TALLINN UNIVERSITY OF TECHNOLOGY

FACULTY OF CIVIL ENGINEERING
DEPARTMENT OF ENVIRONMENTAL ENGINEERING

A GIS-based risk assessment of New Brunswick Province, Canada

GIS-põhine Kanada New Brunswicki provintsi riskianalüüs

EKV70LT

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Tallinn, 2016

Herewith I declare that this thesis is based on my own work.
All ideas, major views and data from different sources by other authors are used only with a reference to the source.

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TASK FOR FINAL THESIS

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1. New Brunswick Hydrographic Network
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3. Land Cover for Agricultural Regions of Canada, circa 2000
4. CanVec – Resource Management Features
5. GIS software ArcMap 10.0

Content of the thesis:

- An investigation of relevant literature, similar studies with the aim to establish assessment guidelines and determining the data requirements for the assessment.
- Collection of all necessary data and data processing using ArcGIS.
- Analysis of the results of the data processing phase.
- Identifying the strengths and weaknesses of the assessment.
- Conclusion and recommendations.

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1. INTRODUCTION

Traditional watershed assessments focus on single or multiple chemical approaches to determine watershed health. Recently, it has become popular in Canada to analyze watersheds at a regional scale using geospatial data. This paper presents a regional watershed risk assessment of the Canadian province of New Brunswick using this modern approach. The watersheds of New Brunswick are analyzed in terms of nine watershed attributes known to be indicative of risks of water quality degradation. Further, the assessment considers municipal water consumption as a means to emphasize risks attributed to watersheds where municipalities abstract water for their supply. The assessment ranks the watersheds in terms of overall relative risk to one another, allowing for the identification of the highest risk watersheds in the province. The results allow for watershed managers to better localize water monitoring efforts as well as identify information gaps which can guide future data collection practices.

1.1 Initial Task

The initial task of this thesis was to develop a regional watershed risk assessment of a specific location with the aid of GIS software. The goal was to provide an assessment, using spatial data, whose conclusions could not be drawn using the existing water monitoring station data. The task was organized into three main phases; research, data processing, and analysis.

The research phase was to contain the following elements. First, an investigation into similar studies was to be completed. This would allow for the establishment of assessment guidelines as well as determining the data requirements for the assessment. The data requirements would be determined based on the watershed attributes and characteristics evaluated in the literature. Once these data requirements were established, a study area was to be found. The area was to be of sufficient size to require a regional assessment, and have data available to provide comprehensive coverage of the study area. The research phase could be concluded with the collection of all necessary data.

The data processing phase required working with the data in ArcGIS. Through working with the software, a numerical value could be assigned to each watershed for each attribute. Upon completion this would permit the establishment of a single risk value based on a combination of all measured attributes.

The final phase of the thesis was to analyze the results of the data processing phase and to determine what conclusions could be drawn. Determining at risk watersheds was the reason behind the investigation and therefore the success of this aspect was to be analyzed in detail. Further, identifying the strengths and weaknesses of the assessment was required in order to contextualize the conclusions and understand the limitations of the assessment.

1.2 Watershed Risk Assessments

Early watershed assessments focused on single-chemical approaches where watershed health would be determined based on the amount of a chosen chemical found in its water bodies, such as a nutrient or pollutant. The emergence of available geospatial data has led to a more integrated approach. Now, it is much easier to analyze multiple stressors simultaneously and to examine the possibility of cumulative effects. Further, the ability to analyze watersheds at a regional scale is also made easier with geospatial data. When employing a single-chemical approach, the monitoring requirements often render large area coverage to be too expensive. (Sterling et al., 2014)

When developing a high-level, integrated approach to watershed assessment for neighbouring province Nova Scotia, Sterling et al. described three primary reasons for doing such an analysis. First, the analysis creates a regional picture of threats to aquatic ecosystems needed to compare threats among watersheds. Through the identification of these threats, specific watersheds are identified of being at risk. This identification allows for the guidance of protection, mitigation, and restoration efforts. Specifically, the high-level integrated approach permits the identification of threats caused by non-point sources. These sources were often difficult to identify using older approaches. (Sterling et al., 2014)

Second, high-level integrated assessments are able to provide guidance regarding localized monitoring in terms or filling gaps in coverage or determining what metrics to measure based on what types of information are already available. (Sterling et al., 2014)

Third, high-level integrated watershed assessments bring together information from a variety of sources that may otherwise not have interacted with one another. This allows for a straightforward identification of information gaps. (Sterling et al., 2014)

Ultimately, a completed high-level integrated watershed assessment provides a visual communication tool that can be used by a variety of groups and individuals including watershed managers, regulatory agencies, policymakers, and local communities.

1.3 Assessment Framework

High-level integrated watershed assessment framework typically uses a combination of effects-based and exposure based variables. There is not an established way of doing such an assessment as it often varies depending on what data is available to the assessors.

1.3.1 Effects-based Variables

Effects-based variables are those which measure localized effects of anthropogenic impacts on the environment. This includes water chemistry, aquatic population, and channel morphology, amongst others. The usefulness of this type of data is obvious as it provides information directly related to the conditions in a given location. However, its ability to represent a given area or region is debateable. For example, the chemical makeup of one stream may or may not be representative of another stream two kilometres away. Or, the health of a fish community of a given lake may or may not be indicative of another nearby lake. (Sterling et al., 2014)

Effects-based variable data is also often expensive to gather compared to exposure based data. A robust effects-based dataset would require time series data in order to guarantee an accurate portrayal of a given characteristic. Also, based on the abovementioned uncertainty with regards to spatial representativeness, it is important to increase the density of the monitoring network to such a level that confidence can be achieved. (Sterling et al., 2014)

1.3.2 Exposure-based Variables

Exposure based variables are typically non-chemical and map based. They are used to identify regional rather than point sourced patterns of concern such as road networks and land use. Unlike effects-based data, exposure-based data does not provide information directly related to the conditions of a given watershed. For example, road density is an exposure based variable, and it has been shown to correlate negatively with the environmental conditions for aquatic wildlife. So, if road density is known, the health of a nearby lake can be estimated but not known. Exposure-based variable data is less expensive to gather compared to effects-based data. (Sterling et al., 2014)

1.4 Data Availability in New Brunswick

New Brunswick, and Canada as a whole, suffers from a lack of effects based data sufficient for a regional assessment. Specifically, data regarding chemicals in rivers either doesn't supply sufficient coverage or is too old to be considered representative. Data regarding aquatic species populations suffers largely from the same fate. Studies have been published and have made their data available however it is not usable in this investigation due to a lack of completeness or simply being outdated. Certain watersheds have been studied in great detail by the province's Department of Environment and Local Government but the majority of the province remains unstudied at any depth.

On the other hand, there is a plethora of exposure based data available. Various provincial and federal governmental departments provide data related to road networks, water networks, land cover and uses, etc. For this reason, this assessment uses mostly exposure based data.

1.5 Assessment Structure

This risk assessment used a two tiered approach. Watersheds are assessed in terms of nine attributes and in terms of municipal water consumption. The nine attributes are as follows:

1. Road Density
2. Drainage Density
3. Stream Crossing Density
4. Agricultural Land Use
5. Human Land Use
6. Average Watershed Slope
7. Dam Density
8. Portion of Stream Network Behind Dams
9. Acid Mine Drainage Risk

Water use is measured in terms of:

1. Municipal Surface Water Consumption
2. Municipal Groundwater Consumption

The following section justifies the inclusion of each watershed attribute and water use measurement. Also, an explanation for how each attribute was calculated scored is found in section 3. Next, the results are presented in terms of each watershed attribute and as tallied scores considering only attributes and attributes and municipal consumption. Finally, the assessment concludes with the successes and limitations of the assessment and how the assessment could be used to guide decision making.

2. METHODS

This section explains what elements were included in the assessment, why they were chosen and how they fit into the overall assessment. First, the study area is defined and introduced with some relevant facts about the area. Second, the watershed delineation methods are explained and the watershed units are defined. Third, each watershed attribute is explained in terms of its relevance to the assessment and how it was calculated in terms of the data and software. Fourth, the water use data is introduced and its role in the assessment framework is explained. Finally, the scoring scheme for the assessment is defined, explaining how the attributes come together to form a single overall risk score for each watershed unit.

Figure 2.0 – Map of Canada with New Brunswick coloured in red (Wikipedia)

2.1 Study Area

This report investigates watersheds located in the province of New Brunswick, Canada and the spatial limits of the investigation are identical to the provincial limits.

New Brunswick is one of Canada's Maritime Provinces located in the eastern part of the country. Its location within Canada is shown in Figure 2.0. It borders two other Canadian provinces; Nova Scotia to the east, and Quebec to the west. The longest land border is with the American state of Maine, to the west. The province is also bordered by four main water bodies; the Gulf of Chalears to the north, the Gulf of Saint Lawrence and the Northumberland Strait to the east, and the Bay of Fundy to the south. The total area of the province is 72 908 km^2 making it the third smallest province or territory in the country.

Figure 2.1 – Map of New Brunswick including major settlements and bordering entities (http://wwp.greenwichmeantime.com/images/canada/new-brunswick.jpg)

New Brunswick has three settlements with a population exceeding 50 000 people: Saint John, Moncton, and Fredericton. The location of these settlements is shown above in Figure 2.1. The population of the entire province is only approximately 750 000 people resulting in a population density of 10.51 people per km^2. For comparison, Estonia has a population density of 29 people/km^2, Finland has 16 people/km^2, and Russia has 8 people/km^2.

The province has eight major river systems called the Saint Croix River, Saint John River, Kennebecasis River, Petitcodiac Magaguadavic River, Miramichi River, Nepisiguit River, and the Restigouche River.

Experts have divided the province into seven ecoregions based on climatic differences. These differences are typically caused by major landforms, elevation, latitude, marine influences, and species distribution. The differences between the regions will not be discussed in detail however tables 2.1 and 2.2 below provide a snapshot into the climatic differences between ecoregions. For each ecoregion, a single climate monitoring station was chosen to represent the region.

Table 2.1 – Annual Precipitation by Ecoregion

Location		Annual Precipitation (mm)		
Ecoregion	**Monitoring Station**	**Rainfall**	**Snowfall**	**Total**
Central Uplands	Edmundston	753	258	1011
Eastern Lowlands	Moncton	842	282	1124
Fundy Coast	Saint John	1055	240	1295
Grand Lake	Fredericton	826	252	1078
Highlands	Mount Carleton	797	322	1119
Northern Uplands	Charlo	734	336	1070
Valley Lowlands	Woodstock	858	272	1130

Table 2.1 shows information regarding the annual precipitation in a town in each ecoregion. The Fundy Coast ecoregion, on the south eastern coast receives much more precipitation than the other regions but also the lowest amount of snowfall.

Table 2.2 – Average Temperature by Ecoregion

Location		Average Temperature (°C)		
Ecoregion	**Monitoring Station**	**July**	**January**	**Annual**
Central Uplands	Edmundston	18.2	-12.9	3.6
Eastern Lowlands	Moncton	19.5	-8.2	6.1
Fundy Coast	Saint John	17.1	-7.9	5.2
Grand Lake	Fredericton	19.3	-9.4	5.6
Highlands	Mount Carleton	17.3	-13.5	2.9
Northern Uplands	Charlo	17.9	-12.6	3.4
Valley Lowlands	Woodstock	19.0	-11.5	4.8

Table 2.2 shows annual temperature information for each ecoregion. For all locations in the province, July is the warmest month and January the coldest. Average July temperatures range between 17.1°C and 19.5°C. The range is much larger in January with a range of -7.9°C to -12.9°C. This is explained by Saint John experiencing a coastal climate with its temperature being influenced by the Bay of Fundy. Edmunston and the Central Uplands ecoregion have a continental climate and therefore a larger temperature fluctuation is expected as there is no large water body nearby to regulate the temperature.

2.2 Watershed Delineation

The watershed boundaries for this assessment were those delineated by the New Brunswick Department of Natural Resources as part of the New Brunswick Hydrographic Network. The boundaries represent all of the second level drainage basins in the province.

