Nigadoo River Watershed Report – Atlantic salmon habitat potential

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This document is split into two sections. The first section outlines the baseline data that can be accessed through public domains that outline the physical characteristics, land cover, forest cover, streams, wetlands, and road networks. The second section outlines our stream-road crossing analysis and our recommendations for remediation.

Section 1: Descriptive riverscape attributes

Geology & Landscape Characteristics

The Nigadoo catchment is made up of Pre-Cambrian-Middle Ordovician Zones tectonic divisions. The Southern portion of the catchment being Gander and the Northern and Western portions being Dunnage. Both tectonic divisions are known as lithostratigraphic divisions from the Cambrian to mid-Ordovician era.

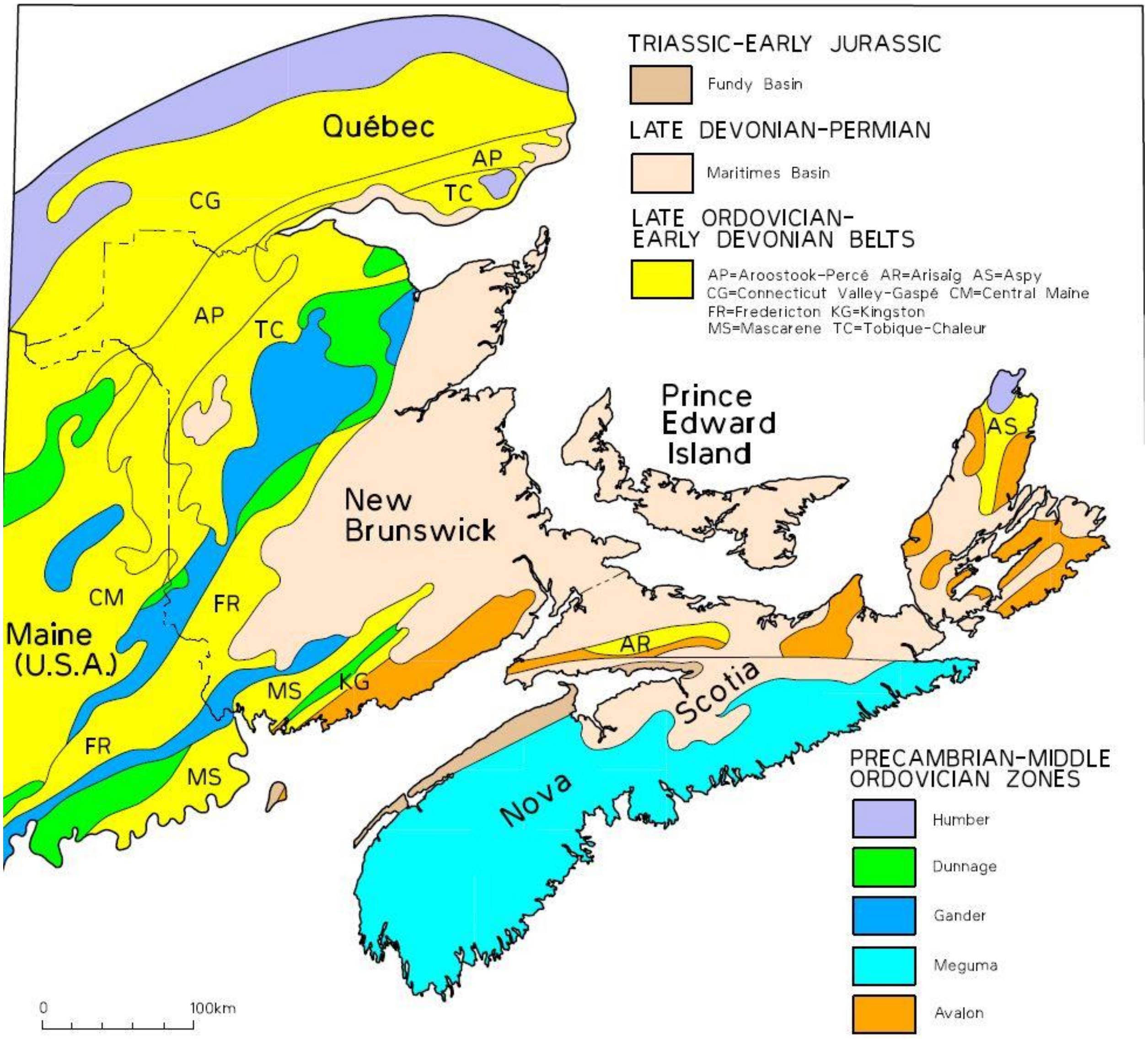


Figure 1. Tectonic divisions in Eastern Canada. Figure sourced directly from the Department of Natural Resources Minerals. Policy and Planning Division. Direct hyperlink (https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www2.gnb.ca/content/dam/gnb/Departments/en/pdf/Minerals-Minerales/Bedrock_Geology_MapNR1-e.pdf&ved=2ahUKEwjY4M7_oPqJAxXvOTQIHdrbD-UQFnoECA0QAQ&usg=AOvVaw3MzYpUl8_uDo9B9SoZCUCa)

The Southern and Eastern potions of the underlying bedrock geology are made up of a Simpsons Field Formation which is characterized by sedimentary rock and a thin layer of calcareous mudstone. Calcareous mudstone is a fine-grained sedimentary rock that is made up of various clays or muds, making the coastal region more erosion prone to extreme weather events. The central portion of the catchment is called the Free Grant Formation which is characterized by fragments of rock or minerals that result from weathering and erosion from source rocks. The buried portions that don't experience weathering or erosion can become compacted and cemented which would form sedimentary rock. The Northern portion of the catchment is called the Elmtree Formation which is characterized by a specific band of limestone that is part of the Chaleur Group which consists of a sedimentary, carbonate, and volcanic rocks. Additionally, there are small bands of calcareous rocks named the LaPlante Formation and the La Vielle Formation mixed throughout the watershed that have similar characteristics as the limestone deposits. Areas where limestone is present could be future areas of interest for mining operations. The area has had quarries in the area as far back as 1880, with small quarries operating in the 1930's, 1960's, and 1990's. The quarry would produce over 100,000 tons of limestone annually. If the limestone quarries were expanded and operating again, the downstream portions of the watershed could see excess sedimentation causing habitat alteration or destruction. The Western portion of the catchment is called the Weir Formation, which is characterized by coarse-grained clastic sedimentary rocks made up of conglomerations of rounded and breccia (angular) rocks that are larger than 2 millimeters. As with other clastic formations, these rocks will either go under lithification or cementation and will eventually become sedimentary rocks. Clastic sedimentary rocks usually form in high energy landscapes which makes the Western portion vulnerable to high flow events causing erosion and altering or destroying downstream habitats.

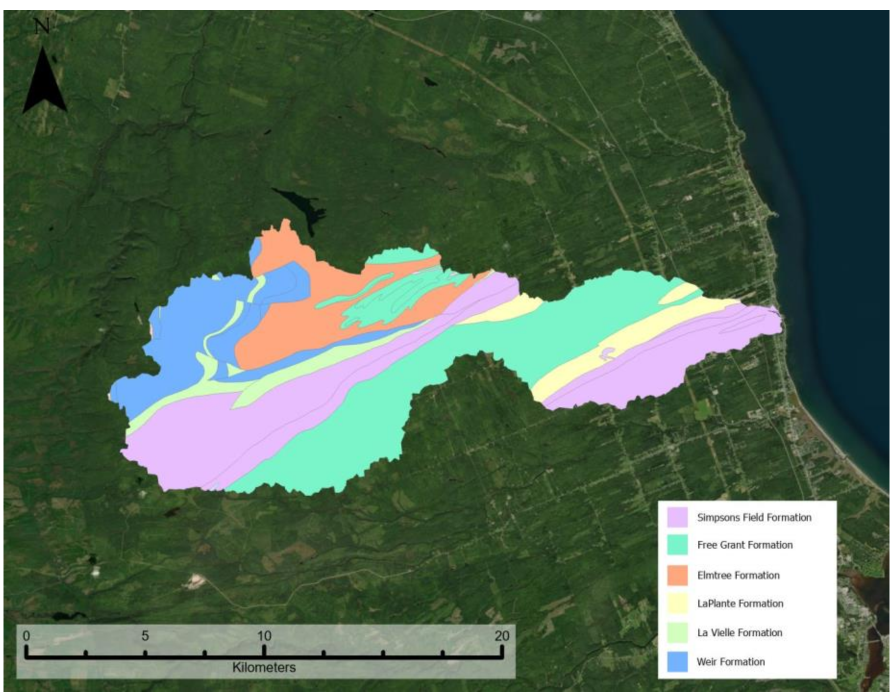


Figure 2. Bedrock geology of the Nigadoo catchment classified by name of formations

Hydrological Characteristics

Stahler stream order 1 makes up approximately 181 kilometers (51%), stream order 2 is 80 kilometers (23%), stream order 3 is 50 kilometres (14%), stream order 4 is 17 kilometers (5%), and stream order 6 is 24 kilometers (7%) (Figure 3; Table 3).

