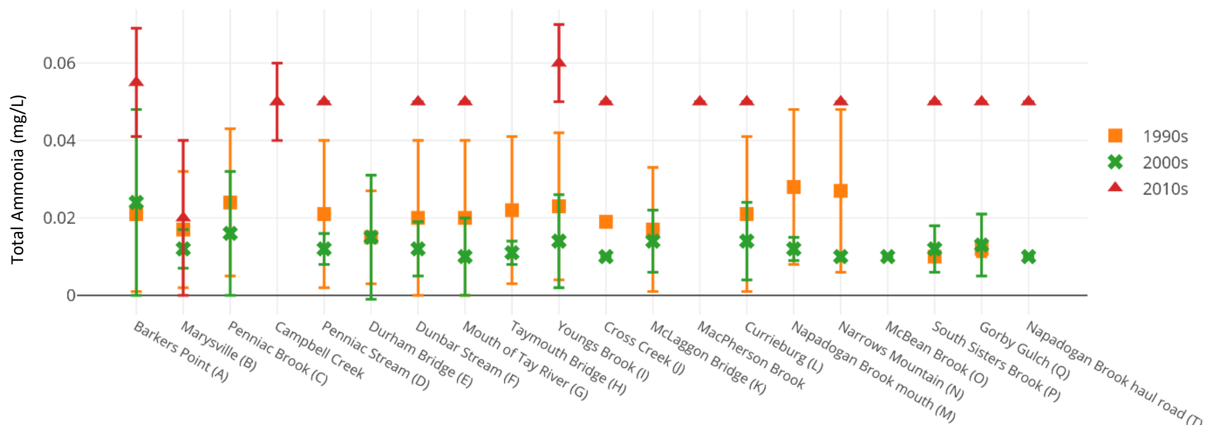

Figure 12. Total ammonia (NH_{3T}) concentrations per site per decade. Error bars represent standard deviation.

It is difficult to discern a trend in total ammonia concentrations because the detection limit increased in September 2016 (from 0.01 to 0.05 mg/L). Mean ammonia concentrations dropped between the 1990s and the 2000s, but this drop was not significant an most sites (Fig. 12). Higher levels of ammonia are usually indicative of organic pollution. Results were well under the CCME guideline.

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. CCME does not set limits for phosphorous, nitrite, or nitrogen as they are not considered toxic to aquatic life; however, the lowest Canadian trigger range (ultra-oligotrophic) for total phosphorus is 4 ppb or 0.004 mg/L and the eutrophic trigger limit is 0.035 mg/L. 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. 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 with phosphorus levels typically around 0.01 mg/L and nitrate and nitrite levels below the detection limit of 0.05 mg/L at most sites. The highest levels of nitrite and nitrate were noted at NASH-B (Marysville), with nitrite concentrations spiking at 0.23 mg/L in 2015 and MacPherson Brook, which had a nitrate concentration of 0.35 mg/L in July 2017.

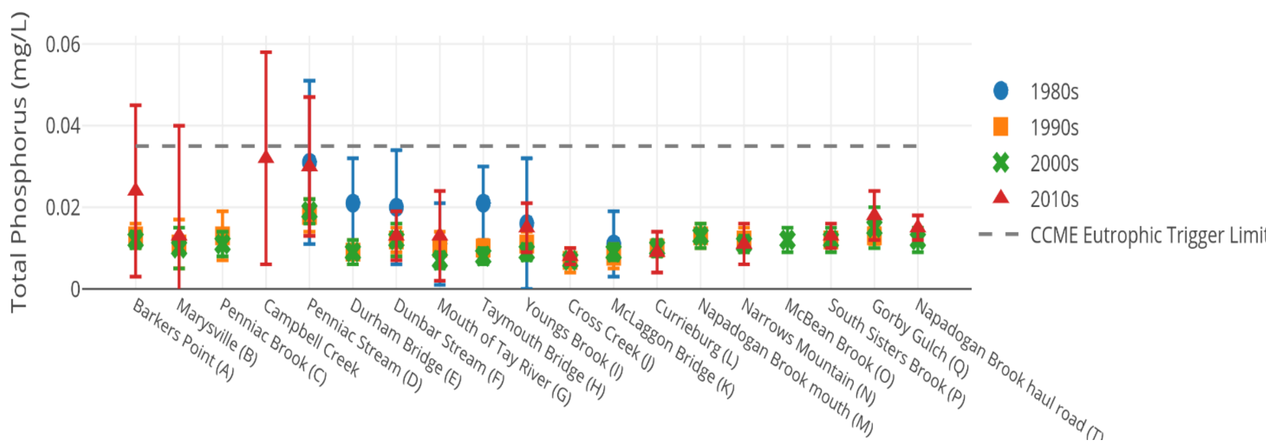

Figure 13. Total phosphorus concentrations (mg/L) per site per decade in the watershed. Error bars represent standard deviation and the dashed line represents the CCME Canadian Trigger for Eutrophic Waters (0.035 mg/L).

As with other nutrients, spikes in total phosphorus have been recorded after a heavy rainfall event. In 2019, the average values were highest at Marysville (an overall mean of 0.04 mg/L), Penniac (0.0188 mg/L average), and Campbell Creek (0.0220 mg/L). Agricultural inputs, soil erosion, and the presence of wildlife may be the source(s). It appears that phosphorus concentrations have remained relatively stable over time at most sites except at NASH-A (Barker's Point), where mean concentrations were highest in the last 3 years as compared to historical values and in the central watershed (Penniac to Young's Brook), where mean concentrations were highest in the 1980s (Fig. 14).

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.

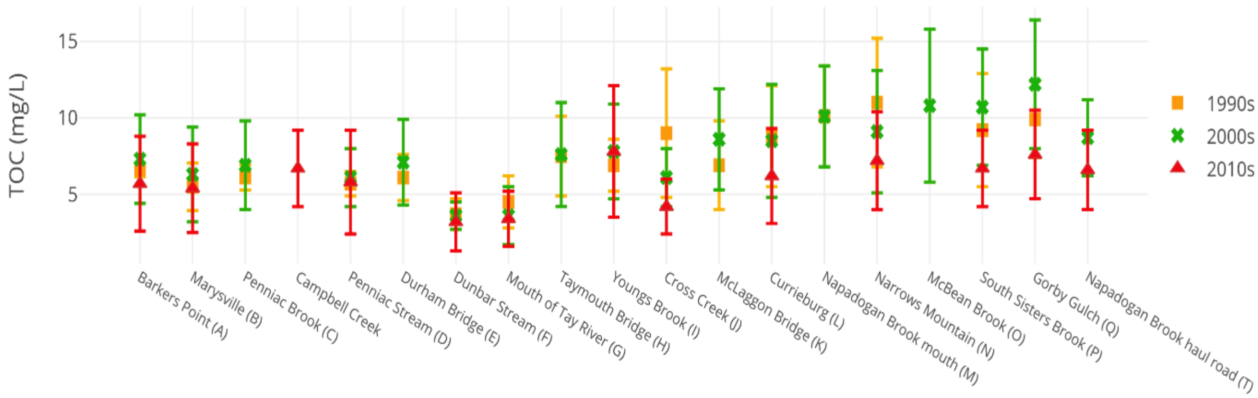

Figure 14. Total Organic Carbon concentrations (mg/L) per site per decade. Error bars represent standard deviation.

TOC levels were highest in the upper watershed at above Young's Brook and particularly above McBean Brook where average values exceeded 10 mg/L. This may be due to the wetlands in this area. Levels were particularly high throughout the watershed in 2001 but have remained stable over time (Fig. 14). In 2019, levels were highest in Marysville and Campbell Creek,

Conductivity

Conductivity is a measure of a stream's ability to carry an electrical current. It is recorded in micro siemens per centimetre (μs/cm). Conductivity can be influenced by the presence or absence of inorganic dissolved solids such as chloride, nitrite, sulfate, phosphate, sodium, magnesium, iron, and aluminum. It is also affected by water temperature (higher temperature means higher conductivity). Conductivity is generally determined by geology. The igneous rocks (granite) of the headwaters 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. Conductivity 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.

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 4 samples per year with at least 4 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 weren't measured in certain years (e.g., Al wasn't measured in 1980, DO and temperature were not consistently measured, and nitrate and nitrite were measured in the 1990s). In addition, detection limits have changed over time and number of samples did not meet the minimum in certain years.

Parameters used to calculate the 2019 WQI were: arsenic, cadmium, chloride, dissolved oxygen, E. coli, iron, ammonia, nitrite, nitrate, lead, pH, total dissolved solids, temperature, phosphorus, turbidity, and zinc. Results for the 2019 WQI calculations can be found in Figure 15. Water quality was excellent overall throughout the watershed. The poorest WQI results were from NASH-D (Penniac), possibly due to agriculture in the area and high sediment loads in this stream. This site did not meet the guidelines for DO, iron, or phosphorus.

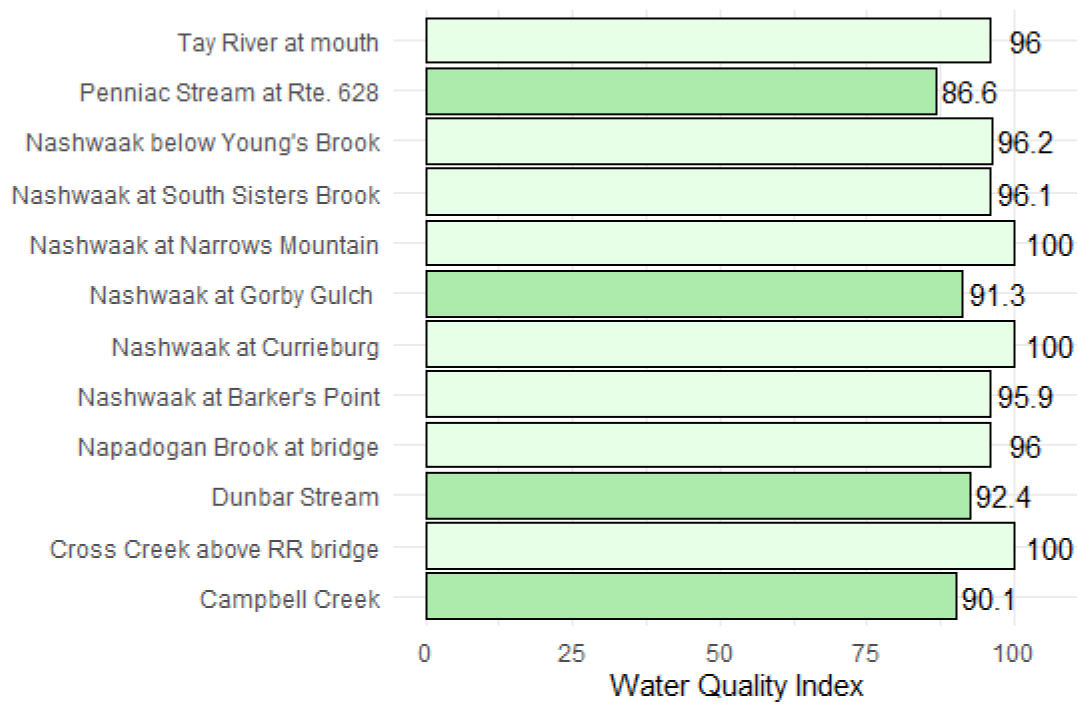

Figure 15. 2018 WQIs. Light green = Excellent, darker green = Very good

Figure 16 compares the 2019 average WQI for the entire watershed to those measures in 2017 and 2018. Overall the WQI for the watershed has improved slightly from very good to excellent.

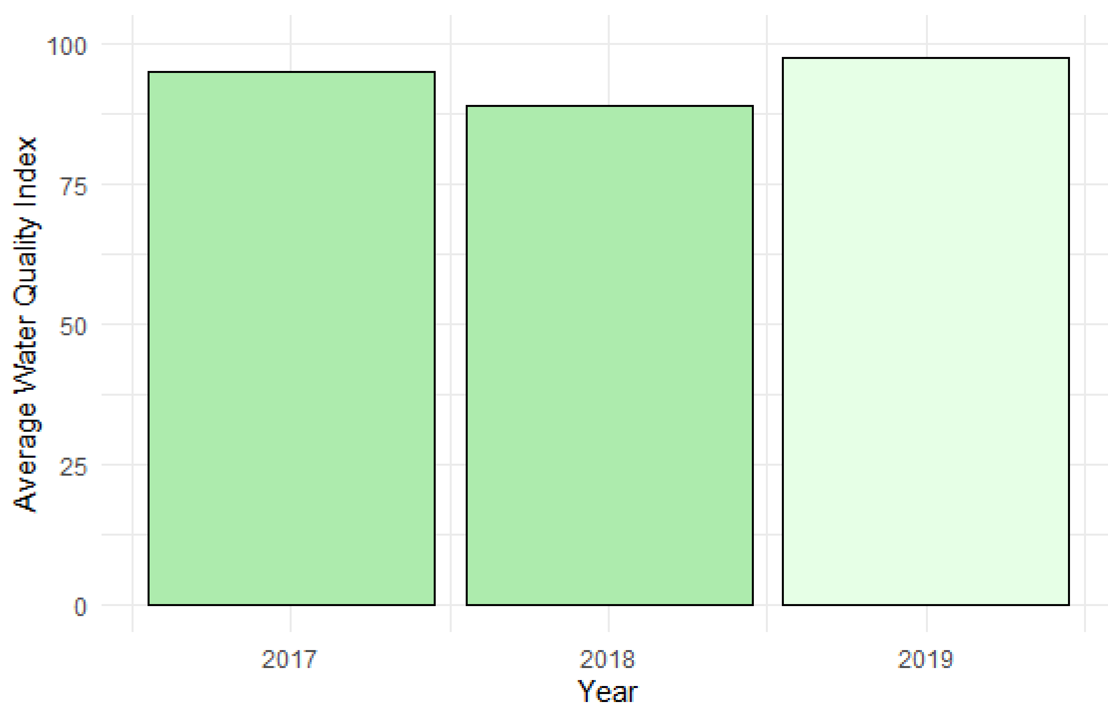

Figure 16. Comparing 2019 WQIs to 2017 and 2018.

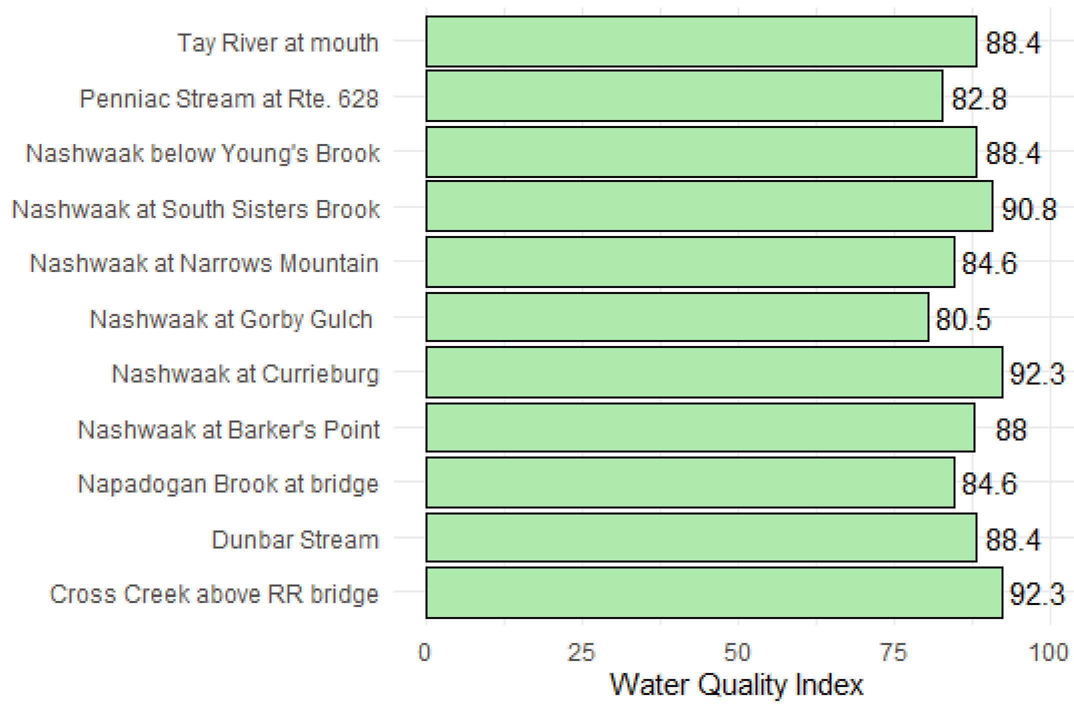

Figure 17. Average WQIs (1980 - 2018) across the watershed.

Figure 17 shows average WQIs for 2017-2018 for all sites. Campbell Creek is not included as it only had two samples in 2017. NASH-Q Gorby Gulch had the worst water quality followed by NASH-D Penniac Stream, while NASH-J Cross Creek and NASH-L Currieburg had the best.