The choice of second level drainage basins was made based on the number of watersheds that would be assessed. There are only thirteen first level drainage systems fully contained in the province with a few others split between the province and Quebec, Maine (USA), or Nova Scotia. It was thought that these drainage basins were too large to assess in a meaningful way. For example, if the results of the assessment are to be used to direct monitoring efforts, narrowing risks down to a first level drainage basin is unlikely to provide much assistance in this regard. By dividing the first level drainage basins into smaller units, the results can be much more useful in pinpointing risks and concerns. Second level drainage basins are defined in this assessment as basins that represent a fifth order or higher watercourse and that have a drainage area of at least 100 km^2. In certain cases, once these second level drainage basins were determined; there were areas smaller remaining that did not meet the aforementioned criteria. These areas were still considered to be second level drainage basins but they were given the name of ‘composite’ to distinguish between basins meeting the criteria, and leftovers. By dividing the province in this way, 144 drainage basins are defined compared with thirteen first level basins. Of the 144 drainage basins, 91 have composite status meaning that the criteria for determining a second level is more useful for understanding methodology than it is as a basin descriptor. For this assessment, all second level drainage basins are referred to simply as ‘watersheds’. (Canadian Rivers Institute, 2003)

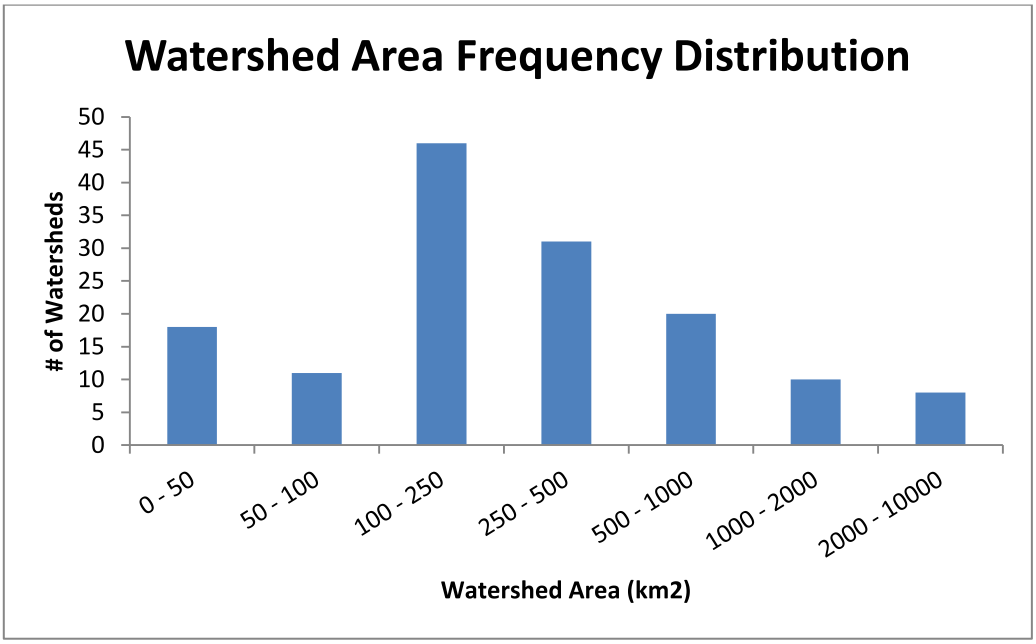


Figure 2.2 – New Brunswick watersheds sorted according to area

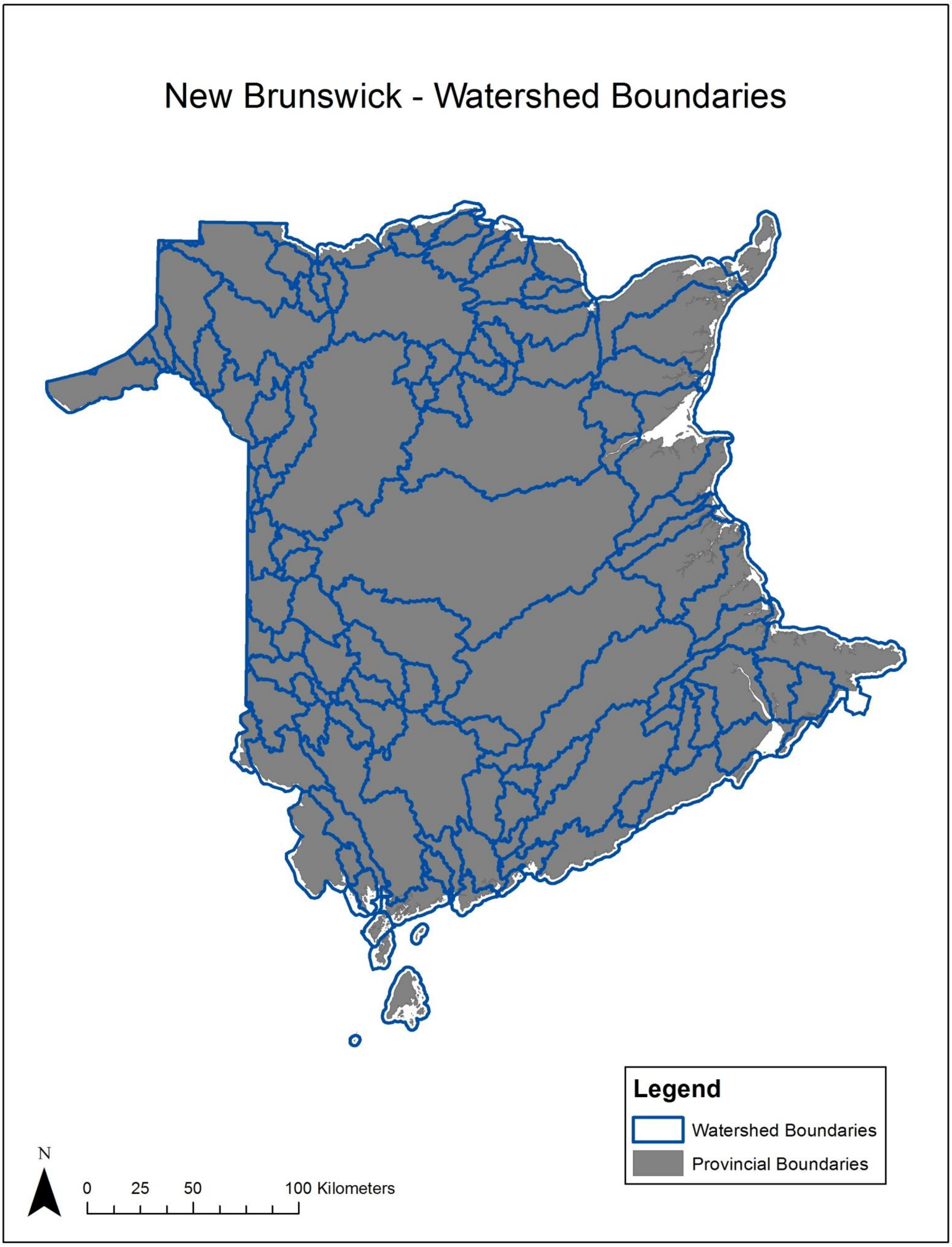


Figure 2.3 – Map of New Brunswick showing watershed boundaries

Due to the location of provincial and national boundaries, there are twenty six watersheds which straddle a border and are therefore not fully represented in this investigation. This leads to the possibility that a watershed may be correctly or incorrectly assessed a risk level that may not be accurate based on the conditions on the other side of the border. Generally speaking, the conditions on either side of the border are expected to be similar. However, in the case of larger watersheds or risks stemming from localized sources such as mines, the risk may only partially reflect reality. The full implications of this are explored later in the assessment. (Canadian Rivers Institute, 2003)

Figure 2.2 shows the distribution of the watersheds in terms of drainage area. The mean watershed size was 537 km^2 and the median size was 235 km^2. Figure 2.3 shows the watershed boundaries overlain on the provincial boundaries.

2.3 Attribute – Agricultural Land Use

Agricultural land use is measured as the area of land used for agricultural purposes divided by the total watershed area. This attribute is expressed as a percentage of total watershed area.

2.3.1 Importance

Agricultural land is a threat to watershed health based on the potential substances and materials that could be picked up by runoff and enter the waterways. These contaminants can be divided four ways; pesticides, fertilizers, heavy metals and agricultural bio-waste. Each category of contaminant can affect watershed health in different ways and each is important to consider. (Ongley, 1996)

Pesticides are chemicals which are used to destroy or repel pests. Pesticides can be divided into many categories, with the most important being herbicides (controlling plants), insecticides (controlling insects), and fungicides (controlling fungi and moulds). In New Brunswick, pesticides are regulated by both federal and provincial legislation (Government of New Brunswick, 2012). Pesticides can reach the water system through leaching into groundwater, runoff into streams, or by being attached to eroded soil particles. Less natural means of entering the water system include applying pesticides outside of the intended application zone, wind carrying pesticides into waterways when being applied, or spills. In most countries, pesticides can be detected in every waterway at some level. At high enough quantities, pesticides can be toxic to aquatic life. This can result in fish kills, as well as other species death. The number and variety of pesticides is incredibly diverse and therefore the toxicity and related impacts to wildlife varies significantly as well (Ongley, 1996). In Canada, limits for pesticides in the environment are found in the Canadian Environmental Quality Guidelines published by the Canadian Council of Ministers of the Environment (Government of New Brunswick, 2012).

Fertilizers are applied to agricultural land to provide crops with sufficient nutrients, mainly nitrogen and phosphorus. Fertilizers are often applied to fields in the form of synthetic fertilizers, composts, manures, etc. If improperly managed, fertilizers can end up entering streams through runoff or leaching into groundwater. A primary concern with fertilizers in waterways is eutrophication. Eutrophication occurs when conditions of excess nutrients occur. The nutrients stimulate algal and plant growth resulting plant and algal density much higher than would occur under normal conditions. When these plants and algae die off, the microbial degradation that takes place consumes oxygen in the water. Due to the unnatural amount of deceased plant and algal life, the resulting consumption of oxygen results in anoxic zones. These conditions are unable to support many species in the waterways resulting in the death of fish and shellfish that live within the zone. (Hascic & Wu, 2006)

Similar to the previous two categories, manure can enter waterways through runoff. As manure can be applied to fields as a fertilizer, its risks include those mentioned in that section. Additionally, manures contain high levels of ammonia. Ammonia is highly toxic to fish at low concentrations. So, manure contains the risk of both nutrient overloading as well as ammonia toxicity. (Gay & Knowlton, 2009)

The sources of heavy metals in agricultural soil are sewage sludge, fertilizers, pig slurries, and certain pesticides. Through runoff and erosion, it is possible for these heavy metals to enter waterways. Heavy metals can be potentially taken up by aquatic plants and enter the food chain. Through this process, it is possible that bioaccumulation will occur and concentrations of heavy metals will become such that they are harmful to aquatic life. (Efremova & Izosimova, 2012)

2.3.2 Data and Calculation Methods

This watershed attribute was calculated using two datasets. Agricultural land use was calculated using data from the *Land Cover for Agricultural Regions of Canada, circa 2000* publication from Agriculture and Agri-Food Canada. This publication provides data for land cover for much of the populated areas of Canada, including all of New Brunswick. Although the data is sixteen years old, agriculturally speaking it is unlikely that the land cover has changed significantly over this time period at the watershed scale. This was confirmed through personal communication with a local indicidual heavily involved in agriculture in the province (M. Edmondson, personal communication, April 15, 2016). More recent data would be preferable however any newer data is only available covering much smaller areas and not suitable for this investigation.

The other dataset used was the watershed boundaries used throughout the investigation. For this calculation, the file needed to be converted to a raster file.

To calculate the land cover percentage used by agriculture the Zonal Histogram tool was used which is part of the Spatial Analyst Tools package in ArcGIS. This calculated the amount of each land cover classification found within each watershed. Land cover classified as Cultivated Agricultural Land, Annual Cropland, and Perennial Cropland and Pasture was all simplified to simply 'Agriculture' in this study. The number of units attributed to each of these categories was totaled and divided by the total number of units to obtain the agricultural portion of land cover as a percentage.

2.4 Attribute – Human Land Use

Human land use is measured as the area of land used for anthropological purposes divided by the total watershed area. Agricultural land use is excluded from this attribute as it is included in another attribute. This attribute is expressed as a percentage of total watershed area.

2.4.1 Importance

Urban land use poses threats to watersheds that are comparable to those associated with agricultural land use. The main concern surrounds the potential pollutants that could enter the stream network via stormwater runoff. The government of British Columbia has published the following list of pollutants that can be found in urban stormwater runoff (Government of British Columbia, 2000):

- *asbestos from brake linings and clutch linings*
- *bacteria from animals and birds, soils, litter, livestock hauling, livestock waste hauling and onsite sewage tanks and fields*
- *bromide from auto exhaust*
- *cadmium from tire fillers and insecticides*
- *chloride from road salts*
- *chromium from moving engine parts and brake linings*
- *copper from bearing and bushing wear, moving engine parts, brake linings and radiator repair*
- *cyanide from de-icing road salts*
- *pesticides (fungicides, herbicides and insecticides) from roadside maintenance*
- *iron from autobodies, moving engine parts, bridges, guardrails, overpasses, lamp standards, and other structures*
- *lead from gasoline, tire fillers, lubricating oil and grease, bearing wear and automotive and radiator repair*
- *manganese from moving engine parts and gasoline additives*
- *nickel from diesel fuel, lubricating oil, bushing wear, brake linings and asphalt paving*
- *nitrogen from the atmosphere, animal wastes, onsite sewage systems, vegetative matter and fertilizers*

- *particulates from pavement wear, vehicles, the atmosphere and road maintenance*
- *PAHs from automobiles and pesticides*
- *PCBs from pesticides, atmospheric deposition and tire catalyst*
- *petroleum from paving, fuels spills, engine blow-by, lubricant leaks, antifreeze and hydraulic fluids*
- *phosphorus from the atmosphere, animal wastes, onsite sewage systems, vegetative matter and fertilizers*
- *potassium from the atmosphere and fertilizers*
- *rubber from tire wear*
- *sediments from construction sites, stream channel erosion, poorly vegetated lands and motor vehicles*
- *sulphate from roadbeds, road salts and fuels*
- *zinc from tire fillers, motor oil additives, automotive and radiator repairs, grease and paint manufacturing*

Of the potential pollutants in the above list, there are those that are of greater concern compared to others. Due to the climate in New Brunswick, road salts and sands are applied to provide traction on roadways and parking lots during freezing conditions. It is estimated that New Brunswick uses approximately 140 000 tonnes of road salt each year (Smith, 2016). These road salts can eventually find their way to freshwater waterways and can create unfavourable conditions. As the organisms in these water bodies are adapted to living in freshwater conditions, saline conditions are often fatal. Specifically, saltier water conditions will favour certain plants over others, altering the natural makeup of plant species. Also, increased salt content can cause problems for certain tree species regarding their susceptibility to fungal infections. For sands, they can end up being carried by runoff as sediment, increasing the sediment load in waterways (Ahmed, 2014).