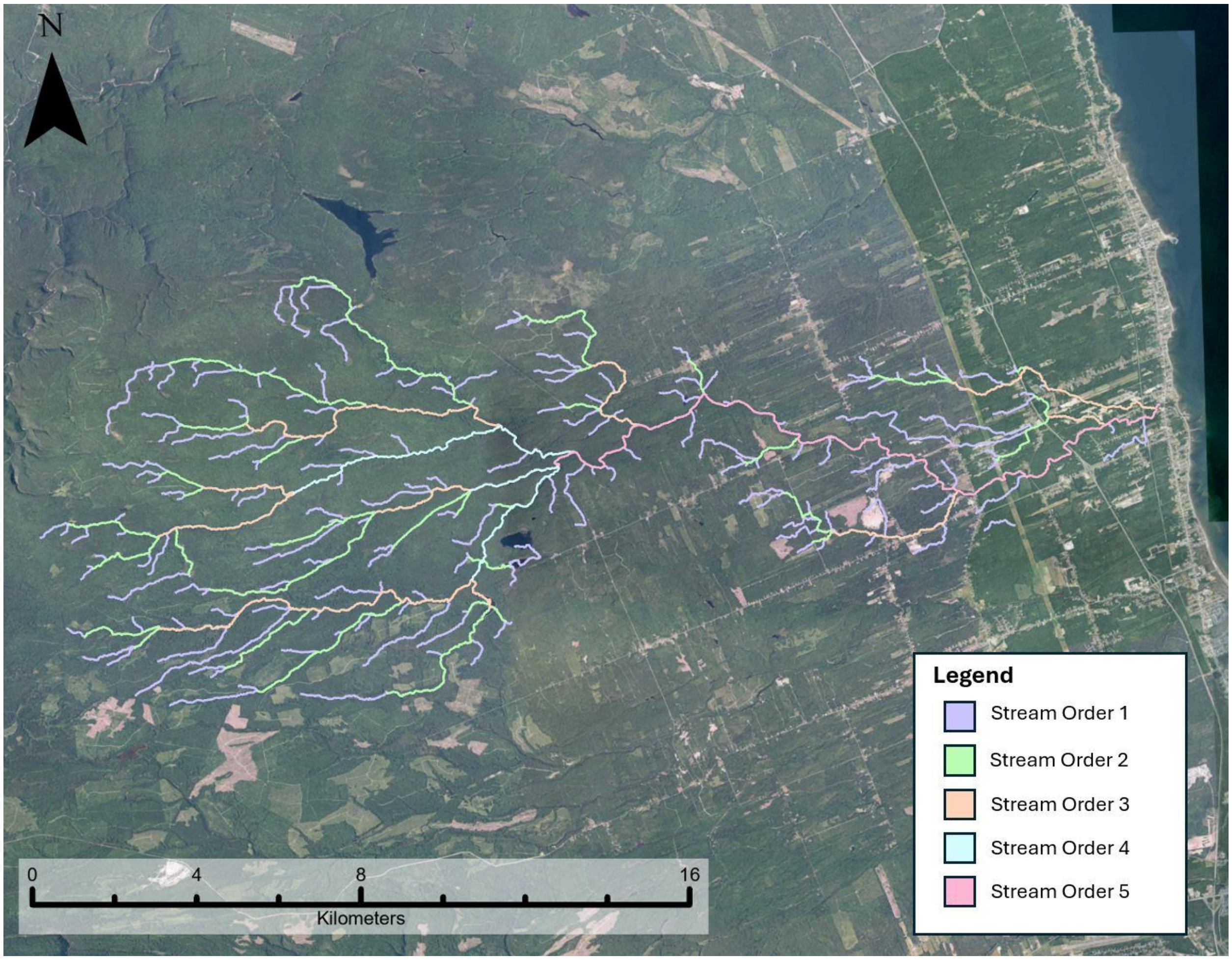


Figure 3. Stream order extracted from stream derived digital elevation model for the Nigadoo catchment in New Brunswick, Canada.

The stream network was created using a hydro conditioned DEM. The stream is approximately 352 linear kilometers. Methodology for how the stream network was created can be found in “Section 2” under “Methods”.

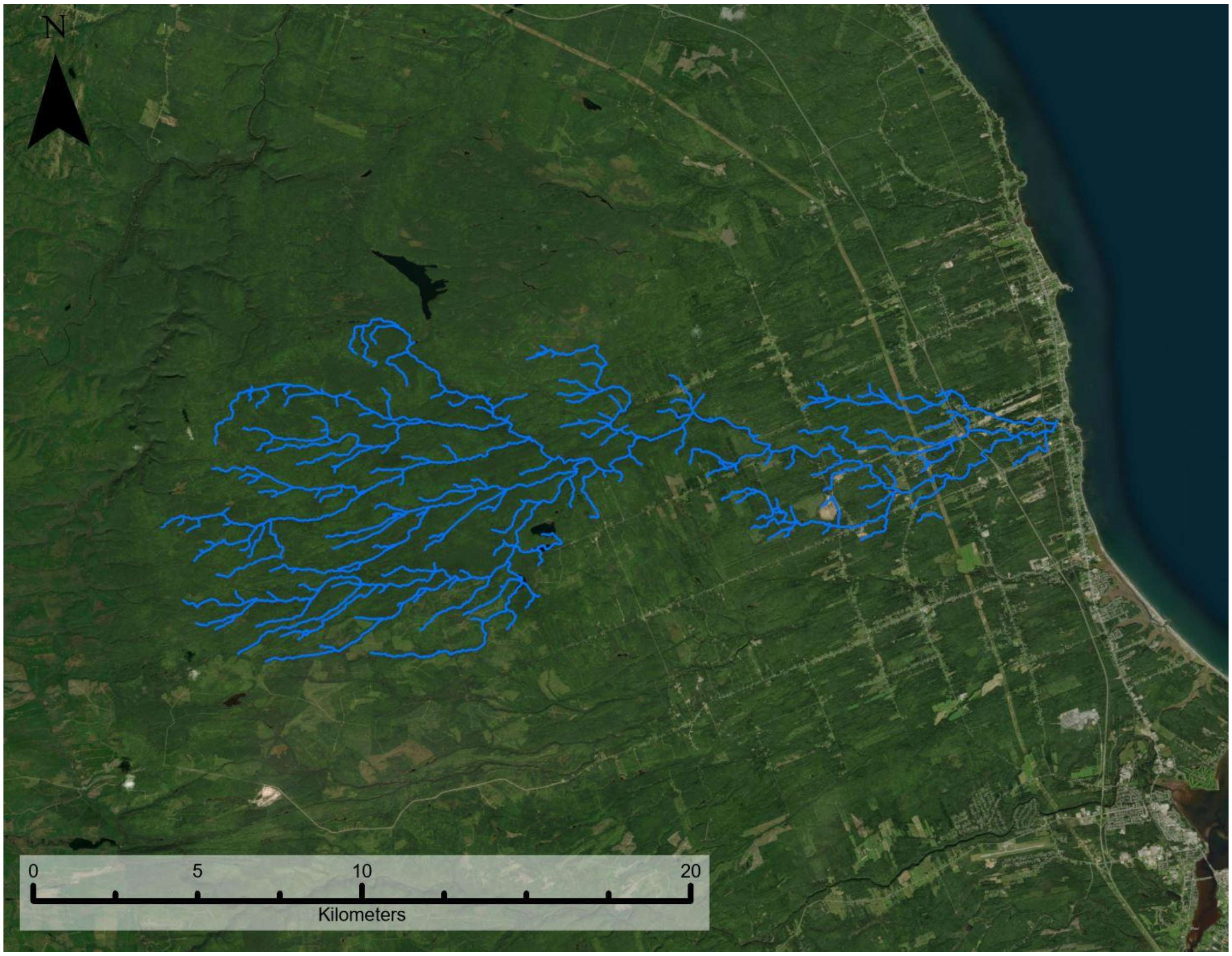


Figure 4. Stream network extracted from hydro-conditioned digital elevation model using a flow accumulation threshold of 180,000 hectares in the Nigadoo catchment in New Brunswick, Canada.

