2021

Maintaining Water Quality Data While Adapting To Climate Change

Final Report # 210115
Presented to the
New Brunswick Environmental Trust Fund
On Behalf of the Hammond River Angling Association

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FORWARD

Founded in 1977, the Hammond River Angling Association's (HRAA) mandate is to protect and preserve the Hammond River watershed through education, conservation, and community interaction. This membership-based group is an affiliate of the Atlantic Salmon Federation, the NB Salmon Council, the New Brunswick Environmental Network and Watershed Caucus, the Saint John River Management Committee, and connects with many provincial watershed and environmental groups, community organizations and schools throughout New Brunswick.

The HRAA has engaged in many Atlantic salmon habitat and population enhancement programs since its inception. These programs include stocking fish, electrofishing for juvenile salmon, salmon spawning assessments, large-scale restoration projects and bank stabilization by tree planting. The HRAA also runs an environmental summer camp, a school education program and community education through volunteer activities that promote watershed stewardship.

The Hammond River watershed is located in southeastern New Brunswick and is a tributary of the Wolastoq-Saint John River. The Hammond River watershed has a total area of 513 km^2 with 561 segments of streams, surmounting a total of 461 km in length (Avg. 0.82±0.91 km) (DNR, 2009). Forest comprises 336 km^2 of the watershed while 64.9 km^2 is recognized for non-forest land use (DNR, 2009).

Hammond River watershed is located on land that has never been ceded- the Mi'kmaq, in northern and eastern New Brunswick; the Wolastoqiyik (Maliseet), along the Saint John River Valley; and the Peskotomuhkatiyik (Passamaquoddy) in the St. Croix River watershed. These three nations are part of the Wabanaki Confederacy, which also includes the Penobscot and Abenaki nations of Maine. Wabanaki is "Land of the Dawn" and designates a large area including Maine and the Maritime provinces.

The Hammond River watershed is situated between Elsipogtog's land claim, filed in 2016, for the district of Siknuktuk, which encompasses 1/3 of the province of New Brunswick, along the Southeastern portion. The Hammond River watershed is also situated in a title claim that was launched in 2020 by the six Wolastoqey communities that make up Wolastoqey Nation New Brunswick. The Hammond River watershed is a tributary of the Wolastoq-Saint John River, meaning "the beautiful and bountiful river". Traditionally, the Hammond River was called Nuhwig'ewauk, a Maliseet name with a possible translation of "slow current". *Photo: S. Blenis.*

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ACKNOWLEDGEMENTS

This project was made possible by generous funding from:

New Brunswick Environmental Trust Fund
with special thanks to
Scott Lloy and Lévis Thériault

The HRAA would like to thank the
Department of Environment and Local Government,
for their continued support on environmental projects.
Special thanks to Sara DeGrace and Justin Chase.

Many thanks to:

Hammond River Angling Association's
Volunteers, Members, Staff, Board and Executive (Past and Present)

Bruce Moore Environmental Consulting

The Saint John Laboratory Service

The Research and Productivity Council

The Department of Natural Resources and the Mineral Occurrence Database

DataStream
With a special thanks to Patrick LeClair

The New Brunswick Environmental Network and Watershed Caucus

J. Blenis Photography

Thank you to all the landowners (past and present) who allow access onto their properties!

EXECUTIVE SUMMARY

In 2021, with generous support from the New Brunswick Environmental Trust Fund, the HRAA began undertaking the project, *Maintaining Water Quality Data While Adapting to Climate Change*.

The HRAA has successfully updated the 2008 and 2015 *Watershed Management Plans* in the 2020 *Watershed Management Plan*, whereby it became apparent that additional measures were needed to ensure that we are successfully compiling data that aligns with the *2018-2028 Water Strategy for New Brunswick.*

Maintaining Water Quality Data While Adapting to Climate Change aims to assess the magnitude of the hydrological alteration associated with climate change, by investigating several tributary confluence points in the main stem river through assessing sediment transport. In 2018 and 2019, the Hammond River experienced two back-to-back historic flooding events, which further altered water quality and habitat. These flooding events contributed to a geomorphological shift in the majority of the tributary confluence points, and documentation of these changes is required.

Climate change and its potential to affect the quality, quantity and distribution of water is an overriding issue that adds to the complexity and magnitude of the other challenges facing the province. Given water's social, environmental, and economic importance, anything that changes its quality, quantity or distribution will have a marked effect on our communities, ecosystems, and economic competitiveness. Climate change therefore represents a significant challenge that will have to be continually assessed and accommodated in public policy decisions (DELG, 2017).

The first objective of this project is to maintain the historical water quality dataset at 12 tributary index sites, while expanding to collect additional water quality data above and below these main sampling sites, with a focus on confluence points. By expanding our data collection to include confluence points, we are able to collect additional water quality data to begin to document the impacts of climate change on the river system.

The second objective of *Maintaining Water Quality Data While Adapting to Climate Change* is to collect and assess water quality and habitat in 6 previously undocumented upper tributaries, located in the Caledonia Highlands mountain range. Our hypothesis is that these 6 upper mountainous tributaries are buffering the impacts of climate change. Point 89 of New Brunswick's *Climate Action Plan* recognizes the importance of these mountainous ecosystems, and their integrated ecosystem services (i.e.: temperature control, erosion control, flood reduction). We suspect that these mountainous tributaries are essential to maintaining necessary oxygen and temperature levels for aquatic life in the upper watershed, and that there is a direct link between the location of these tributaries and salmon spawning and nursery habitat.

According to Canada's *Changing Climate Report*, extreme precipitation amounts accumulated over a day or shorter will continue to increase; seasonal availability of freshwater is changing; increase in risk of water supply shortages; warmer winters will produce higher winter flows in streams and rivers; and warmer summers will increase evaporation of surface water and contribute to reduced summer water availability. Sand bars and braided bars are increasing downstream of confluence points in the Hammond River, indicating that the slope is decreasing while sedimentation is increasing. This project will address climate change adaptation plans through the survey of confluence points and evaluate how our watershed is changing with the changing climate, and how we may mitigate the negative consequences.

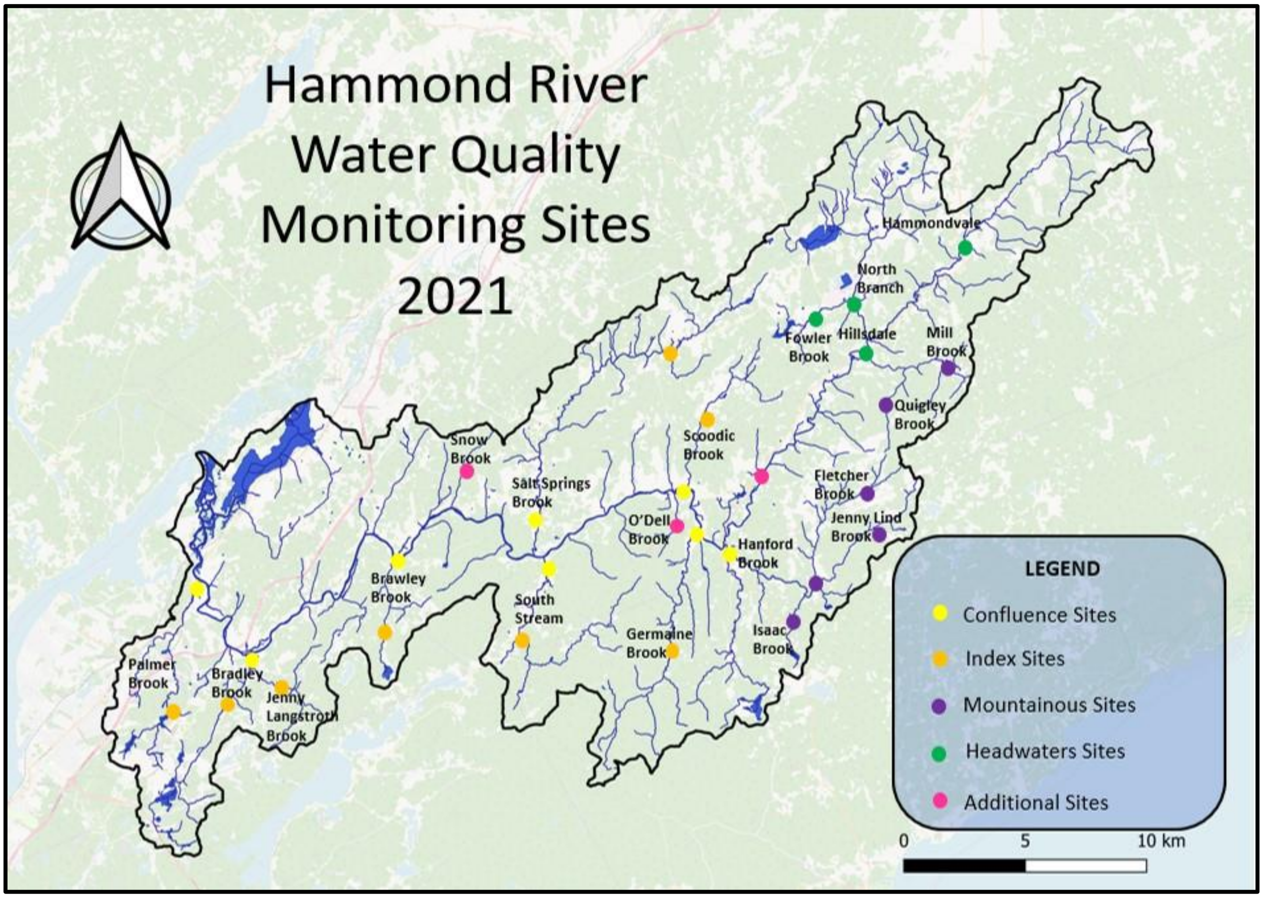
This project upholds goal 90 of New Brunswick's *Climate Action Plan*, by examining climate-vulnerable species, habitats, and landscapes as targets for adaptation action and manage for landscape connectivity to allow for species migration. The confluence points investigated in this project act as migration corridors for terrestrial and aquatic wildlife, and we must ensure that they are stable and properly equipped with healthy riparian zones and healthy water quality. This project provides the HRAA with baseline data on confluence points, which will allow us to track the effects that climate change is having on our watershed. The results of this project will guide HRAA's future riparian restoration and landowner outreach, allowing us to maximize our success while adapting to climate change.

This project also provides a greater sense of the overall health of the Hammond River watershed by examining previously undocumented tributaries, located in mountainous terrain in the upper watershed. The protection and conservation of these upper tributaries may hold the key to the overall long-term success of the Hammond River in the face of climate change.

Maintaining Water Quality Data While Adapting to Climate Change greatly increases our area of water quality sampling coverage, thereby increasing our understanding of overall watershed health. This project examines the complex relationship between land and water by investigating the impact of landscape features (vegetation and geology) and water quality (organic and inorganic) and how these elements affect aquatic biota, resulting in a heightened awareness of climate change and the importance of maintaining integrated ecosystem services.

Photo 1: View of the Hammond River from Tabor Bridge with Upham Mountain, part of the Caledonia Highlands, in the background. *Photo: J. Blenis.*

PROJECT OVERVIEW



Map 1: A map of the Hammond River watershed, highlighting the 12 historical index sites and the confluence points investigated as part of this project, as well as the 6 upper tributaries. *Map: J. Kelly & S. Blenis*

Monthly water quality samples were collected for four months between spring-fall to understand how water quality changes seasonally at each of the 12 index sites and confluence points. Width and depth at each confluence point was documented, as well as deploying a YSI multiparameter probe above, within, and below each confluence point.

Monthly water quality samples were collected for three months between spring-fall, as well as habitat assessments, to provide baseline data on the 6 upper mountainous tributaries. Turbidity and total dissolved solids samples were collected in the main stem river after heavy rainfall events to determine sediment transport.

METHODS

STREAM HABITAT ASSESSMENTS

Stream Habitat Assessments are one of the most powerful tools to observe and collect data. Stream Habitat Assessments provide us with vital information, including identifying which areas are in need of monitoring and/or restoration, identifying pollution sources, and provide us with the ability to identify and remediate activities that are negatively impacting stream quality. Before entering a site to conduct an assessment, landowners must be contacted, and permission must be obtained to cross their property. The stream name, date, GPS coordinates, and names of the personnel conducting the stream assessment should be recorded on a Stream Assessment Data Form. For this project, 6 stream habitat assessments were performed in the 6 upper mountainous tributaries. Documentation occurs at 100m intervals for 600m above and below the designated water quality sampling point, allowing for 1.2km of assessment occurring in each tributary. Results are then averaged and tabulated in Excel for analysis. Stream Assessment Data collected includes:

Substrate

The substrate type (streambed composition) is recorded based on the size of the matter which comprises the streambed at each site. Based on how much substrate falls into each of the following categories a percentage value (0-100%) is given:

Type of Substrate	**Size of Substrate**
Bedrock	ledge
Boulder	>461mm
Rock	180-460mm
Rubble	54-179mm
Gravel	2.6-53mm
Sand	0.06-2.5mm
Fines	0.0005-0.05mm

Substrate Embeddedness

The character of stream substrates is important to both physical and biological stream functions. Increases in embeddedness levels decrease the space between particles and limit the available area and cover for small fish, macroinvertebrates, and periphyton. Shifts to finer materials in particle size distributions can alter biotic communities by reducing species diversity and density (Lenat, Penrose, and Eagleson 1981). An increase in fine sediment reduces geometric mean particle size and gravel permeability and leads to lower dissolved oxygen levels in pore water (Chapman 1988**).**

Percent	**Embedded**
≤ 20%	Majority of substrate is not embedded
20-35%	Substrate is somewhat embedded
35-50%	Substrate is noticeably embedded
≥50%	Substrate is significantly embedded

Undercut Banks

A percentage value (0-50%) is given for both the left (facing downstream) and right stream banks (for a total of 100% of the site) to estimate the percentage of the bank that is undercut/eroding. For example: a particular site may have a left bank that is 25% undercut (half of the left bank) and a right bank that is undercut 50% (the entire right bank).

Woody Debris

Observations of large woody debris (ie: logs) that lie within or partly within a stream are recorded in meters. Documentation of woody debris may indicate potential barriers to fish passage (i.e.: culvert blockage); however, it may also indicate excellent fish habitat. Notes should include whether the debris is potentially helpful or harmful to aquatic species.

Overhanging Vegetation

A percentage value (0-50%) is given for both the left and right sides (for a total of 100%) of the stream to estimate the length of water that has vegetation hanging over it. For example: a particular site may have a left bank that has 25% of its vegetation overhanging (half of the water length on the left bank), and a right bank that has 50% of its vegetation overhanging (the entire length of water on the right bank). Overhanging vegetation provides additional shade, keeping water temperatures lower, and provides excellent fish habitat.

Erosion

At each site, the stability of both the left and right banks are recorded, and a percentage value between 0-50% is given for each bank to total 100%. Erosion is documented as being stable, bare stable, or eroding:

Type	**Description**
Stable	There is no evidence of erosion & bank is secure with vegetation
Bare Stable	There is no evidence of erosion, but bank has little vegetation
Eroding	The bank is unstable and evidence of erosion

Vegetation

An estimate is recorded based on the percentage of stream bank vegetation that falls into the following four categories, in which the vegetation estimate should add up to 100%: bare ground, grasses, shrubs, and trees. For example: a stream could have surrounding vegetation that is 20% bare ground, 10% grass, 30% shrubs, and 40% trees.

Crown Coverage

A percentage value (0-100%) is given based on the amount of water surface that is shaded. The amount of shade is, in most cases, a direct result of the amount of overhanging vegetation, and is also dependent on the time of day and the weather at the time of assessment.

Flow Type

A percentage value (0-100%) to estimate how the water within the stream flows is given based on the following categories: rapid, riffle, run, pool, eddy, flat, cascade, and sheet. The overall habitat should be comprised of a combination of four of the aforementioned flow types, ensuring there is holding pools, nursery, and spawning grounds within the habitat.

Sinuosity

Sinuosity is an extension of flow type and is a percentage value (0-100%) to estimate how much of the stream is straight and how much of the stream is winding.

Forest Maturity

The type of vegetation is described at each site for the left and right banks. By describing vegetation, we can identify primary or secondary forest succession and whether the forest is early or mature. Primary succession describes an area that was not previously colonized (e.g. point bar, sand dune, slip-off slope) and secondary succession is an area that has been disturbed; however, there are remnants of the previous colonizers (e.g., humus, root structure). Early (pioneer) forest succession is indicated by annuals, perennials, and shrubs. Eventually, this community transitions into a softwood-dominated stand with a uniform canopy and then into a mature forest consisting of hardwood stands with multiple canopy layers. Mature deciduous forests are known to increase dissolved organic carbon adsorption in the soil and increase available nitrogen (Yan et al., 2015). Along with the maturity of the stand and the presence of grasses, tree species were identified at each site for both the left and right bank. Forest maturity is observed while sweeping the bank and a general category was assigned to each bank (e.g., immature, mature, wetland, grassland, secondary succession).

Situational Data

Documentation should be made, but is not limited to, the following situations:

- Beaver/Man-Made Dam
- Road Ford
- Large Amounts of Garbage
- Manmade Structures Within or Obstructing Stream Flow
- Cattle Crossings

Anything obstructing the movement or migration of fish should be well documented with many pictures and detailed field notes. Depending on the type of barrier, its removal may be required.

WATER QUALITY

Laboratory Analysis

In addition to in-situ water quality testing with a YSI multiprobe (dissolved oxygen, air temperature, water temperature, salinity, conductivity, pH, total dissolved solids, and turbidity), HRAA collected monthly grab samples.

Samples were collected during normal conditions throughout the spring, summer, and autumn and were processed at the Saint John Laboratory. At each site, HRAA field staff took one 1-liter sample for general chemistry, and one 125ml sample for Total Coliforms, Fecal Coliforms and *E. coli*. Samples were taken upstream of the staff, as to avoid unintended sedimentation from entering the jar.

Samples were labeled with the date, time, and location ID, and were packed in a cooler with ice, and either delivered to the lab on the same day or were held in the refrigerator at the HRAA Conservation Center overnight and delivered to the lab the following morning. Organic chemistry samples are time-sensitive and <u>must</u> be delivered to the lab within 24 hours of sampling.

The following are the parameters that were included in water quality testing (in addition to in-situ water quality testing with the YSI):

Aluminum	Dissolved Oxygen	Nitrogen
Alkalinity	*E. coli*	Nitrate
Antimony	Fecal Coliforms	Nitrite
Arsenic	Fluoride	pH
Calcium	Iron	Phosphorus
Cadmium	Lead	Potassium
Chloride	Magnesium	Sodium
Copper	Manganese	Sulfate
Color	Mercury	Total Dissolved Solids
Conductivity	Nickel	Total Suspended Solids
Total Kjeldahl Nitrogen	Total Coliforms	Turbidity
Total Hardness	Total Organic Carbon	Zinc

These parameters help to identify any major issues in the water quality and allow for potential sources to become easier to pinpoint and identify.

Sample results have been entered into DataStream, a free, open access data portal for water quality data. In 2020, HRAA staff uploaded 22 years of historical data from 1998 to 2020 into DataStream, and we have included our 2021 results in our DataStream database. This allows staff to have a greater understanding of the fluctuations of water chemistry, and potential climate change impacts, and how the health of our river is faring.

Water Quality Index

The Canadian Water Quality Index (CWQI) provided by the Canadian Council of Ministers of the Environment (CCME) is a means to summarize large amounts of water quality data into simple terms (CCME, 2001). The Index is a series of calculations combining multiple parameters to produce a value for each site based on:

i. The number of parameters that exceed guidelines
ii. The number of times guidelines are exceeded
iii. And the amount by which they are exceeded

For the most accurate measurements, sites should be visited at least 4 times, where at least 4 parameters are monitored.). This process is used to assign a score to each sampling site based on how many parameters were within acceptable limits. For each site, this analysis was carried out separately for each of the 4 samples taken, and final scores are based on cumulative results of each replication.

For the protection of aquatic life, the following parameters were examined to determine the overall water quality index score of each site:

Aluminum	Copper	Lead
Alkalinity	Chromium	pH
Antimony	Iron	Phosphorus
Arsenic	Nickel	Temperature
Calcium	Nitrogen	Turbidity
Cadmium	Nitrate	Zinc
Chloride	Dissolved Oxygen	

Once the water quality samples have been calculated based on the CCME's guidelines for the protection of aquatic life, they are assigned an overall health score:

WQI Value	Rating	Degree of Impairment
0-44	Poor	Aquatic life is threatened, impaired, or even lost
45-64	Marginal	Aquatic life frequently may be threatened or impaired
65-79	Fair	Aquatic life is protected, but at times may be threatened or impaired
80-94	Good	Aquatic life is protected, with only a minor degree of threat or impairment
95-100	Excellent	Aquatic life is not threatened or impaired

Bacterial results (*E. coli*, fecal coliforms, and total coliforms) have been analyzed separately from the Water Quality Index calculator. Acceptable levels of *E. coli* for the protection of aquatic fish health are ≤ 400 MPN/ 100 mL (Health Canada, 2012). *E. coli* Used as an indicator of microbial concentrations in water, sources of contamination include human and animal fecal matter. Human sources incorporate failing septic tanks, leaking sewer lines, wastewater treatment plants, combined sewer. Fecal indicator bacteria can be significantly correlated with human density. Animal sources include manure spread on land, livestock in runoff or in streams, improperly disposed farm animal wastes, pet wastes, wildlife, and birds. *E.coli* can be transported to waterways through runoff. The velocity of transport is dependent on the land type (e.g., run off on non-developed land is sopped up by vegetation leading to increase infiltration into the ground and an overall reduction of runoff entering that waterway). Seasonal fluctuations are expected; often an increase in bacteria is associated with heavy rainfall, or higher coliform counts during hotter summer months.