Pesticides also cause a variety of concerns. In urban areas, pesticides are commonly applied to roadside grassed areas and lawns to prevent the growth of weeds. Lawns are also a source of fertilizer as lawn owners aim to grow and aesthetically pleasing lawn. The potential environmental concerns associated with pesticides and fertilizers are discussed in section 2.3.1. (Ahmed, 2014)

Hydrocarbon pollution from vehicles is also a major concern with urban runoff. Gasoline, motor oils, antifreeze, and other fluids often spill or leak onto driveways, roads, and parking lots frequently. In New Brunswick, most roadways and parking lots are covered with an ashphalt surface. Ashphalt surfaces are impervious when compared with dirt roads or soil surfaces. These surfaces do not permit spills and leaks to penetrate the soils and pollute the groundwater and soils. Instead, the pollutants remain on the surface until they are cleaned up or washed away by runoff. Sadly, being washed away by runoff is more likely and this leads to these pollutants making their ways to the stream network where they are often toxic to aquatic life. (Ahmed, 2014)

Urban land use has also been shown to be a source of metallic contamination in surface waters. (Ahmed, 2014)

Another problem with impervious surfaces is that they lead to higher amounts of runoff and higher peak flows in waterways. Disregarding exposed bedrock, most natural surfaces have some rainfall absorption capabilities. When humans alter these surfaces and replace them with asphalt surfaces or roofs, which permit the instantaneous pooling of rainfall on the surface, the amount of runoff increases. As mentioned in previous sections, this leads to an increase of runoff to the stream network which leads to higher peak flows throughout the system. This causes increased erosions which leads to a variety of problems in the watershed. (Ahmed, 2014)

2.4.2 Data and Calculation Methods

This watershed attribute was calculated using two datasets. Human land use was calculated using data from the *Land Cover for Agricultural Regions of Canada, circa 2000* publication from Agriculture and Agri-Food Canada. This publication provides data for land cover for much of the populated areas of Canada, including all of New Brunswick.

The other dataset used was the watershed boundaries used throughout the investigation. For this calculation, the file needed to be converted to a raster file.

To calculate the land cover percentage used by agriculture the Zonal Histogram tool was used which is part of the Spatial Analyst Tools package. This calculated the amount of each land cover classification found within each watershed. Land cover classified as ‘Built-Up’. The publishers defined this type of land cover in the following way:

> *“Land predominantly built-up or developed; including vegetation associated with these cover conditions. This may include road surfaces, railway surfaces, buildings and paved surfaces, urban areas, parks, industrial sites, mine structures and farmsteads. May also include golf courses and ski hills.”* (Agriculture and Agri-Food Canada, 2009)

This category aims to cover all land use by humans that is not attributed to agricultural use. The number of units attributed to each of these categories was totaled and divided by the total number of units to obtain the agricultural portion of land cover.

2.5 Attribute – Acid Mine Drainage Risk

Acid mine drainage (AMD) is a term that refers to a situation where acidic water conditions are created due to a natural chemical reaction with air, water, and sulphide bearing minerals. The term acid rock drainage (ARD) is used when the phenomenon occurs under natural conditions. In this report, the risk of AMD is estimated based on the number of ore mine extraction sites within a watershed. Mines are measured based on the number of pits or shaft openings rather that at an operational level.

2.5.1 Importance

Runoff from mining sites can lead to a variety of problems in terms of water quality. Many of these risks are accounted for in the Urban Land Area section of the report and are not mentioned here. The risk that is unique to mining sites is acid mine drainage.

Acid mine drainage occurs when sulphide minerals (most commonly pyrite, but also many others) are exposed to the atmosphere. These minerals can be exposed to the atmosphere naturally, in which case evidence of ARD can sometimes be used to locate them. Mining activities can expose these minerals on a much larger scale either through bringing them to the surface and storing them as mining debris or by exposing them to the atmosphere via and open pit or a mine shaft. In general, mining activities greatly increase the amount of rock surface exposed to the air which leads to a greater risk of AMD. The oxidation of sulphide minerals produces sulphuric acid, which lowers the pH of the water. If the sulphide mineral is pyrite, the reaction creates sulphuric acid and ferric sulphate. Under the lowered pH conditions, ferric iron can become oxidized to form ferric iron. The ferric iron can oxidize other minerals including lead, copper, and zinc. (Fraser Institute, 2012)

AMD can be devastating to the environment with which it interacts. The conditions created by a low pH and high dissolved metals concentrations are often not suitable for aquatic organisms leading to affected areas being void of life. ARD can contaminate both groundwater and surface water. The magnitude of the impact of ARD is related to the relationship between the amounts of ARD and the size of the receiving water bodies. (Fraser Institute, 2012)

New Brunswick is not known as an area rich in mineral resources except for a few key exceptions. Many coal mining operations have existed in the area to the east of Fredericton during the past several centuries. Most of these operations took place in the surrounding areas of the small community of Minto. In 2009, the mine ceased operations due to the coal no longer being of sufficient quality. The high sulphur and mercury content of the seam meant that it was no longer environmentally viable to extract the coal. The fact that the mine no longer operates does not mean that the AMD risk no longer exists as all that is required is exposure to the atmosphere. There is also extensive mining debris in the area due to the centuries of coal extraction. (The Canadian Press, 2009)

The other area in the province with a history of mining is the area southwest of Bathurst. This area is the host to many volcanogenic massive sulphide deposits where resources such as copper, lead, and zinc are mined. This area also has a lengthy history of mining operations with some still in operation and others that have closed within the past few years. Much of the rest of the province is without any mining operations. (Jutras et al., 2007)

2.5.2 Data and Calculation Methods

Mining tunnels and extraction sites are catalogued by the CanVec database which is a service provided by Natural Resources Canada that provides a wide variety of map based data for the entire country. Sites were assigned to a watershed based on their location. The data was in the form of point data and therefore there was no issue regarding trans-boundary mining sites. Watersheds were evaluated based on the number of extraction sites within their boundaries.

2.6 Attribute – Road Density

Road density measures the length of road per unit area. In this study road density was measured in kilometres per square kilometre (km/km^2). Roads can pose a variety of risks to watersheds and therefore road density is important to consider when assessing watershed risk.

2.6.1 Importance

Road density is an important watershed characteristic due to the numerous studies that demonstrate it having negative impacts on water quality. Specifically, roads can impact runoff regimes, expand the hydrological network, and introduce harmful pollutants into streams and rivers. Studies have designated road density as one of the most influential components in comparing ideal river conditions with the current state. (Radwell & Kwak, 2005)

Roads primarily impact watershed health through how they alter runoff regimes. The hard, compacted surfaces of roads are quite different from their natural counterparts and lead to changes in runoff. Roads generally lead to more runoff, faster flowing water which increases the risk of erosion. With increased runoff, the peak flow of waterways increases as well. (Ahmed, 2014)

Altering the flow rate of rivers and streams also has an impact on the species living in the waterways. Aquatic species are often adapted to live within a certain range of water flow rate and may be displaced if the changes are great enough. Further, biodiversity has been shown to decline in faster flowing streams compared to those which flow at a slower rate. (Ahmed, 2014)

Increased flow rate in streams increases the streams' energy and leads to the erosion of channel banks. Further, the increased sediment loads settle in channels creating shallower pools. The combination of increased turbidity, shallowness, and removal of bank vegetation leads to the temperature of the water being raised. This environmental change will be unfavourable for certain aquatic species and favourable for others. (Coffin, 2007)

The drainage systems that often accompany roads also play a role in water quality. When these drainage systems connect to the rivers and streams, the road network essentially expands the hydrological network to include these manmade drainage pathways. (Coffin, 2007)

Roads have also been shown to contribute negatively to the instability of montane habitats which can cause landslides. This is not considered a significant risk in New Brunwick but small scale instances may still be observed. Landslides, along with the previously mentioned erosion lead to increased debris flow and sediment deposition in waterways. Sediment clouds can lead to unsuitable conditions for many aquatic species. Also, the erosion caused by the increased runoff can increase the amount of nutrients and heavy metals that are leached from soils into the waterways. These chemicals impact the aquatic life in a variety of ways depending on their quantity. (Ahmed, 2014)

Lands near roads are often treated with herbicides and pesticides in order to keep the lands clear of undesirable species. These potentially harmful chemicals can enter into the aquatic environment via runoff and are applied solely due to the roads' presence. De-icing salts are also a major concern due to the icy winter climate in New Brunswick.

Several studies have shown that chemical spills along roadways are significant sources of pollutants. These chemicals can potentially enter the hydrological system through the roadside drainage system. (Coffin, 2007)

Toxic contaminants from roads can enter the water system via runoff. The main concerns are the introduction of hydratated ions, dissolved, colloidal, and gravitoidal particles, and suspended matter. (Coffin, 2007)

Contamination associated from roadway traffic can also enter the water system via roadway runoff. Pollutants such as hydrocarbons, asbestos, lead, cadmium, and copper are all the result of vehicles and are a threat to enter the roadway drainage system. (Coffin, 2007)

2.6.2 Data and Calculation Methods

Two data sets were used to compute road density; the road network and watershed boundaries. The road network data set is maintained by Service New Brunswick and contains lines which correspond to the centrelines of all roads found in the province. This information is sufficient to calculate the summed length of all roads within a watershed. Unlike a standard road map, divided highways are mapped as two segments. Road cover (paved, gravel, etc.) information is contained in the dataset but was not used in this investigation. Road width (number of lanes, width of shoulder, etc.) information was not included.

The other dataset used was the watershed boundaries used throughout the investigation.

Road segments were assigned to a watershed by using the Intersect tool. Road segments were assigned to a watershed and divided along the watershed boundary when necessary. Then, the data was exported to Excel where the total length of roadway in each watershed was calculated. These totals were then divided by the total area of the watershed providing the road density in km/km^2.

2.7 Attribute – Stream Crossing Density

A stream crossing is a location where a roadway and a stream intersect one another. The road typically either crosses the stream with a bridge structure or the stream is directed through a culvert which passes underneath the road. These structures often alter the streams both upstream and downstream of the structure making them a useful watershed attribute in high-level watershed assessments. Stream crossing density was expressed as the number of stream crossings per kilometer of stream network.

2.7.1 Importance

Stream crossings occur when a roadway crosses a stream. Depending on the conditions, stream crossings can take a variety of different forms. In New Brunswick, stream crossings take the form of a bridge or a culvert. If best practices are followed, it is possible for a stream crossing to have a very small impact on water quality. The primary concerns with stream crossings are their impact on stream flow patterns, the increased risk of pollutants entering the stream network from the road, and the potential to limit the fish species able to traverse the crossing. (Forman & Alexander, 1998)

Stream crossing structures can affect flow patterns both upstream and downstream. For culverts, upstream issues often occur during large precipitation events. Culverts are typically designed for a certain type of storm or flood event. In New Brunswick, culverts must be designed to accommodate the flow of a 100-year-flood meaning the peak flow has a 1% chance of occurring in any given year (New Brunswick Department of Natural Resources, 2004). If the culvert was not properly designed, a sizeable storm event can lead to backup and flooding upstream from the culvert as the culvert cannot pass the necessary water at the required rate. These situations can lead to significant erosion and even washing out the culvert. This is highly undesirable from a water quality perspective as it involves a rapid release of sediment into the stream network. In some situations this can cause a domino effect where the sediment flows downstream and clogs another culvert resulting in a similar problem. Other risks associated with culverts are a loss of pools and ripples, changes to the natural stream bed slope, decreased water turbulence and oxygenation, and increased bank erosion downstream (Environment Agency, 2002).

For bridges, the primary upstream concern is bridge scour. Bridge scour is a term used to describe the removal of sediment around abutments and piers. Water often flows faster around these structures which results in the disturbance of sediment which was deposited during a regime of slower flowing water. This disturbance of sediment can be harmful to aquatic life. In extreme cases, scour can lead to bridge failure and collapse which would be very damaging to the waterway (Carroll, 2008). Other risks associated with bridges are increased flood risks due to lower water velocity upstream, and downstream erosion due to increased water velocity (Environment Agency, 2002).