Land classification

The Nigadoo catchment covers an area of approximately 168 km^2 and is part of the Chaleur Bay Composite in Northeastern New Brunswick, Canada. Crown lands make up approximately 116 km^2 of land within the Nigadoo catchment, which is approximately 69% of the total land area in the Nigadoo catchment.

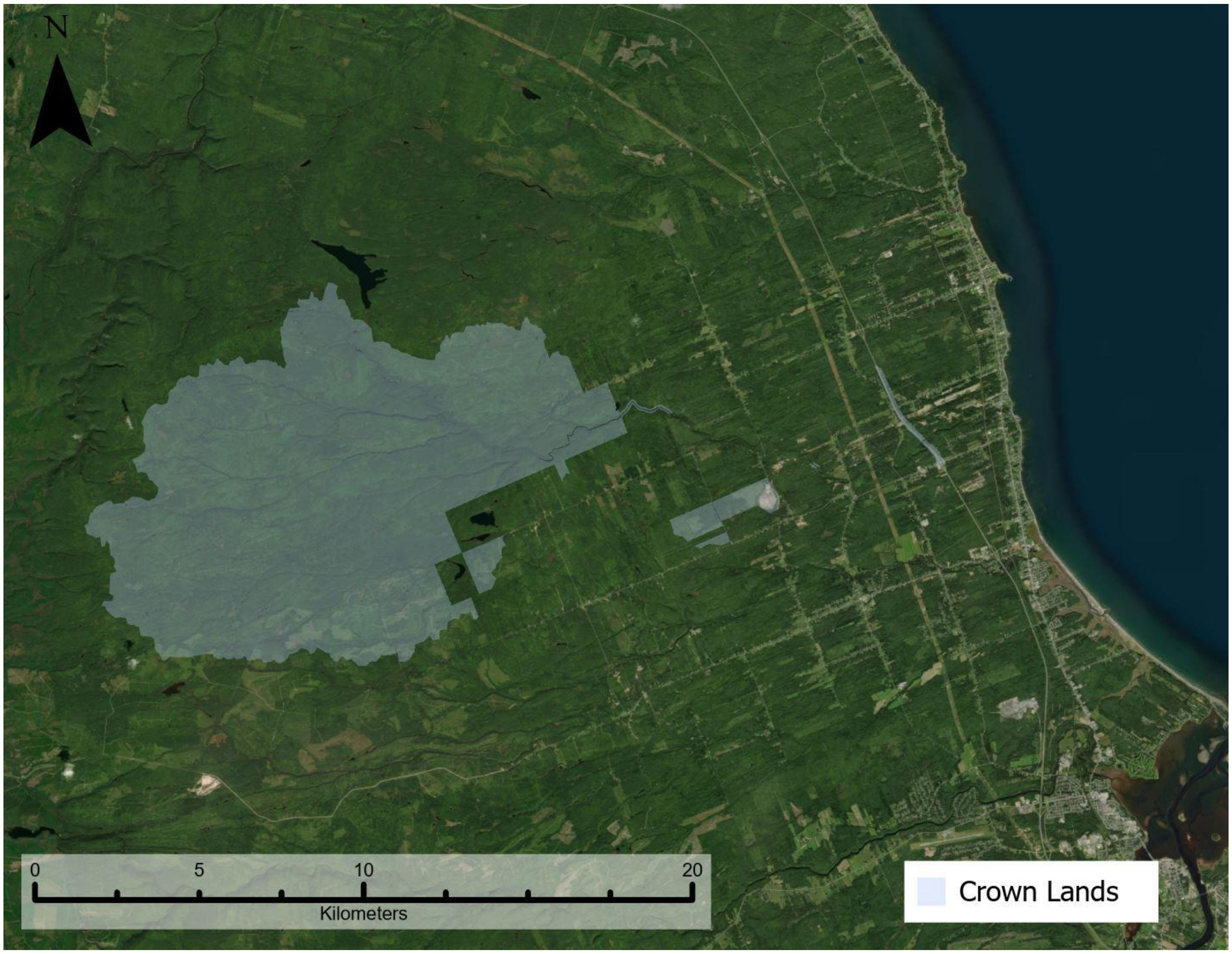


Figure 5. Crown lands within the Nigadoo catchment in New Brunswick, Canada.

Land cover within the watershed is predominantly mixed forest with 106 km^2 (65%), deciduous forest is 31 km^2 (19%), conifer forest is 18 km^2 (11%), shrubland is 5 km^2 (3%), grassland is 3 km^2 (2%), crop land is 1 km^2 (< 1 %), urban is 0.17 km^2 (< 1 %), wetland is 0.16 km^2 (< 1 %), barren lands is 0.07 km^2 (< 1 %), and water is 0.07 km^2 (< 1 %).

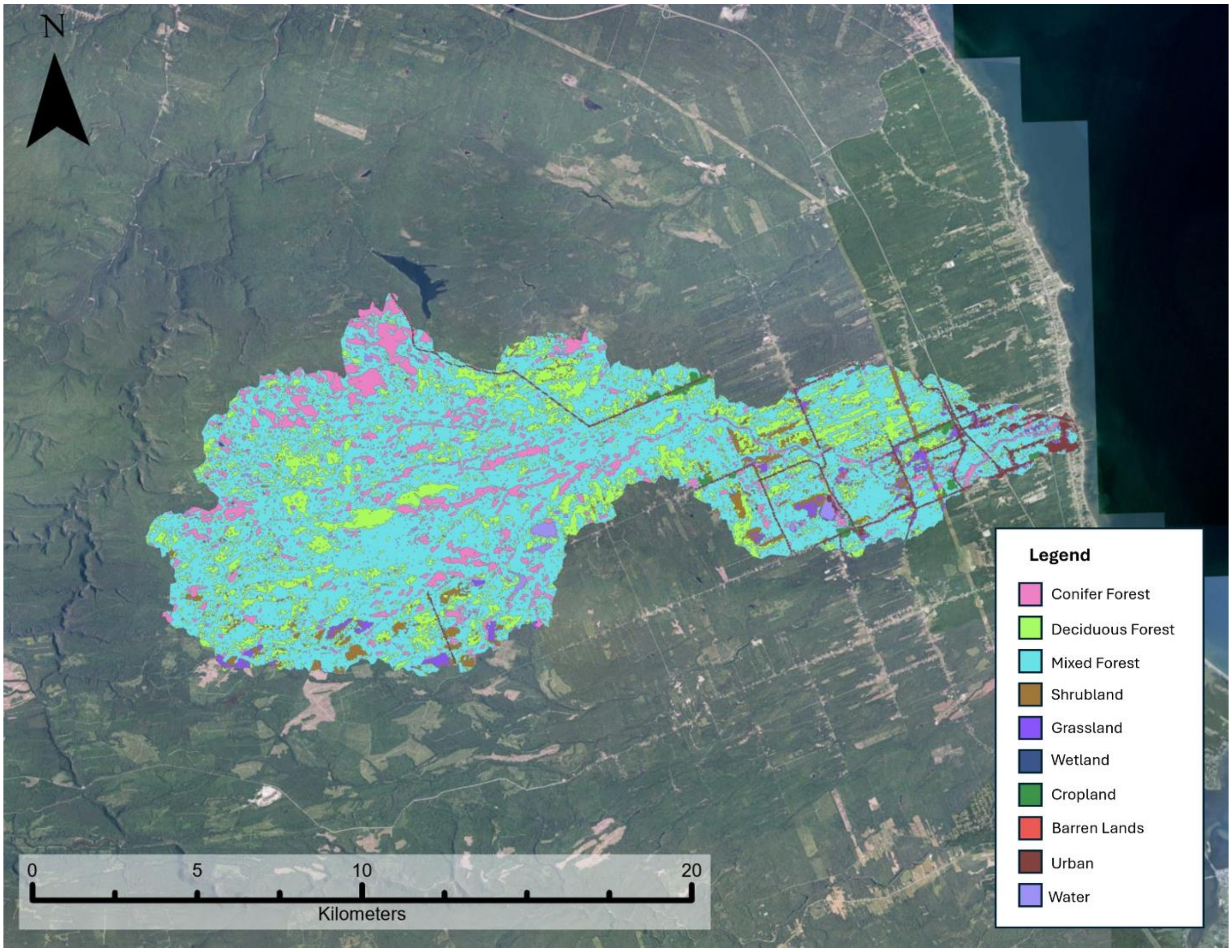
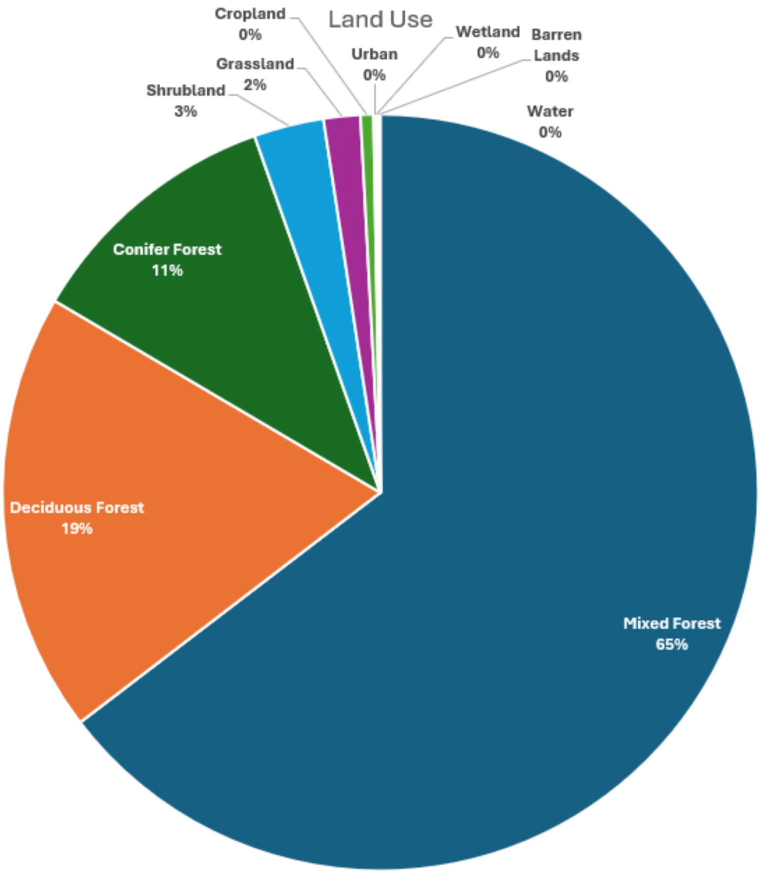