Water Quality Discussion

An action plan was developed (NWAI, 2004) to address the water quality issues noted above; however, the action plan was never implemented as the Water Classification Regulation did not go ahead. The action items from the 2004 report are listed below. These action items have been evaluated and reconsidered for the NWAI's *2017-2020 Action Plan*.

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 DNRE;
- 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;

- Working with farmers to improve topsoil conservation and manure management practices and BMPs;
- 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 DNRE; and
- Riverbank stabilization and problem area assessment.

Temperature Monitoring

36 out of 37 installed loggers were recovered. A map of the logger placement can be found in Figure 3. The loggers were collected between the 3rd and the 17th October. One logger could not be found despite searching for over 30 mins: the one downstream from Route 8 on Campbell Creek. This tributary is popular with anglers, so it is possible that someone took it. We did manage to find a logger that we thought lost in 2018: the logger at the outlet of Nashwaak Lake. It had successfully logged all winter and was recovered in June and read out. One logger (at Five Mile Brook) stopped logging early (September 26th) due to a battery malfunction. 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.

For the calculations below, we used data from 24 loggers in tributaries and 12 loggers in the main stem of the Nashwaak river.

Peak temperatures ranged from 11.7°C in Nixon Brook to 31.2°C upstream of McPherson Brook (Figure 18, Figure 19). Average maximum temperature was 22.8°C in the tributaries (compared to 26.1°C in 2017 and 22.7°C in 2018) and 27.5°C in the main stem of the river (compared to 29.2°C in 2017 and 27.6°C in 2018). Most peak temperatures were recorded on July 31st at 16:00. According to Environment and Climate Change Canada (ECCC), air temperatures in Fredericton peaked at 34.4°C that day (the hottest day of the year).

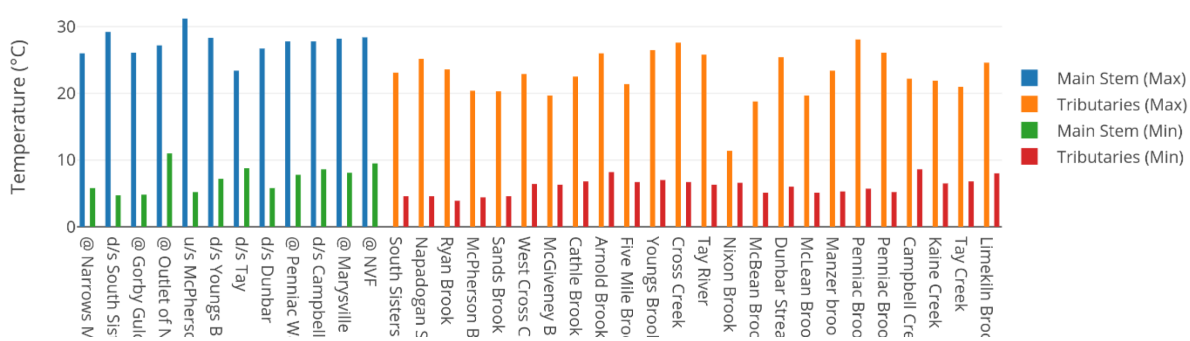

Figure 18. Maximum and minimum temperatures recorded for each logger, grouped by tributaries and main stem.

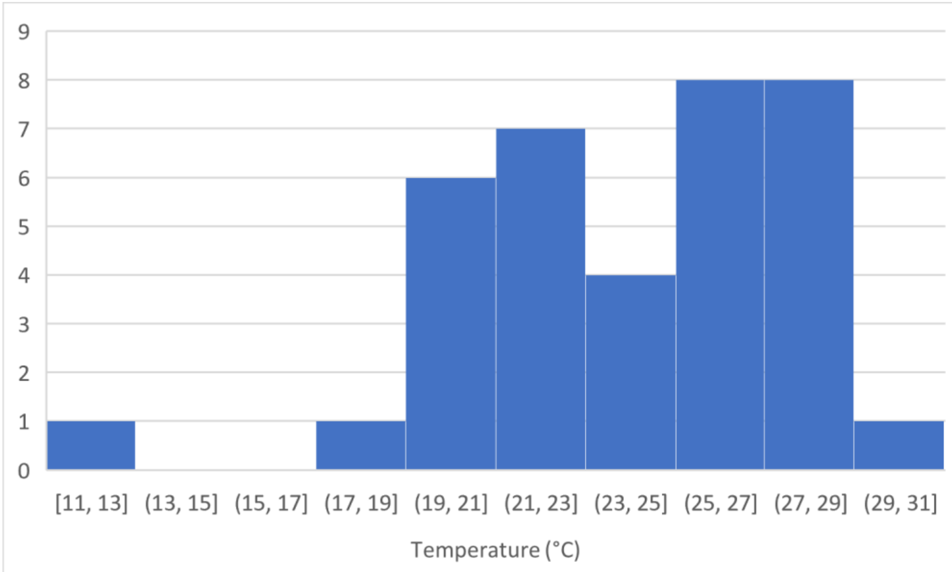

Figure 19 Histogram of maximum daily water temperatures from all loggers.

Minimum temperatures ranged from 3.9°C in Ryan Brook to 11.0°C at the outlet of Nashwaak Lake (Figure 18). Minimum temperatures were mostly recorded just before most of the loggers were pulled out in October. Average minimum temperatures were 6.06°C for the tributaries and 7.3°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 36 loggers was 15.67±3.4°C, very similar to last years average. The overall average for the main stem loggers was 17.6±4.0°C (compared to 18.4±3.9°C in 2017 and 17.6±1.4°C in 2018), while the tributaries averaged 14.7±3.1°C over the entire period they recorded (compared to 15.1±2.2°C in 2018).

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) (Figure 20). Compared to the last two summers, this was the coolest year recorded.

As with last year, the coolest site was Nixon Brook (NWAI021), which averaged 7.7±0.7°C over the summer, indicating that is likely fed by ground water. The temperature at this site only deviated by 3.6°C across the entire recorded period! The warmest site was the outlet of Nashwaak Lake (NWAI005), which averaged 20.6±2.8°C. This was the only site that averaged over 20°C in the summer (compared to four sites last year); however, three main stem sites in the lower Nashwaak averaged between 19.91 and 19.95°C.

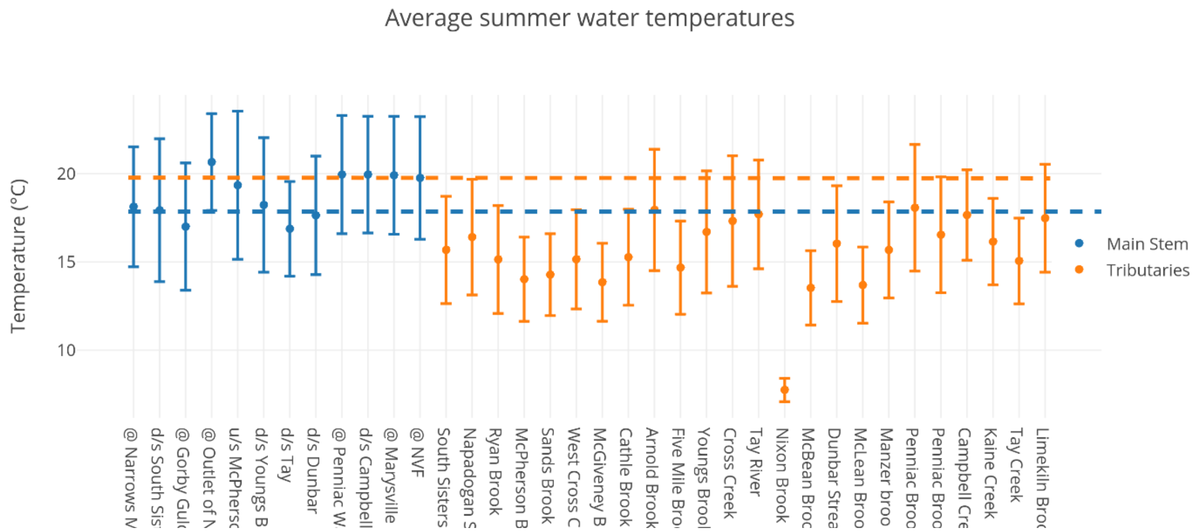

Figure 20. Average summer water temperatures (21 June to 21 September) separated by tributaries and main stem.

Finally, we calculated the number of days when maximum daily water temperatures exceeded 23°C and when minimum daily water temperatures exceeded 20°C (Figure 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 21 days in the main stem (compared to 12 days in 2017 and 24 days in 2018) and 1 day in the tributaries (8 days over all [both main stem and tributaries]). The number of days when the maximum temperature exceeded 23°C was 23 days for the main stem (down from 31 in 2018 and 50 in 2017), 4 for the tributaries, and 11 overall (Figure 21).

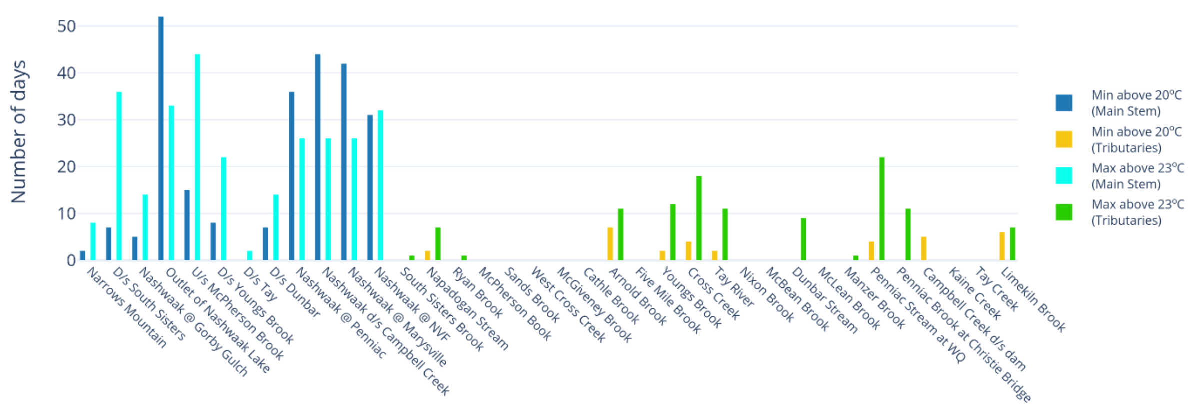

Figure 21. Number of days when minimum water temperatures exceeded 20°C and number of days when maximum daily water temperatures exceeded 23°C.

Based on comparisons of the main stem last year, there were fewer days over 20°C and fewer days over 23°C. Despite extremely high air temperatures in 2018 and very low water in 2017, the average in the main stem was the same both years. This year, both the main stem of the Nashwaak and the tributaries monitored were on average 0.9°C cooler than previous years.

Four tributaries remained below 20°C all summer: Nixon Brook peaked at 11.7°C in August after a heavy rainfall and averaged 7.8°C over the summer; McLean Brook peaked at 19.7°C and averaged 13.7°C over the summer (a degree cooler than last year), McBean Brook peaked at 18.8°C and averaged 13.5°C over the summer (a degree cooler than last year), and McGiveney Brook (not measured previously) peaked at 19.7°C and averaged 13.9°C over the summer. In 2017, MacPherson Brook remained under 20°C but peaked at 20.4°C this year (even though temperatures did not remain over 20°C for the entire day). Sands Brook was close to remaining under 20°C: peaking at 20.3°C and averaging 14.3°C. Analyses of specific tributaries are discussed below.

Summary of Key Tributaries

Penniac Stream

As in 2018, there were two loggers placed in Penniac Stream, one near Rte. 628 and another several kilometres up near the Allen Bridge. 2019 recorded a higher peak temperature than the previous two years at 28.1°C. In 2019 the lower station was warmer than the higher station, which was the opposite from 2018. On average throughout the summer, 2019 was cooler at the lower station with a summer average of 18.1±3.6°C at the lower station but warmer at the higher station 16.6±3.3°C. Compared to 2018, in 2019 there were fewer days when the minimum was above 20°C but more days when the maximum was above 23°C. Again, the higher station remained cooler and recorded no days when the minimum was above 20°C.

Table 2 Summary of the water temperature over the last 3 years in the Penniac Stream (lower station)

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	28.1°C	18.1±3.6°C	4	22
2018	24.5°C	19.1±3.0°C	15	19
2017	27.7°C	19.1±2.6°C	7	29

Table 3 Summary of the water temperature over the last 3 years in the Penniac Stream (higher station)

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	26.1°C	16.6±3.3°C	0	11
2018	25.9°C	15.4±3.3°C	15	19

2017	No data	No data	No data	No data

Tay River

In 2019, the Tay recorded a lower peak temperature of 25.8°C. In 2019, the average temperature over the summer was 2 degrees cooler than in the previous two year at 17.7±3.1°C. In 2019 there were many fewer days when the minimum was above 20°C fewer days when the maximum was above 23°C.

Table 4 Summary of the water temperature over the last 3 years in the Tay River

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	25.8°C	17.7±3.1°C	2	11
2018	27.5°C	19.7±3.2°C	18	29
2017	27.1°C	19.0±2.7°C	4	32

Cross Creek

In 2019 Cross Creek recorded a similar peak temperature to previous years of 27.6°C. However, summer average in 2019 was almost 2 degrees cooler. 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.

Table 5 Summary of the water temperature over the last 3 years in Cross Creek

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	27.6°C	17.3±3.7°C	4	18
2018	28.6°C	19.0±2.7°C	17	39
2017	27.1°C	19.5±3.7°C	13	29

Dunbar Stream

In 2019, Dunbar Stream recorded the highest peak temperatures of the last 3 years at 25.4°C; however, the summer average was slightly cooler than previous years at 16.0±3.3°C. As with previous years, there were no days when the minimum was above 20°C and a similar number of days when the maximum was above 23°C.

Table 6 Summary of the water temperature over the last 3 years in Dunbar Stream

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	25.4°C	16.0±3.3°C	0	9
2018	24.4°C	16.8±2.9°C	0	10
2017	25.1°C	17.2±2.7°C	0	14

South Sisters Brook

In 2019, temperatures were cooler than in 2018 but similar to 2017 in South Sisters Brook. Peak temperature was recorded to be 23.1°C the summer average was 15.7±3.0°C. There were no days when the minimum was above 20°C and only one day when the maximum was above 23°C.

Table 7 Summary of the water temperature over the last 3 years in South Sisters Brook

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	23.1°C	15.7±3.0°C	0	1
2018	24.6°C	17.2±3.1°C	1	6
2017	23.5°C	16.0±2.5°C	0	1

Ryan Brook

Ryan Brook recorded similar temperatures in 2019 compared to 2018 but was much cooler than in 2017. Peak temperatures were 23.6°C, over 3 degrees cooler compared to 2017. The summer average in 2019 was also almost 3 degrees cooler. There were no days when minimum was above 20°C and only one day when the maximum was above 23°C.

Table 8 Summary of the water temperature over the last 3 years in Ryan Brook

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	23.6°C	15.1±3.0°C	0	1
2018	24.1°C	16.7±3.1°C	2	3
2017	26.9°C	17.9±2.7°C	2	16

Napadogan Stream

Napadogan Stream was only monitored in 2018 and 2019. Both peak temperature and the summer average temperature were cooler in 2019 compared to 2018. There were fewer days when minimum was above 20°C and when the maximum was above 23°C.

Table 9 Summary of the water temperature over the last 3 years in Napadogan Stream

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	25.2°C	16.4±3.3°C	2	7
2018	26.0°C	17.8±3.1°C	4	11
2017	No data	No data	No data	No data

McBean Brook

McBean Brook was only monitored in 2018 and 2019. Peak temperatures in both years were similar but the summer average was 1-degree cooler in 2019 compared to 2018. There were no days when minimum was above 20°C and only one day when the maximum was above 23°C.

Table 10 Summary of the water temperature over the last 3 years in McBean Brook

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	18.8°C	13.5±2.1°C	0	0
2018	18.6°C	14.6±2.1°C	0	0
2017	No data	No data	No data	No data

Kaine Creek

Kaine Creek was only monitored in 2018 and 2019. As with other tributaries, 2019 recorded a cooler peak temperature and a cooler summer average temperature.

Table 11 Summary of the water temperature over the last 3 years in Kaine Creek

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	21.9°C	16.1±2.5°C	0	0
2018	22.3°C	17.4±2.4°C	1	0
2017	No data	No data	No data	No data

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. 2017 was a drier year with record low water levels and low precipitation.

Maximum temperatures in 2018 in Campbell Creek were two degrees warmer than in 2017 and 2019. 2019 recorded the lowest summer average from the last 3 years (similar to other tributaries), almost 1 degree cooler than in previous years. 2019 also recorded the fewest number of days where minimum was above 20°C and only one day when the maximum was above 23°C.