The increased risk of pollution and sediments entering the stream networks from the road is explained simply by the short distance between the road and the stream. In these situations there is a lack of natural filtration from plant life and therefore any pollutants or sediments picked up by runoff are going to easily make their way into the stream network. The risks and potential constituents of these sediments and pollutants are described in other sections of this report.

Culverts can be very problematic for fish species. Fish inhabiting a given stream system are typically accustomed to encountering the natural flow regimes of the network. The installation of a culvert can cause problems for fish in a couple of ways. First, if the dimensions of a culvert result in a shallow flow compared to the natural stream bed, it is possible that fish will be unable to pass due to insufficient depth. On the other hand, if the water velocity is too fast inside the culvert, it is possible that fish will be unable to swim upstream, essentially creating a barrier to fish passage. Another concern regarding fish passage is when the downstream culvert entrance floor does not match the downstream natural stream bed elevation. In this scenario, a fish wishing to travel upstream will have to be able to leap from the stream up into the culvert and out the other side. This is an obviously problematic scenario. Culverts in Canada are required to be designed for fish passage according to the Canada Fisheries Act (New Brunswick Department of Natural Resources, 2004) . In theory, this alleviates some risk, however the design challenges and data availability associated with such an undertaking means that the presence of a culvert is still indicative of a risk for fish species.

2.7.2 Data and Calculation Methods

Stream crossing density was calculated using three data sets; the road network, the stream network, and the watershed boundaries. Using the Intersect tool, stream crossings were identified as intersections between the stream network and the road network. The output was a series of points corresponding to the location of each stream crossing.

Next, the count function was used to identify the number of stream crossings per watershed polygon. Once calculated, these numbers were divided by the total watershed stream length as calculated as a part of the drainage density calculations (Section 2.11.2).

2.8 Attribute – Portion of Stream Network behind Dams

The portion of the stream network behind dams attributes measures the percentage of a watershed's stream network that is located upstream of dams. This attribute was included in the assessment due to the habitat fragmentation caused by dams. Habitat fragmentation can be one of the most harmful human activities on natural ecosystems.

2.8.1 Importance

The construction of dams often causes habitat fragmentation in stream networks. A habitat fragmentation occurs when a barrier (in this case, the dam) is formed within a habitat leading to different conditions of either side of the barrier. Fish have been shown to be a victim of habitat fragmentation caused by dams which is why this attribute can be used as an indicator of watershed risk. (Morita & Yokota, 2002)

Dams have been shown to negatively impact both migratory and non-migratory fish. Migratory fish species are those that leave their natal stream and return periodically to spawn or feed. Non-migratory fish species do not leave their natal stream. The installation of a dam often prevents the return of migratory fish to streams found behind dams. Studies have investigated watersheds with dams and found that fish species that occupy all non-dammed upstream habitats often did not occupy those that were dammed. This is not ideal as the absence of a species could lead to some sort of ecosystem disruption. (Morita & Yokota, 2002)

A habitat barrier such as a dam does not only pose risks to migratory fish, but also the non-migratory fish. Stream dwelling fish occasionally fit the description of a metapopulation. A metapopulation describes a situation where two population of the same species are separated spatially in some way but also sometimes interact with each other. It is possible to have a single fish species which has a migratory and non-migratory population. This could be described as a metapopulation as although the two groups would not interact with one another very often, they would interact when the migratory group returns to non-migratory occupied stream on a periodic basis. This interaction between groups has been shown to be crucial to the long term persistence of a species within the habitat. This is thought to be due to source-sink dynamics. For migratory and non-migratory fish, the risk surrounds whether or not the upstream habitat could be described as a sink. A sink is a habitat that is of insufficient quality to maintain the existence of an isolated population. When not isolated, a sink habitat is replenished by the population from the source habitat during their interaction. An individual from a source population electing to remain in a sink habitat appears counterintuitive but is explained in ecology by the ecological trap theory. What this all means is that dam construction not only limits the likelihood of migratory fish reaching upstream habitats but also threatens the long term persistence and therefore extinction of non-migratory fish living in these upstream areas. (Morita & Yamamoto, 2002)

2.8.2 Data and Calculation Methods

Calculating the portion of stream length behind dams required knowing the location of all dams within the province and the stream network layout. Both sets of data were available from the New Brunswick Hydrological Network. New Brunswick has only 48 dams and once their locations were plotted, the upstream length behind the dams was selected manually. From the selection, the stream length could be determined. These lengths were assigned to a watershed based on the watershed boundaries and then divided by the total stream network length. The final results were expressed as percentages.

2.9 Attribute – Dam Density

Dam density is a measure of the number of dams per unit length of the stream network.

2.9.1 Importance

Dam density is used in this watershed assessment based on the numerous harmful environmental effects that dams can cause. Dams are manmade barriers that impound water and underground streams. Dams are typically used to suppress floods, provide water for irrigation, create a reservoir for drinking water abstraction, and generate energy, amongst others. In New Brunswick there are forty eight dams in total. Twelve dams currently supply power to the grid accounting for approximately 22% of the province's energy generation. The presence of these dams can act as an indicator for potential harm in the watershed. (International Rivers, 2014)

A major concern with dams is their ability to trap sediments and prevent them from moving downstream. This can have negative effects on the downstream ecosystem as the sediment deprived river will erode river beds and banks. This leads to riverbed deepening which can have many negative impacts. First, the deepening of the river will lead to a decline in the water table along the river. This can be harmful to plant roots, as they may no longer have access to the necessary groundwater. (International Rivers, 2014)

Another concern surrounds the change from a flowing river system to a reservoir type of habitat. This can lead to changes in many of the properties of the ecosystem including temperature, chemical composition, and dissolved oxygen. Oftentimes these changes lead to the habitat becoming unsuitable for the plants, fish, and other aquatic species that previously occupied the area. There have been many reported instances where dam reservoirs have actually provided an ecosystem for invasive species to thrive, leading to further degradation of the natural inhabitants. (International Rivers, 2014)

The final major concern regarding the presence of dams has to do with fish migration. Migratory fish swimming upstream cannot bypass a dam without the aid of a fish ladder. A fish ladder is a structure that is built to allow fish to bypass the dam to continue the migratory journey. The fish ladder must be designed to suit the species of fish migrating up the river. Fish ladders have not been shown to be highly effective. They do allow some fish to migrate upstream however many are unable to based on the conditions being too challenging for the fishes' swimming ability. A less frequently mentioned concern is how the reservoir conditions cause problems for younger fish. Specifically, with salmon, they are expected to reach the ocean or sea within approximately fifteen days, and failing to do so can lead to problems with swimming behaviour in the future. Additionally, predators are known to prey on fish as they emerge at the foot of a dam. The fish are considered to be stunned from the journey through the dam and make for easy prey for fish-eating birds. Ultimately, the full impacts of dams on fish species are understudied and therefore incomplete. What is known is that many dams prevent many fish from completing their migratory goals. This leads to a disruption of fish reproduction and it not desirable in order to maintain good watershed conditions. (Waldman, 2013)

2.9.2 Data and Calculation Methods

Calculating the dam density required the coordinates of all of the dams in the province, the length of stream network in each watershed. Both data sets were available through the New Brunswick Hydrological Network. Once the dams were plotted, they were assigned to a watershed using the watershed boundaries. Next, the number of dams per watershed was calculated. These results were divided by total watershed stream length in units of 100km to give a final result of the number of dams per 100km of stream length.

2.10 Attribute – Average Watershed Slope

The average watershed slope is a watershed attribute that allows for a comparison on the basis of topography. The average water slope is an important attribute as it is an independent variable which can have a large impact on both time of concentration and runoff generation. Average watershed slope is different from the commonly measured channel slope (sometimes referred to as ‘watershed slope’) in that it measures the entire watershed area and not just the slope along the longest channel. In this study, average slope was expressed as a percentage of average rise over run.

2.10.1 Importance

Average watershed slope is an important watershed attribute due to its ability to impact time of concentration and runoff generation. Generally speaking, watersheds with larger average slopes will generate more runoff compared to those with smaller average slopes. With a small slope, the velocity with which the runoff moves over the land will be comparatively slow, leaving the runoff with more time to infiltrate the surface. This means that with a higher slope, more runoff will reach the stream network. So essentially, the steeper the slope, the faster the runoff and therefore more force to move material (erosion). Slope is considered to be one of four factors contributing to slope erosion, with the others being the amount and rate of rainfall, the amount and type of plant cover, and the type of soil and/or bedrock. The materials brought into the stream network by erosion can cause a variety of issues. Sediment in the water leads to increased turbidity which makes it more challenging for aquatic plants to get the necessary amount of sunlight that they require for photosynthesis. Also, the chemical composition can be toxic to the aquatic wildlife or lead to eutrophication if the eroded material contains nutrients. The contents of erosion will depend on the land cover of the watershed but a higher slope increases the changes of the material reaching the stream system. (Bryant Watershed Project, n.d.)

On a larger scale, slope can also be used as a general indicator for the likelihood of landslides and debris flow within a watershed. These events are undesirable due to the potential for making the water inhabitable for aquatic species. The risk of a large scale landslide in New Brunswick is quite low, but the Geological Survey of Canada Landslide Susceptibility map rates several areas in the province as moderate or high risk areas for a landslide of any size (Bobrowsky & Dominguez, 2012). Landslides are a threat to watershed quality due to the fact that they often lead to a rapid deposition of sediment in the stream network. This is damaging to aquatic wildlife in the same ways as standard erosion however it can be much more devastating due to the suddenness and magnitude of the event. (Highland & Bobrowsky, 2008)

2.10.2 Data and Calculation Methods

The average slope for each watershed was calculated using topography data as well as watershed boundaries. The topographic data was taken from the CanVec series of maps produced by Natural Resources Canada. The map displayed the topography in the form of contour lines. The contour lines were converted to display elevation using the Topo to Raster tool found in the Spatial Analyst Tools package in ArcGIS. This tool interpolates an elevation for each cell based on the contour lines. Next, the elevation data was converted to slope information using the Slope tool, also found in the Spatial Analysis Tools package. This tool provides each cell with a slope value based on the elevation data. Finally, the average watershed slope was calculated for each watershed using the Zonal Statistics tool, once again in the Spatial Analysis Tools package. This tool calculated the average value of all of the slope cells within each watershed boundary. The watershed boundary data was the same used throughout this investigation.

2.11 Attribute – Drainage Density

Drainage density is a measure of the total channel length divided by the area of the watershed. In this study drainage density was measured in kilometres of channel length per squared kilometre of watershed area. Drainage density is important to consider in watershed assessment due to its relationship with runoff delivery.

2.11.1 Importance

Drainage density is a significant characteristic to consider in watershed assessments due to its relationship with runoff delivery. It is assumed that watersheds with higher drainage densities will receive more surface water runoff compared to watersheds with lower drainage densities. (Knighton, 1998)

It is due to this relationship that higher drainage density results in a higher risk of non-point source pollution entering the stream network. Thus, common sources of non-point sourced such as agriculture, forestry, oil & gas fields, and urban development are more likely to have pollutants that reach the stream network compared to a similar watershed with a lower drainage density. The specific risks caused by these non-point source pollution sources are discusses elsewhere in the report. In the absence of these non-point sourced pollution sources, an increase in drainage density is not thought to pose any increased risk. (Rex, 2003)

A 2011 study by Ogden et al. concluded that watersheds with relatively low drainage densities were much more sensitive to changes compared to those with higher drainage densities. Through modelling, it was determined that watersheds with drainage densities between 0.4 and 0.9 km/km^2 were much more sensitive to changes compared to those outside of this range. It was determined that drainage densities above 0.9 km/km^2 had no effect on peak flows, runoff values, or runoff ratios. This finding is important as it suggests that a watershed assessment ought not to treat a drainage density of 1.0 km/km^2 any different than a value of 1.5 $km.km^2$ or 2.0 km/km^2. Although large differences may be observed, their differences may be largely irrelevant to their risk so long as they are outside a certain range. (Ogden et al., 2011)

2.11.2 Data and Calculation Methods

Two data sets were used to compute drainage density; the stream network and watershed boundaries. The stream network data set is maintained by the Department of Natural Resources and contains lines which correspond to the centrelines of all waterways that make up the province's stream network. This information is sufficient to calculate the summed length of all streams within a watershed. Lakes are also represented by lines connecting all of the streams and rivers that flow in an out of the lake.

The other dataset used was the watershed boundaries used throughout the investigation.

Stream segments were assigned to a watershed by using the Intersect tool. Stream segments were assigned to a watershed and divided along the watershed boundary when necessary. Then, the data was exported to Excel where the total length of streams in each watershed was calculated. These totals were then divided by the total area of the watershed providing the road density in km/km^2.

2.12 Water Use

Risks to watersheds can be seen as more severe if more people rely on the water supply for one reason or another. For example, risks to watersheds that supply drinking water to a city of 50 000 people via a municipal distribution system ought to be seen as a higher risk compared to a watershed that has only 400 people relying on it and who all use their own wells. Although not all sources of water consumption are tracked in New Brunswick, municipal water consumption data was made available through communication with an employee in the Environment and Local Government governmental department. The municipalities of New Brunswick use both groundwater and surface water sources to provide their constituents with water. The areas of abstraction are known and explained in the following sections.