Figure 3. Land cover in the Nigadoo catchment located in New Brunswick, Canada.



Land Type	Area (Sq. Km.)	% of Total Area
Mixed Forest	106.58	64.61
Deciduous Forest	31.11	18.86
Conifer Forest	18.37	11.14
Shrubland	4.94	2.99
Grassland	2.59	1.57
Cropland	0.91	0.55
Urban	0.17	0.10
Wetland	0.16	0.10
Barren Lands	0.07	0.04
Water	0.07	0.04

Figure 4. Pie chart of land cover by percentage of total area with raw numbers on a table in the Nigadoo catchment.

Road network

The road network for the Nigadoo catchment was sourced from GeoNB (SNB, 2024) is approximately 246 linear kilometers (Figure 8). Unpaved roads are approximately 202 kilometers (82% of total road length), and unpaved roads make up approximately 44 kilometers (18% of total road length) (Table 1). The lack of forest roads in the Nigadoo catchment area could be a result of the high density of wetlands in the Northwestern portion of the catchment area, making it difficult to create forest roads or growing commercially viable tree stands.

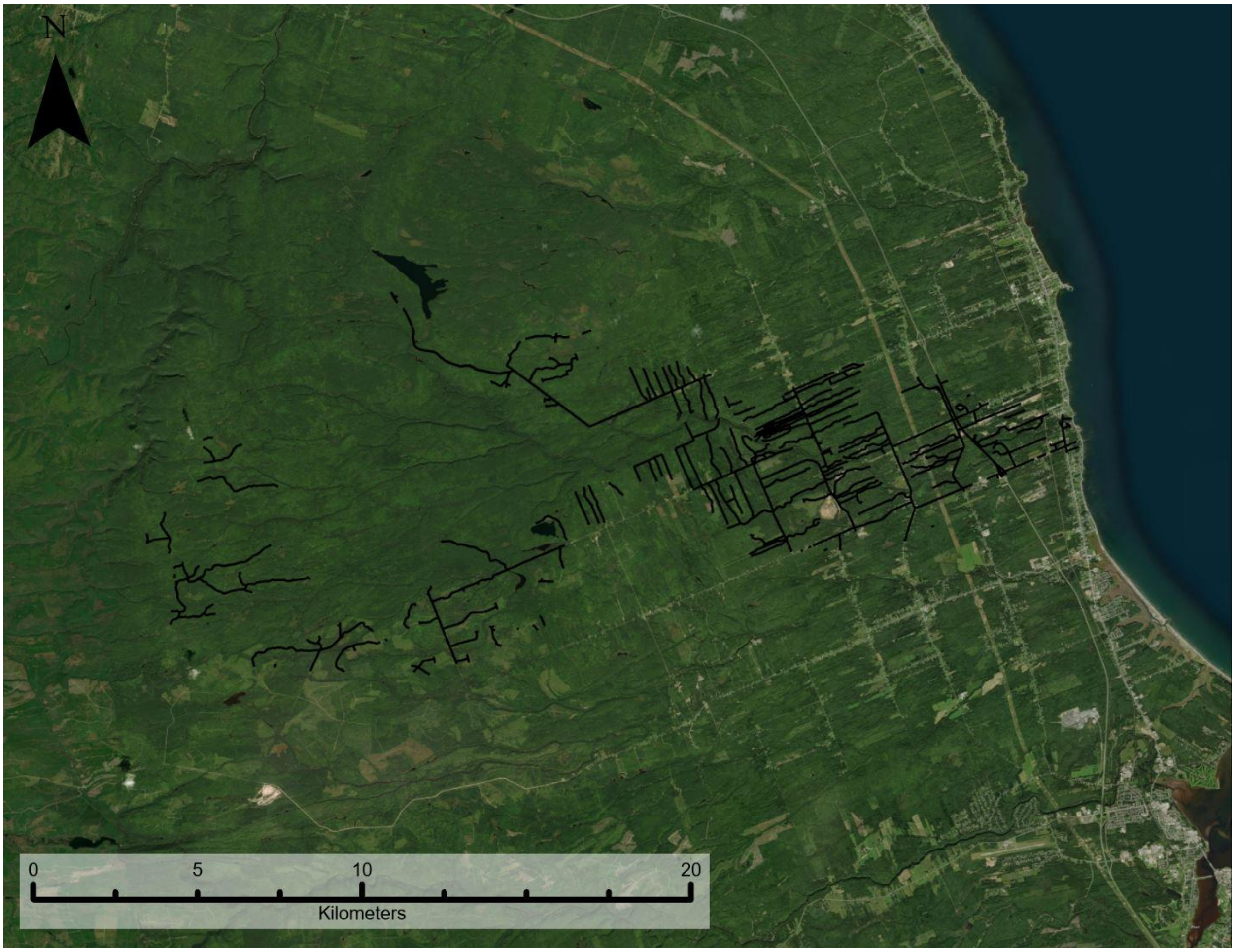


Figure 5. Road network sourced from GeoNB (Service New Brunswick) for the Nigadoo catchment located in New Brunswick, Canada.

Table 1. Total linear kilometers of road-by-road type, unpaved or paved in the Nigadoo catchment.

Road Type	Total Linear Kilometers	% of Total Linear Kilometers
Unpaved	202.53	82
Paved	43.84	18

Climate change adaptation and resilience

As climate change increases the magnitude and frequency of severe weather events and as annual mean temperatures rise, it is vital that we begin to evaluate our local baseline data to better prepare and prevent further habitat and infrastructure impacts. Temperatures within the Nigadoo catchment are reaching average summer temperatures of almost 18 C in recent years. Both the up and downstream temperature probes recorded over a 1 C increase year over year. The upstream recorded average summer temperature in 2022 was 13.49 C and increased to 17.77 C in the summer of 2023 (Figure 9). This direct comparison may be skewed as the downstream thermograph may be positioned in an area influenced by tidal waters from the Bay of Chaleur. Therefore, the upstream thermograph is more representative of the Nigadoo River thermal regime.