Unfortunately, the logger upstream of the dam was lost in 2019 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.

Table 12 Summary of the water temperature over the last 3 years in Campbell Creek (downstream of dam)

Year	Peak Temp	Summer Avg. Temp	# days min. >20°C	# days max. >23°C
2019	22.2°C	17.7±2.6°C	5	0
2018	24.0°C	18.8±2.1°C	21	3
2017	22.3°C	18.5±2.4°C	3	17

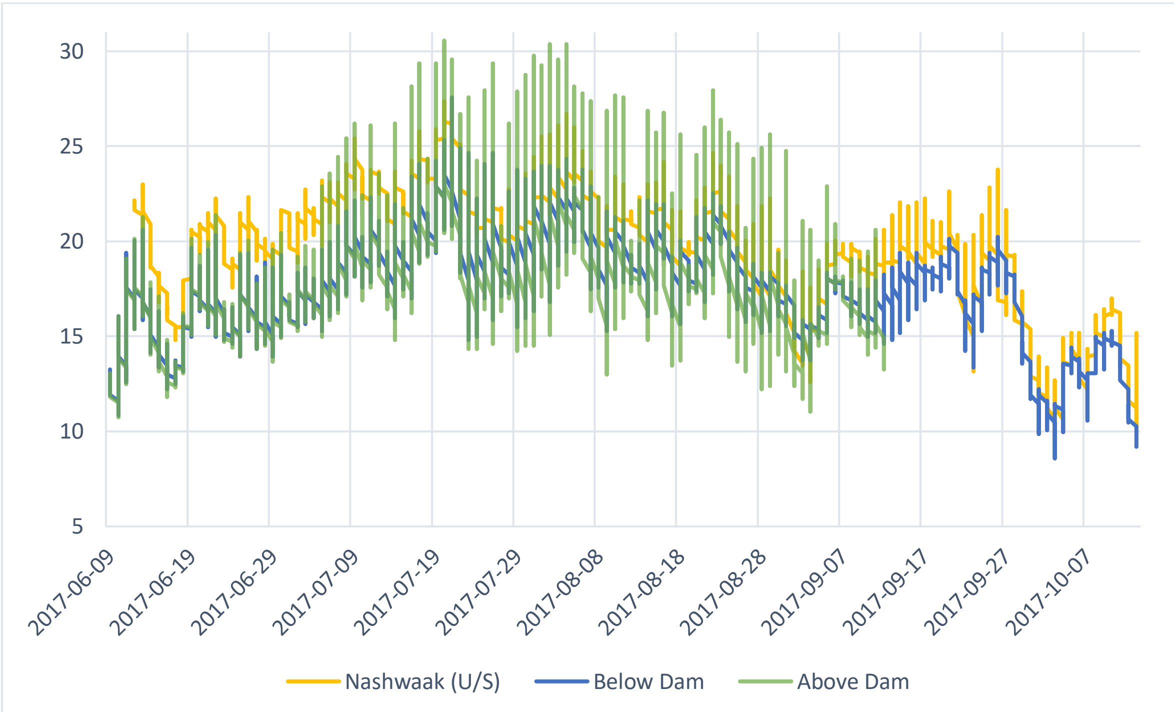

Figure 22. Temperature variation between June and October 2017 above and below the dam in Campbell Creek and upstream of Campbell Creek in the Nashwaak River.

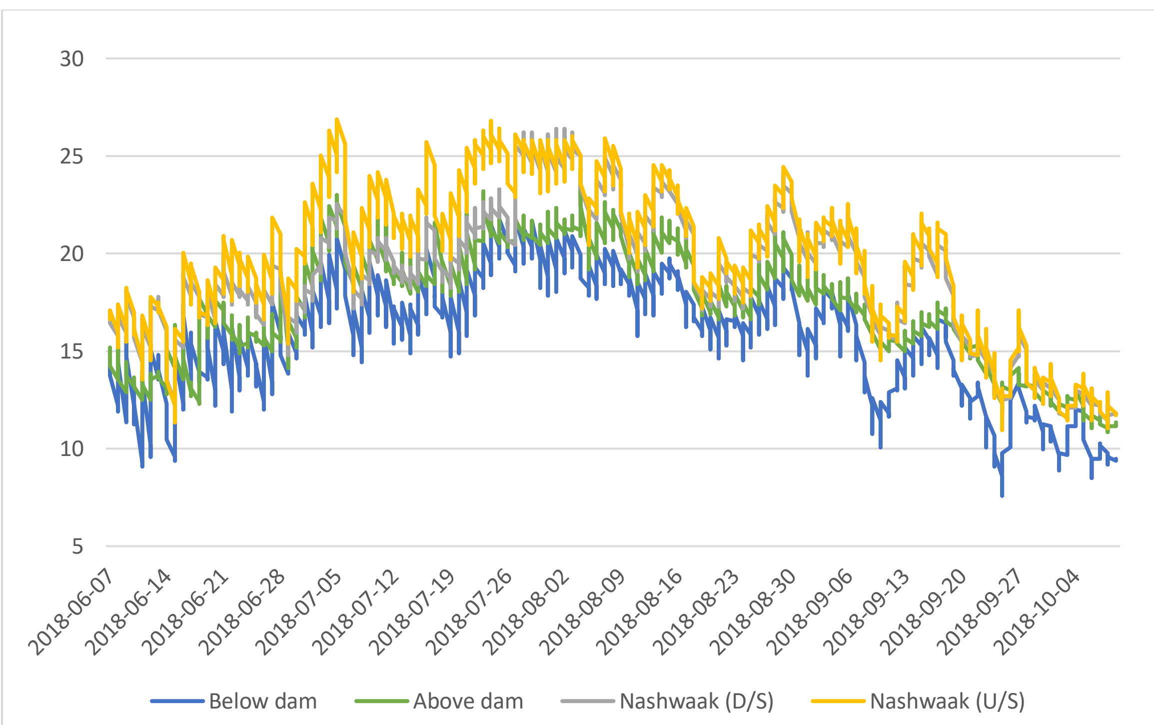

Figure 23. Temperature variation between June and October 2018 above and below the dam in Campbell Creek and upstream and downstream of Campbell Creek in the Nashwaak River.

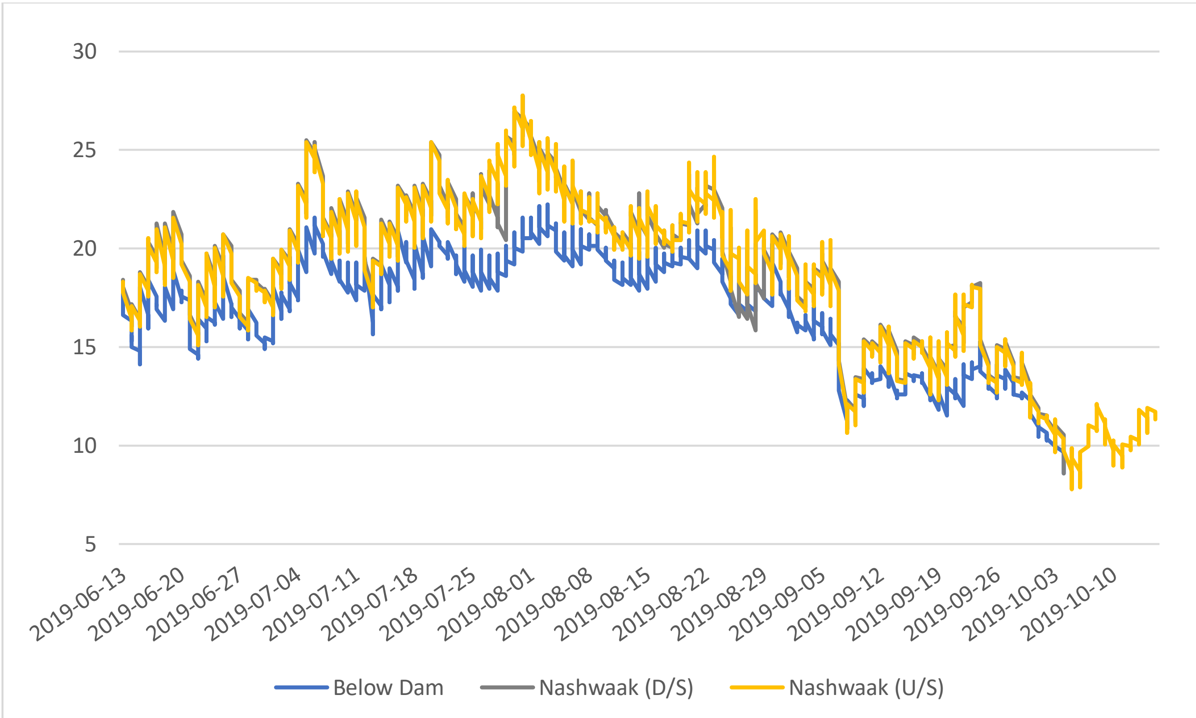

Figure 24. Temperature variation between June and October 2019 below the dam in Campbell Creek and upstream and downstream of Campbell Creek in the Nashwaak River.

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

2019 experienced a fairly cool summer compared to previous years. Peak temperatures were experienced throughout the watershed in early August. Water levels dropped to their lowest levels at the Durham Bridge station (AL002) on August 29th (17.703 m asl). Historical average water levels in August are 18.02 m asl. The AL002 station recorded its highest level of the year (21.22 m asl) on April 2nd, 2019 after a heavy rainfall. Many of the loggers recorded a sharp drop in temperature around the 7th of September related to a very heavy rainfall from Hurricane Dorian.

Water temperatures, in general, got warmer moving from sites closer to the headwaters to sites closer to the mouth of the river (Fig. 24). For the main stem upstream of Giant's Glen, summer averages were 18.6°C and minimum water temperatures exceeded 20°C 52 times and 23°C 44 times. Downstream of Giant's Glen, summer averages were slightly warmer at 18.9°C, minimum water temperatures exceeded 20°C 42 times in Marysville and maximum water temperatures exceeded 23°C on 32 times near Nashwaak Valley Farm.

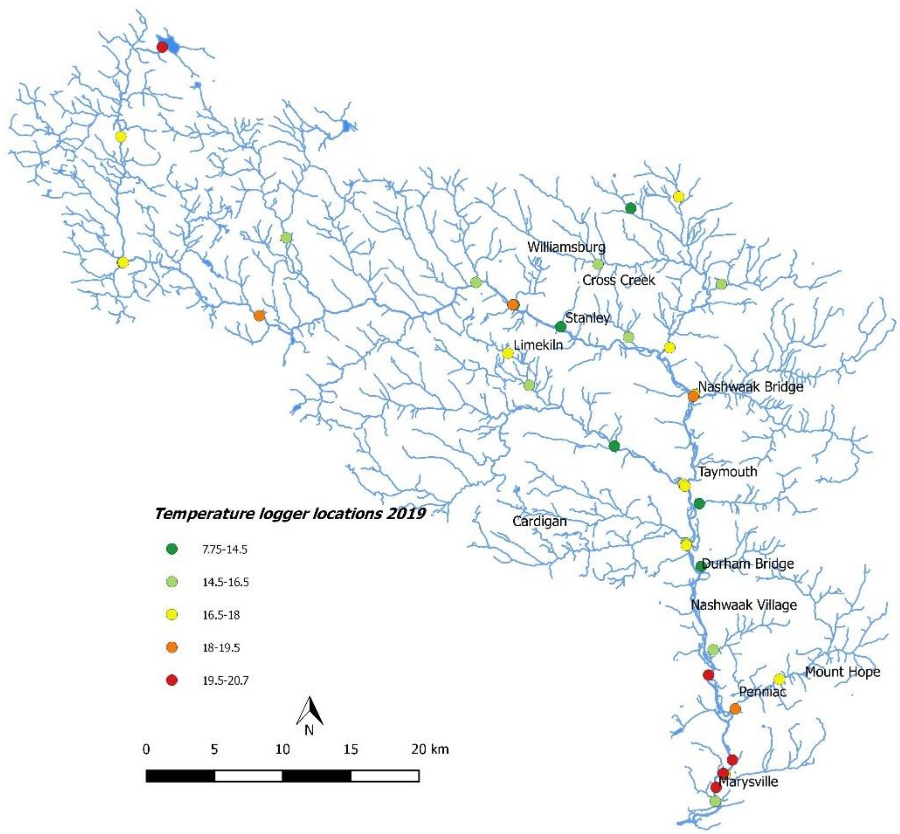

Figure 25. Results of the loggers placed in the watershed in 2019. Coloured symbols show average summer water temperature from green (cooler) to red (warmer).

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 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 2019 and none appeared to be tampered with.

In 2017, we had issues with low water levels and had to move almost all our loggers. In 2019 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 was in 2019 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 that still allows water flow.

Update to NWAI's Action Plan

The NWAI's Action Plan is a living document in that we update it in real time in reflection of the information gained and lessons learned over a particular field season.

The four main goals of this action plan are:

- Maintenance of the Nashwaak watershed a healthy, functional, and connected aquatic ecosystem;
- Increased capacity of the NWAI to monitor, protect, and restore the health of the watershed;
- Restoration of degraded riparian zones and salmon habitat; and
- Increased awareness amongst residents of all ages of the importance of a healthy Nashwaak watershed.

Monitoring the quality and temperature of the watershed addresses Goal 1:

> FILLING INFORMATION GAPS: The NWAI will work to improve the capacity of our organization to monitor the health of the river and use that information to identify and guide restoration projects that will provide the most benefits to water and habitat quality.

This year, we have completed our short-term goals of resuming water quality monitoring; deploying temperature loggers in the main stem and tributaries; and continued to develop a picture of the thermal refugia in the watershed. We have shared this information with Atlantic DataStream.

This project also addressed Goal 2:

> PARTNERSHIPS AND OUTREACH: the NWAI will work with stakeholders to develop management practices pertaining to the protection of the river and the restoration of riparian habitat

We continue to foster our relationships with St Mary's First Nation, the City of Fredericton, CRI, Atlantic DataStream, Atlantic Salmon Federation, and private landowners. We also participated in the Provincial Water Strategy and developed new partnerships with the Maliseet Nation Conservation Council and other watershed groups in the province.

We are working on a new strategic plan for the Association. We hope this will be completed by summer 2020.

Conclusions

Despite the hiatus, the reintroduction of water quality and temperature monitoring in 2017 and its continuation in 2018 and 2019 will contribute to our understanding of the natural state of the water as well as evaluate the impacts of human activities. The NWAI strives to continue to monitor watershed health in order to create a long-term picture and improve our understanding of bot the natural variability of the system and in impacts of 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 Volume
☐ Sample Containers ☐ Hold Time
☐ Sample Temperature Temperature = ________ °C

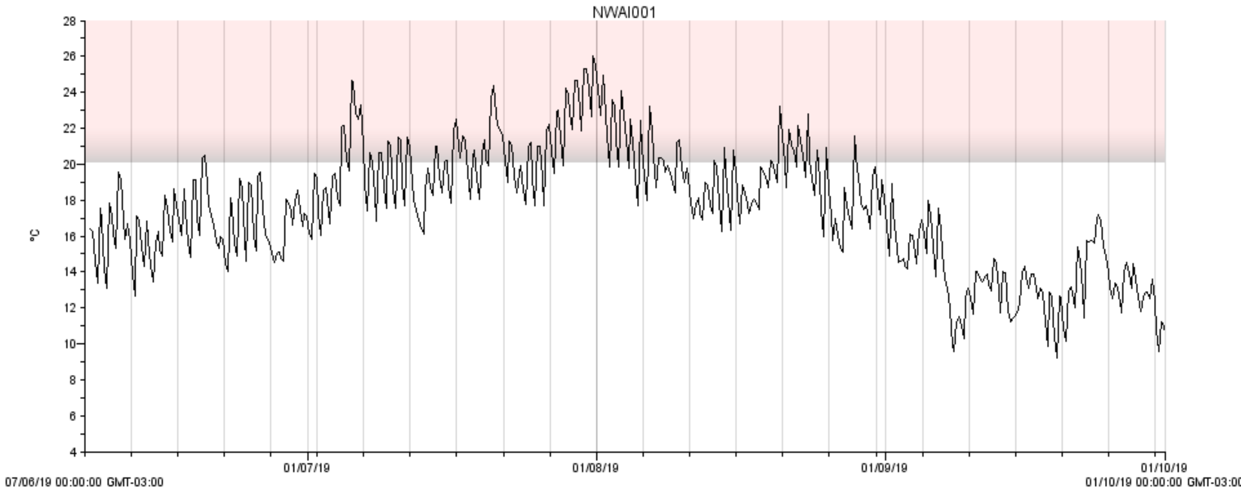
Comments:

Chain of Custody

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

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

Appendix B: Logger data

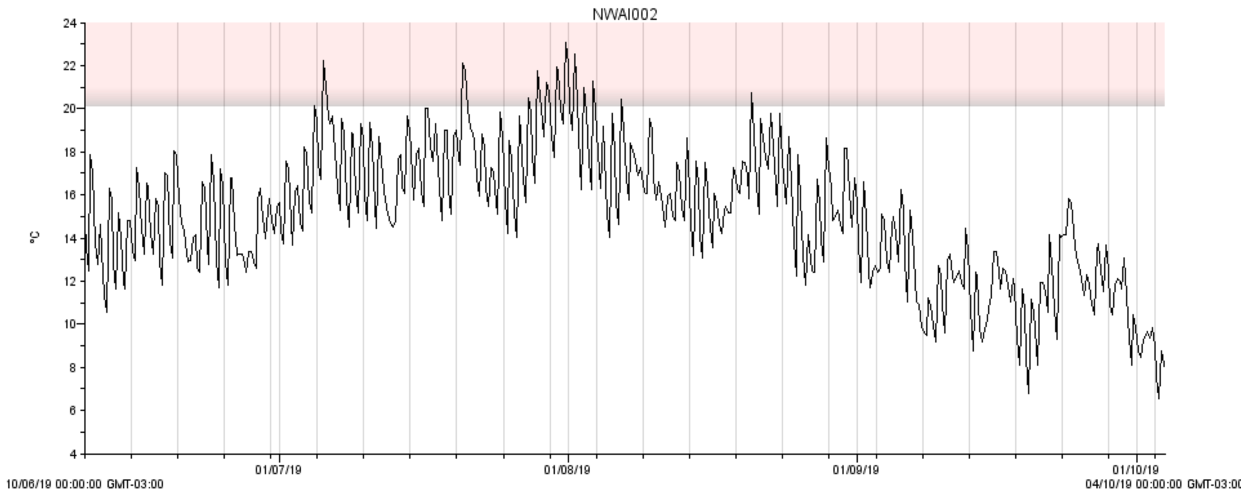


NWAI001. Located in Nashwaak River ~100 m upstream from the Narrows Mountain Bridge [46.2904, -67.02534]

Max temp: 26.00°C

Average summer temp*: 18.1°C ±3.4°C

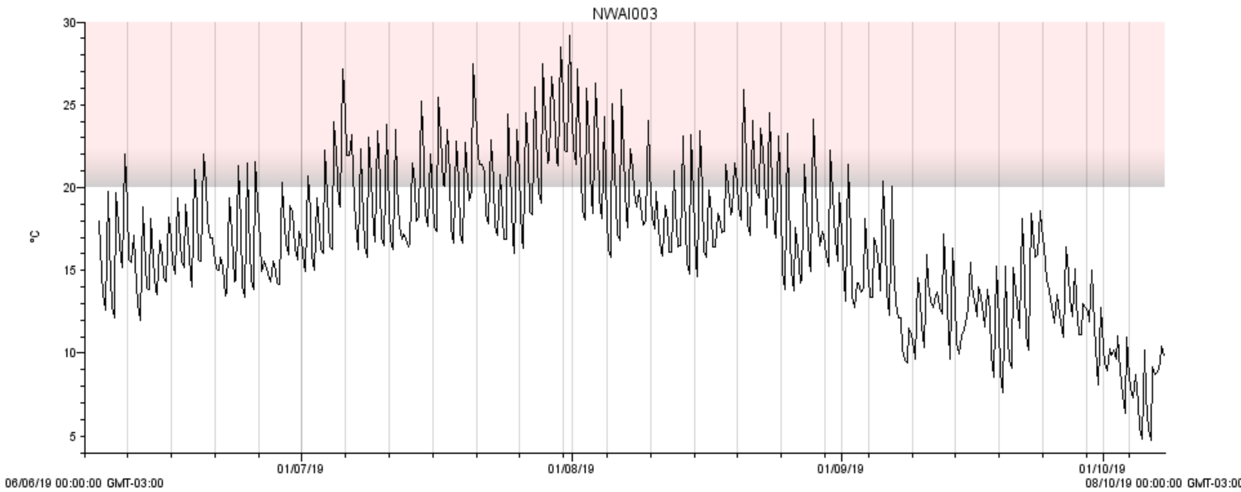
**Average summer temperature is the mean of all readings taken between 00:00 on 21 June to 22:00 on 21 September.*



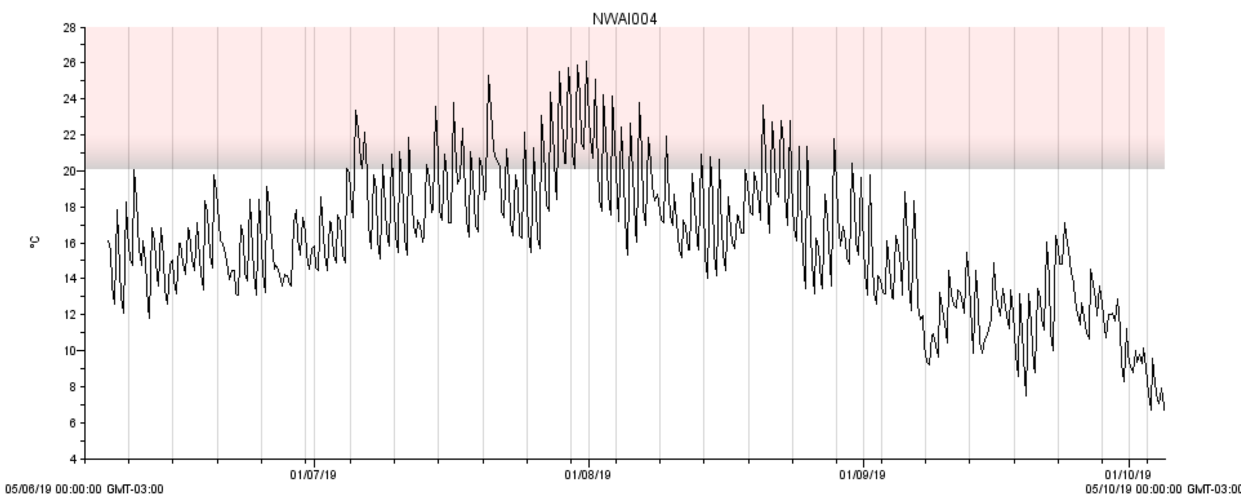
NWAI002. Located in the mouth of South Sisters Brook [46.32531, -67.1564].

Max temp: 23.1°C

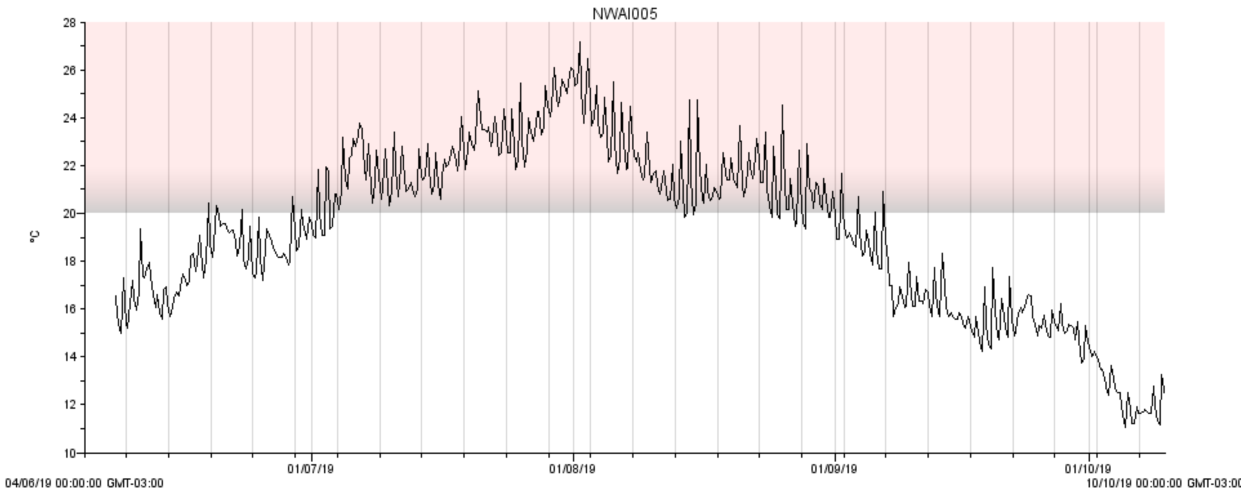
Average summer temp: 15.7°C ±3.0°C



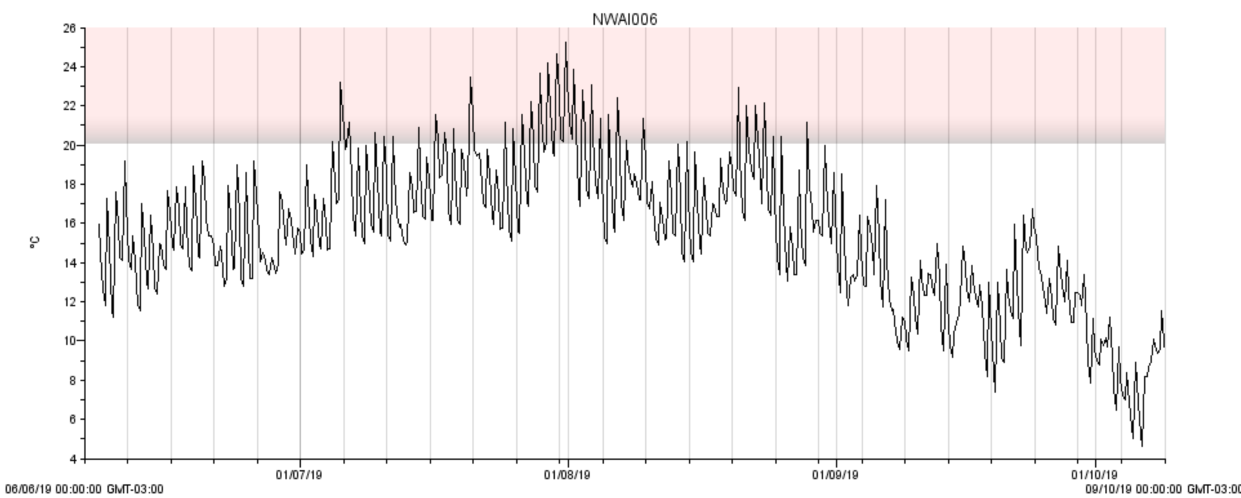
NWAI003. Located in Nashwaak River ~100 m downstream from South Sisters Brook [46.32539, -67.15559]
Max temp: 29.2°C
Average summer temp: 17.9°C ±4.1°C



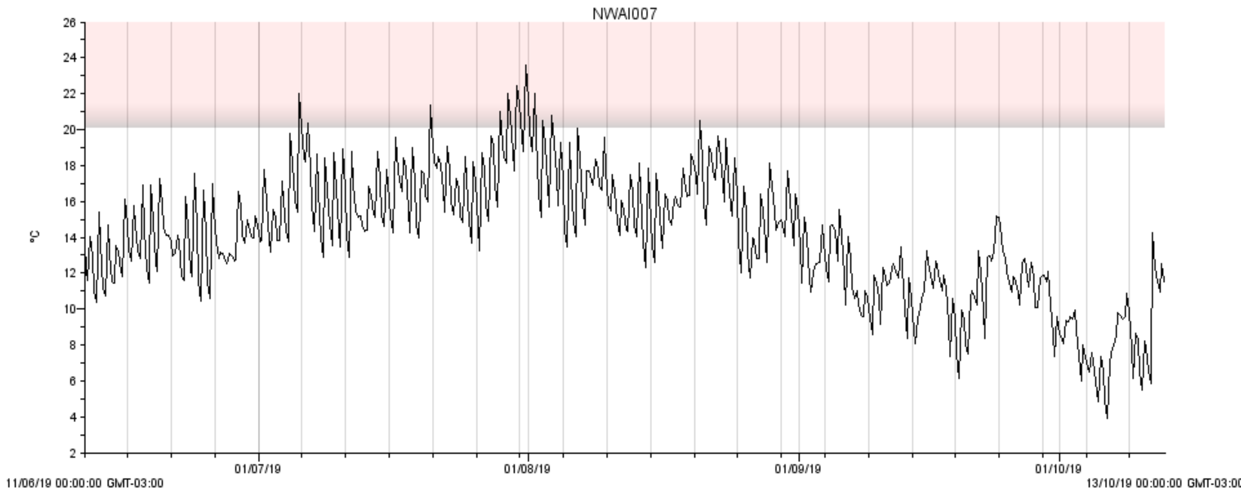
NWAI004. Located in Nashwaak River ~50 m upstream of the Bridge at Gorby Gulch [46.40867, -67.15884]
Max temp: 26.1°C
Average summer temp: 17.0°C ±3.6°C



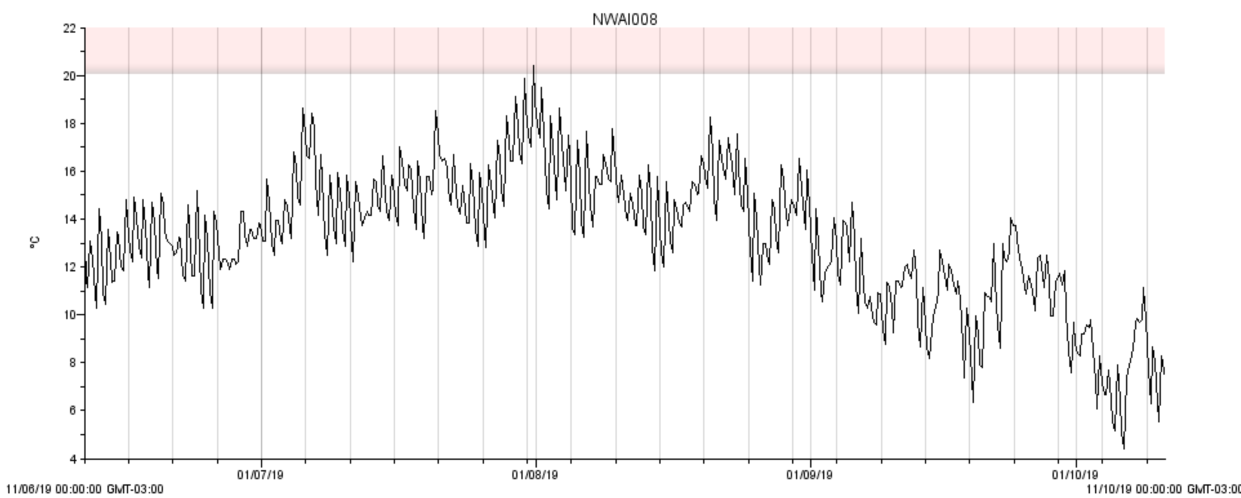
NWAI005. Located at Outlet of Nashwaak Lake [46.4070, -67.2173]
Max temp: 25.1°C
Average summer temp: 17.4°C ±2.9°C



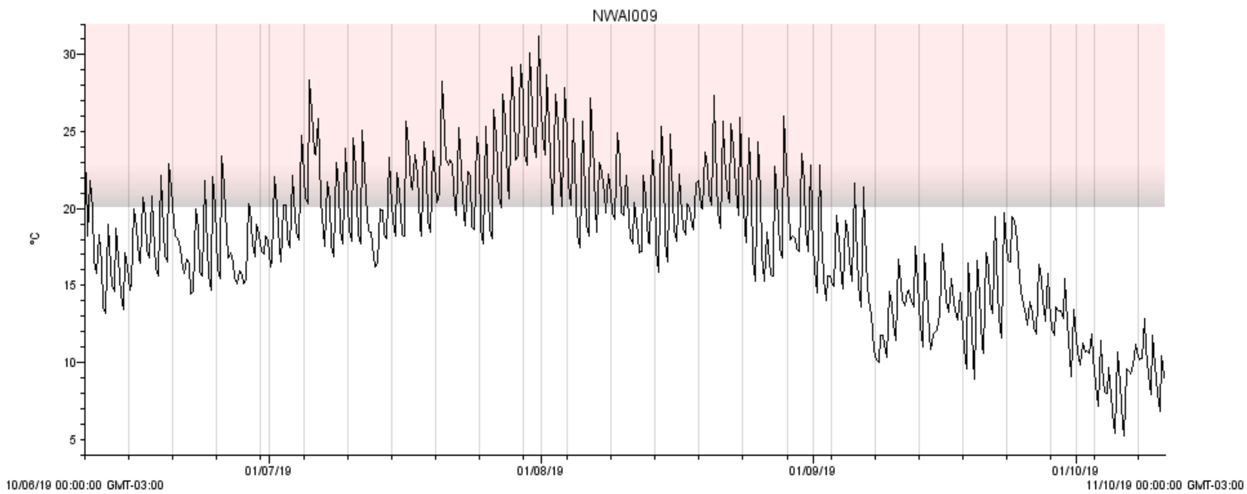
NWAI006. Located in Napadogan Stream at water quality site [46.34243, -67.0004]
Max temp: 25.2°C
Average summer temp: 16.4°C ±3.3°C