2.12.1 Protected Areas – Surface Water

The province's Environment and Local Government department has established three layers of boundaries around watercourses that supply municipalities with drinking water. These layers are called Zones A, B, and C. Zone A is the watercourse itself, Zone B is a seventy five metre setback from the watercourse, and Zone C is the balance of the watershed. These zones are used to limit the activities inside in order to protect the watercourse from human activities. Rather than listing what cannot be done, the province has declared that all activities are not permitted unless otherwise listed. In Zone A, the most protected zone, the following is permitted: use of permitted watercourse crossings, boating and fishing in non-motorized watercraft, surveying and sign-posing, amongst others. Zone B is more lenient and permits many activities such as tree planting, existing agricultural activities, road construction, etc. Zone C is the least protected and permits forestry, and mining and quarrying activities (with limitations). The complete list of permitted activities can be found at (http://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/land_waste/content/reference_manual/watershed_protection.html).

The province currently has thirty protected areas for surface water withdrawal.

2.12.2 Protected Areas – Ground Water

The province has a similar scheme related to municipal drinking water wells. The zonal boundaries are not as well defined as they are for surface water. In this case they are less rigid and more up to the decision making of those drawing the boundaries. The illustration below (Figure 2.4) shows an example protected well field.

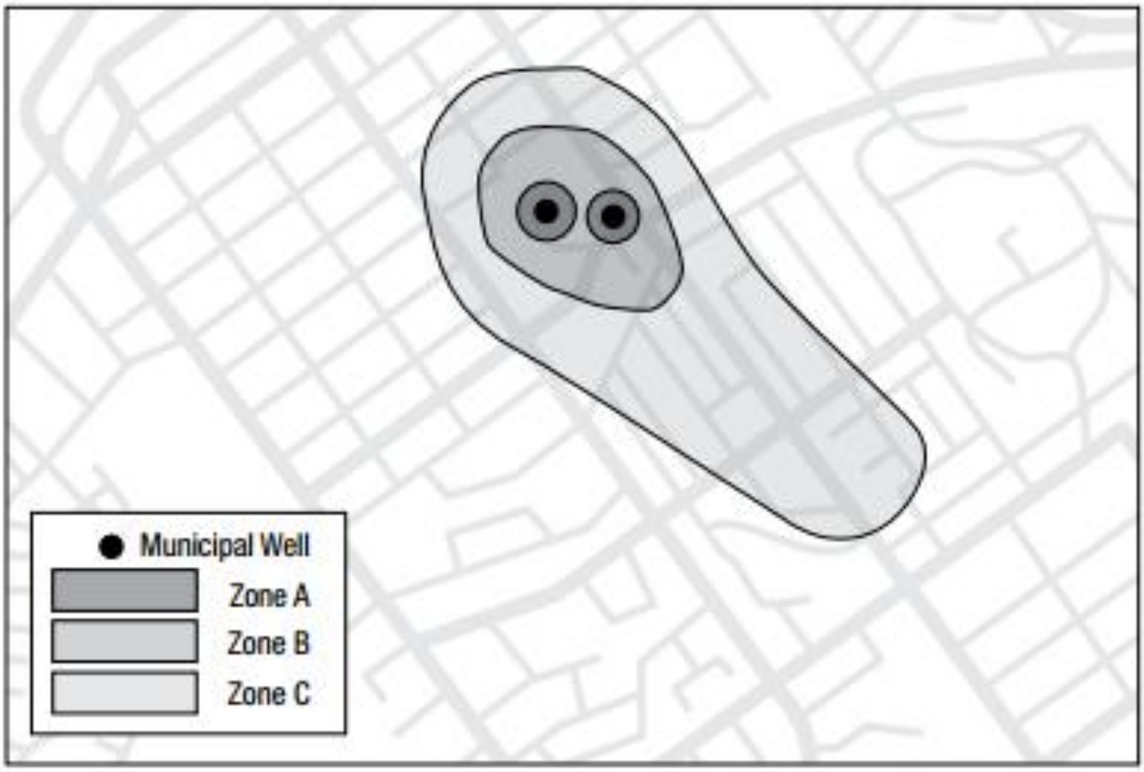


Figure 2.4 – An example of a protected well field zonal boundaries (http://www2.gnb.ca/content/dam/gnb/Departments/env/pdf/Water-Eau/WellfieldProtection.pdf)

Once again, the zones limit the types of activities permitted within their boundaries. Each zone has specified limits on liquid petroleum storage, pesticide storage and application, gardening and fertilizers, general chemical storage, recreational activities, agriculture, road construction, existing and newly constructed residential buildings, commercial and industrial buildings, and forestry.

The province currently has forty eight protected well fields.

2.12.3 Municipal Water Consumption

Through communication with government employees it was possible to secure data regarding the amount of water consumed at all but two of the provinces municipal water treatment plants. Consumption is reported in m^3 per year. The data does not all correspond to the same year as not all municipalities report in the same year however all of the data represents a year between 2010 and 2015.

2.12.4 Calculation

By assigning the consumption data to the protected areas it was possible to determine the amount of water abstracted from each watershed by municipalities. In situations where well fields were not all in the same watershed, consumption was divided in terms of the number of wells found in each watershed. For drinking water, each municipality sourced their water from a single watershed only.

Table 2.3 - Attribute Weighing System

Attribute	Units	Proportional / Tiered	Range	Normalization	Risk Multiplier
Agricultural Land	% of total land area	P	0	0.00	25
			60	1.00	
Acid Mine Drainage Risk	Number of Sites	T	0	0.00	25
			1-4	0.20	
			4-10	0.60	
			10+	1.00	
Human Land Use	% of total land area	P	0	0.00	20
			40	1.00	
Road Density	(km/km^2)	P	0.0	0.00	10
			4.5	1.00	
Stream Crossing Density	Number of crossings/km^2	P	0.00	0.00	10
			1.25	1.00	
Portion of Streams behind Dams	% length of total stream network	P	0	0.00	5
			75	1.00	
Dam Density	# of dams per 100km of stream	P	0.00	0.00	5
			0.85	1.00	
Watershed Slope	%	P	0	0.00	5
			15	1.00	
Drainage Density	km/km^2	T	0.00	0.00	5
			0.00 - 0.40	0.10	
			0.40 - 0.65	0.50	
			0.65 - 0.90	0.75	
			0.90+	1.00	

2.13 Scoring System

The overall watershed scores were calculated using two scoring systems. The first system applied an appropriate weighting system to the attributes in order to properly consider the relative risks that each attribute provided. The second incorporated water use data into the equation in order to further assess watershed risks with a focus on human reliability. This aimed to allocate increased risks to watersheds that New Brunswickers relied upon for their own consumption. Both systems are explained in detail below.

2.13.1 Attribute Weighting

In order to determine an overall risk for each watershed, the results from each attribute assessment were tallied. Each attribute was assigned a risk multiplier in accordance with its perceived overall risk to watershed health. For example, a watershed with a significant agricultural footprint should be considered a larger risk compared to a watershed with a high watershed slope.

First, it was decided whether or not an attribute was scored proportionally or via a tiered system. Attributes that were scored proportionally were assigned a range beginning at zero and ending at a round number close to the maximum value for a single watershed that was measured. These results were then normalized to a value between zero and one, and then multiplied by their risk multiplier to calculate their final score.

Tiered attributes assigned watersheds to a tier which corresponded to a value between zero and one. Attributes were scored using a tiered system when a proportional normalization may not have best represented the associated risks.

Once each attribute was scored, the totals for each attribute were added together to obtain an overall risk score for each watershed. The way that each attribute was scored can be found in Table 2.3.

2.13.2 Consumption Weighting

In order to consider municipal water consumption, additional risk was assigned to the watersheds where water is abstracted for municipal purposes. Each watershed was assigned a baseline score of 1 meaning that if there was no municipal consumption in a watershed, its score remained unchanged from its attribute tally. If water was abstracted from the watershed, the baseline score of 1 was increased according to the amount of water abstracted. The increase was based on a tiered system shown in Table 2.4. So for example, a watershed consuming 50 000 m^3 in one year would have its attribute total score multiplied by 1.25 to obtain its consumption-adjusted score.

Table 2.4 – Water Consumption Weighting Scheme

Annual Municipal Water Consumption (m^3)	Consumption Multiplier
0	1.00
0 - 10 000	1.10
10 000 - 100 000	1.25
100 000 - 1 000 000	1.50
1 000 000 - 10 000 000	1.75
10 000 000+	2.00

The use of these two weighing systems allowed for analysis that more accurately identifies the risks associated with each watershed. With the addition of the municipal consumption multipliers, watersheds can be assessed in terms of their attributes alone but also the extent of the problems faced by the province if the water was to become compromised in some way.

3. Results

The following sections present the results for each watershed attribute. Following attribute results, the overall rankings are presented in terms of attribute-only and consumption-adjusted rankings.

3.1 Agricultural Land Use Results

Agricultural land use in the province ranged between 0% and 55% with an average of 8%. From Figure 3.0 below, seventy five watersheds, or more than half, have less than 5% of their land used for agricultural purposes. Further, only fourteen watersheds exceed 20% agricultural land cover. Globally speaking, most New Brunswick watersheds have an agricultural land cover that would be considered low. For example, according to the World Band, Estonia has an agricultural land cover of 22.8%, Germany has 47.9%, and the United Kingdom has 71.3%. Canada has an agricultural land coverage of 7.2% which is lower than the average watershed agricultural land cover for New Brunswick. This is unsurprising as much of the northern parts of the country are sparsely populated, unfit for agriculture, or both. (World Bank, 2016)

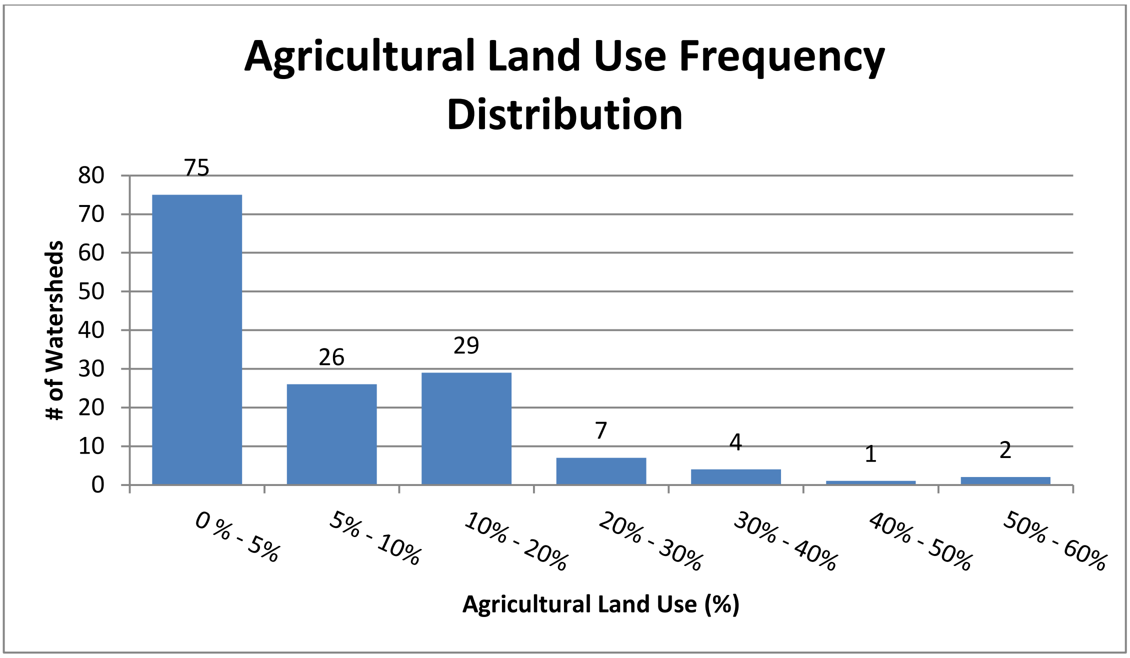


Figure 3.0 – Watersheds sorted by agricultural land use

In terms of provincial distribution, there are two parts of the province that contain clusters of watersheds with relatively high agricultural land cover; the watersheds on or near the border with Maine, and the watersheds surrounding the Moncton and Sussex areas in the southeastern parts of the province. A map showing the values for each watershed is shown in Figure 3.1.These areas are well known for their agricultural production, specifically potatoes. Many of the large, central watersheds have very little agricultural land cover with most falling below 2.5%.