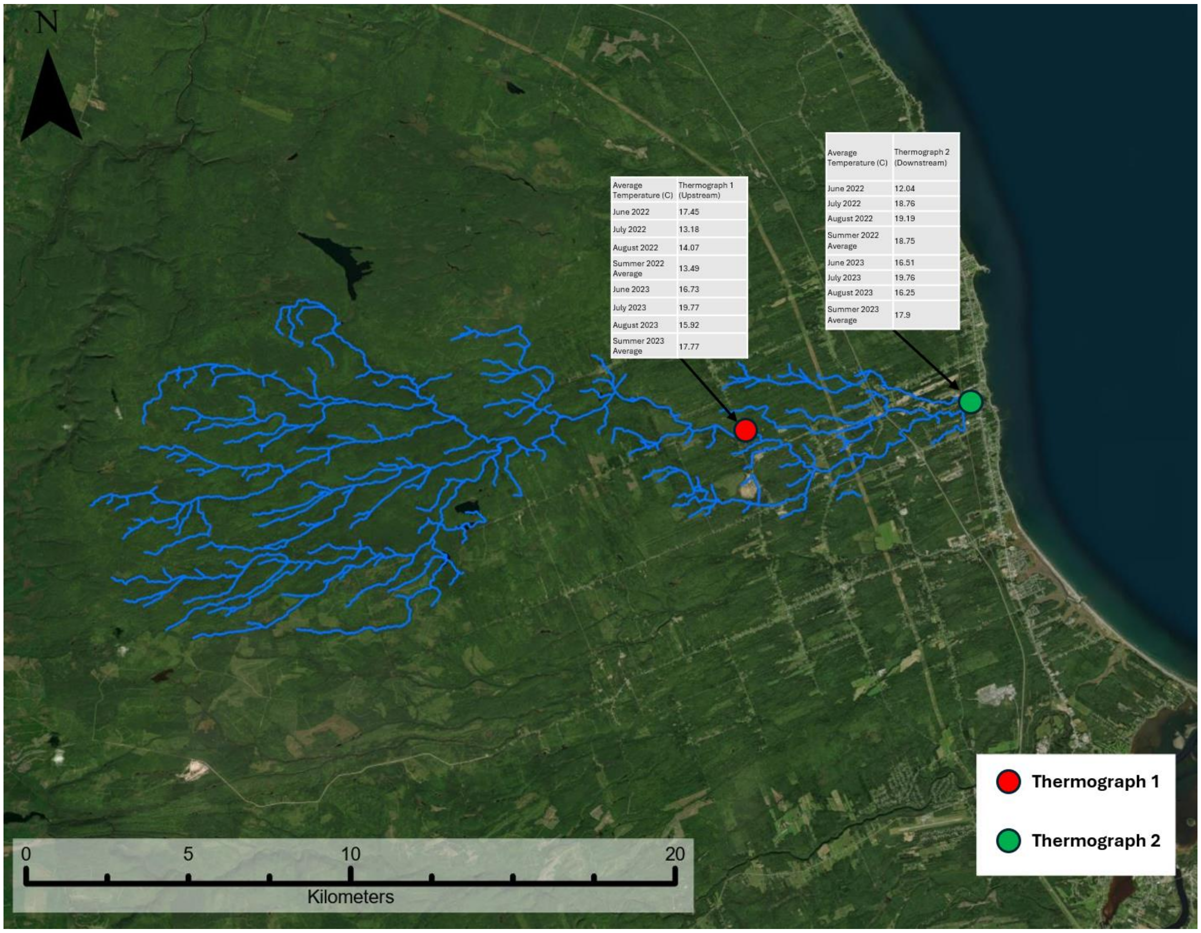


Figure 9. Thermograph (temperature logger) locations and the temperatures by month and average summer temperature for 2022 and 2023.

1 in 20-year and 1- and 100-year floods prediction models created by Service New Brunswick predict minimal residential flooding in the Nigadoo catchment. While there may only be minimal flooding, the magnitude of these storms can cause further downstream erosion which can result in the expansion of the flood plain, increasing the risk of infrastructure being damaged.

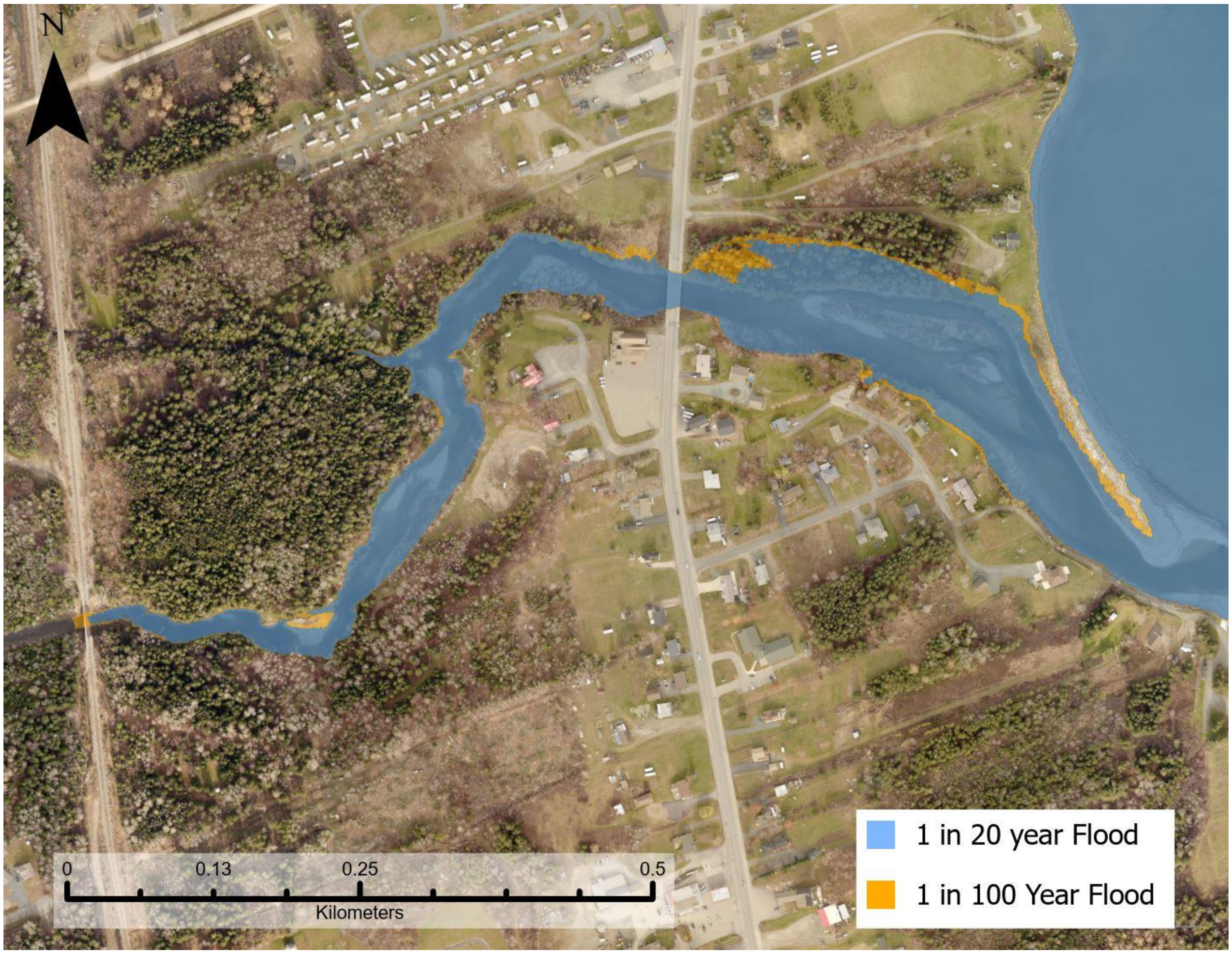


Figure 10. Flood models showing 1 in 20 year and 1 in 100-year floods at the mouth of the Nigadoo catchment in New Brunswick, Canada. This also denotes the tidal influence on Thermograph 2 located between route 134 and the train tracks,