The majority of parameters used to calculate the Water Quality Index are necessary for aquatic life; however, exceedances of the guideline upper limits can have negative impacts on aquatic biota. Descriptions are sourced from the government of New Brunswick facts on drinking water (2015) and acceptable levels for aquatic fish health are described from the CCME water quality guidelines for aquatic fish health (2012):

Alkalinity

A measure of the streams buffering capacity. Indicates the waters capacity to resist changes to pH or neutralize an acid. Alkalinity is derived from the presence of carbonate ions and is closely related to hardness. Water that is too alkaline causes non-toxic ammonia to become toxic. Fish may have trouble breathing. It can also affect the fish's fins and tails, damaging their growth and making them look ragged. Ultimately, fish in a highly alkaline environment may fail to thrive and can eventually die.

Aluminum

The acceptable levels of aluminum for the protection of aquatic fish health is 0.005 if pH is 6.5. Aluminum is an extremely abundant metal in the earth's crust and is often found in the form of silicates such as feldspar. Elevated levels of aluminum can affect some species ability to regulate ions, like salts, and inhibit respiratory functions, like breathing. Aluminum can accumulate on the surface of a fish's gill, leading to respiratory dysfunction, and possibly death. The oxide of aluminum, known as bauxite, provides a convenient source of uncontaminated ore. Aluminum can be selectively leached from rock and soil to enter any water source. Sources include treatment plants using aluminum-based coagulants as well as naturally occurring aluminum that is found in groundwater.

Antimony

Antimony is a naturally occurring chemical parameter caused by erosion and soil run off. Antimony has also been found to leak from plumbing and industrial outflow. Health considerations with regards to antimony are microscopic changes that occur in tissues and organs such as kidneys and liver.

Arsenic

The acceptable level of arsenic for the long-term protection of aquatic fish health is ≤ 5 µg/L. Often a by-product of mining; however, arsenic also occurs naturally with erosion and weathering of soils and minerals. Arsenic exposure in the aquatic environment causes bioaccumulation in aquatic organisms and can lead to physiological and biochemical disorders, such as poisoning, liver lesions, decreased fertility, cell and tissue damage, and cell death. Health concerns associated with arsenic are skin, neurological, and vascular effects. Arsenic is also classified as a carcinogen.

Calcium

Calcium is naturally occurring from erosion and weathering of soils and minerals. It is an essential component of bone and cartilage for aquatic and terrestrial species. Calcium regulates the uptake of nutrients, promotes muscle tone and regular heartbeat.

Cadmium

The acceptable level of cadmium for the long-term protection of aquatic fish health is ≤ 0.09 µg/ L and in the short term is 1 µg/ L. Cadmium is a trace element that is very toxic to fish. It is commonly found in surface waters contaminated with industrial effluents. When dissolved in water, Cadmium can rapidly cause physiological changes in the gills and kidneys of freshwater fish. Cadmium exceedances can be caused by leaching from galvanized pipes as well as industrial and municipal waste. Cadmium has been linked with softening of bones and kidney damage.

Chloride

The acceptable level of chloride for the long-term protection of aquatic fish health is ≤ 120 mg/ L and in the short term is 650 mg/ L. Chloride is naturally occurring and is a component of salt. Sources include industrial effluents, highway salt, sewage, irrigation and naturally occurring salt deposits as well as the potential intrusion of sea water. Use of salt for deicing roads and parking lots in the winter is a major source of chloride. Other sources include wastewater treatment, septic systems, and farming operations. natural sources of salt and brine in geologic deposits. Exceedances of chloride can have a negative impact on fish's ability for osmoregulation.

Chromium

The acceptable level of chromium for the long-term protection of aquatic fish health is 1- 8.9 µg/ L. Chromium can be a byproduct of industrial spills as well as naturally occurring events such as erosion and weathering of minerals. Numerous fish species have fatal effect of chromium like lymphocytosis, anemia, eosinophilia, bronchial and renal lesions. Its high concentration can harm the gills of fish that swim near the point of disposal of metal products in surface waters Potentially adverse effects include enlarged liver, skin, respiratory and gastrointestinal irritation. Acceptable limits of chromium assist with carbohydrate, cholesterol, and amino acid metabolism regulation for fish species.

Copper

Acceptable limits of copper for the protection of aquatic fish health are dependent on hardness and ranges from 2-4 µg/L. Copper is naturally occurring but can also be sourced from leaching copper pipes. Too much copper can cause gill fraying in fish, which limits their ability to regulate the transport of salts and ultimately, effects their cardiovascular and nervous systems.

Copper can be toxic to some sensitive fish species and is highly toxic to many invertebrate species. Even for more tolerant species, chronic copper use can damage gills, kidneys, spleens, and other organs and systems and can depress the immune system. Acceptable limits of copper assist fish species with iron metabolism, red blood cell production and maintenance, skin pigmentation and maintenance of nerve fibers.

Fluoride

Acceptable levels of fluoride for the protection of aquatic fish health with long term exposure is 120 µg/L. Fluoride is a naturally occurring element from soil and rock erosion. High levels of fluoride can result in fish and aquatic invertebrate toxicity.

Iron

Acceptable levels of iron for the protection of aquatic fish health is 0.3 mg/L. Naturally occurring through mineral and rock erosion. Iron fertilization or contamination affects the reproduction and feeding habits of fish and other animals. High concentrations of iron sometimes result in increased acidity of water—killing or hurting aquatic life. Industrialized and sewage effluents are a common source. High levels of iron will build up in tissues and can cause toxicity in fish. Acceptable levels of iron can assist with fish species' ability for tissue oxidation and electron export.

Lead

Acceptable levels of lead are based on hardness and can range from 1-7 ug/L. Lead is a naturally occurring base metal, and limits above guideline levels can accumulates in fish liver, kidneys and gills and may cause structural lesions and physical disturbances. Studies determined that chronic lead exposure can be so lethal that metamorphosis, neurology, and other developmental progressions will be inhibited in aquatic organisms.

Nickel

Acceptable levels of Nickel ranges from 25-180 ug/L. Nickel is a naturally occurring base metal and can be a by-product of manufacturing that is released into the environment. Fish species exposed to high levels of nickel may experience changes including hyperplasia, hypertrophy, shortening of secondary lamellae and fusion of adjacent lamellae. The physiological and histological changes indicate that nickel is very hazardous pollutant that has a high affinity for organic matter. Nickel poisoning in aquatic organisms can result in surfacing, rapid mouth and operculum movements, convulsions, and loss of equilibrium.

Nitrogen

Acceptable levels of Total Nitrogen (as N-calc) for the protection of aquatic fish health is 2.8 mg/L. Nitrogen and phosphorus are nutrients that are natural parts of aquatic ecosystems. Nitrogen and phosphorus support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water, but excessive amounts can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream. The nitrogen cycle is what keeps the chemical balance of water at life-sustainable levels for plants and fish.

Nitrite

Acceptable levels of nitrite (as N) for the protection of aquatic fish health is 0.06 mg/L. Naturally occurring; leaching or runoff from agricultural fertilizer use, manure, and domestic sewage. High nitrite levels are especially harmful to fry and young fish and will negatively affect their growth. Furthermore, the same conditions that cause elevated nitrite often cause decreased oxygen levels, which further stress the fish. Can affect ion regulation, respiratory function, cardiovascular, endocrine, and execratory processes in fish.

Phosphorus

Acceptable levels of phosphorus for the protection of aquatic fish health is 0.03 mg/L. Phosphorus will stimulate the growth of plankton and aquatic plants which provide food for fish. This may cause an increase in the fish population and improve the overall water quality. Too much phosphorus can cause increased growth of algae and large aquatic plants, which can result in decreased levels of dissolved oxygen– a process called eutrophication. High levels of phosphorus can also lead to algae blooms that produce algal toxins which can be harmful to human and animal health. Phosphorus is a limiting nutrient for photosynthesis in fresh water and too much phosphorus can cause eutrophication in water bodies. Phosphorus is a common constituent of agricultural fertilizer, manure, organic wastes in sewage and industrial effluents. Adverse effects only occur at extreme levels.

pH

Acceptable levels of pH must be >6.5 and <9. High pH levels (9-14) can harm fish by denaturing cellular membranes. Changes in pH can also affect aquatic life indirectly by altering other aspects of water chemistry. Low pH levels accelerate the release of metals from rocks or sediments in the stream. Saturation pH is a theoretical pH at which water is stable and will neither form a scale nor corrode. Toxic to fish outside of the acceptable range.

Zinc

Acceptable levels of zinc for the long-term protection of aquatic fish health is ≤ 30 mg/L. Zinc is naturally occurring. High quantities of zinc are toxic to fish; however, zinc is also important for fish species wound healing abilities, provided it is within acceptable limits.

Turbidity

Acceptable levels of turbidity based on the Surface Water Monitoring Data as provided by the New Brunswick Department of Environment and Local Government is 10 NTU. Turbidity is an important indicator of the amount of suspended sediment in water, which can have many negative effects on aquatic life. Large amounts of suspended soils or clay may clog the gills of fish and kill them directly. High turbidity can also make it difficult for fish to see and catch prey, and it may bury and kill eggs laid on the bottom of lakes and rivers. The suspended sediments that cause turbidity can block light to aquatic plants, smother aquatic organisms, and carry contaminants and pathogens, such as lead, mercury, and bacteria. Sources of turbidity include clay, silt, and inorganic matter from natural sources. Turbidity is a measure of water clarity. Increased turbidity may be associated with an increased occurrence of bacteria or pathogens within the water.

Dissolved Oxygen

Acceptable levels of dissolved oxygen for the protection of aquatic life must be ≥9.5 mg/L for early life stages and ≥6.5 mg/L for all other life stages. When dissolved oxygen becomes too low, fish and other aquatic organisms cannot survive. The colder water is, the more oxygen it can hold. As the water becomes warmer, less oxygen can be dissolved in the water. Coldwater fish like trout and salmon are most affected by low dissolved oxygen levels. These fish generally attempt to avoid areas where dissolved oxygen is less than 5 mg/L and will begin to die if exposed to levels less than 3 mg/L for more than a couple days. For salmon and trout eggs, dissolved oxygen levels below 11 mg/L will delay their hatching, and below 8 mg/L will impair their growth and lower their survival rates. When dissolved oxygen falls below 6mg/L, the vast majority of trout and salmon eggs will die.

Temperature, Water

Adult Atlantic salmon prefer water temperatures in the range of 14 to 20°C (Elson 1969) and this life stage is sensitive to water temperatures above 20ºC. Atlantic salmon spawning is triggered by water temperatures between 4.4°C and 10°C. If the water is too warm (above 15°C), salmon egg development speeds up too fast, leading to higher mortality rates and defects.

Photo 2 & Photo 3: Juvenile salmon that were found during the electrofishing survey in the fall of 2021.
Photos: S. Blenis & J. Kelly.

WATERSHED GEOLOGY

The geology of an area is a significant factor in the overall quality of its water resources. The dissolution of numerous minerals from geological formations results in spatial and temporal variations in water quality and consequently influence human and environmental health. As water moves through geologic materials, it dissolves them. The processes of rock weathering on the Earth's surface are strongly influenced by climatic factors such as temperature and the quantity and distribution of precipitation. (Olson, 2012). Geology is known to strongly influence many of the constituents of water chemistry; however, few studies have used geologic data to predict diversity and distributions, even though geology is recognized as one of the abiotic factors controlling taxonomic diversity and distributions of many terrestrial plants and animals (Anderson and Ferree 2010).

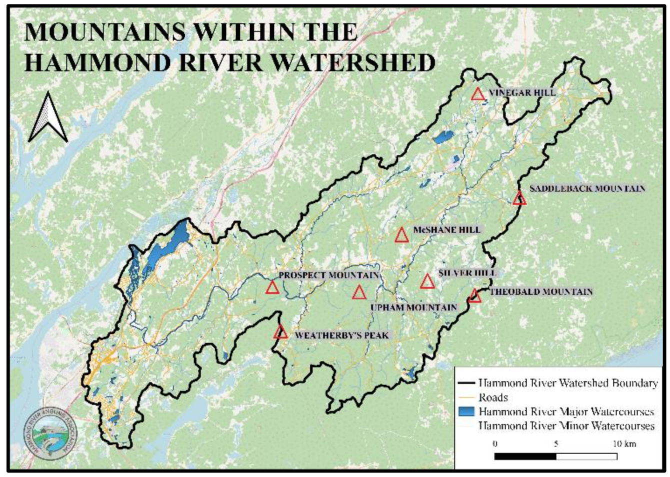
To date, the HRAA has yet to undertake a study on the geological relationship to water quality specific to the Hammond River watershed. *Maintaining Water Quality While Adapting to Climate Change* acts as a steppingstone of investigation between the link of geology and water chemistry, as part of the project's undertakings focused on 6 upper tributaries in the Caledonia Highland range of the watershed.

The rocks of New Brunswick belong to the Appalachian Mountain Range, which borders the Canadian Shield that forms the core of North America. The Appalachians reach from central Alabama northeast to Newfoundland and were continuous with the Caledonides Mountain Range in northwest Europe until the two ranges became severed with the opening of the present Atlantic Ocean some 200 million years ago. Some of the oldest known rocks in New Brunswick are Late Precambrian limestones that were deposited during an early period of ocean opening (Ecosystem Classification Working Group).

The majority of the Hammond River watershed passes through the Caledonia Highlands, and into the Lowlands of southeastern New Brunswick. The Caledonia Highlands, part of the Appalachian Mountain Range, are the remnant of an older mountain-forming episode, and geologic dating suggests the Highlands range in age from 350-690 million years old. The highlands consist of mainly Late Neoproterozoic volcanic, sedimentary, plutonic rocks. The term "Caledonian" is derived from the Latin word for Scotland, and the highlands extend through Newfoundland, Norway, Ireland, Scotland, and Wales.

The geology of the Caledonia Ecodistrict consists almost entirely of Precambrian bedrock. Some formations here are dated at around 600 million years and are among the oldest rocks in the province. Karst topography is a distinctive feature of the Ecodistrict. The extensive deposits of limestone and gypsum are susceptible to solution by circulating groundwater, which results in the formation of caves, sinkholes, and funnel-shaped depressions. Prospectors in the 1800s uncovered many economic minerals in this region: salt, potash, copper, gold, gypsum, zinc, manganese, and bog manganese. The more recent mining operations include a silica quarry and a potash mine, both near Cassidy Lake. Workers at the silica quarry excavate a quartz-rich, unconsolidated sand, and gravel deposit, and process the silica locally. The potash mine was situated south of Cassidy Lake and produced ore between 1985 and its closure in 1997 due to severe underground flooding (Ecosystem Classification Working Group).

In the Hammond River watershed, cold-water tributaries flow from multiple named mountains of the Caledonia Highlands into the Hammond River, including Silver Hill, Prospect Mountain, Weatherby's Peak, Upham Mountain, McShane Hill, Vinegar Hill, Saddleback Mountain, and Mount Theobald (*map: J. Kelly*).



The Hammond River's geology, particularly within the mountain range, is rich with valuable minerals and base metal occurrence, subsequently having an impact on water quality results. Early geological exploration in the 1860's revealed multiple interesting mineral and metal deposits within the Hammond River watershed. In 1861, excitement swirled: "we expect to be able shortly to pronounce that genuine gold is to be found in this Province, say three miles above the Hammond River" (Morning News, 1861). Today, this area is known as "Gold Mine Gully" and it is located in the Caledonia Highlands in the upper portion of the watershed near Hillsdale.

Exploration continued in the late 1860's, with a manganese deposit near the headwaters of the Hammond River in Markhamville. "Allusion has already been made to a ridge of volcanic rock, lying along the southern side of the Hammond River in the Parish of Upham, in which has recently been made a discovery of lodes containing lead and copper", writes Professor Bailey in 1864, "one of these localities is at Henry's Lake…where beds of this group contain spectacular iron in seams" (Bailey et al., 1864). By the 1890's, prospectors were also excited about the potential for a galena, copper, lead or silver mine in the same area: "prospecting for copper, galena, silver, lead, and gold is still going on quietly at the Wannamake place, Hillsdale, on a branch of the Hammond River. It is said some very fine ore has been obtained, but prospectors are observing a discrete silence to their doings" (Weekly Record, 1901).

A mineral-rich deposit was also documented in 1828 in the aptly named and newly formed settlement of Salt Springs. The salt deposit stretches the entire length of the tributary (the longest within the watershed) and connects to the North Branch of the Hammond River. "Indeed, so many saline springs discharge their streams into this river in this neighbourhood that the taste of the water is perceptibly affected" (Weekly Observer, 1928). It is also interesting to note that this discovery also details the discovery of a hot spring within the river: "near a saline spring on Mr. Stewart's property, there rises in the bed of the river a hot spring, which effects the passing current with a suitable warmth" (Weekly Observer, 1928). It would be an interesting undertaking indeed to locate this hot spring's location today and examine how it may be impacting the river and the aquatic diversity!

While interest in the Hammond River watershed's minerals and metals has not waned over the centuries, technology has certainly advanced to assist prospectors. In 2019, Rio Tinto (the 2nd largest copper mining company globally), had staked multiple mining claims along the Hammond River in the Caledonia Highlands as part of their "Braveheart Project". This initial study included a helicopter equipped with a geophysical probe that collects magnetic data over a large area, providing a basis for geologic interpretation and identification of mineral occurrences for further testing. In this particular area, they were searching for occurrences of base metals, including copper and zinc. While the mineral claims were abandoned, it was the "Braveheart Project" that inspired this current project to take stock of our upper, previously undocumented tributaries and the importance they play on the main stem.

Similar technology could be used in the future in partnership with the HRAA, to better map the geological landscape of the watershed and be used in conjunction with water quality results and biodiversity studies to determine the correlation between water and rock. Additionally, future work should be undertaken to translate standard geologic maps into maps depicting chemical and physical rock properties relevant to water chemistry.

Not only does geology impact water chemistry, but it can also influence the rate of river erosion. Rivers flowing over hard rock have a slower rate of erosion, as the bedrock is more resistant. Therefore, in areas where there are both hard and soft rocks, river channels and tributaries are more likely to form along the path of softer rock. Geological factors can also impact water infiltration (infiltrating into ground water vs runoff), which is of particular importance under a climate change lens. Because of geology's role in creating diverse chemical habitats, streams across a range of geologies should be conserved to maximize the number of taxa protected (Olson, 2012).

Historically, Palmer Brook and Bradley Brook, for example, have been rated as Class C tributaries under the now-defunct *NB Water Classification Guide* and received "Poor" water quality index scores based on their exceedances of aluminum, iron chromium, copper, and manganese. It was speculated in the 2008 and 2015 *Watershed Management Plans* that these exceedances may be correlated to the prevalence of industrial spills or industrial byproduct, sewage plants, traffic density, and treatment plants, respectively (CCME, 2014). Have these exceedances been caused by anthropogenic factors, or are they a result of the geology of the lower Hammond River, or perhaps a combination of both? This area has been the focal point for gold exploration from the 1890's to the 1980's, and other minerals commonly occurring with gold are silver, antimony, quartz, iron, lead, zinc, chromium, and copper.

For the purpose of this particular study, an initial investigation into Hammond River geology will assist with understanding the results from our water quality sampling program. Moving forward, it is imperative to investigate all landscape variables, not only stream habitat characteristics, land use and water chemistry, but to include the geological variables in interpreting our results and how this geological lens can apply to species abundance and distribution.

RESULTS

WATER QUALITY INDEX

The following table summarizes the Water Quality Index rankings. It should be noted that there are 3 “Historic Sites” tabulated- during the initial project application, HRAA proposed to sample 12 index site and their subsequent 12 confluence points; however, it was determined that 3 of the index sites did not have a confluence point (two index sites are main stem river; one index site merges with another tributary). This allowed the HRAA to select 3 additional sites for water quality sampling. To the best of our knowledge, these “Historic Sites” have not been sampled for 10+ years. Additionally, it should be noted that bacterial analysis will be discussed later in this report- the following results do not take into account any bacterial exceedances as they are not currently parameters for the CCME Water Quality Index Calculator 2.0.

SITE	TYPE	WQI SCORE	WQI CATEGORY
Jenny Lind Brook	Mountain Tributary	100	Excellent
North Branch	Index	100	Excellent
O'Dell Brook	Historic Site	100	Excellent
Upper Salt Springs	Index	94.6	Good
Upper South Stream	Index	94.6	Good
Hammondvale	Index	94.5	Good
Jenny Langstroth Brook	Index	94.1	Good
McGonagle Brook	Historic Site	94.1	Good
Mill Brook	Mountain Tributary	93.7	Good
Upper Brawley Brook	Index	93.7	Good
Upper Bradley Brook	Index	93.4	Good
Hanford Brook Confluence	Confluence	92.6	Good
Upper Germaine Brook	Index	89.7	Good
Hillsdale	Index	89.5	Good
Upper Scoodic Brook	Historic Site	88.8	Good
Upper Hanford Brook	Mountain Tributary	88.3	Good
Salt Springs Brook Confluence	Confluence	87.6	Good
Isaac Brook	Mountain Tributary	87.3	Good
Brawley Brook Confluence	Confluence	84.6	Good
Germaine Brook Confluence	Confluence	83.3	Good
Bradley Brook Confluence	Confluence	83	Good
Palmer Brook Confluence	Confluence	82.6	Good
South Stream Confluence	Confluence	82.3	Good
Fowler Brook	Index	81.9	Good
Fletcher Brook	Mountain Tributary	81.3	Good
Upper Palmer Brook	Index	81.1	Good
Quigley Brook	Mountain Tributary	53.3	Marginal
Scoodic Brook Confluence	Confluence & Index	52.1	Marginal

Figure 1. Water Quality Index Rankings from all sites sampled in 2021. *Table: S. Blenis.*

CONFLUENCE POINT DATA

Overview

From the spring-fall of 2021, HRAA field staff investigated a total of 8 confluence points of index tributaries. Previously, index sites have been sampled mid-tributary, and this project sought to gain a better understanding of the water quality of these index tributaries when they meet the main stem river. Placing sites at the outpour point enabled the inference of water quality within the sub-catchment because all upstream water must flow through that point.

Until recently, the ecological importance of tributary confluences had received little attention, but that is changing. It is increasingly clear that confluences matter, not only because they can alter environmental conditions and elicit a biological response in the channel that they join, but also because tributaries and their confluence zones are sites of intrinsic ecological value where particular biophysical processes and ecosystem services may be concentrated (Rice et al., 2008).