In Figure 3.1 there are two clusters of watersheds where there is no agricultural activity as well as two other solitary watersheds. In this assessment, land use was measured to one one-hundredth of one percent. This means that a watershed with an actual agricultural land use value of 0.004% would be treated as 0.00% in this assessment. These watersheds with a value of 0.00% are shown in white. These clusters, located along the northern border with Quebec, and in a north-central area of the province have no agricultural activity due to their terrain. Both of these clusters are located in what the province has designated as a 'Highlands Ecoregion'. This ecoregion is defined largely based on its elevation and mountainous terrain. For both areas, more than 95% is forested and the areas are sparsely populated. Essentially, the areas are void of agriculture as the terrain is not suitable for agricultural endeavors. The solitary watersheds without any agricultural activity are found along the eastern coast and in the southern part of the province. The watershed on the eastern coast (#75, Lufsbury Brook Composite) is a coastal area which is inhabited primarily by an aboriginal reserve called Tabusintac Indian Reserve No. 9. This community is not active agriculturally and therefore the area exists without any agricultural land use. The final watershed without any agricultural activity (#66, Lepreau River) has no natural features that would lead to agriculture not being possible. There are contains a plethora of lakes and but very little human activity beyond rural roads. The lack of agriculture can only be explained by a lack of inhabitants in the area.

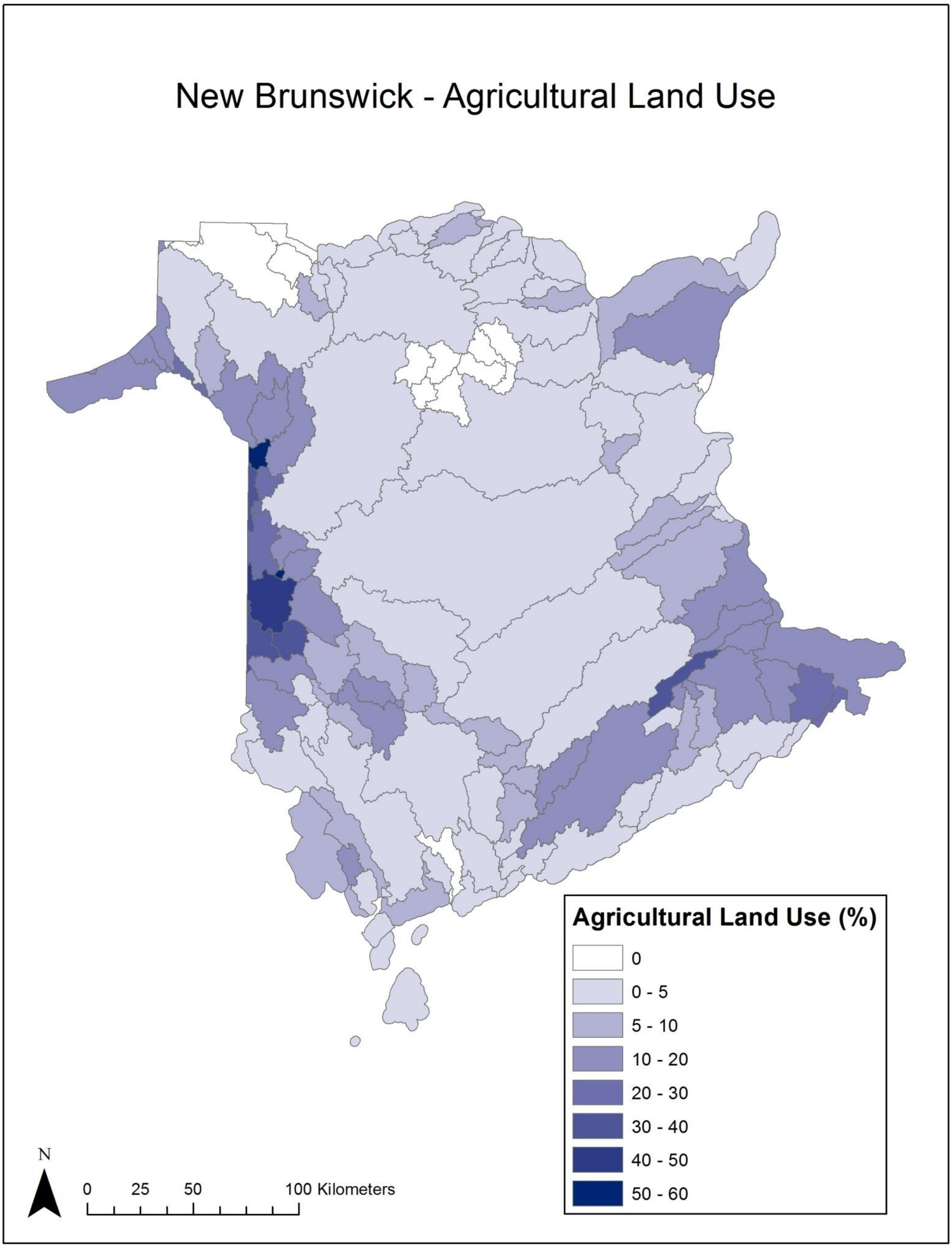


Figure 3.1 – Map of watersheds according to agricultural land use

3.2 Human Land Use Results

Urban land use in the province ranged between 0% and 36.4% with an average watershed value of 3%. 122 watersheds had an urban land use of 5% or less and 67 watersheds fell below 1%. Thirteen watersheds had values equal to or exceeding 10%. Of these thirteen, five were amongst the fifteen smallest watersheds. Also, eight were watersheds found on a border and therefore incomplete and five, predictably, contained some of or all of the cities of Fredericton, Moncton, and Saint John, the province's largest settlements. Figure 3.2 shows the frequency distribution of all 144 watersheds.

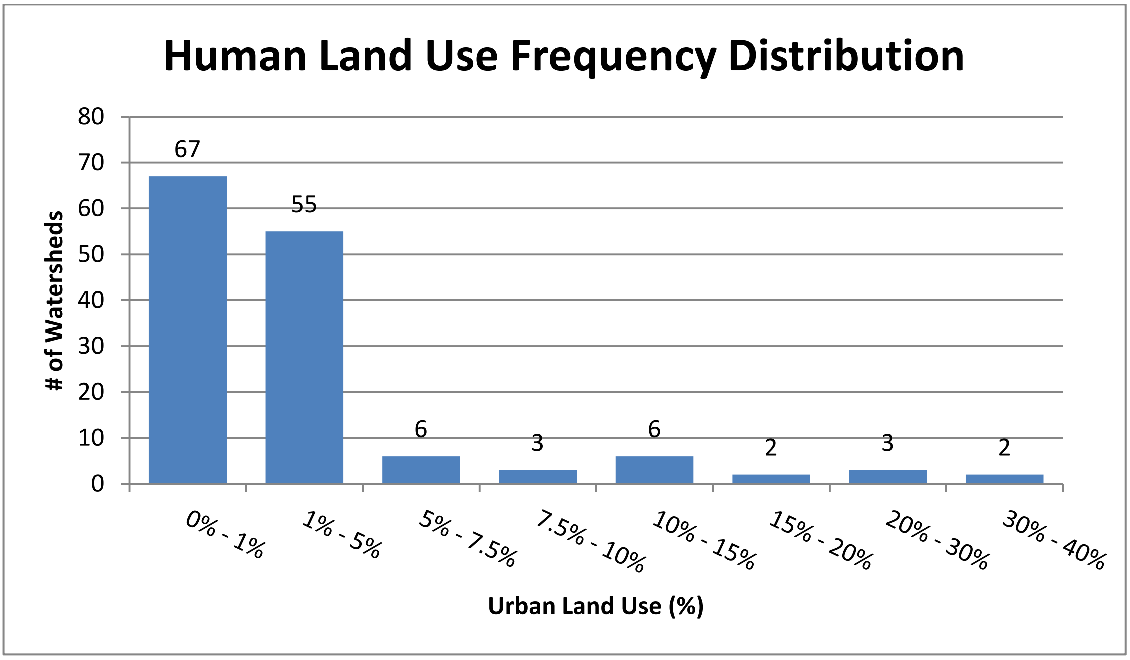


Figure 3.2 – Watersheds sorted according to human land use

From Figure 3.3, there are 21 watersheds that have no human land use (shown in white). As with agricultural land use, land use is only measured to one one-hundredth of one percent, meaning that a human land use score of 0.004% would be rounded to 0.00% in this assessment. Sixteen of these twenty-one watersheds are found in areas with mountainous terrain. These areas were also identified as having no agricultural land use in the previous section (3.1). The reasoning here is similar; the terrain is rugged and compared to nearby areas these are places that are not suitable, or at least not desirable, places to live.

The remaining five watersheds' lack of human land use can be explained as follows. The Benjamin River watershed (#20) is located inland on the northern coast of the province. In this area, all communities are found along the coast with very few found in inland areas. In this case, there were no such communities and therefore no human land use. The Big Salmon River watershed (#22) in the southern part of the province is a sparsely populated area. It has a small agricultural land use score but there are no communities located within the watershed. The remaining three watersheds with a score of 0.00% are located in coastal areas with little to no population.

Overall, the results suggest that urban land use is not a major concern for much of the province. However, for a select few watersheds, urban land use is a major issue. Small, urban watersheds and watersheds which include larger settlements have been shown to have an urban land use much higher than the provincial average. A map showing the human land use values for all watersheds is shown in Figure 3.3.

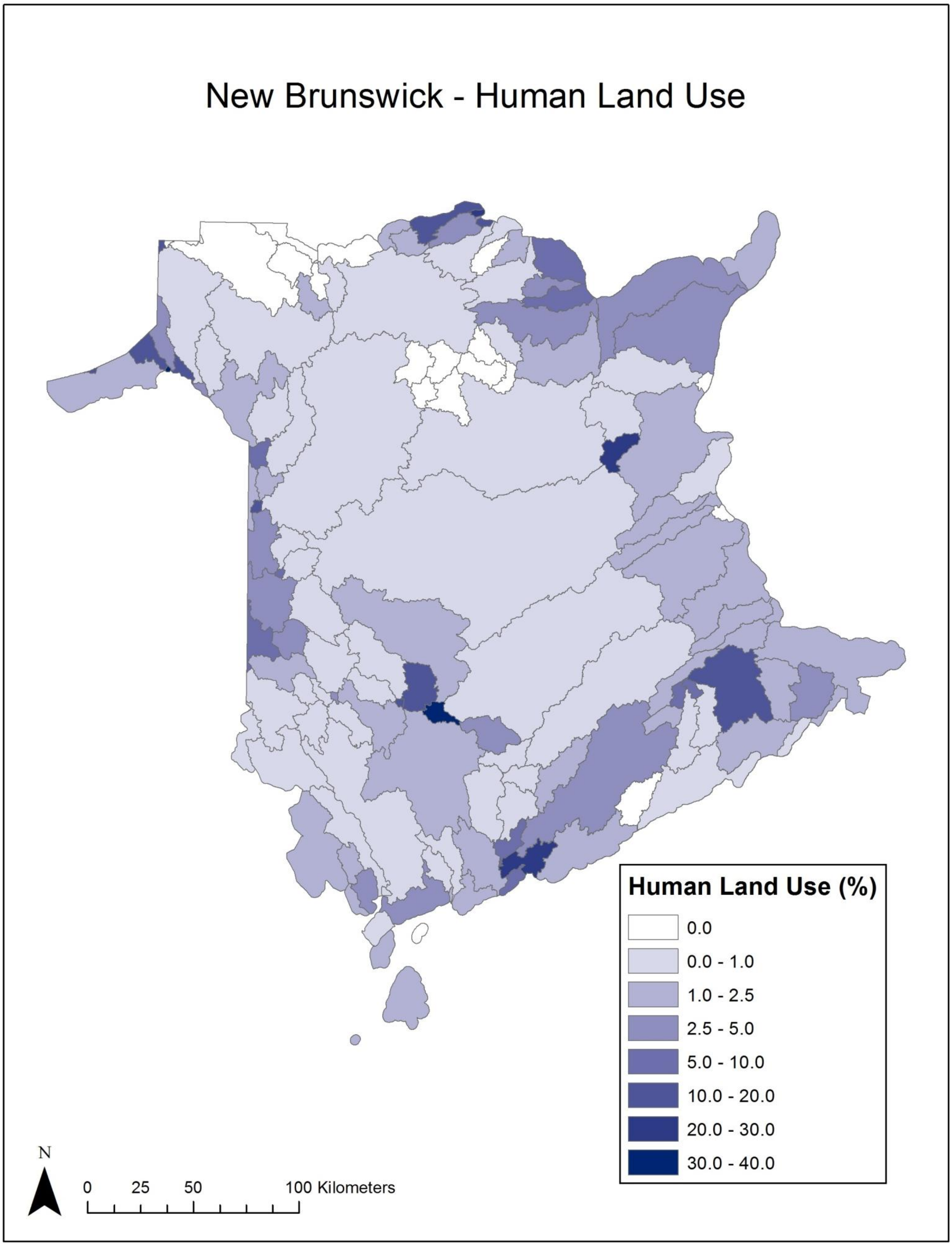


Figure 3.3 – Map of watersheds according to human land use

3.3 Acid Mine Drainage Risk Results

The spatial distribution of the extraction sites were primarily found in the two areas previously discussed. The result of this distribution was that only nine watersheds were found to contain any sites. Of these nine watersheds, six contained a single extraction site, one contained three, one contained four, and one contained fifteen. Figure 3.4 shows how each watershed fared in terms of acid mine drainage risk.