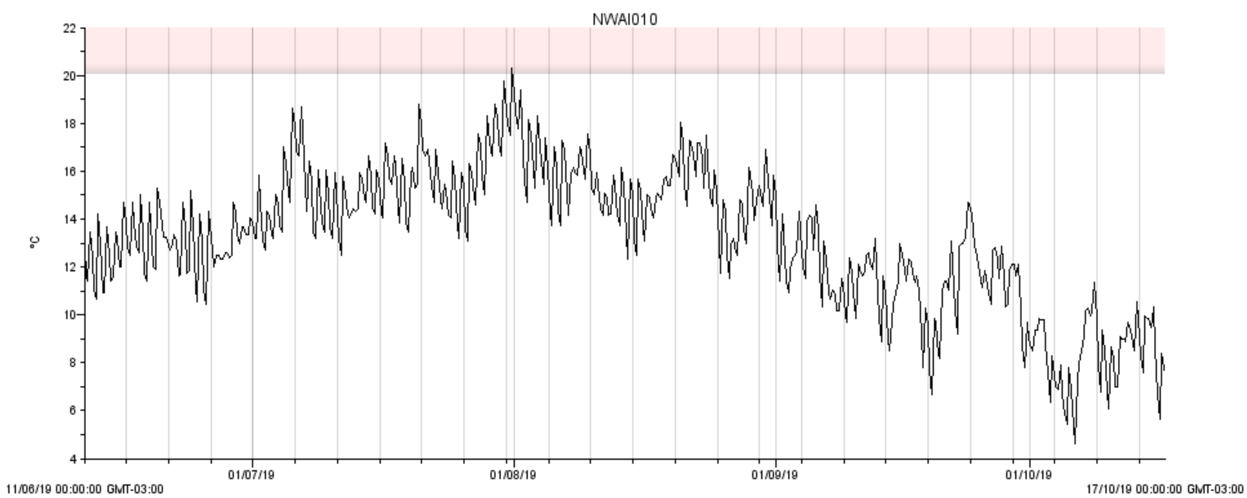
NWAI007. Located in Ryan Brook upstream from the trail bridge [46.31358, -66.81908]
Max temp: 23.6°C
Average summer temp: 15.1°C ±3.1°C



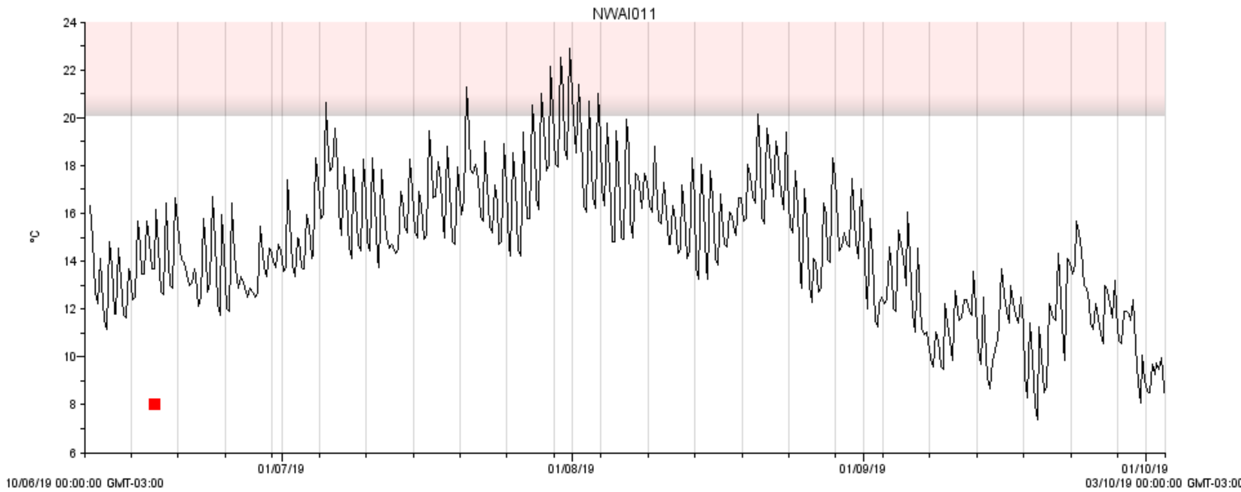
NWAI008. Located in MacPherson Brook at culvert plunge pool [46.29874, -66.78283]
Max temp: 20.4°C
Average summer temp: 14.0°C ±2.4°C



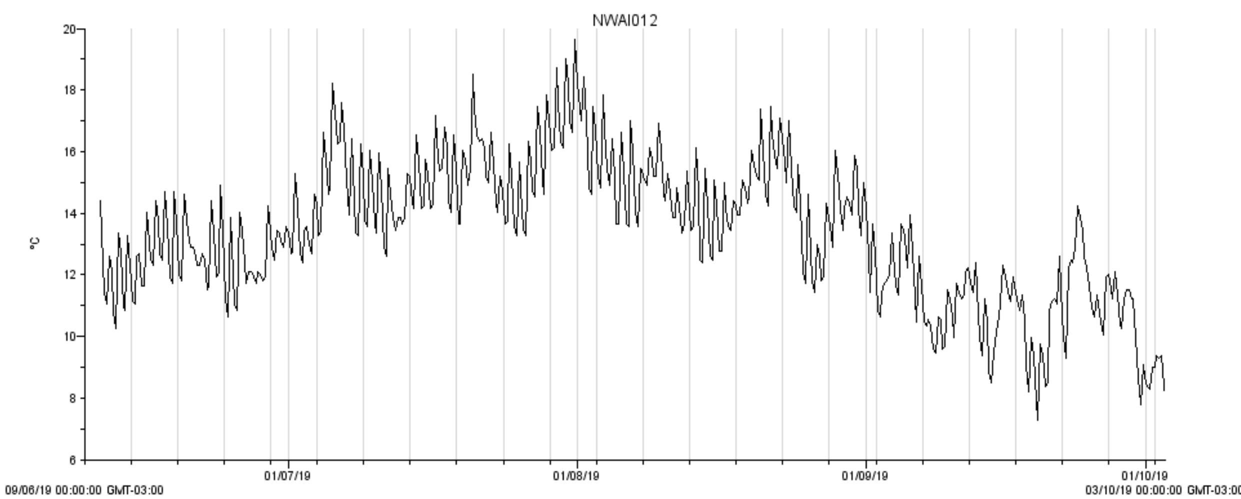
NWAI009. Located in Nashwaak River ~100 m upstream from MacPherson Brook [46.29888, -66.7841]
Max temp: 31.2°C
Average summer temp: 19.4°C ±4.2°C



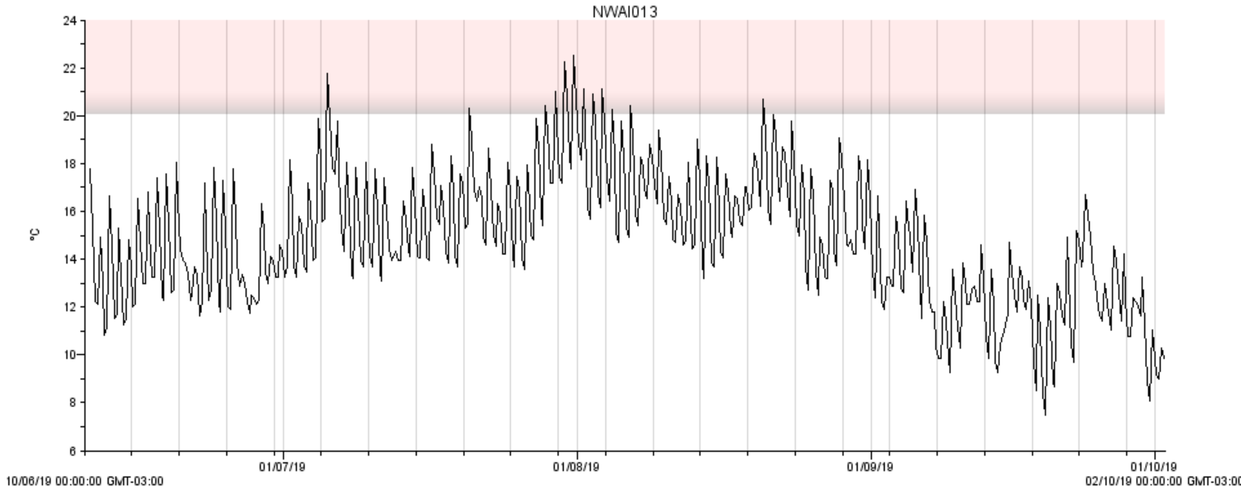
NWAI010. Located in Sands Brook [46.29439, -66.73838]
Max temp: 20.3°C
Average summer temp: 14.3°C ±2.3°C



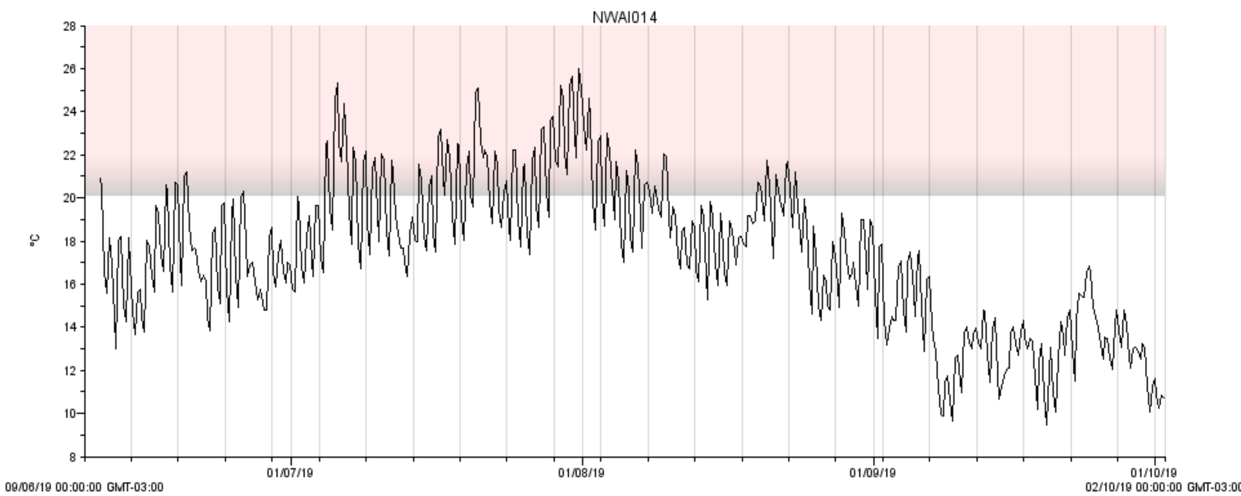
NWAI011. Located in West Cross Creek at Rte. 625 [46.32594, -66.70299]
Max temp: 22.9°C
Average summer temp: 15.2°C ±2.8°C
The logger recorded a bad battery a few days after starting recording



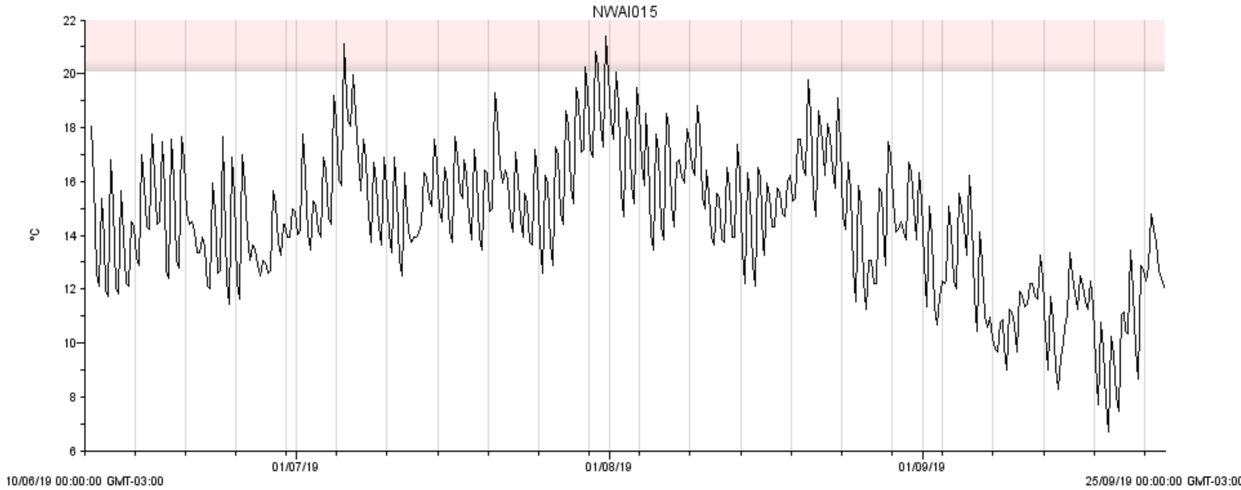
NWAI012. Located in McGiveney Brook at Rte. 625 [46.36309, -66.67183]
Max temp: 19.7°C
Average summer temp: 13.9°C ±2.2°C



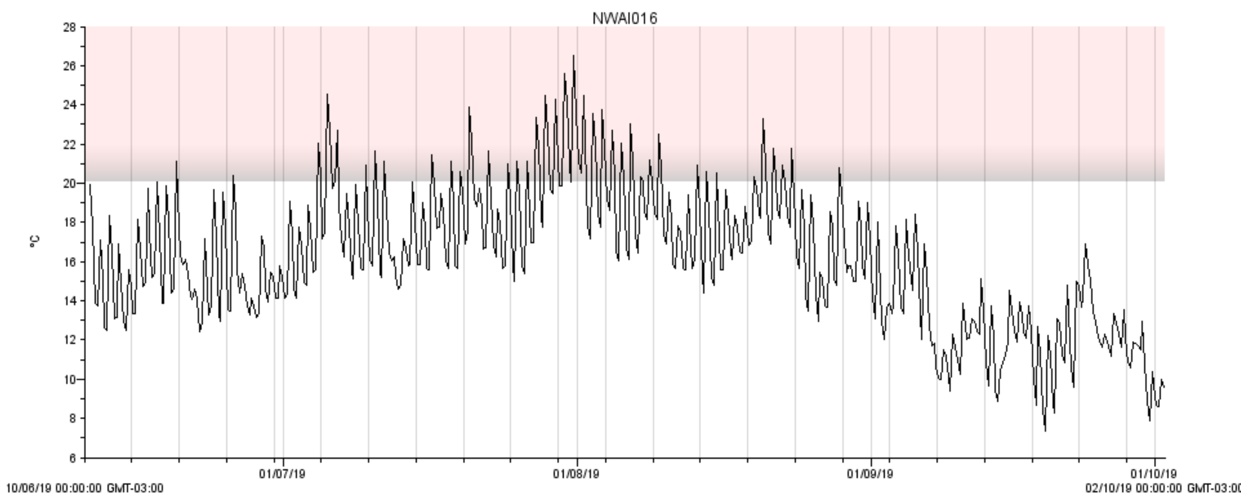
NWAI013. Located in Cathle Brook [46.27755, -66.67384]
Max temp: 22.5°C
Average summer temp: 15.3°C ±2.7°C



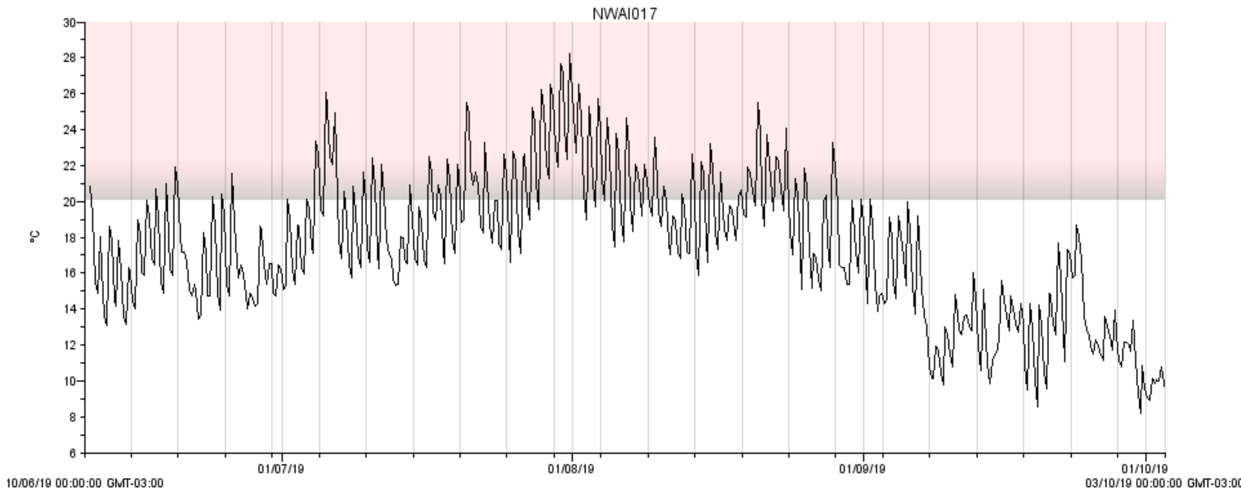
NWAI014. Located in Arnold Brook at the Deersdale Connector [46.3707, -66.62609]
Max temp: 26.0°C
Average summer temp: 18.0°C ±3.4°C