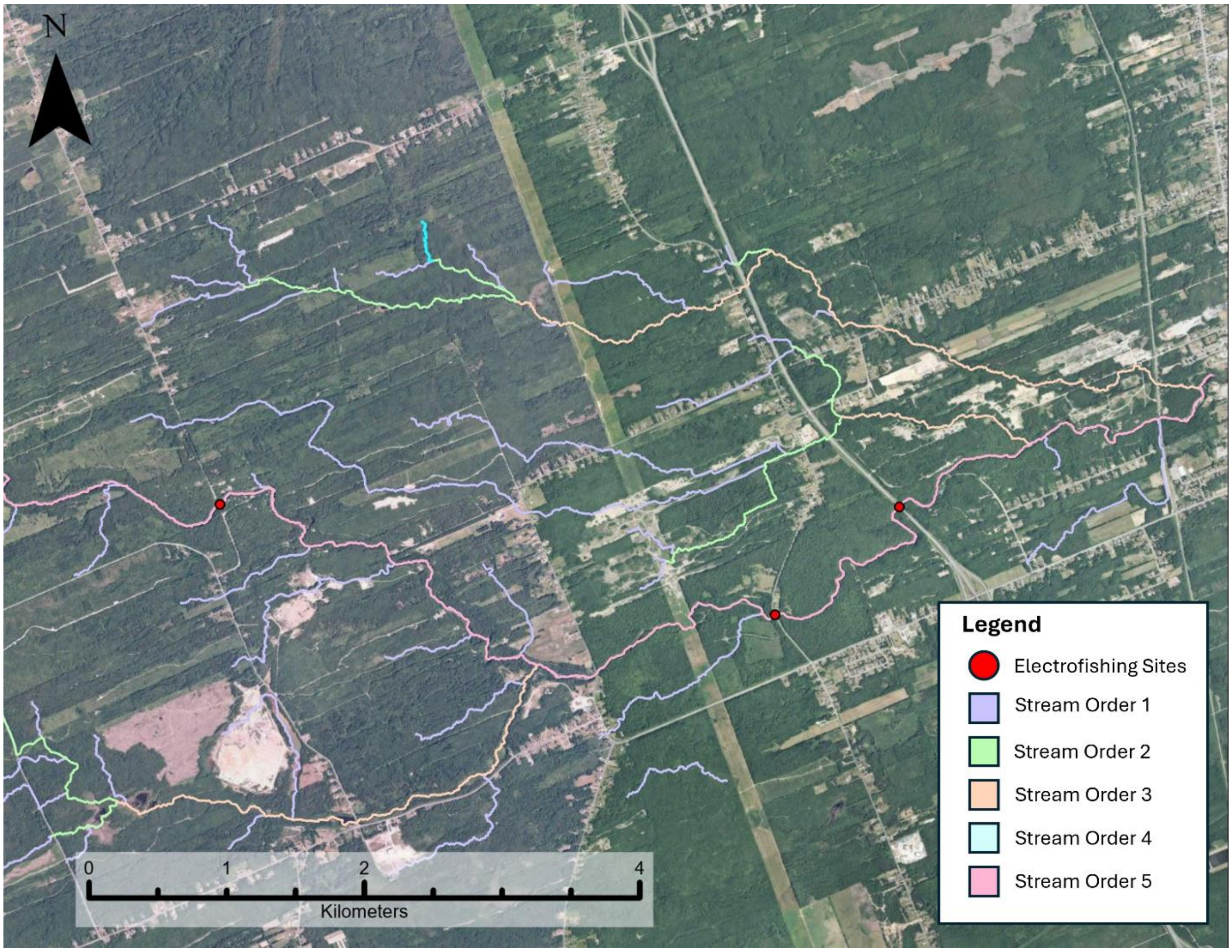


Figure 6. Stream reaches displayed in Strahler stream orders overlaid with 3 electrofishing locations in the Nigadoo catchment. All 3 electrofishing sites are located on a Strahler Stream Order 5.

Three electrofishing sites are located on the mainstem (Strahler stream order 5) of the Nigadoo to conduct fish population surveys. There are no barriers downstream or between the electrofishing sites except for whether Nigadoo Falls is passable or not depending on the time of year (Figure 11; Table 2). Electrofishing results from 2024 revealed low fry densities and average parr densities. A full timeseries analysis would be necessary to determine any trends over time.

Table 2. Total linear kilometers and percentage of total linear stream length by Strahler stream order in the Nigadoo catchment.

Stream Order	Total Linear Kilometers	% of Total Linear Stream Length
1	181.4	51
2	80.6	23
3	50.4	14
4	17.2	5
5	24.2	7

Section 2: Habitat availability and suitability

Introduction

Culverts are the most common instream structures used to direct water under roads that intersect streams. Culverts are the most common flow structure for stream road crossings because of their low cost relative to bridges (Gubernick et al., 2003; Warren & Pardew, 1998). The Gaspé Peninsula's dominant land uses are forestry which require forest roads and additional culverts (Robitaille & Saucier, 1998; Alcock, 1928).

Poor maintenance, under sized culverts, and high flow events are some of the most common causes of a culvert becoming a barrier to fish passage (Gubernick et al., 2003; Furniss et al., 1998). Any instream structure that can alter the flow regime could become a barrier and reduce aquatic connectivity through environmental factors such has water flow, depth, and water velocity (Goerig & Castro-Santos, 2017; Timm et al., 2017). Decreased aquatic connectivity can result in genetic diversity (Morita & Yamamoto, 2002),

Decreased habitat connectivity can have cascading effects on aquatic organisms' survival, species distribution, (Schick & Lindley 2007; Bouska & Paukert 2010). Often, strong-swimming migratory fish are the focus of fish passage studies, while not accounting for smaller, weaker swimmers in fish passage studies (Bourne et al, 2011; Burford, 2005).

Methods

Study Area

The Nigadoo catchment is approximately 168 km^2 and is part of the Chaleur Bay Composite in Northeastern New Brunswick, Canada. Wetlands accounted for 17.33 km^2 (10%) of the total area for the Nigadoo catchment.

One of the challenges for GIS is that remote classification like wetland classification can be inconsistent and depends on variables like the resolution of the orthophotography, methodology of extraction (image classification, manual input, landscape characteristics). In the first section, wetlands made up 0.16 km^2 (0.04%) of the total area of catchment. The first section land cover was classified at a national level and was sourced from the 2020 Land Cover of Canada (GoC, 2020). This raster has a spatial resolution of 30 meters and an accuracy assessment of 86.9% based on 832 random samples.

Comparatively, our second section, the wetland shapefile makes up approximately 17.33 km^2 (10%) that was sourced from GeoNB (GeoNB, 2024). The wetland shapefile is updated annually through collaboration with surveys done by the Department of Environment and Local Government. Some explanations for the large discrepancy could be the resolution between the two files; the GoC shapefile having a 30-meter resolution while the GeoNB shapefile is done manually, with approximate dimensions. Additionally, what is classified as a wetland can differ between methodologies. The GoC does not explicitly mention what they would consider a wetland, but GeoNB uses it specifically for a wetland layer for Watercourse and Wetland Alteration (WAWA) permits. GeoNB considers wetlands to include wetlands that have provincial, national, or international importance, freshwater marshes, aquatic beds, bogs, fens, forested wetlands, and shrubs. It is important to review methodologies and gather data from various sources to ensure that the results encompass the land managers' needs.