The relative lack of mining sites, combined with the large risks associated with AMD mean that the watersheds with a non-zero score for this attribute will end up with a much higher ranking compared to similar watersheds with no mining extraction sites.

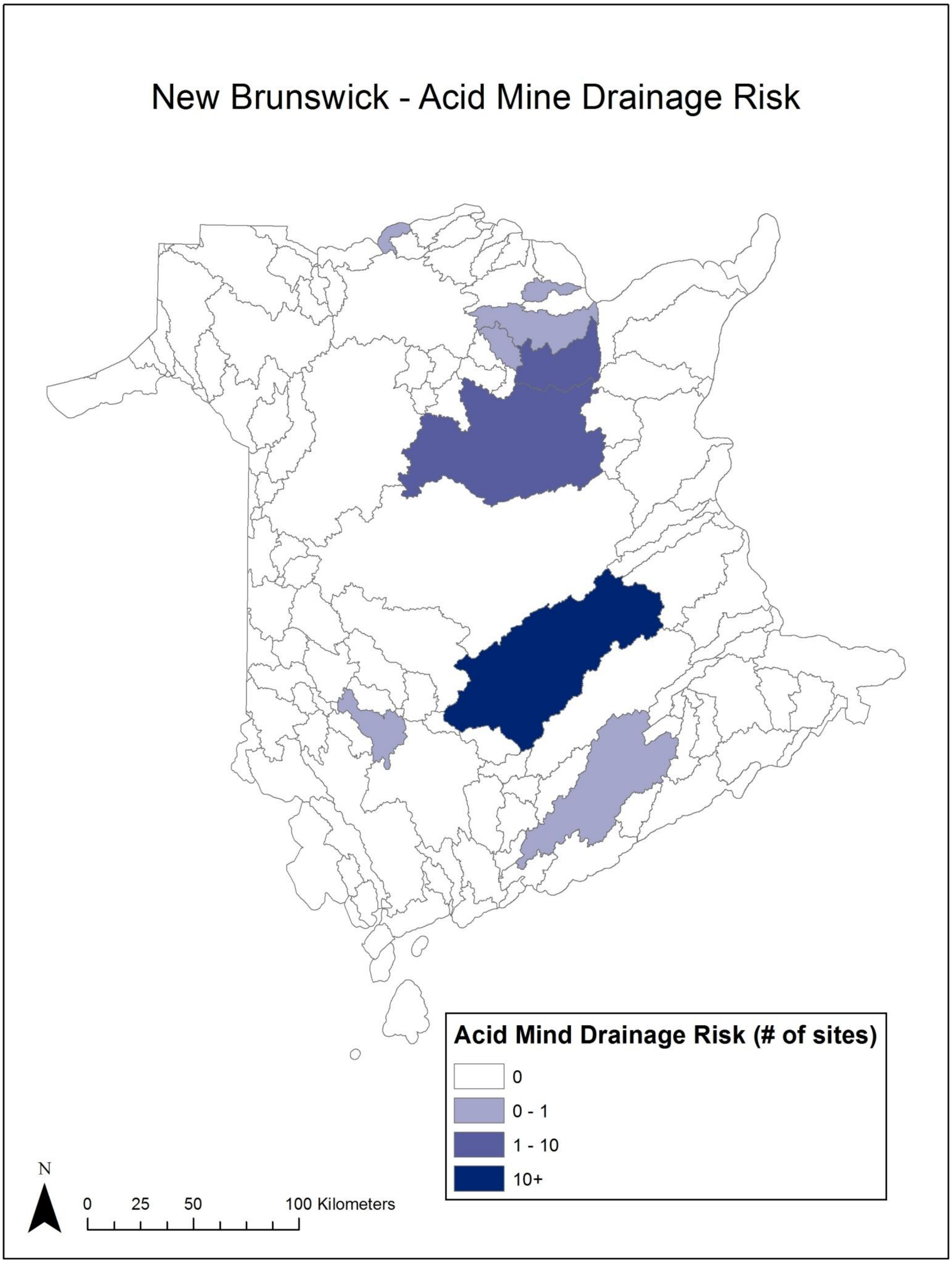


Figure 3.4 – Map of watersheds according to acid mine drainage risk

3.4 Road Density Results

Road density in the province ranged between 0 and 4.20 km/km^2 with an average road density of 0.61 km/km^2. For context, the road density of Estonia is approximately 1,3 km/km^2 and the road density of London, U.K. is approximately 9.42 km/km^2.

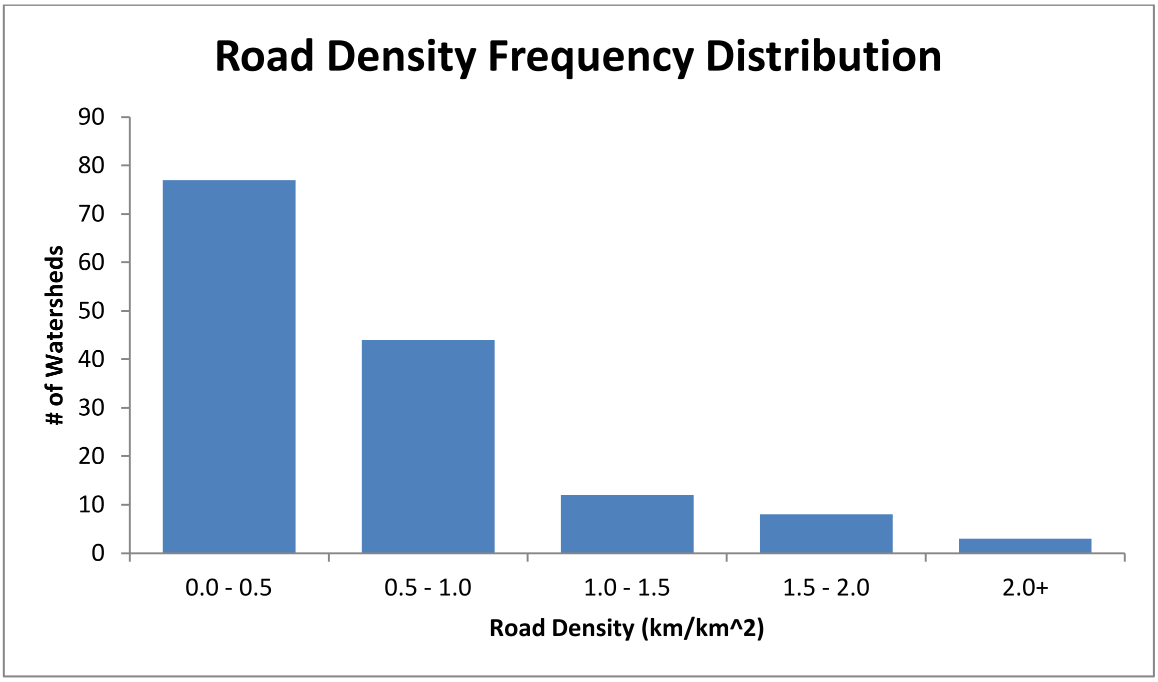


Figure 3.5 – Watersheds sorted by road density

The watersheds with a road density of zero are either relatively small or falls on one of the borders meaning that the entirety of the watershed is not located in New Brunswick. Seventy seven watersheds, which accounts for slightly more than half, had a road density between 0.0 and 0.5 km/km^2. Most of the central parts of the province fell in this category. This was expected as other than Fredericton, most sizeable settlements in the province are situated near a coast or border. Figure 3.5 shows the full frequency distribution for road density.

The highest measured road density was 4.20 km/km^2 in the "West of Rivière Iroquois Composite" watershed, a small watershed straddling the border between New Brunswick and Maine. Only two other watersheds exceeded 2.0 km/km^2 and they contain all or some of the cities of Fredericton and St. John. Figure 3.6 shows the road density value for all New Brunswick watersheds.

Overall, much of the province has a very low road density. However, some watersheds have a significant road density and are therefore at risk of the concerns mentioned previously.

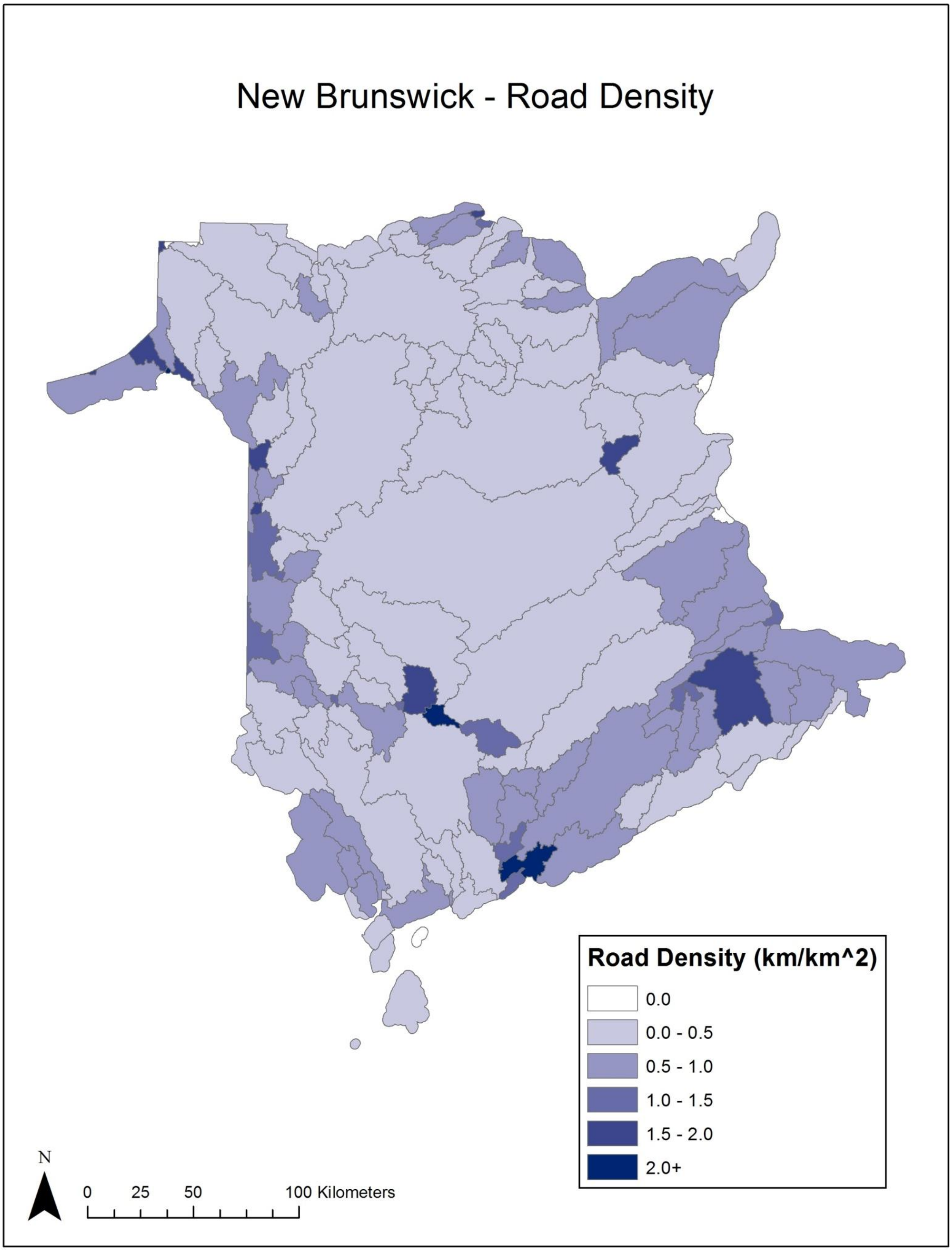


Figure 3.6 – Map of watersheds according to road density

3.5 Stream Crossing Density Results

Stream crossing density ranged between 0 and 1.23 crossings per kilometre of stream network. Seventy eight, more than half of all watersheds had a stream crossing density below 0.25 crossings/km. Only four watersheds exceeded 1.0 crossings/km and they were all small watersheds in areas with towns. Figure 3.7 shows the complete frequency distribution. Stream crossing density results are mapped onto all watersheds in Figure 3.8.