Our first step was collecting data on confluence zone wet bankful width and depth. Our goal is to maintain this dataset and continue to examine the physical properties of the confluence zones to determine if they are changing or shifting over the years.

	BRADLEY	BRAWLEY	SCOODIC	HANFORD	PALMER	GERMAINE	S. STREAM
Width (m)	7.30	4.37	6.42	9.27	28.20	7.10	7.30
Depth (cm)	68.50	27.80	19.50	23.70	N/A	81.00	45.00

Figure 2. Confluence Zone data on width and depth. *Table: J. Kelly*

It should be noted that Palmer Brook Confluence Zone is "N/A" for depth- this area was too deep to measure but can conservatively be estimated to be approximately 2 meters deep.

Tributary confluence zones fulfil ecosystem functions and provide a variety of ecosystem services that will only become more important as anthropogenic pressure on riverine ecosystems grows, and climate change continues. Confluence zones are important as they are places where the recruitment of water, sediment, and organic matter can have a substantial impact on habitat in the recipient channel and may also contribute to abrupt changes in mainstem water volume, water chemistry, organic matter and supplied sediment (Rice et al., 2008).

Our goal is to highlight the physical and biological properties of these confluence zones, as well as the water quality relationship between confluence zones and their index sites and how this may be impacting confluence zone species biota.

CONFLUENCE POINT DATA

Palmer Brook Confluence

The Palmer Brook sub-catchment is located in the lower reaches of the Hammond River watershed and is 19.5 km^2 in size. This sub-catchment is the most highly developed in the watershed; land use in this area consists of the Hampton highway (Route 1), the Trans-Canada Highway, commercial and residential development, open gravel pits, a sewage field for the municipality of Quispamsis, some crop land and fallow pasture (Bradford, 2015). Land management issues in this area have typically consisted of eroding banks and heavy sedimentation (Campbell and Prosser, 2008). These issues are still occurring to date and are mostly attributed to the density of development in the area, as the riparian zone appears largely intact (99.9% undeveloped). Tidal influx is known to cause stagnant water in the Palmer Brook confluence zone resulting in a grease-like film on the water surface. It is the widest and deepest confluence zone documented in 2021.

Photo 4 (left): Palmer Brook Confluence, looking downstream to the main stem. **Photo 5** (right): Palmer Brook Confluence, looking upstream from the main stem. *Photos: J. Kelly*

Currently, fallow pasture which is prone to seasonal flooding and is adjacent the lowest 250 m of Palmer Brook is undergoing revegetation efforts, with 1108 native shrubs planted in the riparian zone in 2021. This area is area is known to contain a spring fed cool water source and holding pools and provides significant habitat for striped bass, American eel, brook trout and nesting salmon. The Palmer Brook confluence zone is the most critical migratory holding pool for Atlantic salmon within the watershed.

In 2008, 2015, and again in 2021, the Palmer Brook confluence zone has had high concentrations of aluminum, calcium, carbonate, chromium, copper, magnesium, manganese, phosphorus, nitrogen, and nitrates in comparison to other sites in the watershed. The water here is also turbid and high in total color units. *E. coli* has been above guideline limits in 2008 and 2015; however, in 2021, the *E. coli* levels did not surpass the guideline of 400 cfu/100mL. Hardness and alkalinity levels are higher than average concentrations for the watershed- both parameters are beneficial to fish species as hardness eases osmoregulation in fish and a high alkalinity indicates the brook had a high buffering capacity for changes to pH and carbonate ions.

CONFLUENCE POINT DATA

Bradley Brook Confluence

Fallow pasture comprises a large proportion of the Hammond River's buffer zone in this area while other major influences are derived mainly from housing settlements and gravel pits. The Bradley Brook Confluence zone also contains water from the Jenny Langstroth brook, both of which have historically been categorized by the HRAA as having poor water quality.

Stream cover at the Bradley Brook confluence zone is minimal, as a result of years of agriculture. This leads to poor shade, and higher water temperatures in the peak summer months. During heavy rainfall events, there is high levels of sedimentation occurring in the confluence zone, and the water color appears very tannin and murky, particularly in comparison with other confluence zone sites. Substrate is significantly embedded (80%) at this site, and mainly compromised of sand and fines, and does not provide ideal fish habitat.

Photo 6 (left): Bradley Brook Confluence looking upstream from the main stem. **Photo 7** (right): Bradley Brook Confluence looking downstream to the main stem. *Photos: J. Kelly.*

While Bradley Brook Confluence contained higher levels of alkalinity and hardness, indicating that the confluence zone may adapt to changes in pH and provide suitable water quality for aquatic species, this site historically contains higher concentrations of iron, copper, and potassium, and this was confirmed again in 2021. 2021 also recorded higher levels of chloride and sulfate, with a spike in August recording 17mg/L of sulfate- the highest level for all confluence zones in 2021.

While the CCME does not currently have a guideline for aquatic species protection for sulfate exceedances, recent research suggests that elevated sulphate concentrations may have indirect effects on aquatic ecosystems in terms of increasing phosphorus availability and susceptibility to eutrophication and excessive algal growth, and mercury mobilization (Meays et al., 2013). *E. coli* is present in the confluence zone; however, it does not exceed guideline levels. One historic *E. coli* dataset has been discovered from 1998, with *E. coli* levels averaging 195 cfu/100mL in the summer months, in comparison with averaged levels during the summer 2021 at 180 cfu/100mL.

CONFLUENCE POINT DATA

Brawley Brook Confluence

Brawley Brook is 5 kilometers in length and has one of the smallest outpour sites out of the surveyed confluence points, only being 4.7m wide and a depth of 27.80cm. Historically, the Brawley Brook confluence site has been an electrofishing site, and was a salmon fry stocking site from 2005-2008. Juvenile salmon have not been recorded in this site for the past 3 years consecutively; however, there is now documented presence of juvenile smallmouth bass in the confluence area.

Brawley Brook confluence area contains dense shrub and tree canopy, providing excellent shade to the brook. Its dissolved oxygen contents remained at acceptable levels (9.5 mg/L to maintain early life stages and 6.5 mg/L to maintain other life stages) throughout the sampling period. The confluence area offers a mix of substrate with a low embedded score (<20%), providing excellent fish habitat.

Photo 8 (left): View of Bradley Brook confluence point from the main stem. **Photo 9** (right): View from Bradley Brook looking downstream towards the main stem. *Photos: J. Kelly*

Sodium, sulfate, and chloride were high in comparison to other confluence zones; however, it is anticipated that this is a result from road salts entering the watercourse from the bridge that crosses Brawley Brook at the confluence point. Bacterial levels were consistently below guideline levels throughout the sampling period; however, *E. coli* levels were slightly higher in the confluence zone than in the index site, with a seasonal average of 60 cfu/100mL versus 20 cfu/100mL respectively.

Brawley Brook confluence zone received a water quality index score of 84.6 or “Good” and was the third highest ranking confluence zone in 2021. There is little development in the area, with no point source pollution discharges, and the confluence area maintains a healthy riparian zone, substrate complex, and excellent fish habitat.

CONFLUENCE POINT DATA

South Stream Confluence

The South Stream Confluence was sampled once in 2015, and was characterized by substrate that was 25% embedded, the stream was characterized by a clear coloration with great visibility and defined as 100% riffle. The stream cover was 65% and provided decent shade to the watercourse. In 2020, South Stream received a water quality index score of 100% or "Excellent"- it was the only area within the watershed to receive a perfect score in 2020; however, HRAA field staff recognized that South Stream received this perfect score because the index sampling site was located well above the confluence point.

During stream habitat assessments in 2020, HRAA staff documented a high density of livestock having unfettered access to South Stream, below the index sampling site. South Stream, in part, was the original inspiration for creating *Maintaining Water Quality Data While Adapting to Climate Change*- we recognized that we did not have up to date data (and, in some cases such as South Stream, almost no data) on confluence points.

Photo 10 (left): View downstream from South Stream at the confluence, looking at the main stem. **Photo 11** (right): View from the river, looking upstream of South Stream confluence. *Photos: S. Blenis & J. Kelly*

Our suspicions of potential bacterial excess in the watercourse were confirmed with water quality sampling in 2021- *E. coli* spiked in June, with levels reaching 1340 cfu/100mL, over three times higher than guideline limits. Dissolved oxygen and phosphorus levels failed 75% of the tests run through the water quality index calculator, and the South Stream confluence area could be classified as eutrophic, with high levels of macrophyte coverage and substrate embeddedness.

In the fall of 2021, HRAA staff decided to include the South Stream confluence area as part of their electrofishing project. Staff electrofished approximately 1 kilometer upstream from the confluence zone, and only found 2 blacknose dace. The index site in South Stream, which had received the perfect score in 2020, consistently contains an abundance of fish species, including juvenile salmon; however, it is a stark contrast with the fish species documented in the confluence zone. South Stream confluence ranked the second worst confluence site within the watershed and should become a focal point for future studies (particularly a macroinvertebrate study) and landowner engagement, particularly with livestock fencing and riparian planting.

CONFLUENCE POINT DATA

Scoodic Brook Confluence

The Scoodic Brook site is located adjacent to a DTI building in Upham, and this site represents the historic index site as well as the confluence point. This site has historically been rated as a Class C brook and has always ranked extremely low (if not the lowest) in historic water quality index ratings. Unfortunately, this site has once again reclaimed its title as poorest water quality health in the Hammond River watershed.

The flow type changes drastically throughout the sampling period, from riffle (50%) and run (50%) to include many stagnant pools caused by low water levels and exposed substrate in the peak summer months. Aluminum levels, as well as phosphate, nitrogen, and turbidity, are above acceptable levels for the protection of aquatic life. The site transitions from oligotrophic to mesotrophic during the July and September measurements and this periodic transition most likely causes the prevalent algal film on the substrate. This site has been the focal point for 2 consecutive years for sampling for the presence of potentially toxic cyanobacterial benthic mats; however, we are still awaiting results from the samples collected.

Photo 12 (left): View from the Hammond River, looking upstream of the Scoodic Brook confluence. **Photo 13** (right): View from Scoodic Brook, looking downstream to the Hammond River. *Photos: S. Blenis & J. Kelly*

Given that this site is both the historic index site and the confluence site, a second site needed to be selected in the upper region of Scoodic Brook, which allowed the HRAA an opportunity to further investigate a larger section of this tributary. It is interesting to note that both the upper and lower sites of Scoodic Brook both exceeded levels of aluminum for the protection of aquatic life; however, the upper site contained many brook trout, and would be an ideal candidate for future electrofishing surveys or eDNA analysis to determine presence or absence of juvenile salmon. In 1998, 2020, and 2021, it should be noted that arsenic has been detected in Scoodic Brook; however, its occurrence is below guideline levels with an average of 1.5 µg/L. While the Scoodic Brook area has been a major focal point for restoration and outreach engagement since HRAA's inception, it still remains as one of the most water quality stressed tributaries in the entire watershed, and it should remain as a top area for further investigation in the future.

CONFLUENCE POINT DATA

Hanford Brook Confluence

Hanford Brook confluence is located Southwest of Upperton and contains low levels of land development (4%), agriculture use (2.73%) and comparatively low gravel pit density (0.2 %) according to the 2015 *Watershed Management Plan* (Bradford, 2015). Hanford Brook, in general, has a very large drainage area of 5,022 hectares, and receives water from Porter Brook, Isaac Brook, Jenny Lind Brook, Quigley Brook, Fletcher Brook, Porcupine Lake, Henry Lake and Tracy Lake.

The confluence sampling site is located approximately 600m downstream of the confluence point of Porter Brook- in 2008, it was determined that the habitat within Porter Brook was insufficient to maintain aquatic life given its exceptionally high concentrations of cadmium, iron, and aluminum. Porter Brook could potentially have a negative impact on the Hanford Brook confluence area; however, the Hanford Brook confluence site was the highest-ranking confluence site on the water quality index in 2021.

Photo 14 (left): View of Hanford Brook confluence, looking upstream from the main stem river. **Photo 15** (right): From Hanford Brook confluence, looking downstream towards the river. *Photos: S. Blenis & J. Kelly.*

While the majority of the water quality samples were within acceptable limits (or below detection limits) for the protection of aquatic life, a major spike occurred in September's results. Copper, which has a guideline limit of 2-4 µg/L (depending on hardness), spiked to 37 µg/L or 9x the acceptable limit. Fluoride, which has a guideline limit of 120 µg/L spiked to 60,000 µg/L in September, or 500x the acceptable limit. Lead, which has a guideline limit of 1-7 µg/L (based on hardness), spiked to 132 µg/L or 18x the acceptable limit. While this decreased the overall water quality index score, these higher levels were not sustained throughout the sampling season and would not have resulted in long term exposure on aquatic life.

The Hanford Brook confluence site was included in 2021's electrofishing project and had the second highest density of juvenile salmon in the watershed (maintaining its status quo with historical electrofishing data). Given that Hanford Brook receives water from multiple sources, a larger, site-specific project (i.e.: sampling all of Hanford's tributaries) may be warranted to provide greater context to the water quality at the confluence point.

CONFLUENCE POINT DATA

Germaine Brook Confluence

The Germaine Brook confluence area has been a historic site for HRAA restoration activities, given severe erosion has been occurring at the mouth of the brook. The lower portion of Germaine Brook was planted in 2007; however, this rehabilitation work was regarded as unsuccessful. In 2010, a second attempt at riparian restoration efforts was successful at removing blockages created by bottlenecked debris and creating a 10-meter buffer zone along the bank of the brook. Subsequently, this work has eroded away, and the lower Germaine Brook is experiencing major changes to the channel pathway causing significant bank erosion, damage to adjacent farmland and the loss of important salmon spawning habitat (Bradford, 2015).

In 2008, it was noted that high natural densities of juvenile salmon have determined that stocking was not recommended for this tributary; however, HRAA staff have not been able to locate any juvenile salmon in 3 consecutive years during electrofishing. The Germaine Brook confluence area was also once regarded as having the highest density of salmon spawning redds in the watershed; however, only 1 small redd was recorded in 2021, and zero were recorded in 2020.

Photo 16: Germaine Brook confluence, with the main stem river in the background. Note the sand bar and fines deposited in the mouth of the confluence point. *Photo: S. Blenis.*

Germaine Brook confluence experienced similar spikes of copper, fluoride, iron, and lead in September, similar to Hanford Brook. Given the close proximity of these tributaries, it is probable that they share similar geologic makeup. Germaine Brook confluence received a decent water quality index score of 83.3, or "Good", erosion is having an impact on turbidity and total suspended solids, and the degrading riparian zone has been having a negative impact on fish habitat. This site needs to be given top priority for future riparian restoration initiatives in order to (hopefully) restore its salmon spawning and juvenile habitat.

CONFLUENCE POINTS AND INDEX SITES: A COMPARISON

It is apparent that tributaries and confluence zones are important sites in their own right, with intrinsic biological value beyond their importance for structuring communities at larger scales. As pressures on riverine ecosystems grow, particularly from climate change, nutrient loading and anthropogenic factors, the ecosystem value of tributary confluence zones will become increasingly important (Rice et al., 2008).

Maintaining Water Quality While Adapting to Climate Change was one of the first major undertakings from the HRAA to investigate the water quality in confluence zones; however, the HRAA has performed many other studies in these confluence zones, particularly electrofishing. Historical electrofishing data has revealed a tendency to have the highest density and greatest species abundance in many of these confluence zones compared to index sites further up in the tributary, even though the index sites may have overall better water quality.

With one exception, (Hanford Brook confluence), all of the confluence sites ranked in the lower half of the water quality index rankings, below their respective index site's rankings. Palmer Brook confluence site was the only other site that out-ranked its index counterpart, and this can be attributed to higher mine density, road density, agriculture, and other anthropogenic stressors located in the upper Palmer Brook index site.

A comparison of the bacterial parameters (*E. coli*, fecal coliforms, and total coliforms) also confirms that confluence areas tend to have elevated nutrient and bacterial levels compared to the upper reaching index sites.

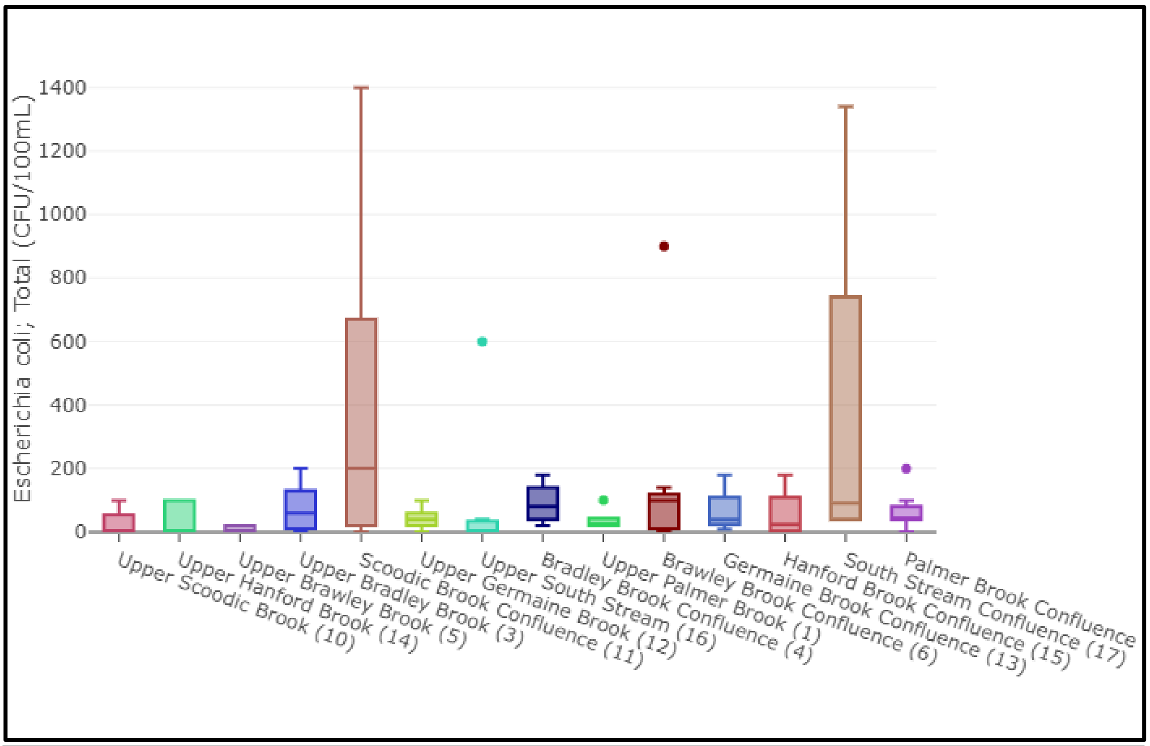


Figure 3. Comparison of *E. coli* levels in confluence points and their respective upper index sites. *Figure: S. Blenis.*

For water uses, such as drinking water (if untreated) and recreation, bacteriological parameters need to be included in the calculation of the CCME WQI. For aquatic life protection, bacteriological parameters need not be included (CCME 2017); however, investigating bacterial content in freshwater sources may pinpoint potential land use issues that may have far-reaching affects (i.e.: high *E. coli* levels may indicate that livestock are nearby a watercourse, and said landowner may be using additional nutrients to grow hay for the livestock, increasing nutrient loading in the watercourse).

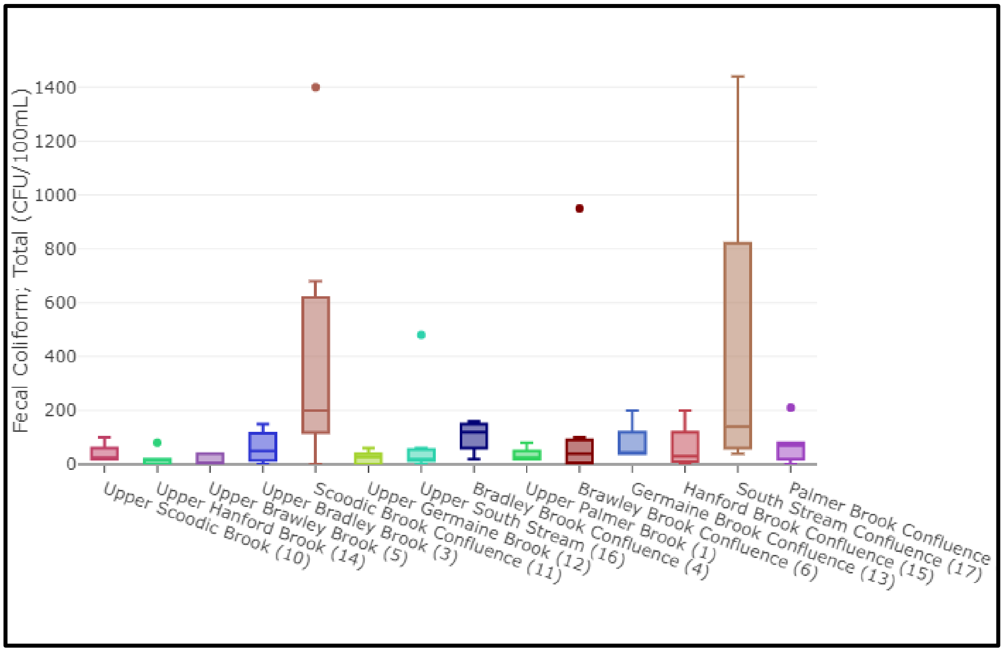
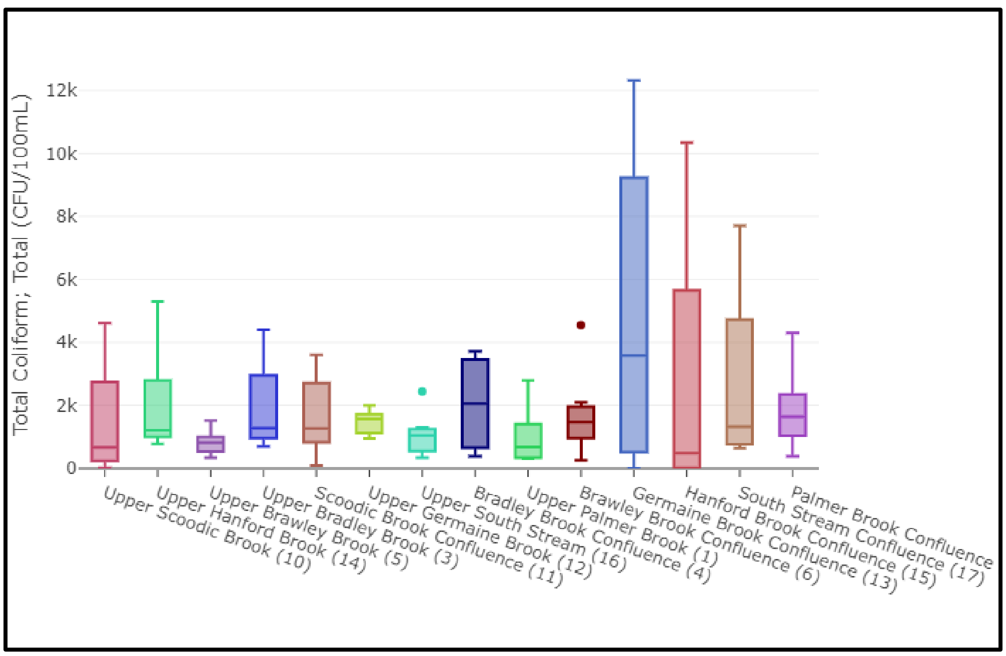


Figure 4 (upper): A comparison of fecal coliform levels between confluence points and upper index sites. Table: S. Blenis. **Figure 5** (lower): A comparison of total coliform levels between confluence points and upper index sites. *Figure: S. Blenis.*



The CCME guideline recommends that dissolved oxygen should be 9.5 mg/L to maintain early life stages and 6.5 mg/L to maintain other life stages of aquatic life. All of the index sites and their respective confluence points maintained average dissolved oxygen levels acceptable to support other life stages of aquatic life. Upper Brawley Brook, Brawley Brook Confluence, Upper South Stream, South Stream Confluence, and Upper Germaine Brook consistently maintained dissolved oxygen levels to support early life stages of aquatic life; however, it should be noted that early life stages of salmon (i.e., fry, parr) were documented in Hanford Brook Confluence in 2021 with the second highest density of juvenile salmon in the watershed.