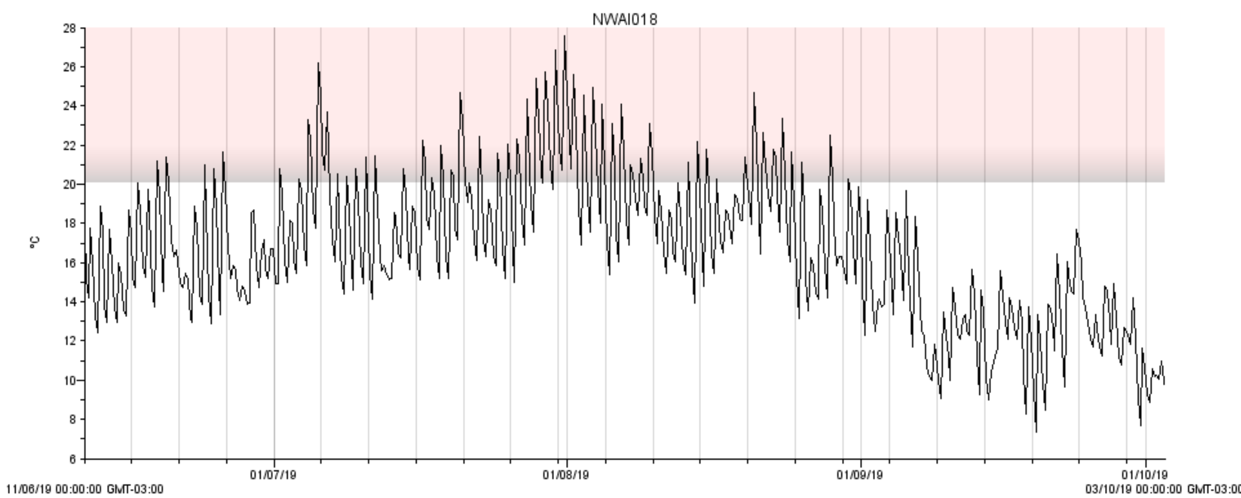
NWAI015. Located in Five Mile Brook upstream from Rte. 8 bridge [46.31281, -66.58536]
Max temp: 21.4°C
Average summer temp: 14.7°C ±2.6°C
The logger malfunctioned and stopped logging a few days early



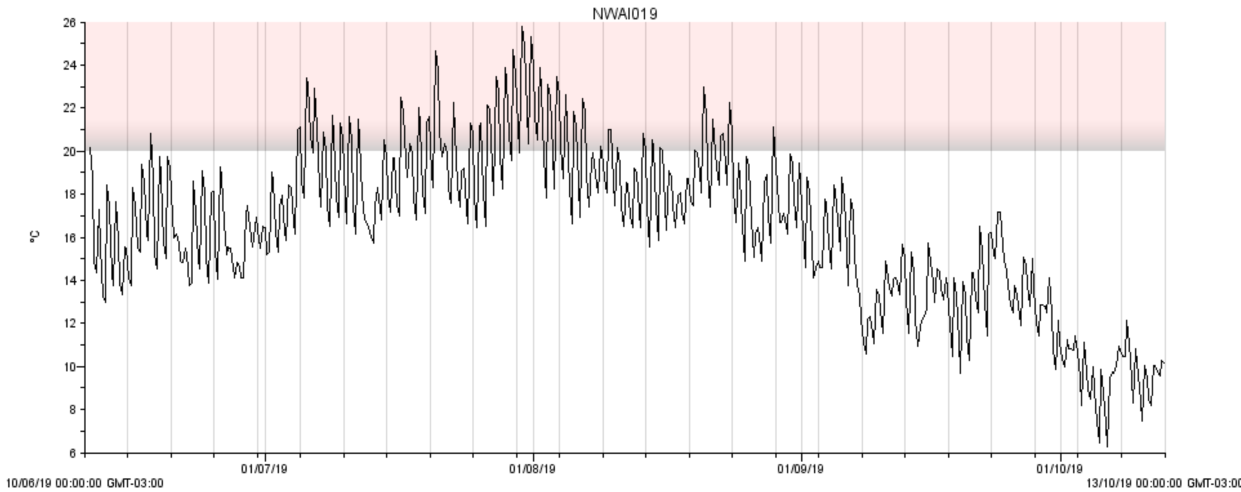
NWAI016. Located in Young's Brook [46.23964, -66.61092]
Max temp: 26.5°C
Average summer temp: 16.7°C ±3.5°C



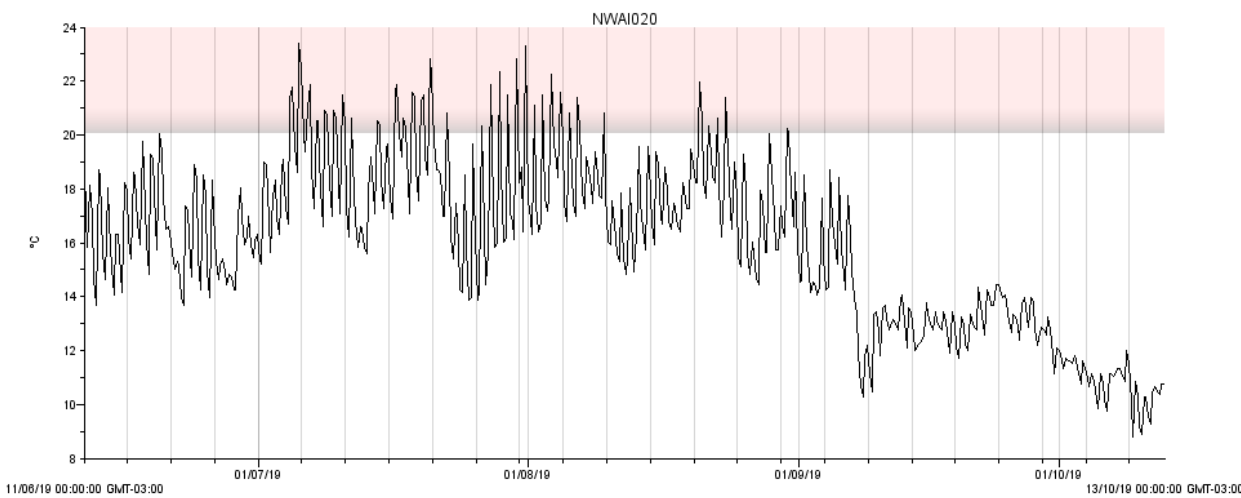
NWAI017. Located in Nashwaak River ~150 m downstream of Young's Brook [46.23853, -66.61196]
Max temp: 28.3°C
Average summer temp: 18.2°C ±3.8°C



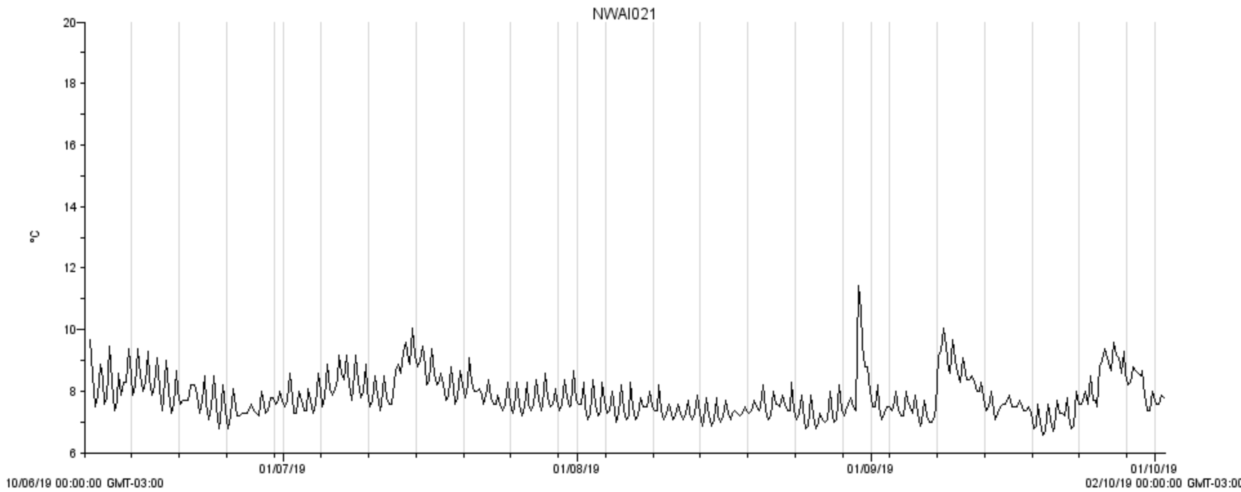
NWAI018. Located in Cross Creek at our water quality site [46.2707, -66.63455]
Max temp: 27.6°C
Average summer temp: 17.3±3.7°C



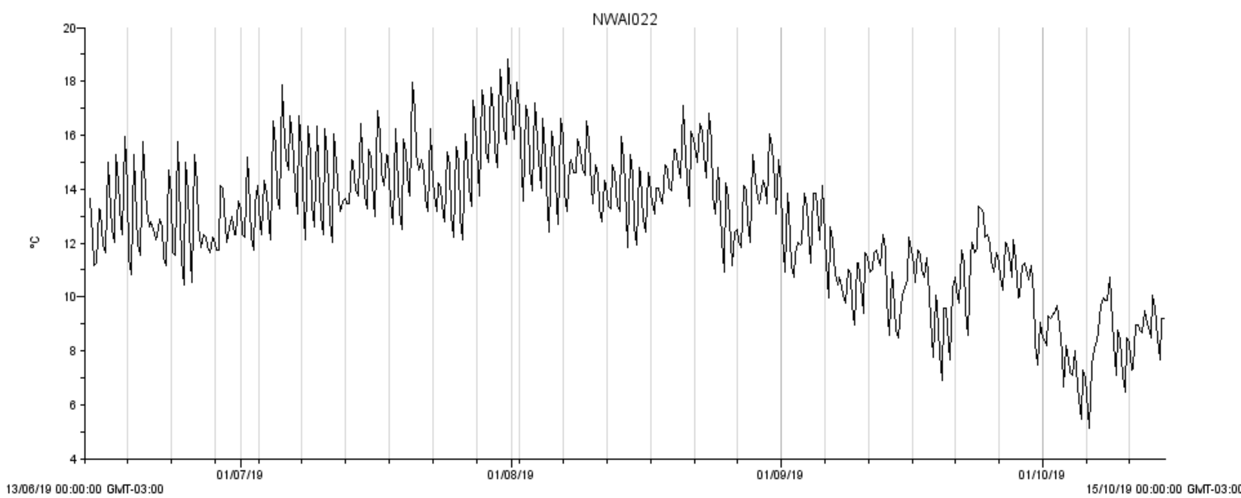
NWAI019. Located in Tay River at the mouth [46.18039, -66.62136]
Max temp: 25.8°C
Average summer temp: 17.7°C ±3.1°C



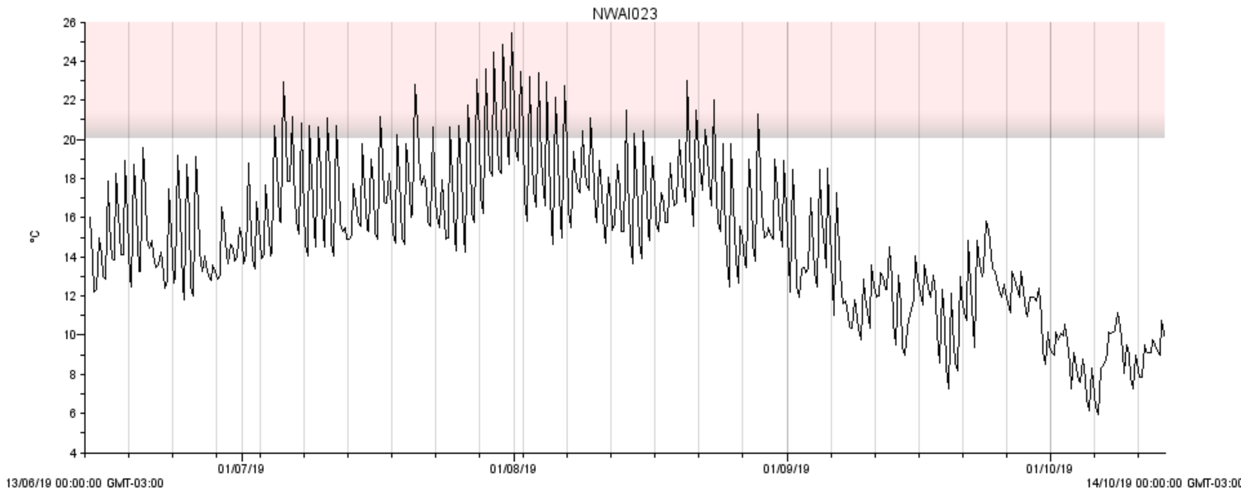
NWAI020. Located in Nashwaak River ~150 m downstream of Tay River [46.17903, -66.61982]
Max temp: 27.5°C
Min temp: 7.7°C
Average summer temp: 19.7°C ±3.2°C
Number of days >20°C = 18
Number of days >23°C = 29



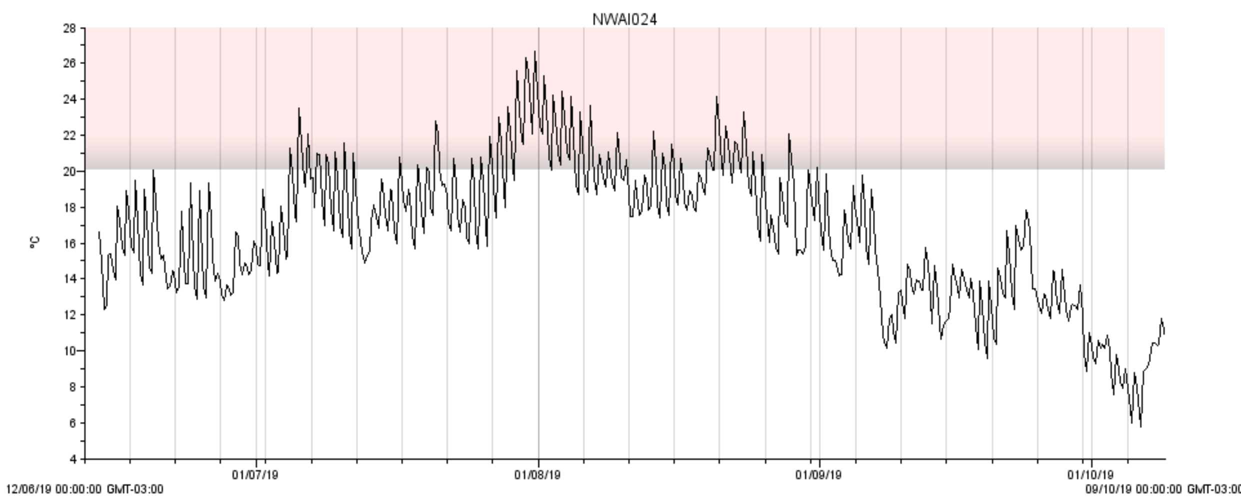
NWAI021. Located in Nixon Brook [46.20545, -66.68704]
Max temp: 11.4 °C
Average summer temp: 7.8°C ±0.7°C