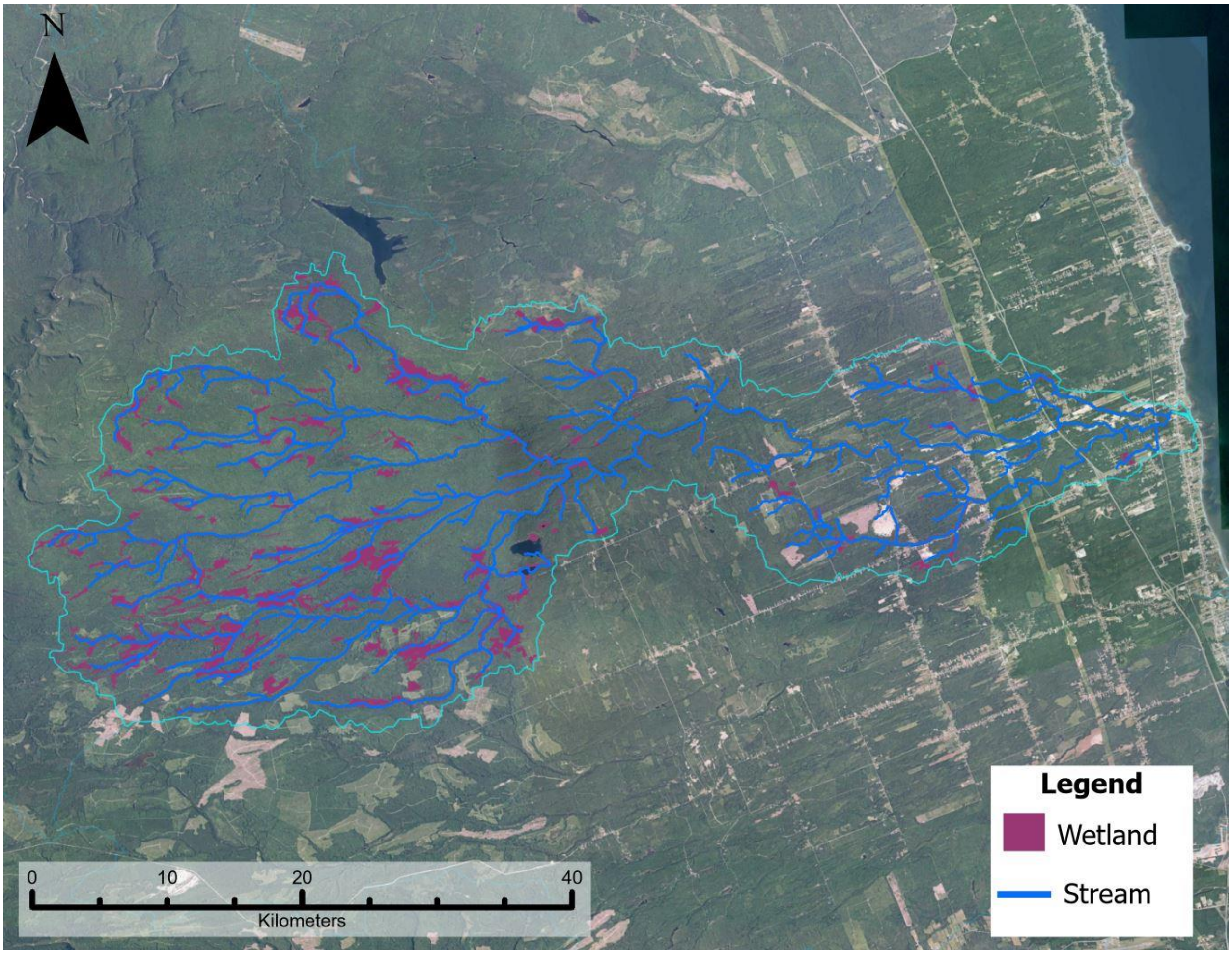


Figure 7. Wetland, stream, and study area for the Nigadoo Catchment located in New Brunswick, Canada.

Stream Crossing Workflow

The methodology of our stream crossing analysis is a modified version of Arsenault et al. (2022) and can be broken down into 9 steps:

1. Collect all publicly available data from GeoNB which includes the road network, stream network (optional), wetlands, and DEM's

2. Hydrocondition the DEM

3. Extracting the stream network flow lines from hydroconditioned DEM

4. Intersect stream and road network to identify potential crossing locations

5. Visual classification of crossings

6. Digitize culvers using polylines

7. Extract elevations from DEM by creating points at the end of each culvert polyline

8. Calculate length and slope using extracted elevation values and culvert polyline

9. Measure how many linear kilometers of stream are above impoundments or culverts that have a slope that exceeds the designated threshold

Road shapefiles were sourced from publicly available data on GeoNB. There is approximately 246 linear kilometers of road within the catchment. The stream network created using the selective breaching model is approximately 352 linear kilometers. Wetlands accounted for 18.2 km^2 (10.7%) of the total area for the Nigadoo catchment.

In Step 1, the Province of New Brunswick hosts a geographic information hub called GeoNB (http://www.snb.ca/geonb1/e/index-E.asp) that can be used to access and download GIS files. We utilized GeoNB for our road network, wetlands, and DEM. There is approximately 246 linear kilometers of road within the catchment.

In step 2, the digital elevation model contained depressions and artifacts which are cells within the DEM that have no downstream neighbor. This can result in flow routing methods for stream extraction to stop since there is nowhere for the flow to go (Temme et al., 2006; O'Callaghan & Mark, 1984). To resolve this problem, the DEM needs to be hydro conditioned, which is a processing method that removes these depressions and artifacts. Removal of depressions can be achieved through raising the elevations within the depressions to allow the channel to flow downstream or to carve through artifacts to reach a cell that allows the flow to move downstream (Jenson & Domingue, 1988; O'Callaghan & Mark, 1984). The issue for most filling methodologies is that the filling process could fill natural depressions and misrepresent the real-world flow. A least-cost breaching method created by Lindsay & Dhun (2015) was used to resolve these depressions and artifacts. This methodology focuses on removing the artifact dams from roads while maintaining natural depressions (Lindsay & Dhun, 2015). Lindsay & Dhun (2015) found that this breaching algorithm overcame 87.7% of major stream-road crossings and reduce the impact to the DEM by 80% when compared to traditional depression filling or stream-burning (Lindsay & Dhun, 2015). The breaching algorithm is available in an ArcGIS toolbox on the Whitebox Box Geo website (https://www.whiteboxgeo.com/).

In step 3, we used ArcGIS Pro geoprocessing tools to extract our stream network from our hydroconditoned DEM. The flow initiation threshold was set to 180,000 hectares to encompass all permanent streams with minimal ephemeral streams. The stream network created using the selective breaching model is approximately 352 linear kilometers.

The road and stream networks were then intersected and visually classified. Crossings were classified as a culvert, bridge, ford, or impoundment. Non-fish bearing crossings such as drainage ditch culverts were not included in the analysis. We used the classification methods from Arsenault et al., (2022), which use a combination of orthophotography and DEM to determine each crossing manually. Impoundments can be described as a crossing that has a dramatic elevation change with no evidence of a crossing and water pooling on the upstream end.

After each crossing was classified, in step 6, 7, and 8, culverts were digitized as a polyline representing the culvert. For each crossing that was classified as a culvert, points were created at the endpoints of the digitized culvert lines. We then used the tool "calculate geometry attributes" to calculate the culvert length and used "extract values to points" to extract the elevation values from the DEM at each end of the culvert. After length and elevations were calculated, the field calculator can be used to calculate slope.

Step 9 depends on the goals of the user, where the slope percent threshold can be chosen based on the user's remediation goals. An example of this is Arsenault et al., (2022) providing 4 different species present in the Restigouche Watershed. For our purposes, the slope threshold of 2% will be used because it represents the slope threshold for Burbot (*Lota lota*) and Lake Chub (*Couesius plumbeus*), some of the weakest swimmers in the study area (Macpherson et al., 2012; Bourne et al., 2011).

In the final step, culverts that had a slope exceeding 2% were considered a barrier. The area above each of the barriers was measured in linear kilometers to determine how many kilometers of stream the barrier restricts.

Results

Atlantic salmon habitat quality

When reviewing the data available for the Nigadoo catchment, we researched if it was possible to derive habitat types and identify riffles, runs, and pools to determine if we could measure Atlantic salmon (*Salmo salar*) habitat by extracting those variables. We determined that unfortunately, it is not possible to identify the habitat types by remote sensing because the LiDAR camera used did not have the capability of processing the needed bands of light. To expand, LiDAR works on the near infrared to infrared scale and Orthophotography records on the visible spectrum (RGB). Classifying habitat using LiDAR or any other airborne laser scanning (ALS) requires a bathymetric or green wavelength ALS (McKean et al., 2009). If the catchment was scanned with either a bathymetric capable ALS or a high resolution (< 20 cm) LiDAR and Orthophotography ALS, then it would be possible to map Atlantic salmon habitat using the LiDAR. Studies like Kuiper et al. (2022) created a random forest model that was designed to identify stream characteristics associated with salmonid abundance and habitat quality using high resolution ALS. They found that stream gradient was a good proxy for fish bearing potential, with 82.9% accuracy. The limit to this method is that stream width is difficult to determine using LiDAR or orthophotography due to resolution, angle, season, and angle of the sun (Biron et al., 2013). To resolve this, studies like Johansen et al., (2010) had successful results from measuring stream width on larger streams using object-based image analysis. This study would also require higher resolution LiDAR and orthophotography to accomplish this deliverable.

Crossing Classification

A total of 119 crossings were classified. Of those 119 crossings, 75 (63%) were culverts, 18 (15%) were bridges, 14 (12%) were impoundments, and 12 (10%) were fords.

Crossing Analysis

Of the 75 digitized culverts, 20 had a slope exceeding 2%. The 20 culverts are blocking approximately 28 linear kilometers of stream. The 14 impoundments block approximately 24 linear kilometers of stream. We estimate that approximately 12% of all streams are barriers to fish passage within the Nigadoo catchment (Figure 13).

Table 3. Total and percent of total linear stream kilometers with the number and percent of stream that is blocked categorized by Strahler stream order in the Nigadoo catchment.

Stream Order	Total Linear Kilometers	% of Total Linear Stream Length	Linear Kilometers Blocked	% Blocked by Barrier
1	181.4	51	12.1	42
2	80.6	23	16.1	56
3	50.4	14	0.5	2
4	17.2	5	0.0	0
5	24.2	7	0.0	0

Figure 84. Field visit and assessment of Barrier FID 0, the most downstream barrier to fish passage in the Comeau Brook sub-catchment. Parr habitat is determined to be adequate in this sub-catchment, but there are other fragmentations upstream that limit productivity.