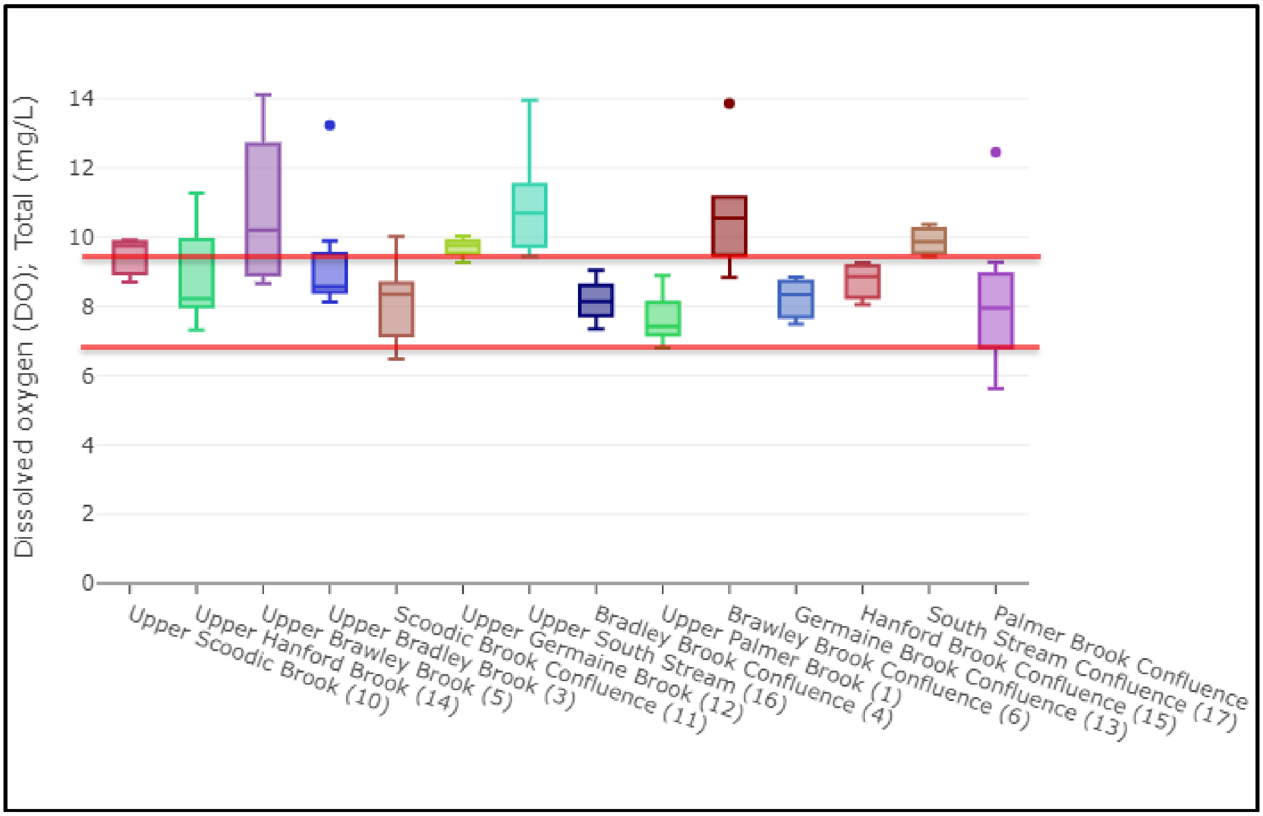


Figure 6. Comparison of average dissolved oxygen levels between the index sites and their respective confluence points. *Figure: S. Blenis.*

Dissolved oxygen is affected by water temperature making cool habitats a crucial component to any healthy stream system in the summer. When dissolved oxygen is low, the community will become stressed and further reductions in dissolved oxygen can occur as well as emigration. Late summer measurements indicated warm water temperatures (> 21ºC) and low dissolved oxygen levels (> 6.5 mg/L) occurred in the Palmer Brook confluence zone and Scoodic Brook confluence zone. Decreases in dissolved oxygen >6.5 mg/L in peak summer months in both Palmer Brook confluence and Scoodic Brook confluence have been regularly documented in HRAA's historical water quality dataset; however, the first 200m upstream from the Palmer Brook confluence is closed to angling after June 30th, which assists with decreasing potential angling stress on fish during hotter water temperatures and lower dissolved oxygen levels.

Turbidity and total suspended solids (TSS) are the most visible indicators of water quality. These suspended particles can come from soil erosion, runoff, discharges, stirred bottom sediments or algal blooms. An increase in turbidity can also indicate increased erosion of stream banks, which may have a long-term effect on a body of water. Erosion reduces habitat quality for fish and other organisms, while settleable solids can suffocate benthic organisms and fish eggs and may smother insect larvae and other fish food sources. Sources of turbidity include clay, silt, and inorganic matter from natural sources. Turbidity is a measure of water clarity. Increased turbidity may be associated with an increased occurrence of bacteria or pathogens within the water. Acceptable levels of turbidity based on the Surface Water Monitoring Data as provided by the New Brunswick Department of Environment and Local Government is 10 NTU.

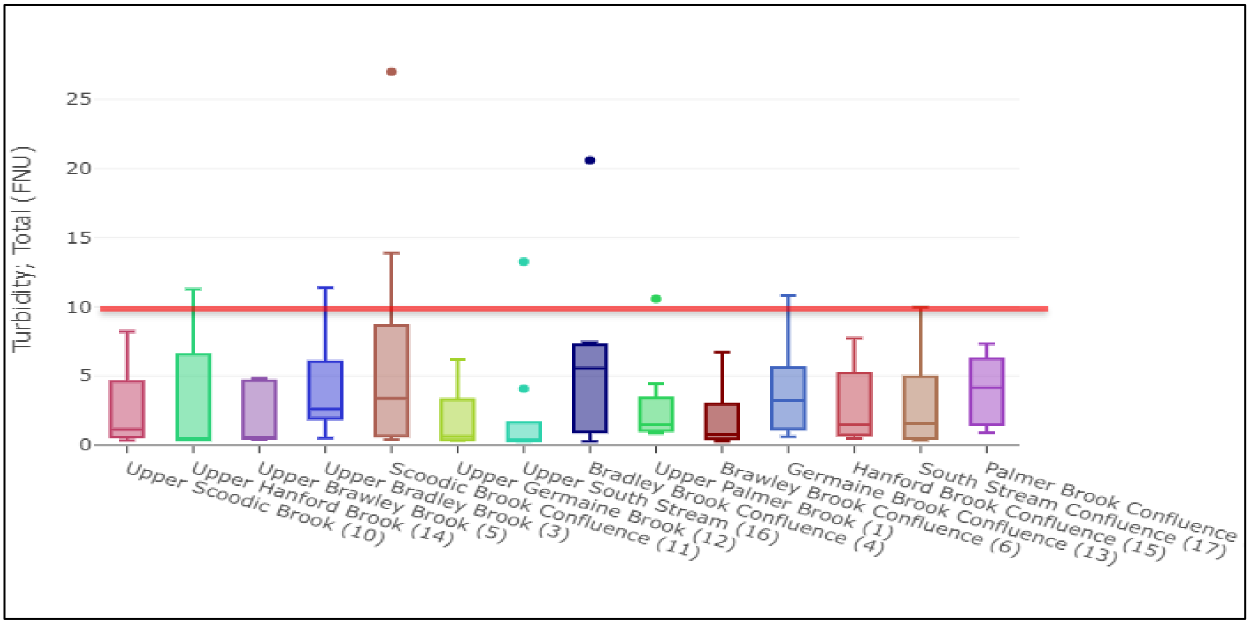


Figure 7. Comparison of turbidity in index sites and their respective confluence points. *Figure: S. Blenis.*

HRAA field staff monitored for turbidity throughout the 2021 field season and collected additional data on turbidity post heavy rainfall events at index and confluence sites. On average, the long-term turbidity levels in each sampling site remained below 10 NTU. After heavy rainfall events, turbidity levels spiked above 10 NTU in Upper Hanford Brook, Upper Bradley Brook, Scoodic Brook Confluence, Upper South Stream, Bradley Brook Confluence, Upper Palmer Brook, Germaine Brook Confluence and South Stream Confluence, with the highest spike recorded in Scoodic Brook Confluence after 2 separate heavy rainfall events. Total suspended solids results reflected turbidity levels, with spikes occurring post heavy rainfall events in the Palmer Brook Confluence, South Stream Confluence, and Scoodic Brook Confluence.

While turbidity and TSS do not have CCME guidelines for the protection of aquatic life, long-term exposure to high levels of turbidity and can impact feeding and nesting behaviors, as fish often flee areas of high turbidity for new territories. For the fish that remain in the turbid environment, suspended sediment can begin to physically affect the fish by clogging gills (Myer & Shaw, 2006).

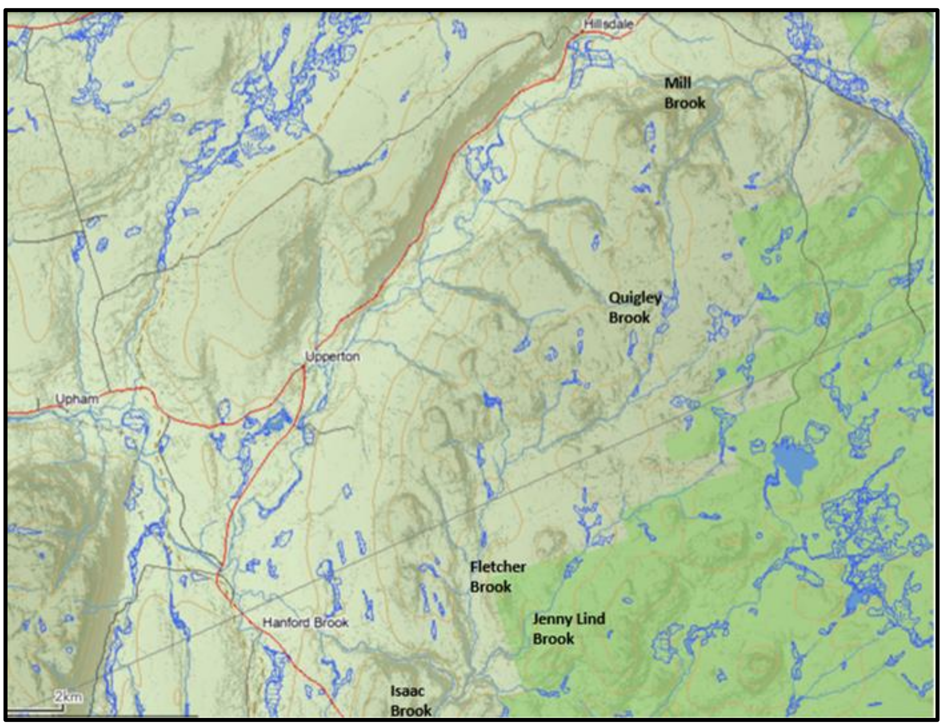
MOUNTAINOUS TRIBUTARIES

Overview

Maintaining Water Quality Data While Adapting to Climate Change sought to explore new regions of the watershed to determine their impact on the main stem river, particularly in the face of climate change. Many scientists believe that the changes occurring in mountain ecosystems may provide an early glimpse of what could come to pass in lowland environments, and that mountains thus act as early warning systems (Koehler & Maselli, 2009).

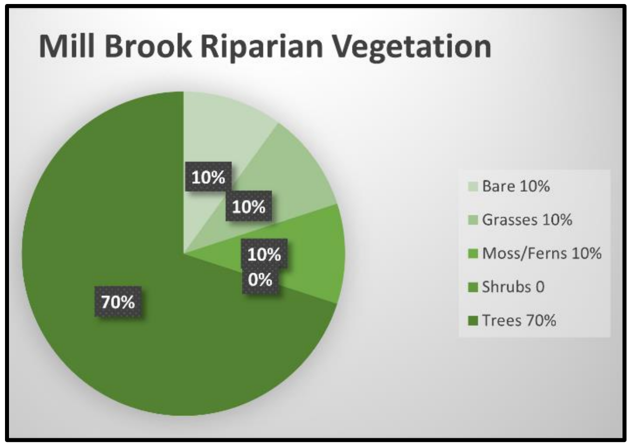
HRAA staff selected 6 previously undocumented tributaries that lie in the Caledonia Mountain region within the watershed- Mill Brook, Quigley Brook, Fletcher Brook, Isaac Brook, Upper Hanford Brook, and Jenny Lind Brook. While there are many other mountainous tributaries located in the Hammond River watershed, staff specifically selected these 6 tributaries as they are close to the headwaters of the Hammond River and can all be easily accessible via the same route off of the Vaughan Creek Road for ease of sampling and documentation.

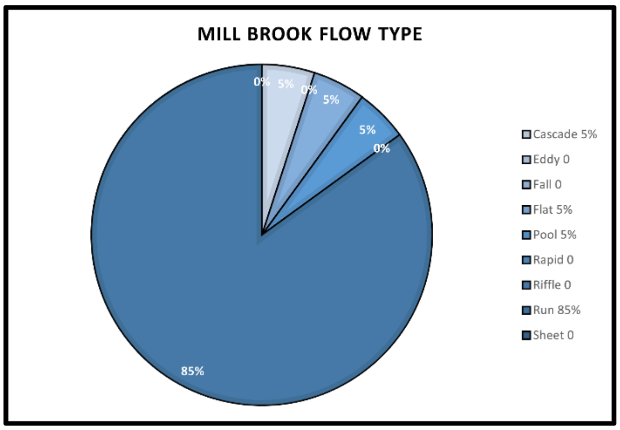
All 6 tributaries immediately have multiple aspects in common- there are no residential dwellings bordering on these tributaries; there is no agriculture alongside of these watercourses; there is no road salt, minimal road maintenance, and low traffic density; these tributaries are by and large naturally occurring with no human interference. The main anthropogenic stressor that all 6 tributaries face is forestry and lumber harvesting.

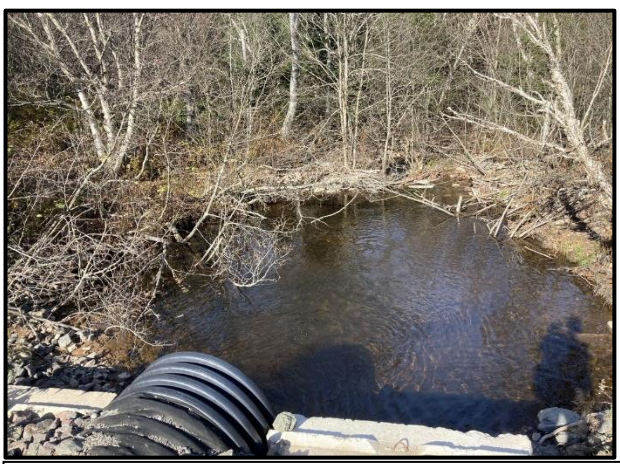


Map 2: Highlighting the 6 mountainous tributaries surveyed in 2021. Quigley Brook flows into Fletcher Brook, which subsequently flows into Hanford Brook. Jenny Lind Brook and Isaac Brook are also tributaries of Hanford Brook. *Map: base layer: GNB; additional sites: S. Blenis.*

Mill Brook







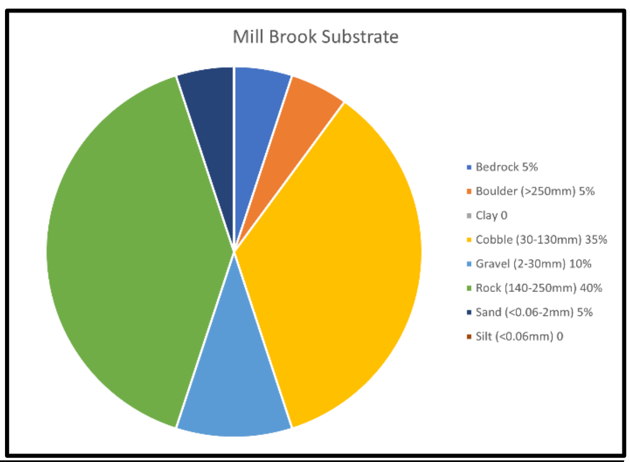
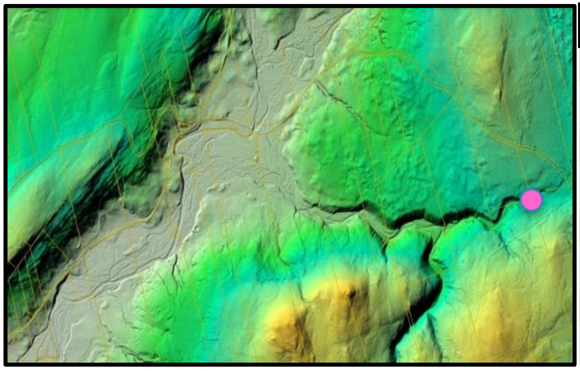


Photo 17 (top left): Upper reach of Mill Brook survey. **Figure 8** (top right): Riparian vegetation. **Figure 9** (middle left): Flow Type. **Photo 18** (middle right): Middle of Mill Brook. **Photo 19** (bottom left): Sampling site for Mill Brook. **Figure 10** (bottom right): Substrate Types. Brook trout and bait fish (minnows, dace, sculpin) were observed in the culvert outflow pool throughout the 2021 season- culvert provides fish passage, with some angling occurring at the outflow pool. *Photos: J. Kelly. Figures: S. Blenis.*

Mill Brook

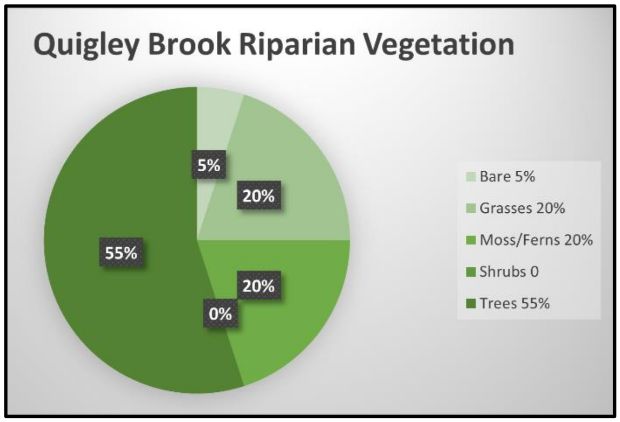


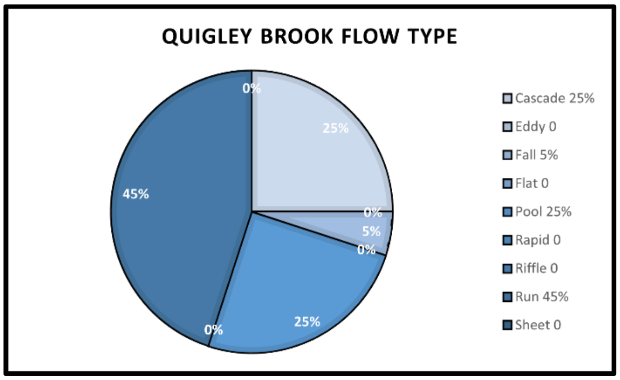
Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	50%	50%
Undercutting	5%	5%
Shade	45%	45%
Stable	40%	40%
Bare Stable	5%	5%
Eroding	5%	5%

Map 3 (top left): LiDAR imaging, demonstrating the valley that Mill Brook passes through before reaching the main stem. **Figure 11** (top right): Bank Characteristics. **Photo 20** (bottom center): Mill Brook below the sampling site. Substrate embeddedness was <20% embedded. Brook is clear in color, with steep slopes occurring on both the left and right bank. Mill Brook would be an excellent candidate for future electrofishing surveys or eDNA analysis for presence/absence of salmon. *Map: DNR. Figure: S. Blenis. Photo: J. Kelly.*