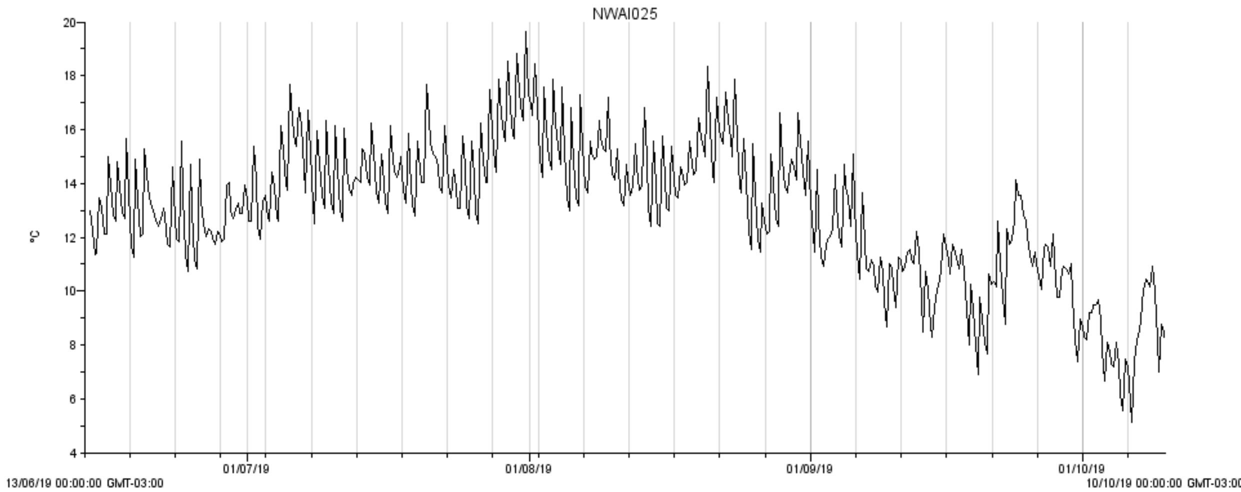
NWAI022. Located in McBean Brook downstream of Rte. 628 [46.16744, -66.60613]
Max temp: 18.8°C
Average summer temp: 13.5°C ±2.1°C



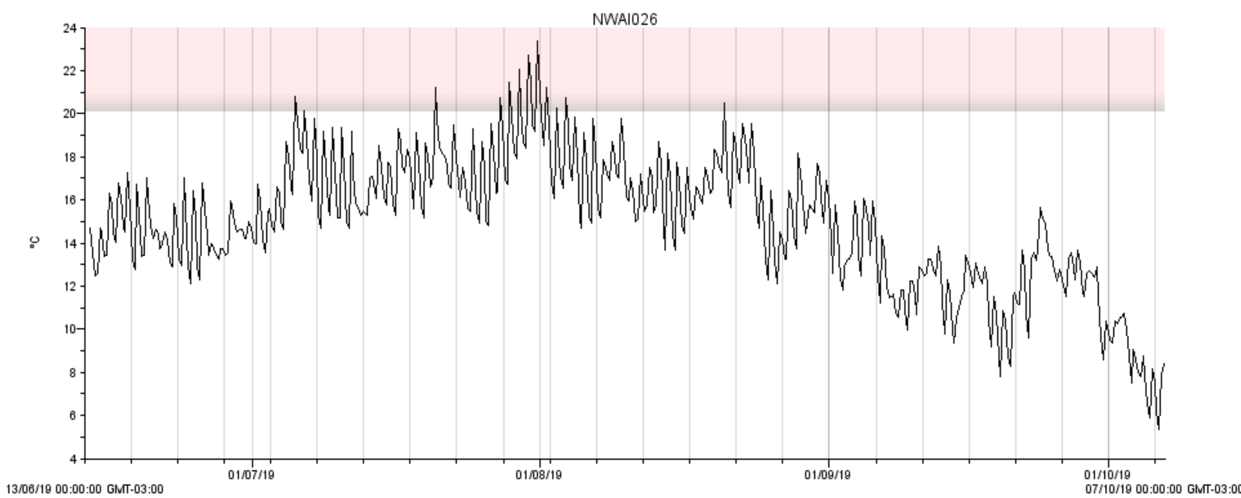
NWAI023. Located in Dunbar Stream at our water quality site [46.14139, -66.61873]
Max temp: 25.4°C
Average summer temp: 16.0°C ±3.3°C



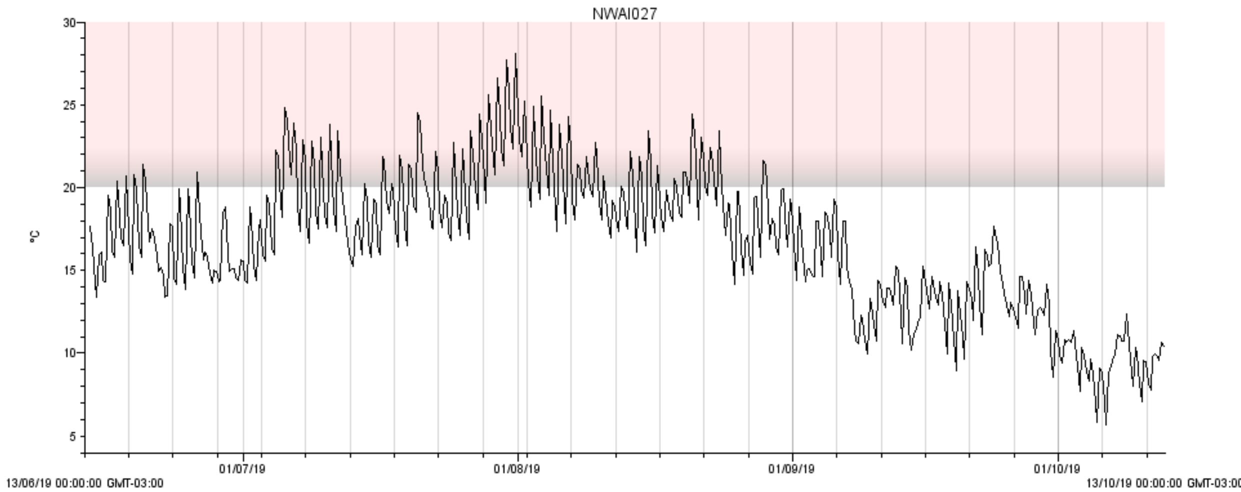
NWAI024. Located in the Nashwaak downstream from Dunbar Stream [46.13981, -66.61839]
Max temp: 267°C
Average summer temp: 17.6°C ±3.4°C



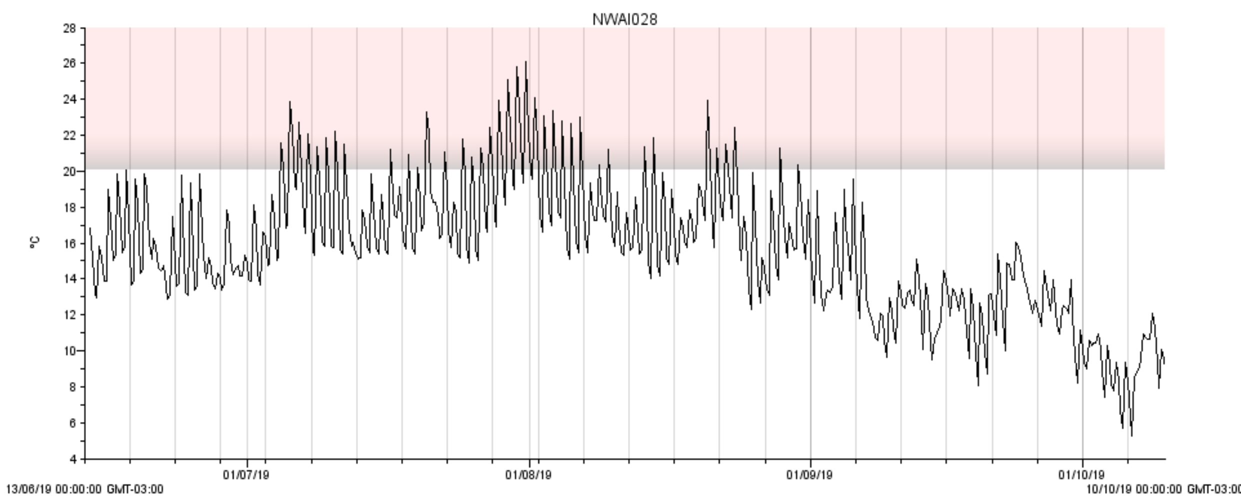
NWAI025. Located in McLean Brook downstream of the Rte. 628 bridge [46.1259, -66.60435]
Max temp: 19.7°C
Average summer temp: 13.7°C ±2.1°C



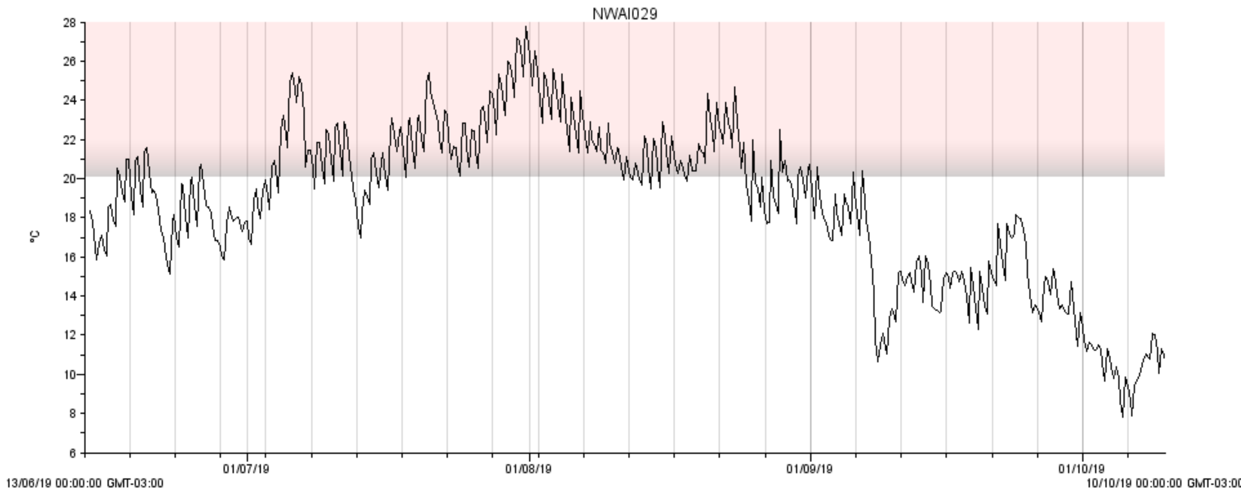
NWAI026. Located in Manzer Brook downstream from the Rte. 628 culvert [46.07066, -66.59277]
Max temp: 23.4°C
Average summer temp: 15.7°C ±2.7°C



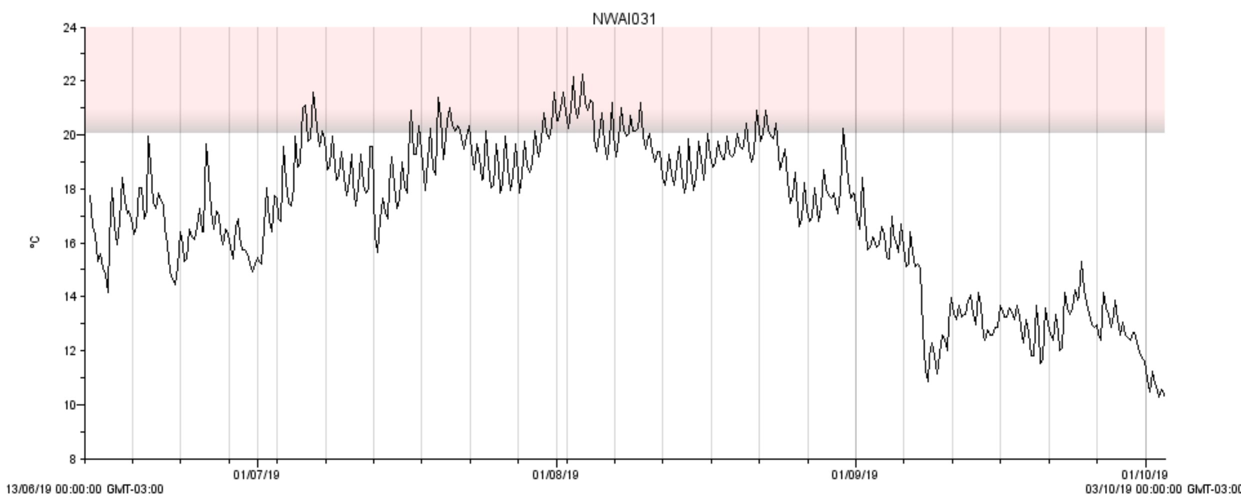
NWAI027. Located in Penniac Stream at our water quality site [46.03152, -66.57178]
Max temp: 28.1°C
Average summer temp: 18.1°C ±3.6°C



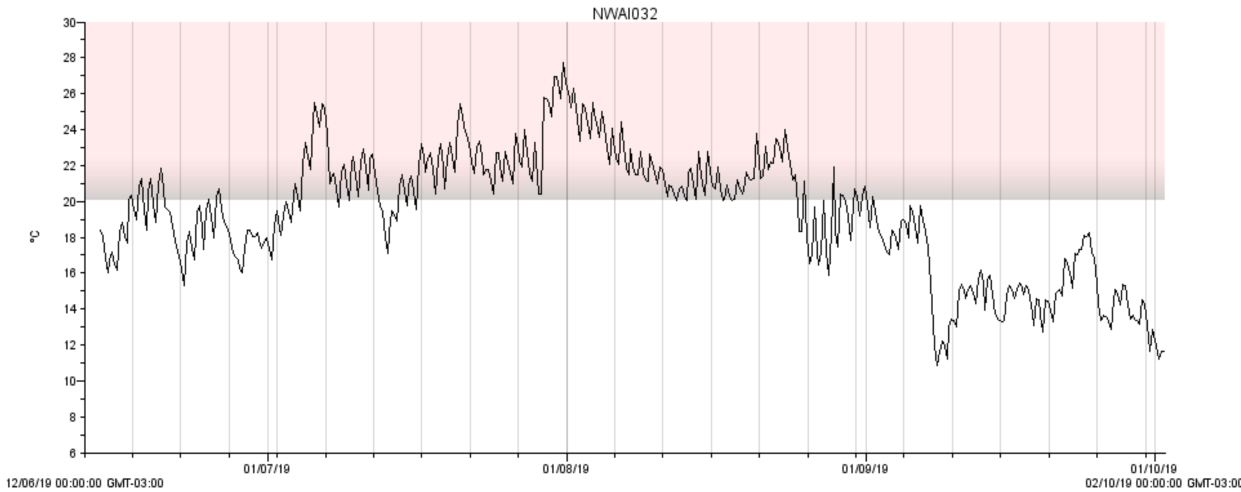
NWAI028. Located in Penniac Stream downstream of the Christie Bridge [46.05109, -66.52991]
Max temp: 26.1°C
Average summer temp: 16.5°C ±3.3°C



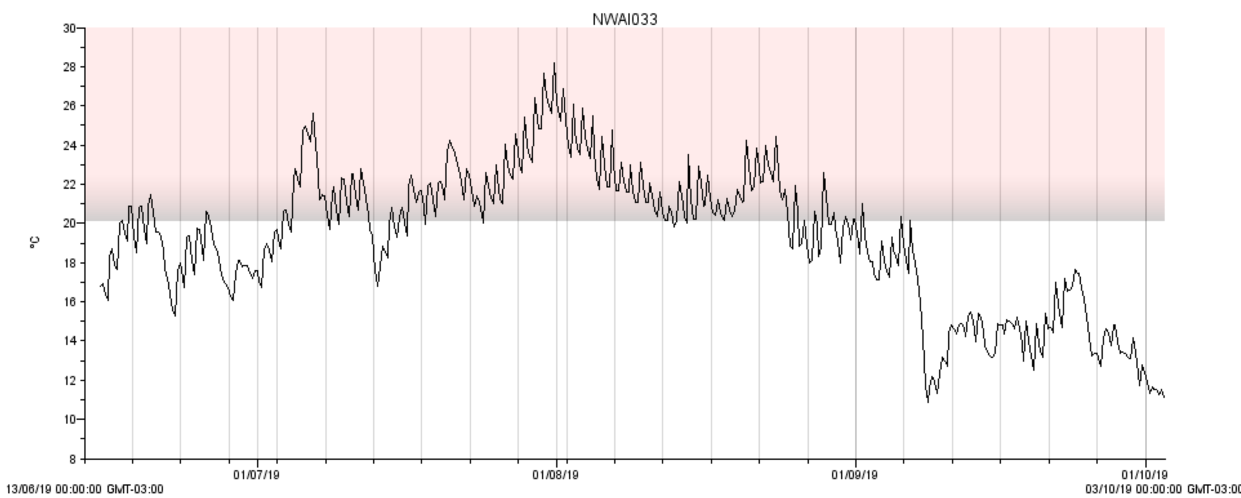
NWAI029. Located in Nashwaak River upstream of the Penniac walking bridge [45.9977, -66.57445]
Max temp: 27.8°C
Average summer temp: 19.95°C ±3.4°C