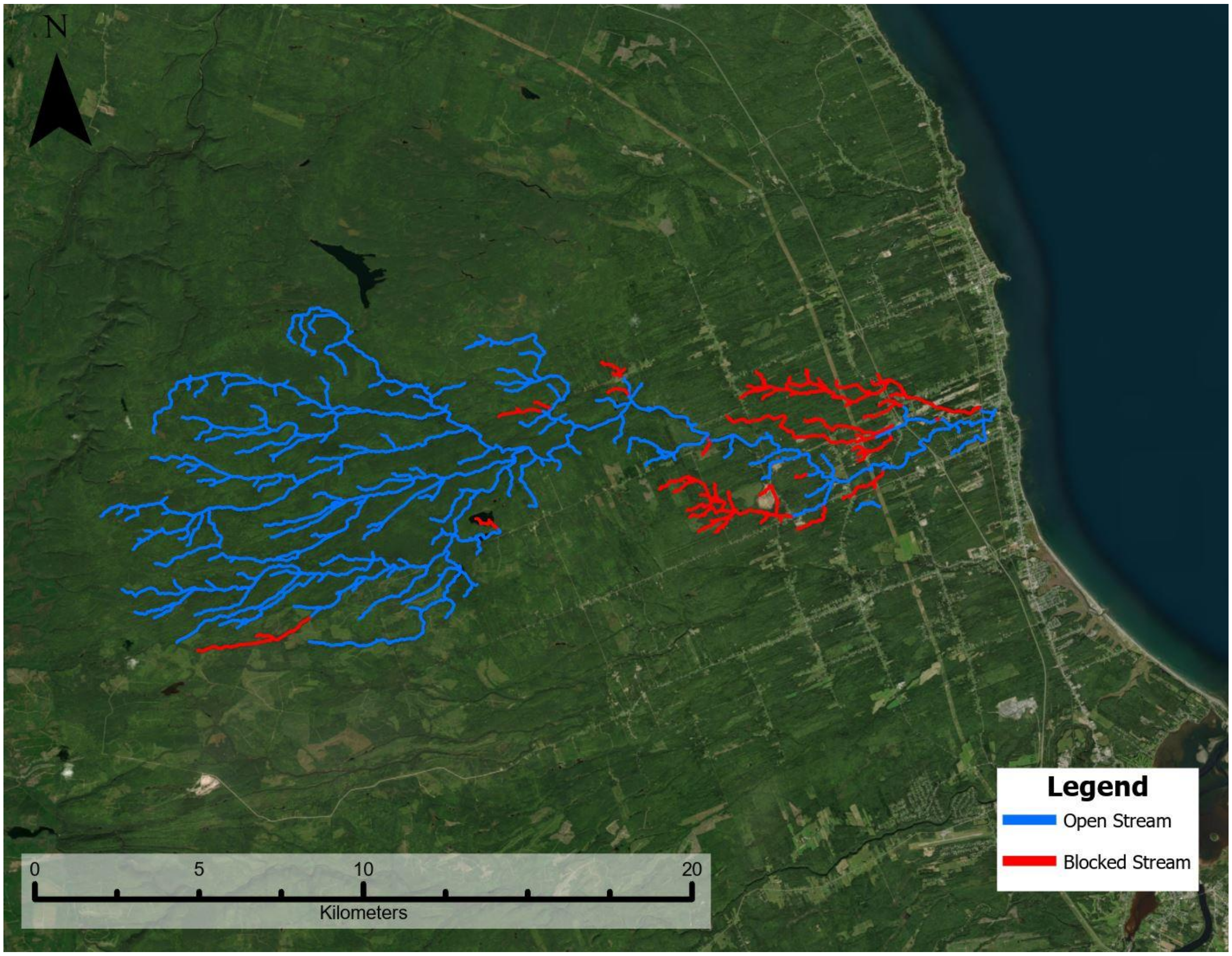


Figure 93. Stream blocked by stream crossings in the Nigadoo Catchment located in New Brunswick, Canada.

Discussion

The Nigadoo River catchment offers a high-quality habitat for Atlantic salmon, with unimpeded access for all life stages across the lower 24 kilometers of its mainstem (Stream Order 5) for rearing and spawning. This section of the river, with an average width of 14 meters, provides a wetted habitat area of 336,000 m², making it a significant environment for salmon in the Bay of Chaleur region.

The mainstem includes a variety of habitat types essential for Atlantic salmon:

1. **Riffles**: Provide oxygenated water for juvenile rearing.
2. **Runs**: Offer transitional zones for movement and foraging.
3. **Pools**: Serve as resting areas, although the river lacks deep pools for adult salmon holding. While the limited number of deep pools may pose challenges for holding, this feature is typical of other coastal salmon rivers in the region.

To further enhance the understanding of the Nigadoo River's salmon habitat quality and stock status, spawning habitat could be determined by:

- Targeted surveys of salmon redds in late fall to assess the population's reproductive levels and recruitment
- Identify gravel bed quality and flow conditions in adjacent sections of characterized redds. Determine suitable areas for redd enhancement.

Overall, the Nigadoo watershed provides good habitat for salmonids, adequate land use, some barriers to connectivity only found on smaller order tributaries and average water temperatures within the thermal optimum of Atlantic salmon. In fact, the Nigadoo catchment is in a more optimal position for remediation than most other catchments in New Brunswick. From previous stream crossing analysis within the province, we would typically expect 40-50% of culverts to be barriers to fish passage, while the Nigadoo catchment has half of that at 27%. Given that there are 20 culverts, we found that laying out a priority plan for remediation would be the best approach. The plan can be found under “Remediation Recommendations”, and it will cover the stream crossings, impoundments, and erosion sites in the order of most impactful, to the least.

Beaver Dams

Beaver dams in stream systems can cause a shift in biodiversity and age structure of fish populations if the beaver dam is not passable (Rosell et al., 2005). A study in Catamaran Brook, New Brunswick by Mitchell & Cunjak (2007), found that beaver dams can cause Atlantic salmon distribution to be reduced and patchy due to the loss of access to upstream from the beaver dam (Collen & Gibson, 2001). Autumn stream flow is vital to Atlantic Salmon spatial distribution and the reduction of accessible habitat from beaver dams further reduces the available habitat. Mitchell & Cunjak (2007), identified that streamflow and location of the beaver dams are critical to Atlantic Salmon spatial distribution, biodiversity, connectivity, recruitment, age structure class, survival, and fish community structure (Beard & Carline, 1991).

In the context of the Nigadoo River, beaver dams located in the lower gradient upstream areas of the catchment provide buffer from drought conditions, runoff and warm air temperatures, thus ensuring some base flows throughout the summer months and cooler water temperatures from shaded wetlands with low turbidity. Beaver dams have the benefit of increasing the water table, which in turn increases the groundwater level. The result can be decreased water temperatures downstream of the beaver dam (Dittbrenner et al., 2022; Majerova et al., 2015) which is beneficial to Atlantic salmon.

Remediation Recommendations

In addition to our baseline data and stream crossing analysis, we have provided an excel spreadsheet that outlines each of the barriers within the catchment with notes. The sites are grouped according to individual stream reaches; if there was no name for the stream reach, it would be categorized as a tributary of the next downstream named stream. Each site provides the barrier type, the Barrier ID number that correlates with a custom Google map for easier viewing, the X, Y coordinates in decimal degrees, length of the barrier, elevation difference, slope, and the number of linear kilometers the barrier is blocking.

The Google map can be accessed here:
https://www.google.com/maps/d/u/1/edit?mid=1ZhgAgKJvGdVhPT2-5wFK7PDHXZHeGBE&usp=sharing

Conclusion

The remote sensing analysis successfully identified fragmentations and barriers; however, the assessment of salmon habitat quality fell short of expectations. While habitat quality was not accurately determined through remote sensing, the analysis identified available habitat for salmon. The limited electrofishing data (one data point in 2024 from three sites, instead of a comprehensive time-series database) does not allow us to discern whether the stock status is linked to the quantity and quality of available habitat or to low adult returns and egg deposition. To address these gaps, we recommend conducting redd inventories in the fall of 2025 throughout the 24 km Atlantic salmon habitat section, collecting environmental DNA (eDNA) in unfragmented upstream sections (Strahler Order 4), and performing an inventory of benthic macroinvertebrates to evaluate prey availability. Additionally, thermographs should be installed upstream of the tidal influence zone, with at least one at each electrofishing site, one in Comeau Brook, and four in Strahler Order 4 segments: two in the Northwest Branch, one in the Central Branch, and one in the Southwest Branch. These actions will enhance our understanding of habitat quality, prey availability, and environmental conditions, improving our capacity to evaluate the factors influencing salmon stock status and productivity of the Nigadoo River.

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