MOUNTAINOUS TRIBUTARIES- CHARACTERISTICS

Quigley Brook





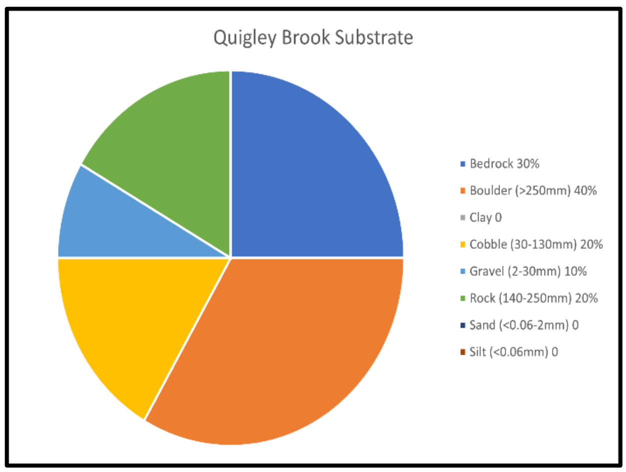
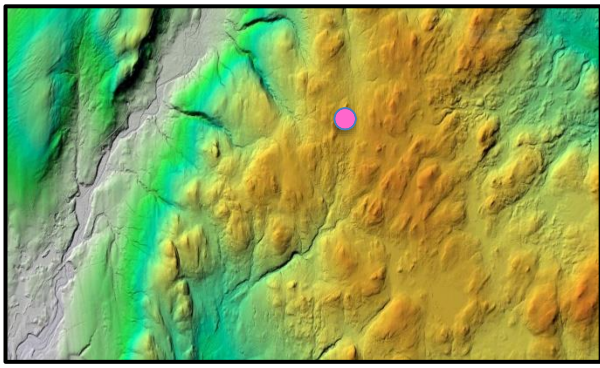


Photo 21 (top left): Upstream of the sampling site. **Figure 12** (top right): Riparian vegetation. **Figure 13** (middle left): Flow type. **Photo 22** (middle right): Downstream of the sampling site. **Photo 23** (bottom left): The sampling site at the culvert outflow. **Figure 14** (bottom right): Substrate. Brook trout were observed in the culvert outflow pool throughout the 2021 sampling season. Culvert allows fish passage. *Photos: J. Kelly, S. Blenis. Figures: S. Blenis.*

Quigley Brook

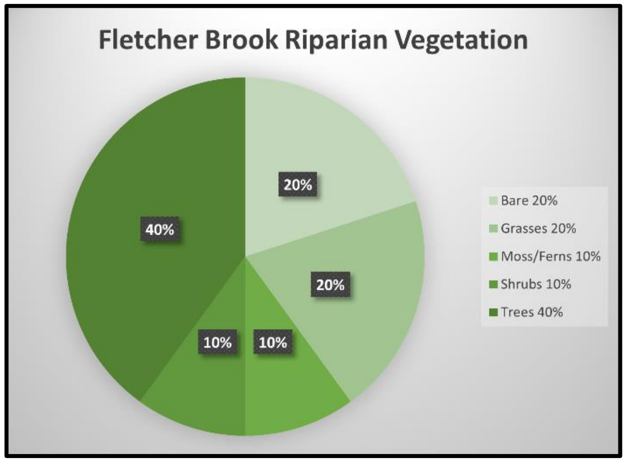


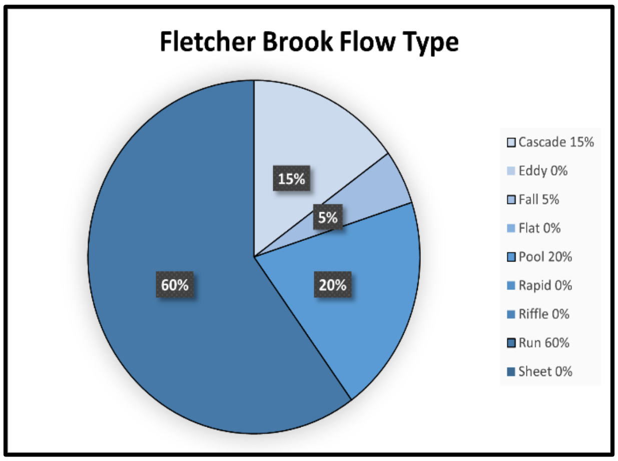
Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	30%	25%
Undercutting	5%	5%
Shade	20%	20%
Stable	45%	50%
Bare Stable	0%	0%
Eroding	5%	0%

Map 4 (top left): LiDAR imaging of Quigley Brook. **Figure 15** (top right): Bank characteristics. **Photo 24** (bottom center): Quigley Brook below the sampling site. Steep slopes, excellent riparian coverage, and substrate is <20% embedded. Undercut banks make for excellent fish habitat, while the cascades allow for excellent dissolved oxygen. *Figures: S. Blenis. Photo: J. Kelly.*

MOUNTAINOUS TRIBUTARIES- CHARACTERISTICS

Fletcher Brook





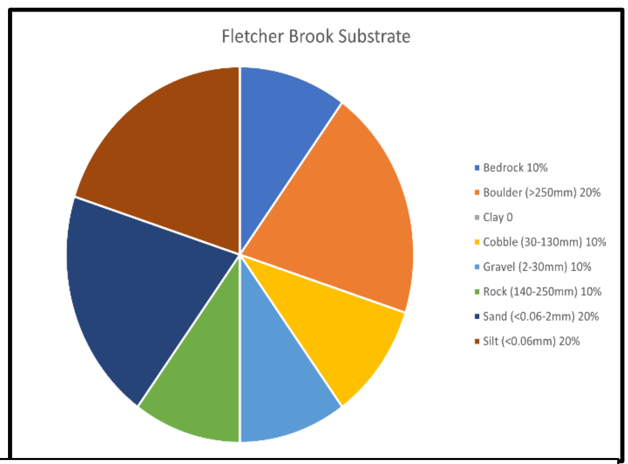
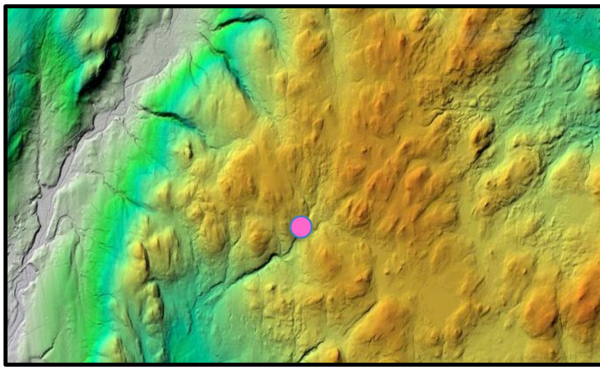


Photo 25 (top left): Upstream of the sampling site. **Figure 16** (top right): Riparian vegetation. **Figure 17** (middle left): Flow type. **Photo 26** (middle right): Downstream of the sampling site. **Photo 27** (bottom left): The sampling site at culvert outflow. **Figure 18** (bottom right): Substrate type. Brook trout were observed throughout the sampling season at the culvert outflow pool. Culvert allows fish passage.
Photos: S. Blenis & J. Kelly. Figures: S. Blenis.

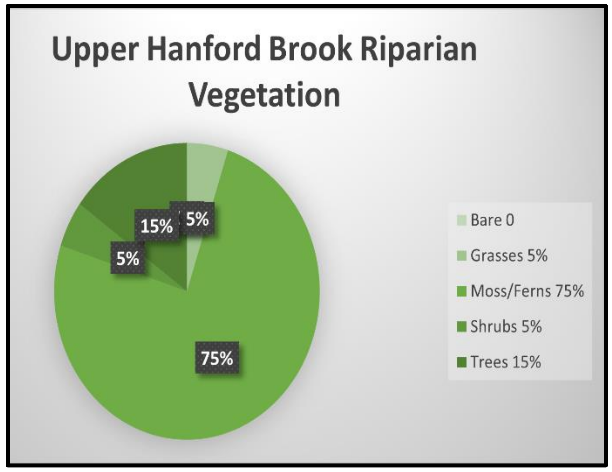
Fletcher Brook

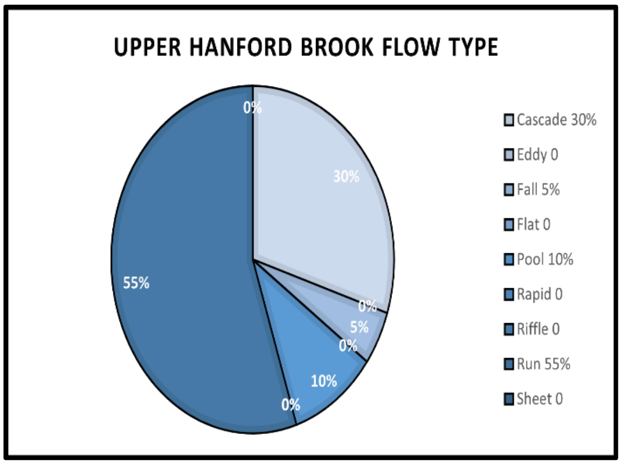


Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	30%	30%
Undercutting	0%	5%
Shade	50%	50%
Stable	25%	25%
Bare Stable	5%	5%
Eroding	20%	20%

Map 4 (top left): LiDAR imaging of Fletcher Brook. **Figure 19** (top right): Bank characteristics. **Photo 28** (bottom center): Fletcher Brook below the sampling site- this picture was taken at noon on a bright sunny day, demonstrating the high level of shade that is cast over the brook. Fletcher Brook offers an excellent matrix of flow types, as well as undercut banks and woody debris in the brook, providing excellent fish habitat.
Photos: J. Kelly. Figures: S. Blenis.

Upper Hanford Brook





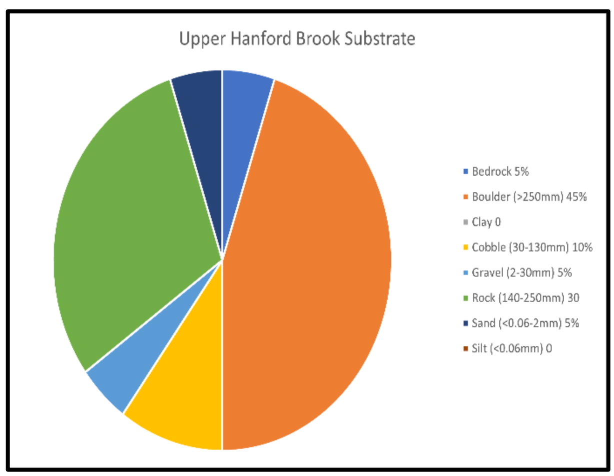
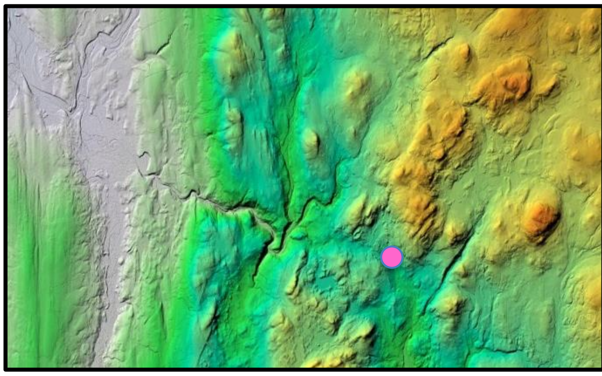


Photo 29 (top left): Upstream of the sampling site. **Figure 20** (top right): Riparian vegetation. **Figure 21** (middle left): Flow Type. **Photo 30** (middle left): Downstream of the sampling site. **Photo 31** (bottom left) The sampling site. **Figure 22** (bottom right): Substrate. Brook trout and minnows were observed in this stretch in the 2021 sampling season. *Photos: J. Kelly. Figures: S. Blenis.*

Upper Hanford Brook

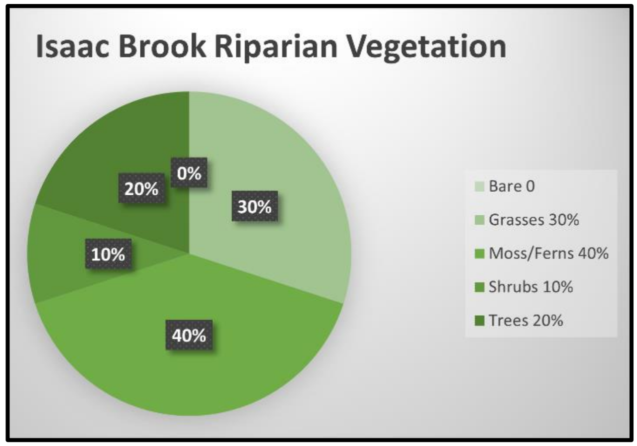


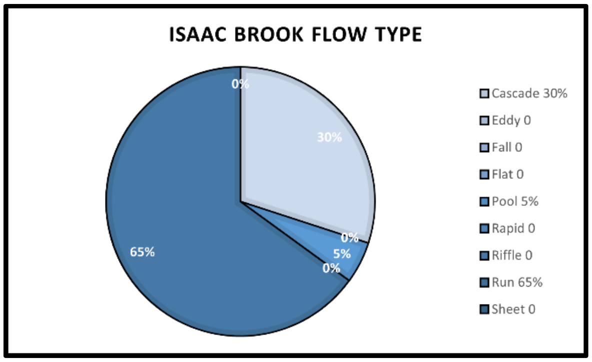
Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	40%	40%
Undercutting	0%	5%
Shade	50%	50%
Stable	45%	50%
Bare Stable	0%	0%
Eroding	5%	0%

Map 5 (top left): LiDAR imaging of Hanford Brook. **Figure 23** (top right): Bank characteristics. **Photo 32** (bottom center): Upstream of the sampling site, representing the upper reach for fish passage. Above this area, Hanford Brook is fed by a large wetland, and above the wetland is Porcupine Lake. HRAA has proposed a new project for the 2022 season that will further investigate Porcupine Lake, Hanford Brook and the tributaries that feed into it. *Figures: S. Blenis. Photo: J. Kelly.*

MOUNTAINOUS TRIBUTARIES- CHARACTERISTICS

Isaac Brook





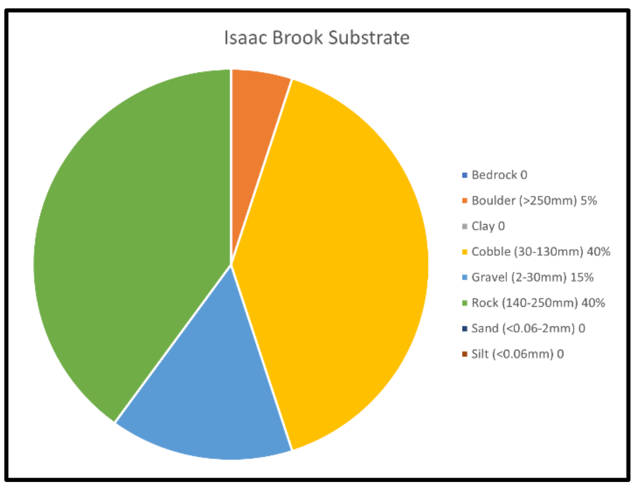
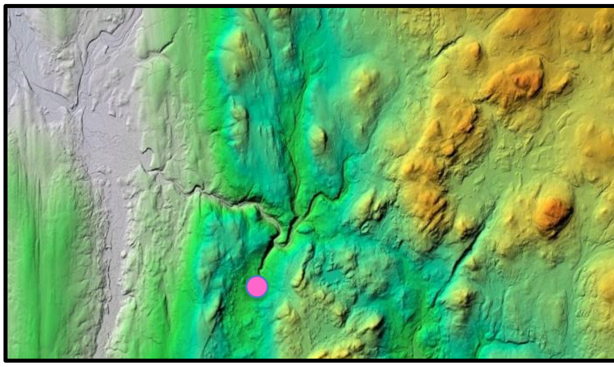


Photo 33 (top left): Upstream of the sampling site. **Figure 24** (top right): Riparian vegetation. **Figure 25** (middle left): Flow type. **Photo 34** (middle right) Downstream of the sampling site. **Photo 35** (bottom left) The sampling site with HRAA's YSI kit and sampling bottles. **Figure 26** (bottom right) Substrate type. Brook trout and minnows were observed in this stretch throughout the 2021 sampling period. *Photos: J. Kelly. Figures: S. Blenis.*

Isaac Brook

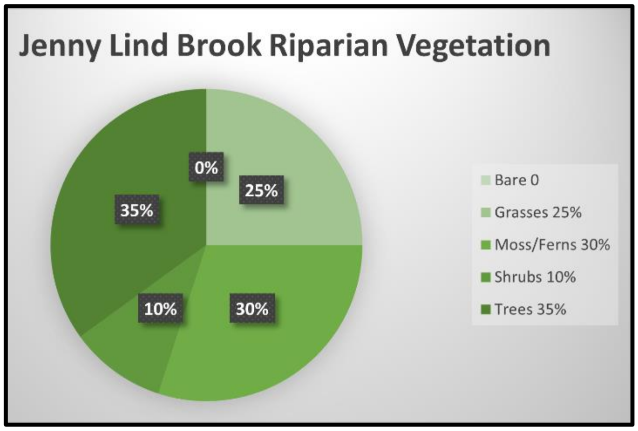


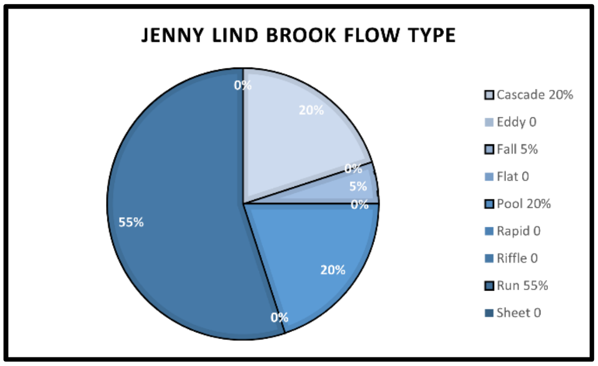
Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	40%	40%
Undercutting	5%	5%
Shade	50%	50%
Stable	50%	50%
Bare Stable	0%	0%
Eroding	0%	0%

Map 6 (top left): LiDAR imaging of Isaac Brook. **Figure 27** (top right): Bank characteristics. **Photo 36** (bottom center): downstream of the sampling site. The headwaters of the Isaac Brook is Tracy Lake. Tracy Lake received a "Marginal" water quality index score in HRAA's 2021 Lake Assessment due to its trace metal exceedances, which can also be found within Isaac Brook. Despite exceedances, both the lake and brook are teeming with aquatic life. *Figures: S. Blenis. Photo: J. Kelly.*

MOUNTAINOUS TRIBUTARIES- CHARACTERISTICS

Jenny Lind Brook





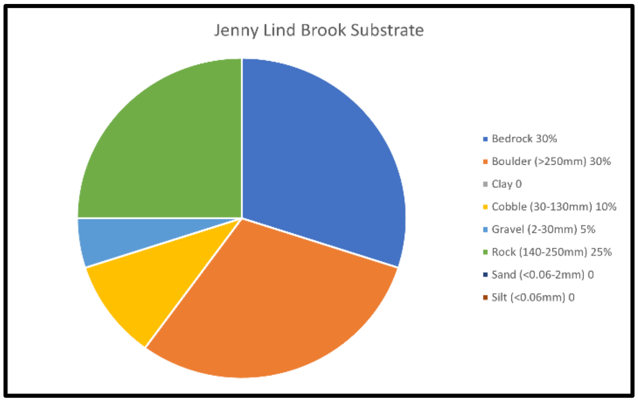
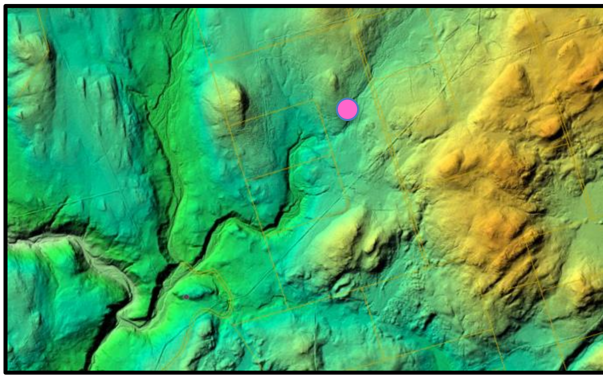


Photo 37 (top left): Upstream of the sampling site. **Figure 28** (top right): Riparian vegetation. **Figure 29** (middle left): Flow type. **Photo 38** (middle right): Downstream of the sampling site. **Photo 39** (bottom left): The sampling site. **Figure 30** (bottom right): Substrate type. In 2020, the HRAA submitted the Jenny Lind Brook, Theobald Lake, and upper Irish River to the province of New Brunswick as a Candidate Protected Natural Area, and this candidacy was approved in 2021 through the Nature Legacy Program. The Jenny Lind Brook received a perfect water quality index score and is indeed worthy of conservation and protection! *Photos: S. Blenis & J. Kelly. Figures: S. Blenis.*

Jenny Lind Brook

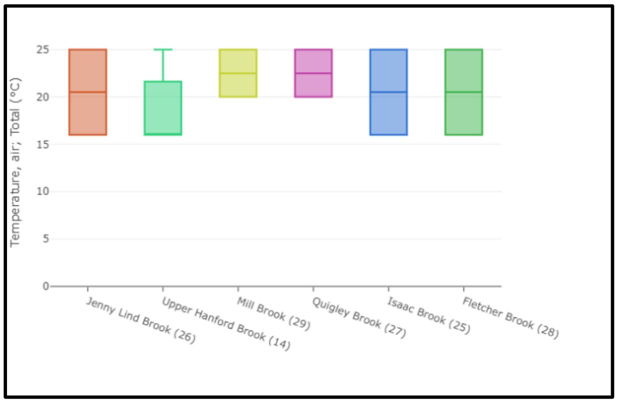


Bank Characteristic	Left Bank	Right Bank
Forest Maturity	Mature	Mature
Slope	High	High
Overhanging Vegetation	40%	45%
Undercutting	10%	5%
Shade	40%	40%
Stable	50%	50%
Bare Stable	0%	0%
Eroding	0%	0%

Map 7 (top left): LiDAR imaging of Jenny Lind Brook. **Figure 31** (top right): Bank characteristics. **Photo 40** (bottom center): Below the sampling site. The Jenny Lind Brook is an absolute gem of the Hammond River watershed, and the HRAA field staff felt extremely grateful to the NB Environmental Trust Fund for allowing us the opportunity to investigate these upper mountainous tributaries! *Figures: S. Blenis. Photo: J. Kelly.*

MOUNTAINOUS TRIBUTARIES- WATER QUALITY

All 6 tributaries demonstrated excellent crown coverage and excellent riparian zones, leading to beautiful shade over the tributaries. A major focus on investigating these mountainous tributaries was to determine their overall impact on the Hammond River- are they providing cold-water refugia for aquatic species, and are they contributing to keeping the main stem cool during the summer months? Indeed, these mountainous tributaries are contributing significantly to the headwaters of the Hammond River watershed.