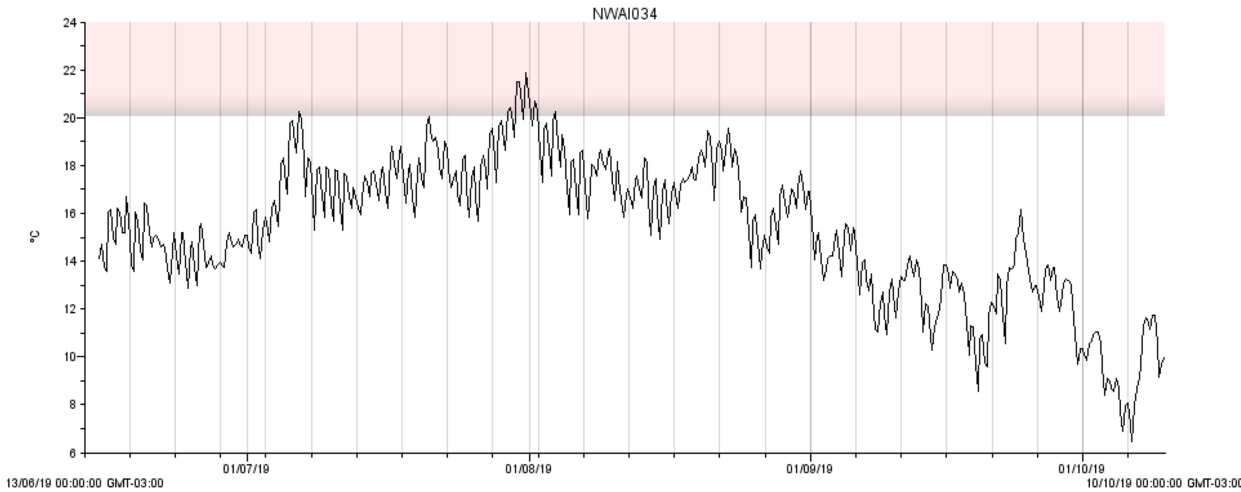
NWAI031. Located in Campbell Creek ~100 m downstream of dam [45.98825, -66.58157]
Max temp: 22.2°C
Average summer temp: 17.7°C ±2.6°C



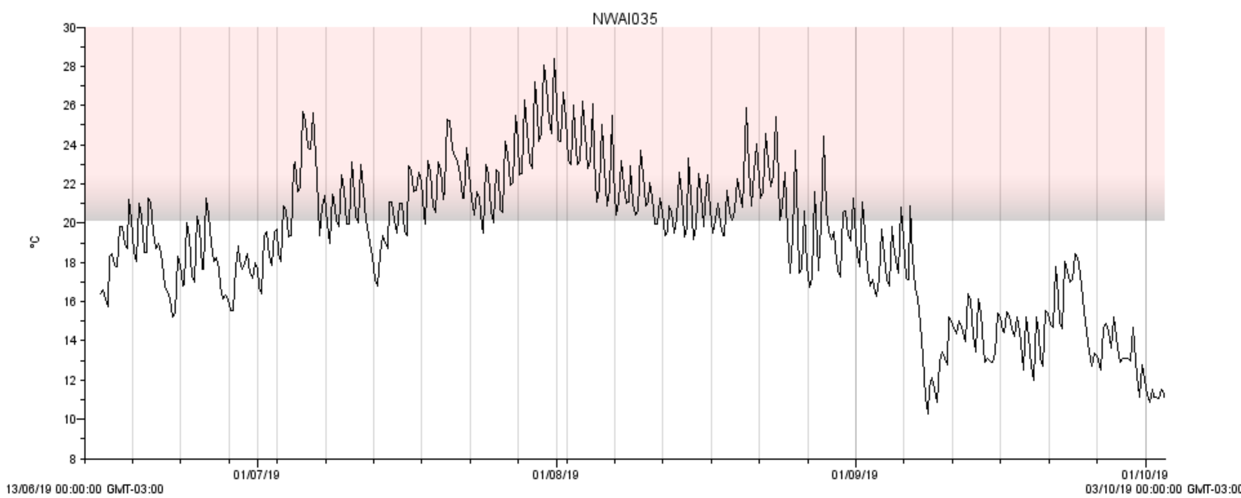
NWAI032. Located in the Nashwaak downstream from Campbell Creek [45.98881, -66.58311]
Max temp: 27.8°C
Average summer temp: 19.95°C ±3.3°C



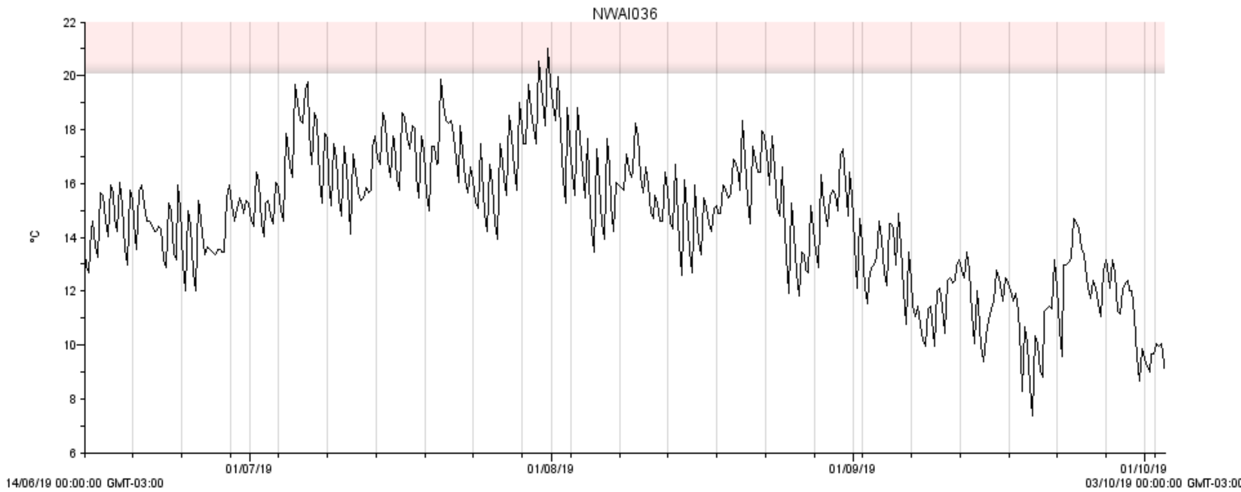
NWAI033. Located in Nashwaak River above Marysville Bridge [45.97952, -66.58989]
Max temp: 28.2°C
Average summer temp: 19.9°C ±3.3°C



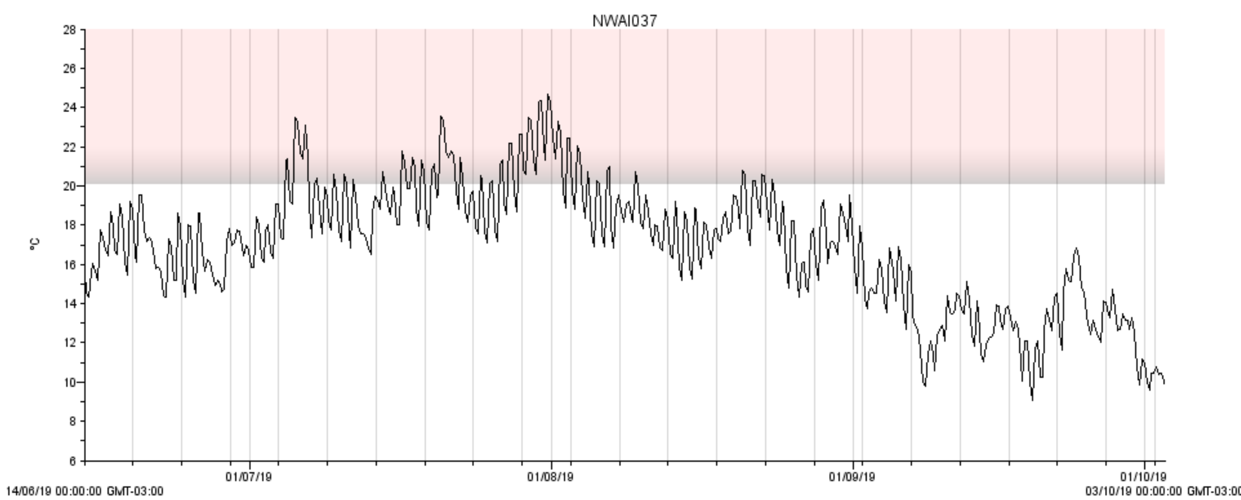
NWAI034. Located in Kaine Creek downstream from Canada Street [45.9703, -66.59058]
Max temp: 21.9°C
Average summer temp: 16.2°C ±2.5°C



NWAI035. Located in Nashwaak at Nashwaak Valley Farm [46.05394, -66.59721]
Max temp: 28.4°C
Average summer temp: 19.8°C ±3.5°C



NWAI036. Located in Tay Creek at Tay Falls Road [46.24554, -66.7689]
Max temp: 21.0°C
Average summer temp: 15.1°C ±2.4°C



NWAI037. Located in Limekiln Brook at Rte. 620 [46.26674, -6678859]
Max temp: 24.6°C
Average summer temp: 17.5°C ±3.1°C

Logger Name	T/M	Date deployed	Date recovered	Interval	Location	Lat	Long	Max temp	Min temp	Avg temp	SD	Summer avg	SD	# days min ≥20C	# days max ≥23	Notes
NWAI001	M	7/6/2019	10/10/2019	6 hrs	Nashwaak at Narrows Mountain	46.29074	-67.02534	26.00	5.80	16.88	4.02	18.13	3.40	2	8	
NWAI002	T	7/6/2019	10/10/2019	6 hrs	South Sisters Brook	46.32531	-67.1564	23.10	4.60	14.67	3.50	15.68	3.04	0	1	
NWAI003	M	7/6/2019	10/10/2019	6 hrs	Nashwaak d/s South Sisters	46.32539	-67.15559	29.20	4.70	16.69	4.52	17.93	4.05	7	36	
NWAI004	M	7/6/2019	10/10/2019	6 hrs	Nashwaak at Gorby Gulch	46.40867	-67.15884	26.10	4.80	15.82	4.10	17.00	3.61	5	14	
NWAI005	M	7/6/2019	10/10/2019	6 hrs	Nashwaak at outlet of Nashwaak Lake	46.46817	-67.11993	27.20	11.00	19.25	3.53	20.66	2.74	52	33	
NWAI006	T	7/6/2019	10/10/2019	6 hrs	Napadogan Stream	46.34243	-67.0004	25.20	4.60	15.34	3.76	16.41	3.28	2	7	
NWAI007	T	10/6/2019	11/10/2019	6 hrs	Ryan Brook	46.31358	-66.81908	23.60	3.90	14.08	3.55	15.14	3.06	0	1	
NWAI008	T	10/6/2019	11/10/2019	6 hrs	McPherson Book	46.29874	-66.78283	20.40	4.40	13.17	2.86	14.02	2.39	0	0	
NWAI009	M	10/6/2019	11/10/2019	6 hrs	Nashwaak upstream of McPherson Brook	46.29888	-66.7841	31.20	5.20	17.93	4.84	19.35	4.20	15	44	
NWAI010	T	10/6/2019	17/10/2019	6 hrs	Sands Brook	46.28439	-66.73838	20.30	4.60	13.22	2.91	14.28	2.32	0	0	
NWAI011	T	10/6/2019	3/10/2019	6 hrs	West Cross Creek at Rte. 625	46.32594	-66.70299	22.90	6.40	14.61	2.90	15.15	2.81	0	0	
NWAI012	T	10/6/2019	3/10/2019	6 hrs	McGiveney Brook at Rte. 625	46.36309	-66.67183	19.70	6.30	13.40	2.32	13.85	2.21	0	0	
NWAI013	T	10/6/2019	3/10/2019	6 hrs	Cathle Brook	46.27755	-66.67384	22.50	6.80	14.78	2.82	15.27	2.72	0	0	
NWAI014	T	10/6/2019	3/10/2019	6 hrs	Arnold Brook at Deersdale Connector	46.3707	-66.62609	26.00	8.20	17.34	3.57	17.95	3.44	7	11	
NWAI015	T	10/6/2019	stopped early	6 hrs	Five Mile Brook	46.31281	-66.58536	21.40	6.70	14.53	2.59	14.68	2.64	0	0	
NWAI016	T	10/6/2019	3/10/2019	6 hrs	Youngs Brook	46.23964	-66.61092	26.50	7.00	16.07	3.61	16.70	3.46	2	12	
NWAI017	M	10/6/2019	3/10/2019	6 hrs	Nashwaak d/s Youngs Brook	46.23853	-66.61196	28.30	7.20	17.47	4.04	18.23	3.81	8	22	
NWAI018	T	10/6/2019	3/10/2019	6 hrs	Cross Creek at WQ	46.2707	-66.63455	27.60	6.70	16.69	3.82	17.32	3.70	4	18	
NWAI019	T	10/6/2019	15/10/2019	6 hrs	Tay at Mouth	46.18039	-66.62136	25.80	6.30	16.36	3.82	17.70	3.08	2	11	
NWAI020	M	10/6/2019	15/10/2019\	6 hrs	Nashwaak d/s Tay	46.17903	-66.61982	23.40	8.80	15.90	3.15	16.88	2.68	0	2	
NWAI021	T	10/6/2019	3/10/2019	6 hrs	Nixon Brook	46.20545	-66.68704	11.40	6.60	7.83	0.68	7.75	0.66	0	0	
NWAI022	T	13/6/2019	15/10/2019\	6 hrs	McBean Brook at 628	46.16744	-66.60613	18.80	5.10	12.69	2.60	13.53	2.11	0	0	
NWAI023	T	13/6/2019	15/10/2019\	6 hrs	Dunbar Stream	46.14139	-66.61873	25.40	6.00	14.83	3.79	16.04	3.28	0	9	
NWAI024	M	13/6/2019	15/10/2019\	6 hrs	Nashwaak d/s Dunbar	46.13981	-66.61839	26.70	5.80	16.22	4.12	17.64	3.36	7	14	
NWAI025	T	13/6/2019	15/10/2019\	6 hrs	McLean Brook at 628	46.1259	-66.60435	19.70	5.10	12.83	2.64	13.69	2.16	0	0	
NWAI026	T	13/6/2019	7/10/2019	6 hrs	Manzer brook at 628	46.07066	-66.59277	23.40	5.30	14.93	3.09	15.68	2.72	0	1	
NWAI027	T	13/6/2019	15/10/2019\	6 hrs	Penniac Brook at WQ	46.03152	-66.57178	28.10	5.70	16.67	4.30	18.07	3.59	4	22	

NWAI028	T	13/6/2019	15/10/2019\	6 hrs	Penniac Brook at Christie Bridge	46.05109	-66.52991	26.10	5.20	15.38	3.82	16.54	3.28	0	11	
NWAI029	M	13/6/2019	15/10/2019\	6 hrs	Nashwaak at Penniac Walking Bridge	45.9977	-66.57445	27.80	7.80	18.36	4.36	19.95	3.35	36	26	
NWAI030	T	13/6/2019	LOST	6 hrs	Campbell Creek d/s Rte 8	45.98859	-66.56336									Lost
NWAI031	T	13/6/2019	4/10/2019	6 hrs	Campbell Creek d/s dam	45.98825	-66.58157	22.20	8.60	16.96	2.96	17.66	2.56	5	0	
NWAI032	M	13/6/2019	4/10/2019	6 hrs	Nashwaak d/s Campbell Creek	45.98881	-66.58311	27.80	8.60	19.14	3.70	19.95	3.31	44	26	
NWAI033	M	14/6/2019	15/10/2019	6 hrs	Nashwaak at Marysville Bridge	45.97952	-66.58989	28.20	8.10	18.32	4.37	19.91	3.34	42	26	
NWAI034	T	14/6/2019	17/10/2019	6 hrs	Kaine at Canada St	45.9703	-66.59058	21.90	6.50	15.00	3.12	16.15	2.45	0	0	
NWAI035	M	14/6/2019	3/10/2019	6 hrs	Nashwaak at NVF	46.05394	-66.59721	28.40	9.50	19.04	3.76	19.76	3.47	31	32	
NWAI036	T	13/6/2019	3/10/2019	6 hrs	Tay Creek at Tay Falls Rd	46.24554	-66.76819	21.00	6.80	14.63	2.55	15.06	2.43	0	0	
NWAI037	T	13/6/2019	3/10/2019	6 hrs	Limekiln Brook	46.26674	-66.78859	24.60	8.00	16.92	3.24	17.48	3.06	6	7	
						Avg	**Tributaries**	**22.82**	**6.06**	**14.71**	**3.12**	**15.49**	**2.77**	**1.33**	**4.63**	
						Avg	**Main Stem**	**27.53**	**7.28**	**17.59**	**4.04**	**18.78**	**3.44**	**20.75**	**23.58**	
						Avg	**All**	**24.39**	**6.46**	**15.67**	**3.43**	**16.59**	**2.99**	**7.81**	**10.94**	