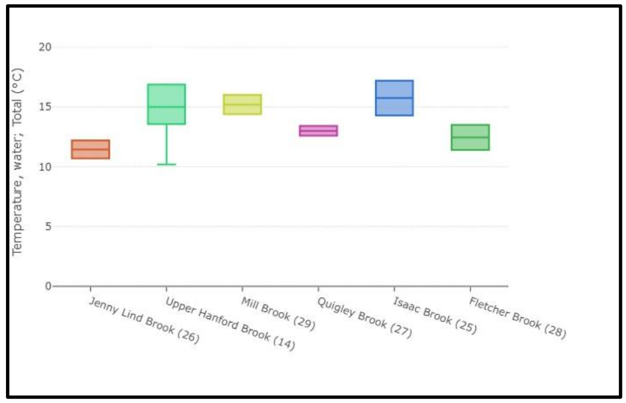


Figure 32 (left): Air Temperature. **Figure 33** (right): Water Temperature. *Figures: S. Blenis*

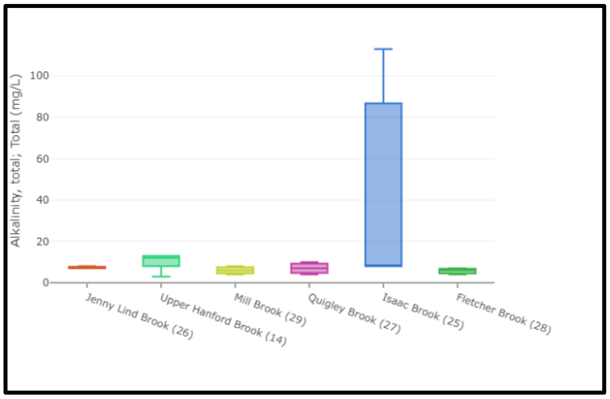
Peak summer air temperatures hit 25°C in the upper tributary locations; however, peak water temperatures in the summer only hit a maximum temperature of 16.5°C in Isaac Brook, while the majority of the mountainous tributaries remained below 15°C. The Jenny Lind Brook, which received a perfect water quality index score, remained an excellent cold-water tributary throughout the year, reaching maximum water temperature of 13.5°C in August, when many of the index sites and main stem were peaking at >20°C.

Water temperature is one of the driving factors for biological processes in river ecosystems and often defines critical habitats for biota. Aquatic habitats are facing threats from human altered landscapes, including impacts on river thermal regimes and the increasing air temperatures and changes in precipitation patterns with a warming climate (O'Sullivan et al., 2019). These mountainous tributaries are predominately unaltered by anthropogenic factors and have retained their ability to provide cold water habitat.

For cold water fishes in shallower rivers, warm summer temperatures increase physiological stress and in response, individuals will relocate to colder river sections if such are accessible (O'Sullivan et al., 2019). Brook trout were observed in all of these 6 mountainous tributaries throughout the field season, indicating that there is suitable habitat and temperature. It is also possible that fish are emigrating from the main stem river and seeking out these cold water refugia during the hot summer months. Additionally, these cold-water tributaries are flowing into the headwaters of the Hammond River, contributing to cooling the main stem during the peak summer months. On average, the 6 mountainous tributaries were 5°C cooler than the lower index tributaries throughout the summer!

MOUNTAINOUS TRIBUTARIES- WATER QUALITY

Alkalinity is the ability of a water body to buffer against sudden changes in pH. Hardness is a result of major cations like magnesium and calcium sopping up excess H + ions. In general, high levels of alkalinity and hardness represent favorable conditions for fish health, by easing osmoregulation in fish and resilience in the system (WHO, 2011).



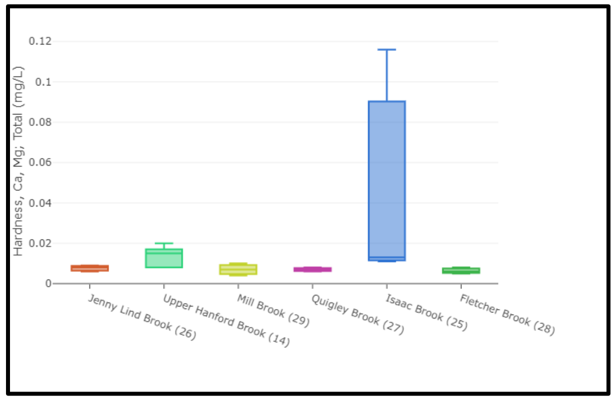


Figure 34 (left): Alkalinity in the 6 mountainous tributaries. **Figure 35** (right): Hardness in the 6 mountainous tributaries. *Figures: S. Blenis*

Isaac Brook demonstrates significantly higher levels of alkalinity and hardness in comparison to the other 5 mountainous tributaries. Although a fish density survey was not complete in any of the mountainous tributaries, it is anticipated that Isaac Brook contains a significantly higher density of fish based on *HRAA's 2021 Lake Assessment*, which found a variety of fish species in Tracy Lake, the headwaters of Isaac Brook.

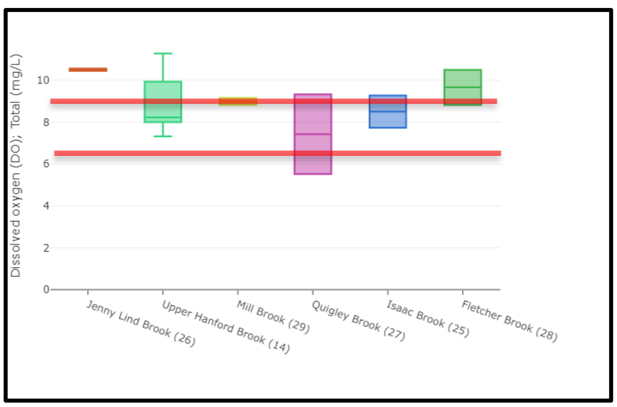
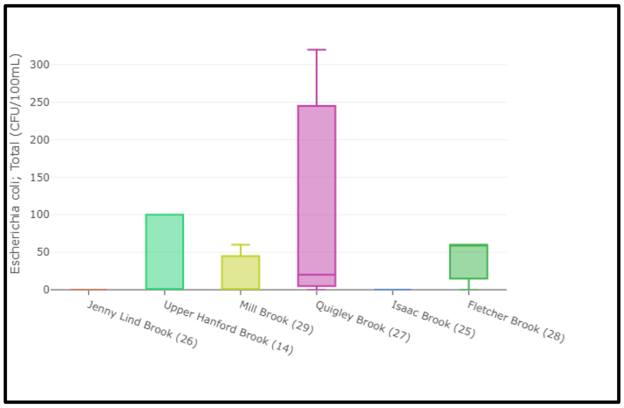
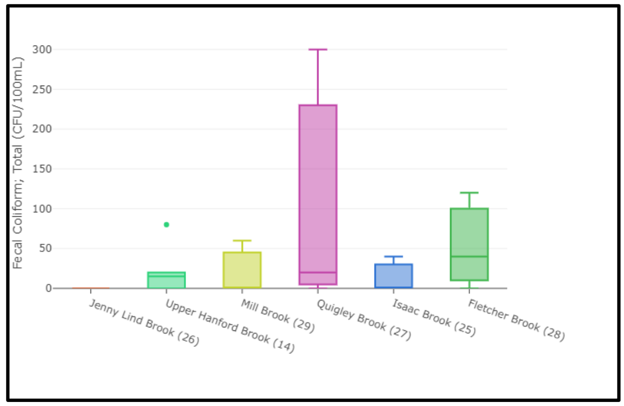


Figure 36. Dissolved oxygen levels in the 6 mountainous tributaries. All tributaries demonstrated acceptable dissolved oxygen levels to sustain other life stages of aquatic life, while the Jenny Lind Brook, Upper Hanford Brook, and Fletcher Brook consistently demonstrated acceptable dissolved oxygen levels to sustain early life stages of aquatic life. Quigley Brook's dissolved oxygen levels were slightly lower than the other 6 tributaries; however, this is a result from poor site selection for sampling (i.e.: in hindsight, the sampling site was not representative of the overall tributary). *Figure: S. Blenis.*

MOUNTAINOUS TRIBUTARIES- WATER QUALITY

Bacterial analysis was performed throughout the field season in each of the 6 mountainous tributaries. It should be noted that there are no residential dwellings or industrial facilities in proximity to these tributaries- any bacterial content is to be considered naturally occurring (i.e.: from wildlife).





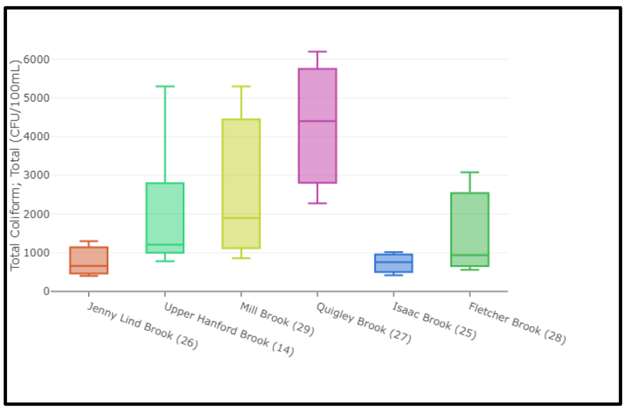
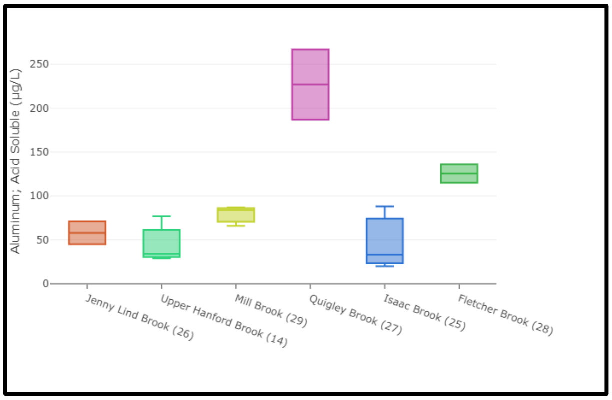


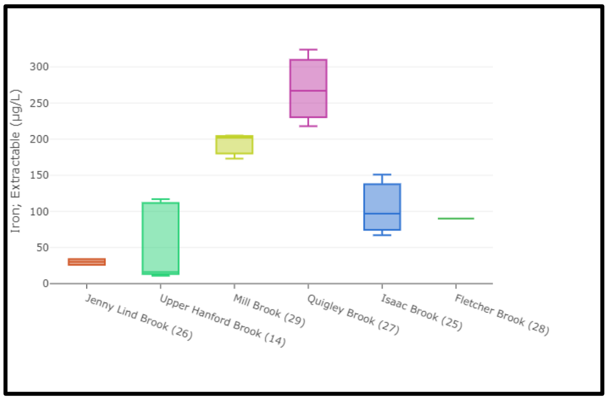
Figure 37 (top left): *E. coli* levels in the mountainous tributaries. **Figure 38** (top right): Fecal coliforms in the mountainous tributaries. **Figure 39** (bottom center): Total coliform levels in the mountainous tributaries. *Figures: S. Blenis.*

Acceptable levels of *E. coli* for the protection of aquatic fish health are ≤ 400 MPN/ 100 mL (Health Canada, 2012). *E. coli* Used as an indicator of microbial concentrations in water, sources of contamination include human and animal fecal matter, and in the case of the upper 6 tributaries, all sources of *E. coli* are therefore contributed to wildlife fecal matter. Quigley Brook had the highest level of *E. coli* in the mountainous tributaries; however, it did not exceed ≤ 400 MPN/ 100 mL. Higher bacterial levels can increase algae growth, thus decreasing dissolved oxygen; however, algal abundance and macrophyte coverage was generally very low in all 6 of the mountainous tributaries with wonderful water clarity and low turbidity levels, indicating that the 6 mountainous tributaries can be classified as oligotrophic (waters are clear to great depths and have few algae). eDNA metabar analysis would be an interesting undertaking in these mountainous tributaries, to determine if there are terrestrial species at risk in the area (i.e.: Canada lynx, or perhaps the legendary Eastern Cougar), particularly considering that these 6 mountainous tributaries are far out of reach of human interference.

MOUNTAINOUS TRIBUTARIES- WATER QUALITY

The Caledonia Highlands have long been the focal point for metal resource exploration, with a particular focus on investigating copper resources in 2018; however, copper was not detected in any of the water quality samples for the 6 mountainous tributaries in the 2021 field season.





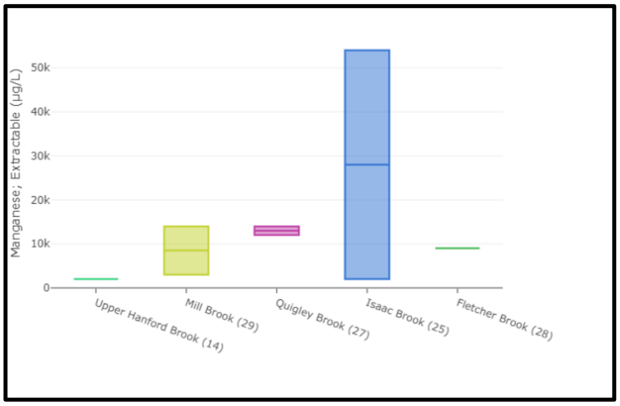


Figure 40 (top left): Aluminum concentrations in the mountainous tributaries. **Figure 41** (top right): Iron concentrations in the mountainous tributaries. **Figure 42** (bottom center): Manganese concentrations in the mountainous tributaries. *Figures: S. Blenis.*

During the initial proposal for *Maintaining Water Quality Data While Adapting to Climate Change*, it was hypothesized by HRAA staff that the 6 upper tributaries would receive high water quality index scores, or be classified as Class O tributaries, according to the *NB Water Classification Guide.* While all 6 offer excellent riparian characteristics, flow types, substrate, and embeddedness all <20%, high dissolved oxygen, low water temperatures, low turbidity, and acceptable levels of pH, alkalinity, conductivity, and hardness, several of the mountainous tributaries ranked fairly low in the water quality index score as a result of trace metals in the water quality samples. While the Jenny Lind Brook received a perfect score and did not have high levels of trace metals, the other 5 tributaries (particularly Quigley Brook and Isaac Brook) contained very high concentrations of aluminum, iron, and manganese. Manganese has been previously documented in the watershed in high concentrations in the headwaters in Markhamville (including the 1800's manganese mine); however, the discovery of such high levels of manganese in Isaac Brook is a new discovery within the Hammond River watershed for the HRAA. As a result of the trace metals, Quigley Brook ranked as "marginal", while Isaac Brook and Fletcher Brook ranked in the lower half of the water quality index ratings.

HEADWATERS WATER QUALITY

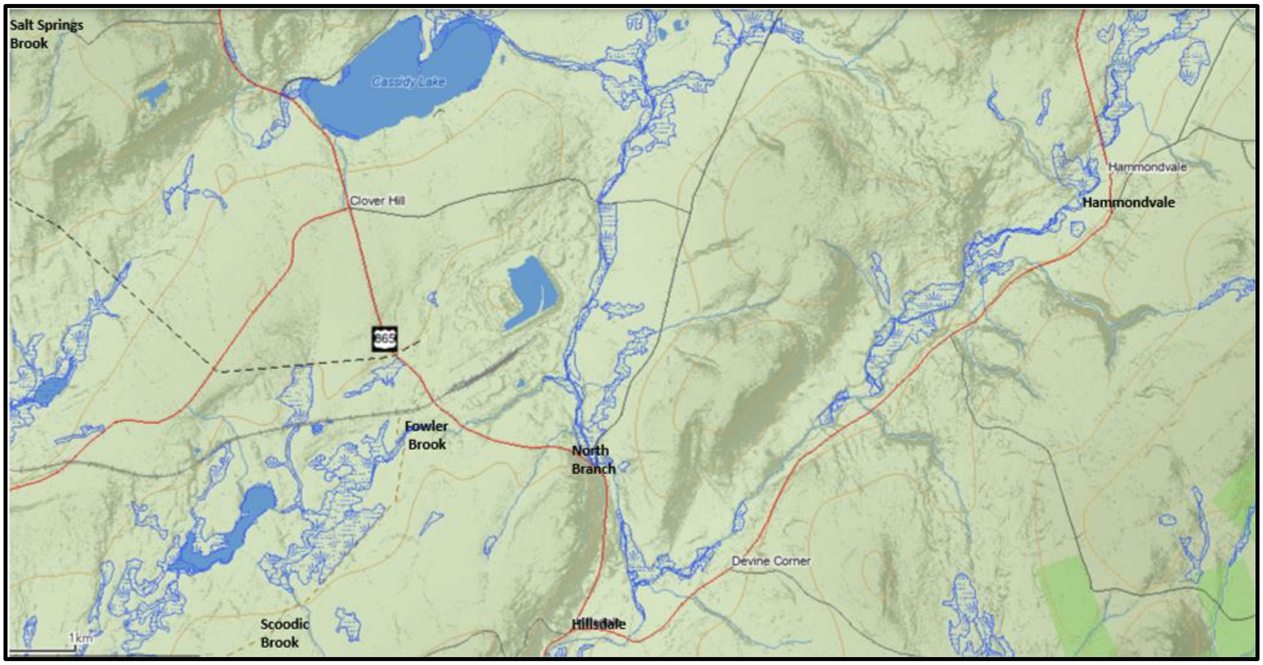
The focus of *Maintaining Water Quality While Adapting to Climate Change* was comparing index sites to their confluence points and investigating mountainous tributaries, part of the project included maintaining water quality data collection throughout the watershed. Hammondvale, Hillsdale, and the North Branch, (with its tributary, Fowler Brook), are the headwaters of the Hammond River, and they are historical main stem index sites (i.e.: they do not have confluence points); therefore, the discussion on these sites is separate from the other 2 components of this report.

These sites are located in the northwest watershed within the townships of Hillsdale, Hammondvale and Markhamville. This area received a Class A rating under the *NB Water Classification Program* in 2008; however, the *2015 Watershed Management Plan* and *2020 Watershed Management Plan* assessments indicated that this sub-catchment may have deteriorating environmental conditions, including a stressed riparian buffer and benthic macroinvertebrate community, and this area is now considered a priority area. This area is also considered a priority for water quality monitoring, given its close proximity to the Cassidy Lake potash mine and its brine line.

This sub-catchment is 93.75 km^2 in size, and road density (1.7 km/km2) was measured to cause moderate stress in this area, which has led to high stress from aquatic fragmentation (99 out of 144 stream segments are disrupted). Unfortunately, this sub-catchment is the largest and has the lowest quality of riparian buffer (18.88 % is undeveloped) warranting a rating of impacted. Attempts at riparian restoration in 2020 at the Hammondvale site were unfortunately undone by agriculture practices mowing over 1,000 freshly planted willow stakes, despite achieving landowner permission for the planting. Headwaters, like the waterways in Hammondvale, Hillsdale, and the North Branch, are usually characterized by strong riparian areas that shade the stream, cool water temperature, and limited autotrophic production with the majority of energy input from organic matter detritus (Vannote et al., 1980); however, this is no longer the case, with anthropogenic stressors greatly impacting the overall quality of the headwaters of the Hammond River.

A river's tributaries are typically smaller and often cooler than main stems because of smaller scale effects that can increase groundwater contributions to baseflow and where the interception of solar radiation by riparian canopy can be important (O'Sullivan et al., 2019); however, the headwaters are the most fragile component of a watershed (Daniel et al., 2014) and jeopardizing their integrity and resilience can have longstanding implications for environmental quality downstream.

It is even more crucial to protect this area because it provides important spawning habitat for salmon. Despite all stressors, all sites in the headwaters produced juvenile Atlantic salmon in the 2021 electrofishing survey, as well as producing salmon spawning redds during the 2021 redd count survey, and historically, the headwaters has continuously maintained the highest density of juvenile salmon and spawning salmon. It should also be noted that the 6 mountainous tributaries join the Hammond River in the headwaters area and are directly contributing to maintaining the water quality and habitat for aquatic life.

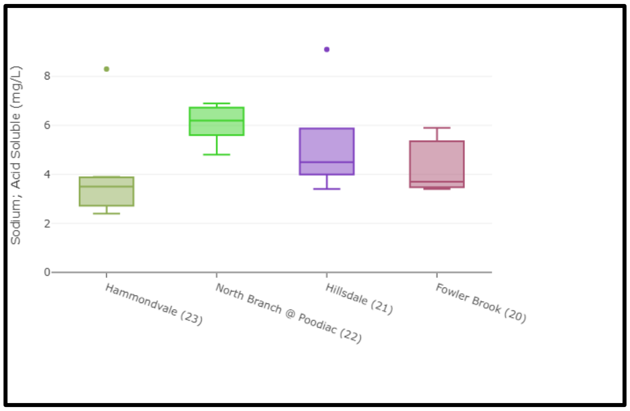


Map 8: Demonstrating the headwaters of the Hammond River, including index sampling sites Hammondvale, Hillsdale, North Branch and Fowler Brook. Included in this map is the upper reach of Salt Springs Brook and the upper reach of Scoodic Brook. *Map: DNR & S. Blenis.*

Photo 41: Looking upstream of the North Branch from the index sampling site. This area consistently produces juvenile Atlantic salmon and spawning redds. *Photo: S. Blenis.*

Headwaters Water Quality

While the potash mine has now closed, the Cassidy Lake Division of the PotashCorp (PCS) tailings pond and brine line still exist. The 2008 *Watershed Management Plan* describes a significant brine spill that occurred in the 1980's, 1994, and 2009. In 2008, HRAA staff had detected that chamber #1, located directly above Fowler Brook, had failed and a large brine spill occurred. An imperfect liner in the tailings pond of Cassidy Lake Division has also been leaking brine into the environment since 2008. As it continues to age and deteriorate, the probability of future failures and brine line spills increases, increasing the need to maintain water quality monitoring in the headwaters of the Hammond River.



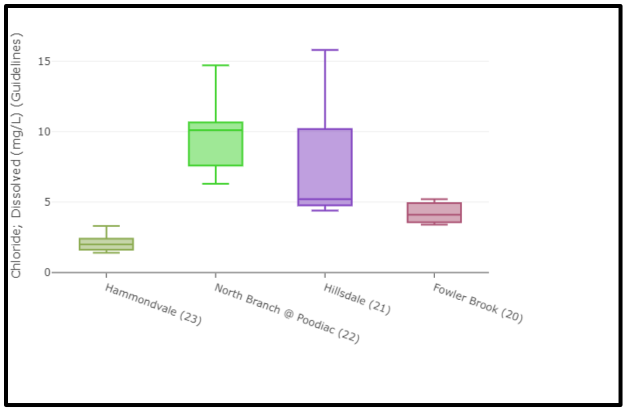


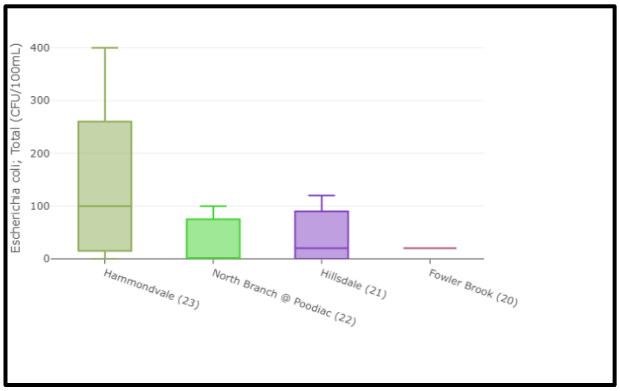
Figure 43 (left): Sodium results for the headwater area. **Figure 44** (right): Chloride results for the headwater area. *Figures: S. Blenis.*

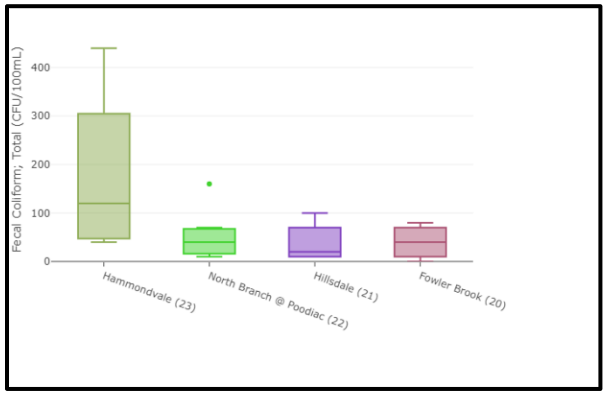
The two most reliable brine spill indicators are chloride and bromide. Degradation of water quality by brine is indicated where chloride concentration is equal to or greater than 400 milligrams per liter; bromide concentration is equal to or greater than 2 milligrams per liter; the ratio of lithium to sodium is equal to or less than 0.01, and the chloride concentration is equal to or greater than 400 milligrams per liter; or the ratio of sodium plus chloride to dissolved solids is equal to or greater than 0.64 (Morton, 1984). Other ratios of secondary importance that also indicate water-quality degradation by brine in the area are a sodium/chloride ratio of about 0.46; a sodium/bromide ratio of about 92; and a bromide/chloride ratio of about 0.0048.

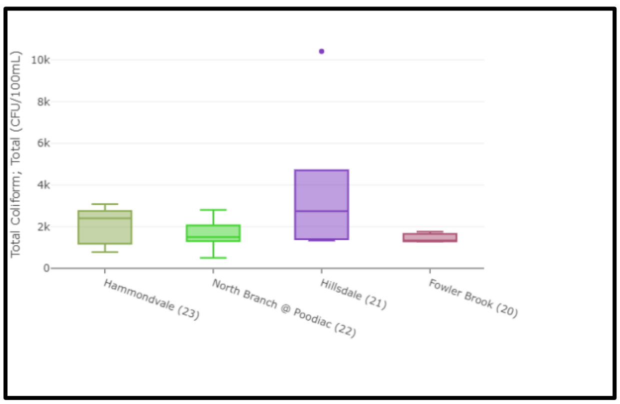
All sites sampled in 2021 were void of bromide. The Hillsdale site was used to determine ratio of sodium/chloride, as it is the lowest point in the headwaters and would be the receiving environment of a brine spill. With a maximum result of 9.1 mg/L of sodium and 15.8 mg/L of chloride, the results indicate a ratio of sodium/chloride of 0.56 indicating that the slow leak from a degraded liner may still occurring; however, the overall chloride levels are still below 400 mg/L to indicate a large, steady spill is occurring. Additional water quality samples are warranted, and a full, long-term monitoring plan of the headwaters in relation to the brine line and the Cassidy Lake PotashCorp tailings pond should be undertaken as a priority in the near future.

Headwaters Water Quality

Bacterial exceedances have been an on-going concern in the headwaters of the Hammond River, particularly within the Hammondvale site. Substrate embeddedness continues to increase in the Hammondvale site, as a direct result of erosion and sedimentation caused by a degraded riparian zone. By mid-summer, Hammondvale and Hillsdale begin to develop significant algal growth, and the water becomes increasingly turbid and tannin in color, indicating a shift from oligotrophic to mesotrophic. The weak vegetative riparian buffer and poor water drainage may contribute significantly to reductions in water attenuation, filtration, and normal headwater function.







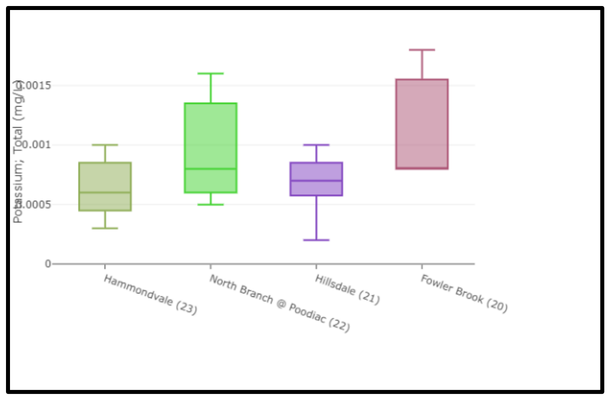


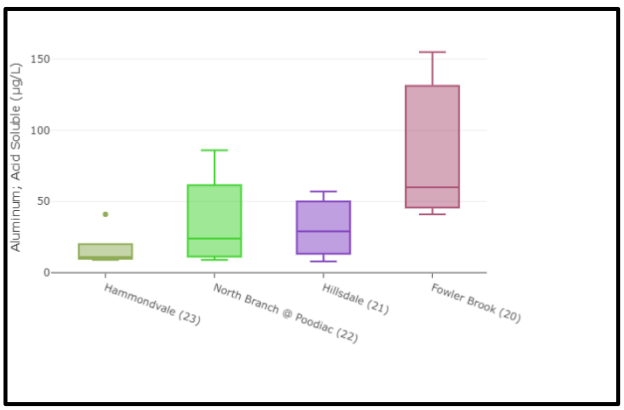
Figure 45 (top left): *E. coli* in the headwaters area. **Figure 46** (top right): Fecal coliforms in the headwaters area. **Figure 47** (bottom left): Total coliforms in the headwaters area. **Figure 48** (bottom right): Potassium in the headwaters area. *Figures: S. Blenis.*

While nitrate, nitrite, and phosphorus levels were consistently all below detection limits throughout the sampling period, the headwaters area had relatively higher levels of potassium, which is the third key ingredient in many agricultural fertilizers; however, it may be possible that the higher levels of potassium are from the potash deposit in the area, or perhaps a combination of both a geological resource being exposed to groundwater and deposited into the watercourses from fertilization practices. The bacterial content and potassium content may be increasing algal growth in this area, decreasing dissolved oxygen, and increasing water temperatures. Given the area's high importance level for salmonids, it is imperative that the HRAA continue to engage surrounding landowners and encouraging them to maintain best practices with regards to their agricultural practices.

Headwaters Water Quality

One of the most surprising results from water quality sampling in 2021 was the overall ranking of Fowler Brook. Fowler Brook, a tributary of the North Branch, appears to be in pristine condition, with beautiful riparian coverage, substrate, fish habitat and species abundance (including juvenile salmon) and relatively low anthropogenic stressors; however, it ranked the 5th lowest scoring tributary in the watershed according to the CCME Water Quality Index score.

Photo 42 (left): Upstream view of Fowler Brook. **Photo 43** (right): Downstream view of Fowler Brook. *Photos: S. Blenis.*



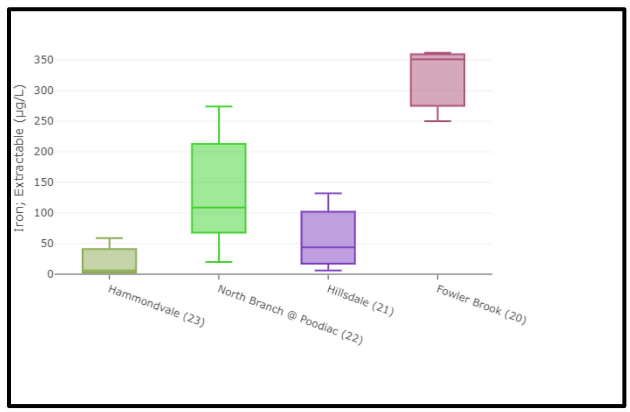


Figure 49 (left): Aluminum concentrations in the headwaters area. **Figure 50** (right): Iron concentrations in the headwaters area. *Figures: S. Blenis.*

Fowler Brook's headwaters is a wetland that also feeds into Scoodic Brook, giving Fowler Brook very similar exceedances in aluminum and iron, subsequently dropping it down in the water quality index rankings, similar to Scoodic Brook. Fowler Brook also contained high levels of manganese (26 mg/L); however, the CCME does not currently have a guideline for acceptable levels of manganese to protect aquatic life. Manganese is a naturally occurring substances that is present in surface waters and biota. Aquatic organisms have exhibited toxic responses to manganese in surface waters and regulatory bodies in some jurisdictions have established guidelines for levels of manganese in surface water to protect aquatic life. In British Columbia, a range of 0.6 mg/L at a hardness of zero to 1.9 mg/L at a water hardness of 325 mg/L CaCO3 was established by the Ministry of Environment, Lands and Parks, although it was recognized that the scientific data on which this guideline was based were weak (Reimer, 1985).

ADDITIONAL SITES

McGonagle Brook & O’Dell Brook

As per the initial proposal for *Maintaining Water Quality Data While Adapting to Climate Change*, HRAA staff proposed to regularly sample 12 index sites and their subsequent confluence points throughout the 2021 season; however, we realized that 2 of these index sites were located in the main stem river, thus not containing a confluence point- Hammondvale and Hillsdale. This provided the HRAA with the flexibility to investigate two additional sites whose water quality data not been updated in over a decade- McGonagle Brook and O’Dell Brook.

Photo 44: Upstream of the sampling site. Willows pictured on the right and left bank are from the restoration project in 2000. *Photo: S. Blenis.*

Both McGonagle Brook and O’Dell Brook represent historic HRAA restoration sites from 2000. These sites were severely degraded and lacked a vegetated riparian buffer and were allowing full livestock access to both brooks. In 2000, HRAA staff installed fence posts and limited livestock access to the brooks, as well as planting approximately 2,500 willows, mountain ash, and dogwood. Both sites are considered to be two of the top restoration efforts in HRAA’s history, as these sites now appear almost fully naturalized, with less erosion and turbidity, and exceptional crown coverage.

In 2000, the major stressors facing O’Dell Brook and McGonagle Brook included nutrient loading (nitrate, nitrite, phosphorus) and bacterial content (*E. coli*, fecal coliforms, total coliforms), turbidity, water clarity, algal growth, warmer water temperature and low dissolved oxygen. Both brooks were cited as having decreased fish abundance in comparison with other sites within the watershed.

After 21 years of growth, the riparian restoration initiatives, along with land use practice adjustments from the landowners, both brooks have had a noticeable improvement in their overall water quality. It was a very worthwhile endeavor indeed to document the success of these two!

McGonagle Brook & O’Dell Brook

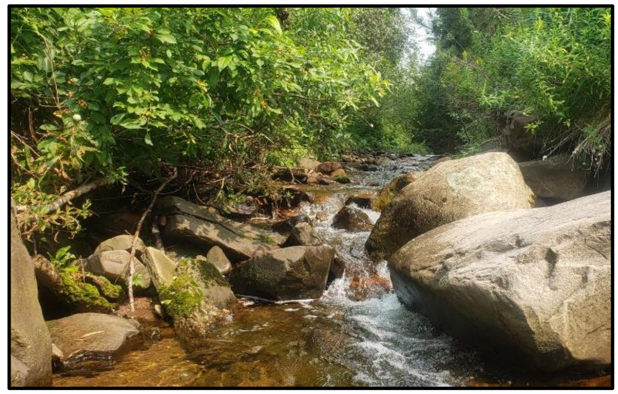
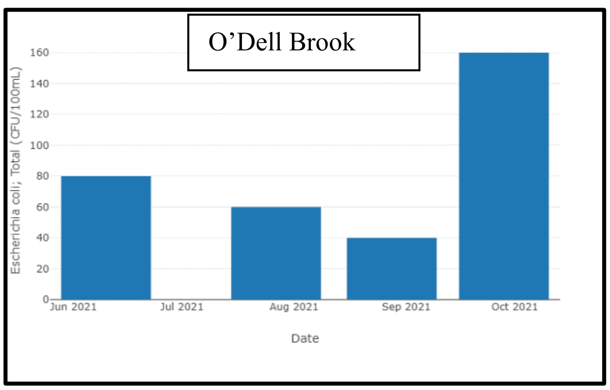


Photo 45 (left): McGonagle Brook. **Photo 10** (right): O’Dell Brook. *Photos: S. Blenis.*

In 2021, O’Dell Brook received a perfect score on the Water Quality Index, and McGonagle Brook ranked fairly high out of all sites surveyed, ranking at 9th place overall, with a score of 94.1, or “Good”. McGonagle Brook came very close to receiving a perfect score, like O’Dell Brook, except two of the dissolved oxygen results came in at a conservative 9 mg/L, just shy of the 9.5 mg/L required for early life stages of aquatic life. In both cases, bacterial levels, particularly *E. coli*, decreased dramatically.



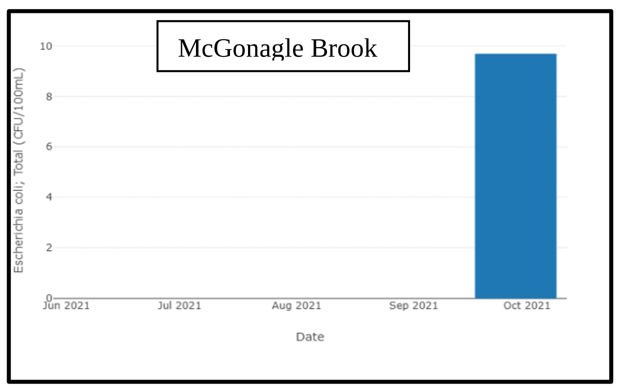


Figure 51 (left): *E. coli* levels in O’Dell Brook. **Figure 52** (right): *E. coli* levels in McGonagle Brook. *Figures: S. Blenis.*

As in 2000, both brooks have high densities of livestock (cows) surrounding the tributaries; however, the riparian restoration initiatives have helped limit livestock access and have provided a vegetative buffer around both tributaries. Turbidity has significantly decreased, as has erosion, and total suspended solids. During heavy rainfall events, the brooks have significantly improved water clarity. Both of these brooks were observed to contain brook trout throughout the 2021 field survey; however, neither brook was part of the electrofishing survey. Determining if there is salmon presence in these brooks in the future would be an interesting undertaking. O’Dell Brook, with its perfect score, would make an excellent candidate as a “Demonstration Site” to promote riparian restoration to other landowners, as it is a shining example within the watershed!

Salt Springs Brook

Salt Springs Brook is approximately 22.5 kilometers in length and is the longest tributary in the Hammond River watershed. Two sample sites were selected for the 2021 sampling season, based on historical index site records. Originally, Salt Springs Brook would have been part of the index site-confluence point investigation; however, HRAA staff were not able to obtain landowner permission to cross the land to access the confluence point. The confluence point is also approximately 2.2 kilometers from the nearest access point, creating difficulties to regularly sample the confluence point, regardless of landowner permission. As a result, Salt Springs Brook has not been included in the aforementioned discussion of index sites and confluences; instead, it is being discussed separately, as to not interfere with the integrity of the index-confluence point examination.

HRAA staff selected a historic index site at the upper reach of Salt Springs Brook and determined that a suitable secondary historic site located at the lower reach of the tributary, below all residential or agricultural uses, would provide a similar comparison of “upper versus confluence”, as per the theme of this project.

Historically, Salt Springs Brook contains the highest juvenile salmon densities, and second highest redd densities in the watershed, and these numbers were once again confirmed in the fall of 2021. As its name suggests, Salt Springs Brook is indeed spring fed with vast salt deposits and salt caverns, creating high levels of salinity, sodium, chloride, and conductivity.

Salt Springs Brook, both its upper and lower reach, is bordered by forest, forested wetland, housing developments and pasture in the lower reaches. Moderate stress is caused by the second highest occurrence of aquatic fragmentation in the watershed, high road density and agricultural land density is the third highest in the watershed; however, despite its vast length, juvenile salmon have been documented in both the lower and the upper reach in 2021, indicating that decent fish passage occurs throughout its entirety despite fragmentation. Substrate is significantly less embedded in the upper reach (<20%), while the lower reach of Salt Springs Brook is fairly embedded (20-35%) in certain areas that have experienced bank undercutting and erosion, the majority of the lower reach of Salt Springs Brook contains excellent gravel substrate, suitable for salmon spawning beds.

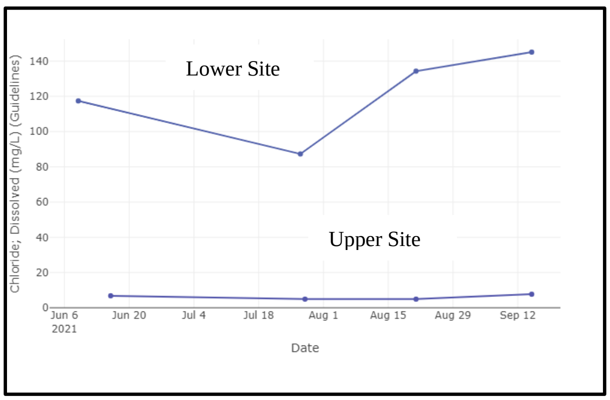
The *2008 Watershed Management Plan* determined that on the whole, Salt Springs Brook received a Class B Water Classification ranking, and noted that *E. coli* had a tendency to spike as high as 320 cfu/100mL in the peak summer months. The *2015 Watershed Management Plan* ranked the Salt Springs Brook as the 6th priority tributary out of 9 tributaries, while the *2020 Watershed Management Plan* determined the Salt Springs Brook to be one of the top priority brooks in the watershed, due to the erosion that is occurring in the lower reach of the brook in salmon spawning and juvenile habitat.

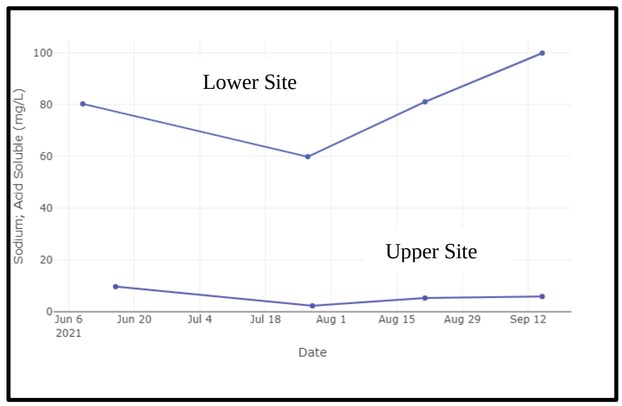
In 2021, efforts are currently underway to discuss riparian replanting initiatives with landowners along the lower reach, in order to ensure that the salmon habitat remains intact and viable for future salmon generations.

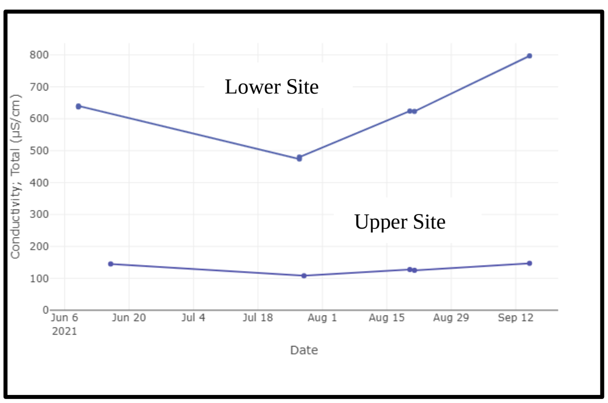
Salt Springs Brook

Salt Springs Brook has one of the most intriguing geological makeups in the watershed- it is underlain with salt deposits and salt caverns- these caverns were a hot topic in the late 1990's, as it was initially proposed to store liquid natural gas within these caverns. Community opposition aided in deterring this potentially environmentally hazardous project.

In 1901, water from Salt Springs became notorious for its holistic properties, and the creation of Mah-Pu Mineral Spring Co Ltd bottled spring water followed shortly thereafter, with a claim that "the water from this spring comes from a depth of 268 feet, through an iron pipe (the Spring was discovered by boring forth under great pressure rising to the height of 18 feet above ground, rising to the height of 18 feet. It is therefore free from impurities liable to occur in water of surface mineral springs. It has obtained an excellent reputation for its remarkable curative effects for rheumatism, gout, kidney, and intestinal disorders."







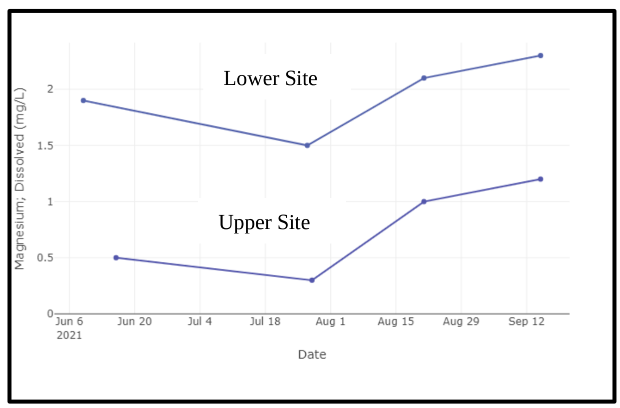
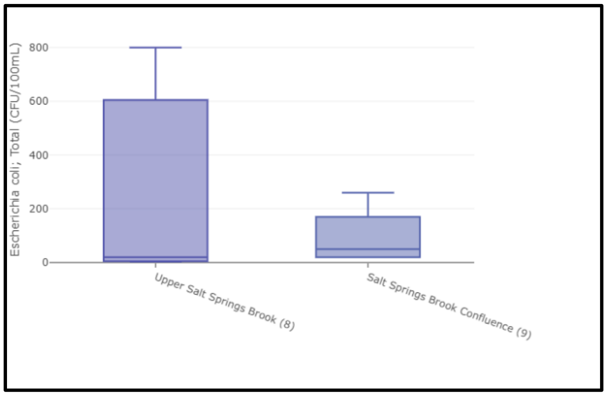


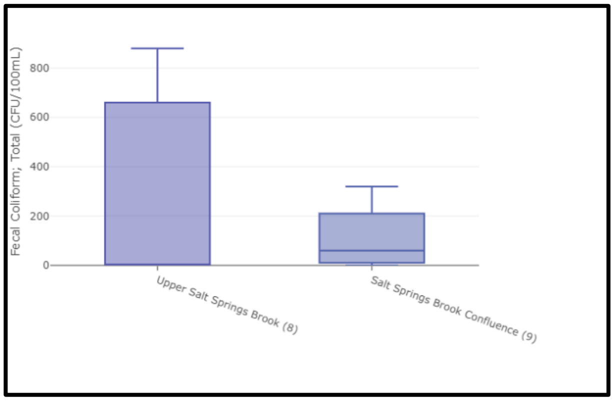
Figure 53 (top left): Chloride in upper and lower sites. **Figure 54** (top right): Sodium in upper and lower sites. **Figure 55** (bottom left): Conductivity levels in upper and lower sites. **Figure 56** (bottom right): Magnesium in upper and lower sites. *Figures: S. Blenis.*

This area is part of the Early Carboniferous (Early to Middle Visean) Windsor Group clastic sedimentary rocks, carbonates and evaporites in the Maritimes Basin. These deposits occur in two distinct intrabasinal, fault-bound troughs in the southwestern half of the subbasin near Sussex, one referred to here as the Penobsquis-Plumweseep evaporite structure and the other called the Clover Hill-Salt Springs evaporite structure (Webb, 2010).

Salt Springs Brook

The upper Salt Springs Brook site received a higher water quality index score, 94.6, in comparison to its lower site, 87.6, as a result from the elevated levels of chloride and potassium. The lower site is also prone to higher levels of turbidity, and lower levels of dissolved oxygen, as a result from surrounding land use practices. The upper Salt Springs Brook site, however, contains higher bacterial levels than the lower site.





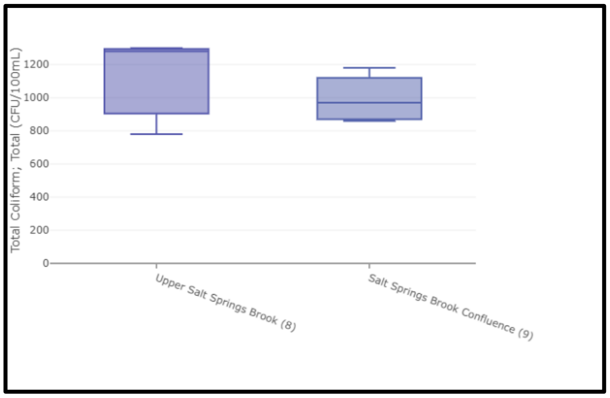


Figure 57 (top left): *E. coli* levels. **Figure 58** (top right): Fecal coliform levels. **Figure 59** (bottom center): Total coliform levels. *Figures: S. Blenis.*

The upper Salt Springs Brook site consistently had higher bacterial levels in comparison to most other sites within the watershed, and this occurrence has been documented in the 2008, 2015, and 2020 *Watershed Management Plans*. The bacterial content, which spikes mid-summer, is contributing towards the shift from oligotrophic to mesotrophic, with increased algae growth, decreased water clarity, and increased turbidity.

Snow Brook

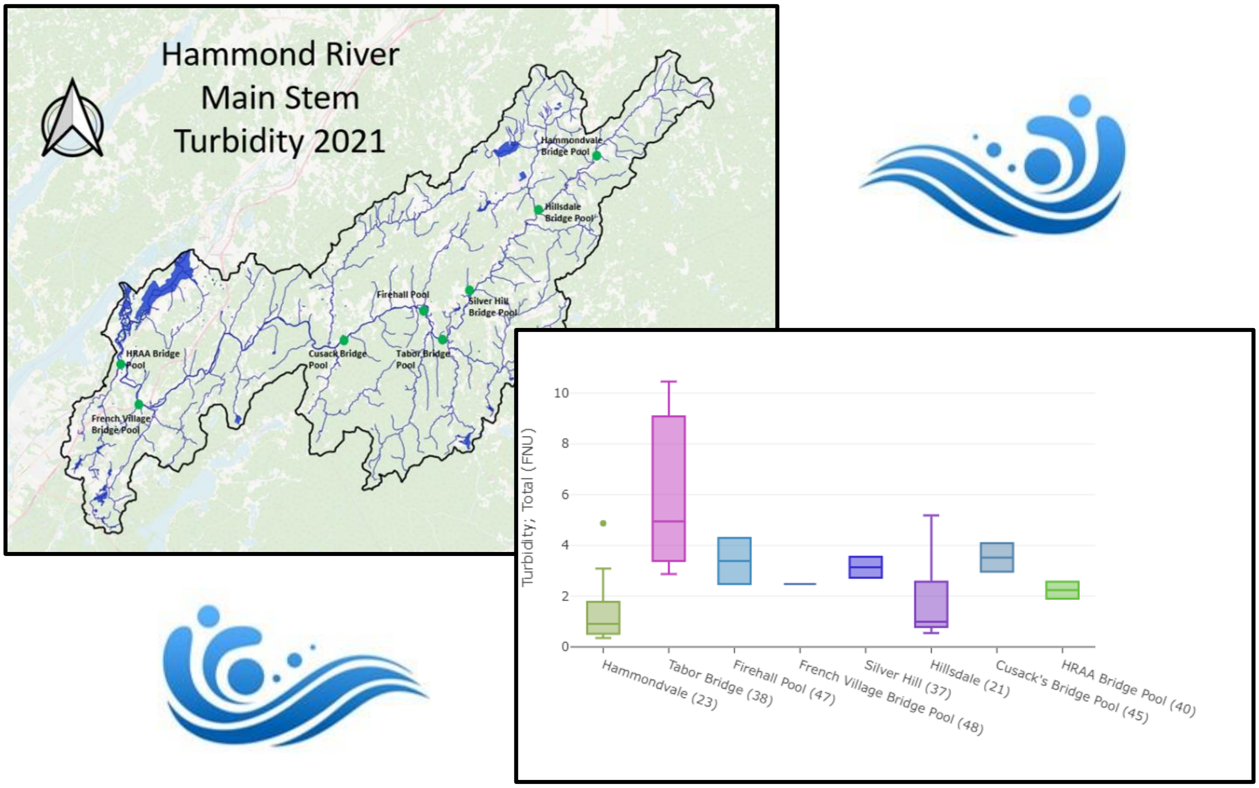
In the summer of 2021, HRAA staff received an email from a local resident, with concerns on the water quality in a tributary, Snow Brook, that was adjacent to a former dump site. To the best of our knowledge, Snow Brook has never been included in any water quality monitoring program since the inception of HRAA; however, our field staff determined that this was a worthwhile concern and performed a preliminary investigation.

This dump would have been in operation in the early 1970's, operated by the Department of Transportation, as 1 of the 11 dumpsites within the Fundy Region. This dumpsite was operable until approximately 1989, when Minister of Environment, Vaughan Blaney, closed the site. HRAA staff reached out to several nearby landowners to see if we could acquire additional information on the defunct landfill. According to landowners, the site's closure and remediation were limited to trucking in fill and dumping it on top of the dumpsite. Given that this site was operable in the early 1970's, before there were regulations regarding what sort of material can be deposited into landfills, Snow Brook should be included in future water quality studies. HRAA were able to take 1 grab sample from Snow Brook for laboratory analysis; however, without baseline data, or additional data from 2021, it is hard to determine the overall water quality health of the tributary. From the one sample extracted, it appears that Snow Brook may have higher levels of iron and aluminum, as well as *E. coli* (which was a whopping 10,180 cfu/100mL!). HRAA staff spoke with DELG staff, and it was recommended to test Snow Brook on a regular basis, with a focus on trace metals, BTEX, phenols, cyanide, and hydrocarbons.

Photo 46 (left): some of the debris that was located adjacent to Snow Brook. **Photo 47** (right): a tire that was located (and subsequently removed) from Snow Brook. Metal and glass debris could be spotted sticking out of the ground in various areas along Snow Brook, and this site would be a good candidate as a future clean up initiative. *Photos: J. Kelly*.

MAIN STEM
Turbidity

In the 2021 field season, HRAA staff collected additional water quality data with the YSI handheld multiparameter probe and turbidity meter at 7 sites within the main stem river, post heavy rainfall events (>25mm precipitation), to investigate sediment transport (*Map : J. Kelly. Figure: S. Blenis)*.



Turbidity results were averaged, revealing that the Tabor Bridge catchment area was the most susceptible to turbidity post heavy rainfall. The Tabor Bridge Pool would be the receiving environment of both Hanford Brook and Germaine Brook- Germaine Brook has significant erosion occurring at the confluence point and is a main contributor to the high turbidity levels in the main stem after heavy precipitation. Turbidity was also higher in the headwater sites, Hammondvale and Hillsdale, of the main stem- there is a high density of agricultural land use practices in this area, including a failed riparian restoration initiative along the Hammond River in the Hammondvale site. In the early spring of 2021, a large landslide occurred on the riverbank above the Cusack Bridge Pool sampling site, exposing a steep, dirt cliff. This dirt is being washed into the river after heavy rainfall events, impacting turbidity readings below the bridge pool.

Sediment transport data are often used for the evaluation of land surface erosion, reservoir sedimentation, ecological habitat quality. Studies of sediment transport are important for many projects and are highly complex. The input data requested for such studies is flow and bed characteristics and the quantity of sediment in motion. (Brisset et al., 2005). In the future, HRAA should expand on its available tools (bedload sampler, flow meter) in order to perform a more in-depth examination of sediment transport in the Hammond River.

PROJECT DELIVERABLES

Protecting Our Environment

- In total, HRAA collected 115 water quality samples (organic and inorganic) throughout the 2021 field season to determine water quality health of the Hammond River.

- HRAA performed 6 habitat assessments in 6 previously undocumented mountainous tributaries within the watershed, totaling 7.2 kilometers of assessment in the upper tributaries alone!

- HRAA collected 21 additional water quality samples post heavy rainfall events to examine turbidity.

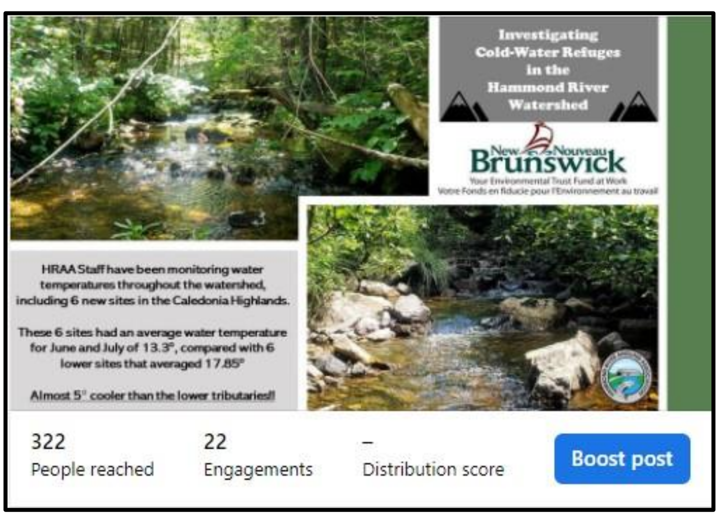
- HRAA performed habitat assessments, collected, and analyzed data from 7 confluence points and compared with data from their respective historical index sites to determine the potential impact of climate change on these confluence points.

Increasing Environmental Awareness & Addressing Climate Change

- HRAA engaged in numerous conversations with multiple landowners along the Hammond River during the 2021 field season. Conversations included land use, water quality, and listening and acting upon landowner concerns.

- HRAA uploaded all data onto the publicly accessible online program, DataStream, to ensure that the public can stay informed, aware, and engaged with our data collection.

- HRAA publicized the project and its components throughout project life on all of our social media platforms (Instagram, Twitter, and Facebook). The project was also discussed at 2 meetings (approximately 10 people in attendance for each meeting) and featured prominently in our spring and fall newsletter. HRAA's educational outreach on climate change and the importance of riparian buffers reached well over 1,000 people over the project life.



CONCLUSION

The goal of *Maintaining Water Quality While Adapting to Climate Change* is twofold: to increase our understanding of confluence points, and to increase our understanding of the geologic landscape, particularly the mountainous region of the watershed. Geology is arguably the most fundamental of all enduring landscape features and plays an important role in the overall water quality health of our watershed. Confluence zones are yet another important characteristic in determining the overall health of our watershed, and the results of this project have indeed determined there to be a link between geology, confluence points, species abundance and watershed health.

Photo 48. S. Blenis angling on the Hammond River, with a visible gypsum outcropping in the background, with substantial erosion occurring. *Photo: P. Walsworth.*

The Hammond River is peppered with calcareous and karstic outcroppings of gypsum and limestone, which weather the most rapidly of all rock types under moist conditions, as they react chemically with the carbonic acid often found in precipitation and ground water (Ecosystem Classification Working Group). As climate change continues to increase, we must become more aware on how changes in precipitation will affect the state of the watershed. Geology is known to strongly influence many of the constituents of water chemistry. This finding implies that as climates become warmer in the future, stream chemistries will change (Olson, 2012). The geology of an area is a significant factor in the overall quality of its water recourses. The dissolution of numerous minerals from geological formations results in spatial and temporal variations in water quality- we may then begin to anticipate changes in water chemistry as a direct response to climate change. As a result of this project, it is recommended that HRAA undertake geological mapping along the main stem of the river to determine locations of Precambrian outcrops (limestone, gypsum). These areas may become prone to additional erosion as a result of climate change and have the potential to substantially contribute towards future sedimentation of the main stem river. Documenting these potential future 'erosion hotspots', from a geological standpoint, would be an excellent undertaking, particularly when overlapping these areas with sensitive spawning areas.

One of the key recommendations from the results of this project is to determine if exceedances, particularly trace metals, are anthropogenic or naturally occurring. Many of the elements that caused exceedances, particularly aluminum, chromium, manganese, chloride, and iron are often correlated to the prevalence of industrial spills or industrial byproduct, sewage plants, traffic density, and treatment plants (CCME, 2014), or in short, human-caused. As a result, HRAA has historically relied on the water quality index rankings to determine priority areas for future restoration and outreach to curb these exceedances; however, the results from this study indicate that these exceedances are more likely attributed to the watershed's geological landscape and are naturally occurring.

In the *2015 Watershed Management Plan*, mine and gravel pit density were strongly correlated to several water quality parameters, indicating a very strong likelihood that mines and gravel pits are contributing many pollutants (aluminum, manganese, iron, phosphorus, magnesium) to the water column. The correlation between mine/gravel pit density and water colour, hardness and alkalinity similarly suggest a link between poor water quality and the density of mines in adjacent lands (Bradford, 2015). While mine and gravel pit densities throughout the watershed are indeed contributing additional levels of trace metals to the water column, it must be pointed out that groundwater that is passing through these naturally occurring deposits is also playing a contributing factor to the water chemistry in the watershed. Markhamville and Hammondvale have historically displayed higher levels of manganese, which has been contributed to the manganese mine; however, this mine has been defunct since the early 1900's. It is far more likely that the continuing presence of manganese in the water column is a result from groundwater passing through the deposit, and no longer a direct result of manganese mining. Scoodic Brook and Palmer Brook have long been classified as two of the lowest ranking tributaries in the watershed due to their exceedances of trace metals, which have been consistently attributed to anthropogenic factors; however, the results of this study indicate that both tributaries are being impacted by naturally occurring deposits. These findings emphasize the need to begin thinking about past geological and climatic processes that occurred within the watershed from a Neoproterozoic lens, and how these naturally occurring minerals are impacting the watershed today and using this information to guide predictions on water chemistry in the future as a result of climate change.

The mountainous Caledonia Highland stretch in the watershed is also mineral-rich, with higher levels of trace metals. *Maintaining Water Quality While Adapting to Climate Change* has established baseline data on 6 mountainous tributaries, which has provided a glimpse into benchmark water chemistry as it naturally occurs in response to its geologic landscape. The results of this project underscore the concept that a river is connected to its valley (Hynes, 1975), and both are inextricably linked to the geologic landscape. Throughout the 2021 sampling period, the mountainous tributaries maintained cooler water temperature, demonstrating that the river valley landscape, and adjacent hillslopes and uplands, influences surface and groundwater interactions across broad and localized scales (O'Sullivan, 2019).

Mountains provide freshwater to half of the world's population and climate change will affect the availability of water (Kohler). *Maintaining Water Quality While Adapting to Climate Change* investigated the link between mountainous terrain and water temperature; however, the investigation was limited to grab samples and in-situ probe readings. Subsurface processes are often overlooked in river temperature modelling (Caissie et al., 2007) due to inherent heterogeneities and complexities associated with data acquisition as measurement scale increases. However, the riverscape is best viewed as a confluence of surface water and groundwater (Winter et al., 1998; Hynes, 1975), and therefore bedrock and surficial geology influence on subsurface processes with need increasing consideration for river temperature modelling (O'Sullivan, 2019). While this project provided an overview glimpse of the connection between mountainous tributaries and main stem health, additional research (i.e.: geothermal imaging, geophysical magnetic data survey etc.), are warranted in the future to provide a greater understanding of the impact that these tributaries are truly having on the watershed. Few studies have used geologic data to predict diversity and distributions, even though geology is recognized as one of the abiotic factors controlling taxonomic diversity and distributions (Olson, 2012). The results from *Maintaining Water Quality While Adapting to Climate Change* suggest that the geologic landscape of the upper watershed is directly linked to the abundance and distribution of spawning salmon, as well as providing suitable habitat for juvenile salmon.

In 2020, the HRAA submitted an application for the Theobald Lake and Jenny Lind Brook to be included in New Brunswick's Nature Legacy- this area is now a Candidate Protected Natural Area. It is recommended that HRAA staff continue to follow up with the Government of New Brunswick to ensure that this area does indeed become a fully fledged Protected Natural Area, particularly given that the Jenny Lind Brook received a perfect water quality index score. Additionally, it is recommended that HRAA continue to investigate mountainous tributaries in the Caledonia Highlands and seek out more mountainous areas for future protective measures. Increasing land conservation, particularly mountainous terrain in the upper watershed, will be an excellent defense against climate change and will allow the Hammond River system to maintain climate resiliency.

Maintaining Water Quality While Adapting to Climate Change served as a primary investigation into the geologic landscape and mountainous region of the watershed, as well as providing an initial examination on confluence points. Confluences are just one example of the important connections that characterize river networks (Rice, 2008), and further research is needed to determine the relative importance of this connection within the broader context of river basics, including geology and groundwater flow. Densities, diversities, and spawning activities of fish were noted in higher abundance in many of these confluence points in the 2021 field season, as part of HRAA's fish studies, indicating that confluence points play a pivotal role in assisting aquatic biota to flourish. While the majority of the confluence points scored lower than their upper index sites on the water quality index, this may be attributed to a combination of geologic influences and higher densities of anthropogenic stressors. Continuing and ongoing data collection from confluence points may provide the HRAA with early warning signs of negative impacts from climate change, heralded by changes in water temperature, flow, volume, chemistry, and supplied sediment. Habitat variability is likely to be greater along a stretch of river including a confluence than along a similar reach without a confluence. In this sense, tributaries are one of many factors, like variations in geology or valley confinement, that enhances in-channel heterogeneity in river systems (Rice, 2008). Maintaining data collection at each of the confluence sites in the long-term is therefore imperative to maintaining the health of the watershed. Sites that are currently lacking in riparian vegetation, such as Palmer Brook, Bradley Brook and Germaine Brook confluence zones should be a priority. Diverting livestock from Scoodic Brook and South Stream confluences should also be considered a top undertaking in the near future. Continued investigation and protection of confluence points will assist with maintaining healthy aquatic biota throughout the watershed.

Overall, results from this report have given the HRAA a fresh geologic perspective for managing the Hammond River watershed over the short and long term in the face of climate change. To quote Ralph Waldo Emerson, “we learn geology the morning after the earthquake”- this must not become the case in the Hammond River watershed. *Maintaining Water Quality Data While Adapting to Climate Change* should be the initial ‘steppingstone’ (geology pun intended) to expand our understanding of the riverine ecosystem services and the influence of geology on the Hammond’s characteristics, so we may be well equipped to combat climate change and its future impacts on our riverine landscape.

Photo 49: Geologic folding pattern- one of the most captivating geologic sights within the watershed at Tabor Bridge Pool. *Photo: J. Blenis.*

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