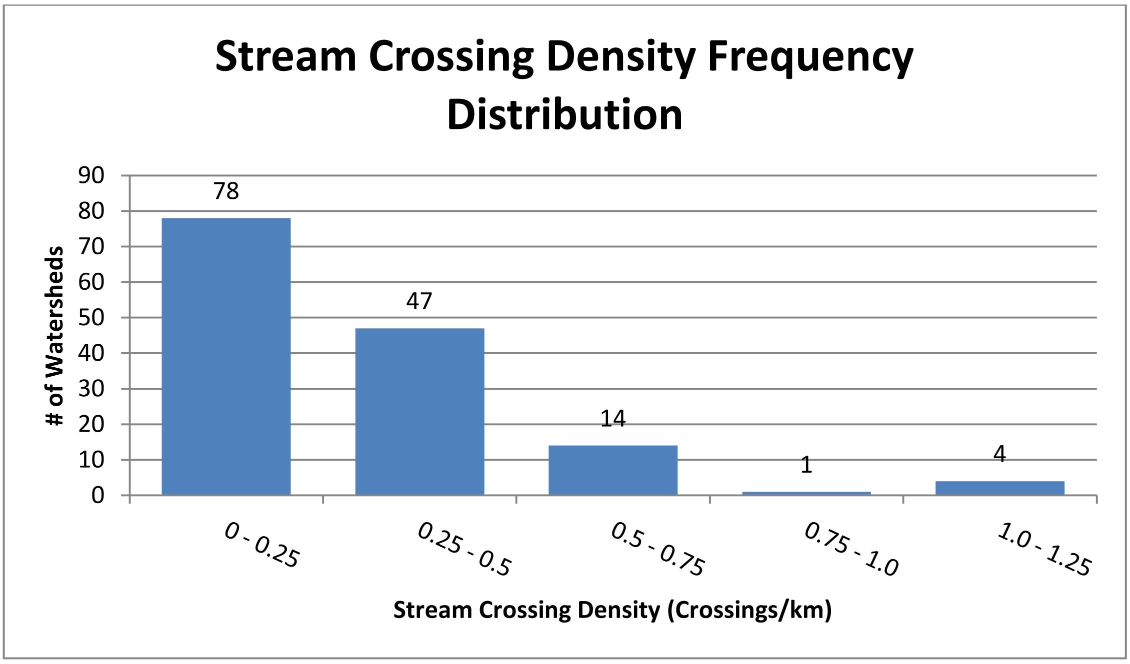


Figure 3.7 – Watersheds sorted by stream crossing density

The majority of watersheds with stream crossings exceeding 0.25 are found along routes where the greatest amount of highway traffic is expected. Starting at the border with Nova Scotia to the east, there is a sequence of connected watersheds that pass through the Moncton, St. John, and Fredericton regions before moving westward towards the border with Maine. Along this path from Nova Scotia to the border with main is the Trans-Canada highway, the largest highway in the province (TransCanada FoundLocally Inc, 2016). The fact that this highway is divided means that it will have double the amount of stream crossings compared to a smaller highway. Further, the highway passes through or nearby many of the provinces largest settlements and therefore it is logical that the results exhibit this pattern.

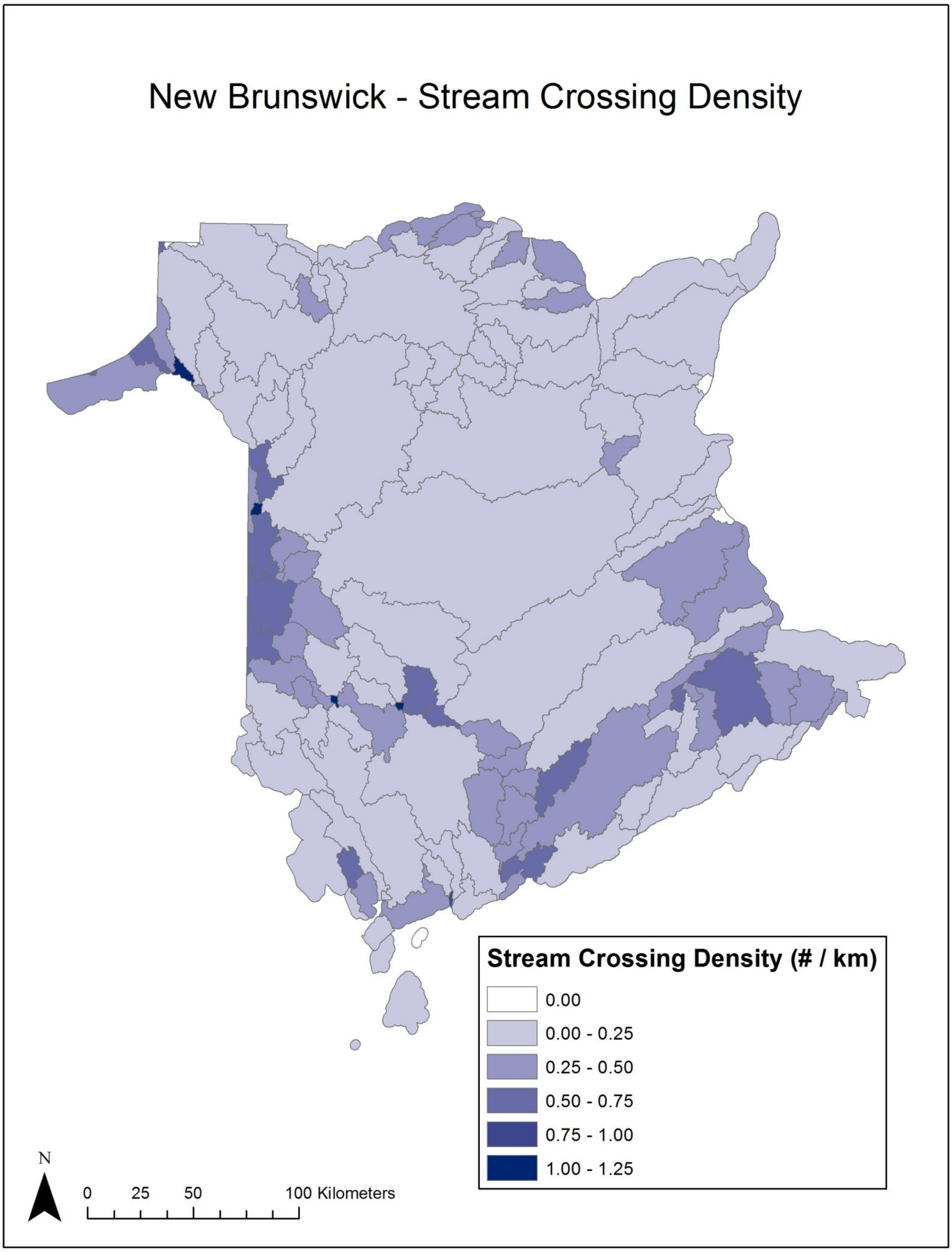


Figure 3.8 – Map of watersheds according to stream crossing density

3.6 Portion of Stream Network behind Dams Results

Due to the numbers of dams in the province being only forty eight, it follows that most watersheds will have no stream length upstream from dam. Of the watersheds that did contain a dam, the upstream stream length varied between 0.02% and 74%. The watersheds are sorted according to this attribute in Figure 3.9.

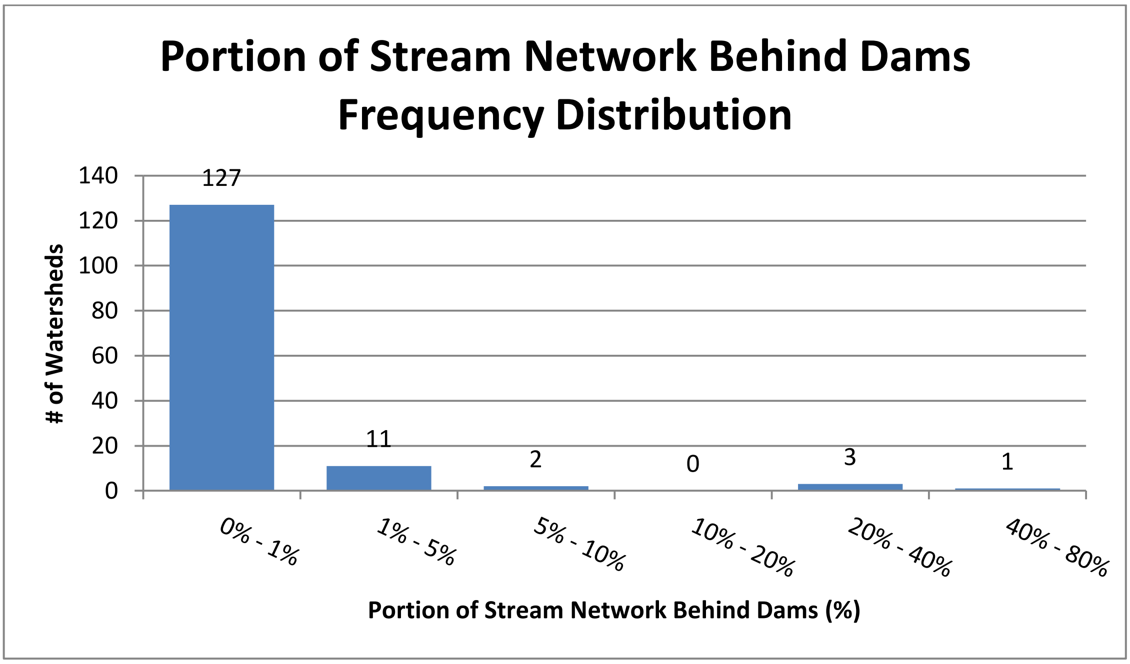


Figure 3.9 – Watersheds sorted by portion of stream network behind dams

The spatial distribution of high risk watersheds did not display any patterns as can be seen in Figure 3.10. Overall, although many watersheds do not have any risks associated with this attribute, certain watersheds have quite a large risk.

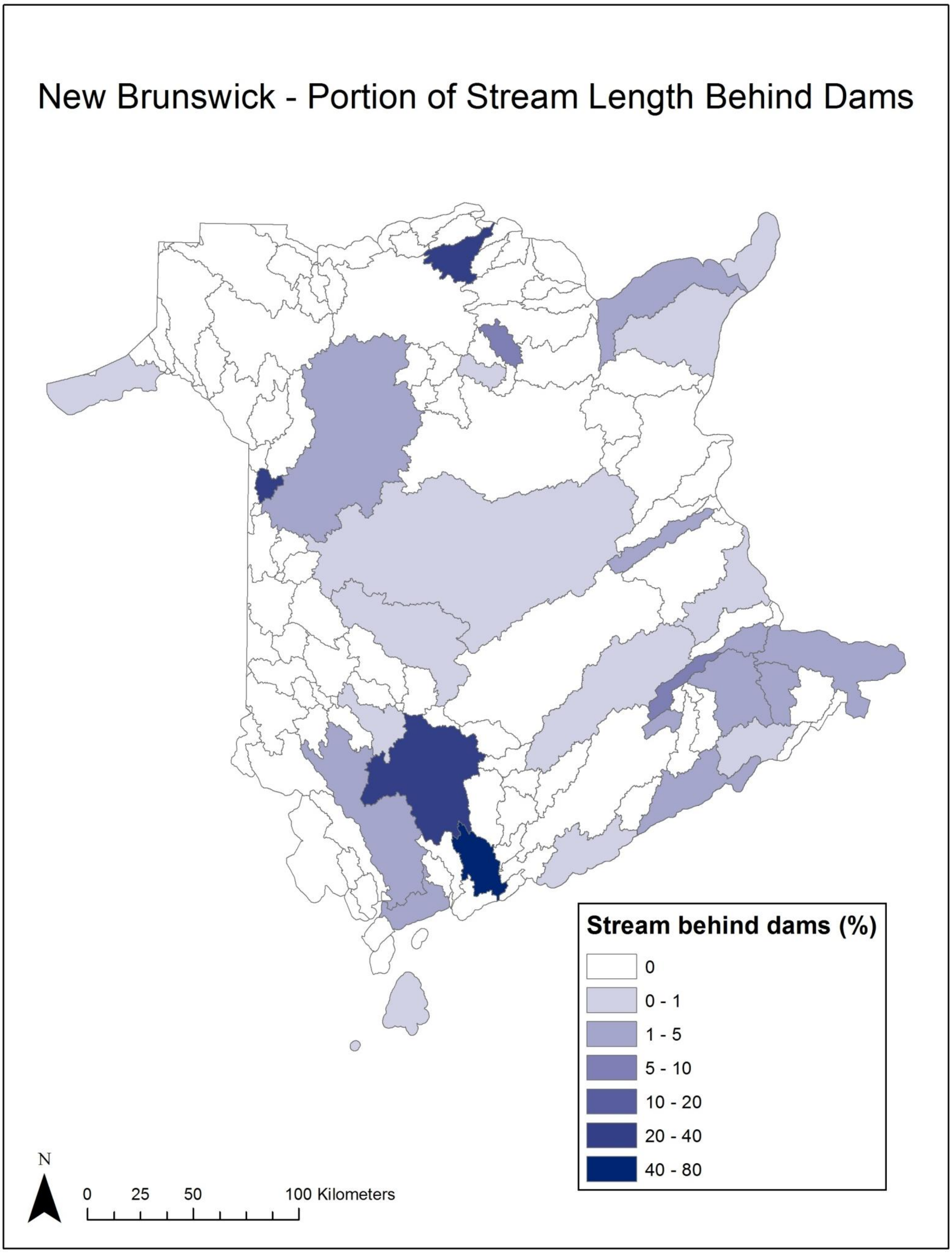


Figure 3.10 – Map of watersheds according to portion of stream network behind dams

3.7 Dam Density Results

Due to the fact that there are only forty eight dams in New Brunswick, it is necessary that most watersheds do not contain a single dam. The results show that only thirty watersheds contained at least a single dam. In terms of density, twenty eight of the dam containing watersheds had a dam density of 0.5 dams per 100km or less. Watersheds are sorted according to dam density in Figure 3.11.

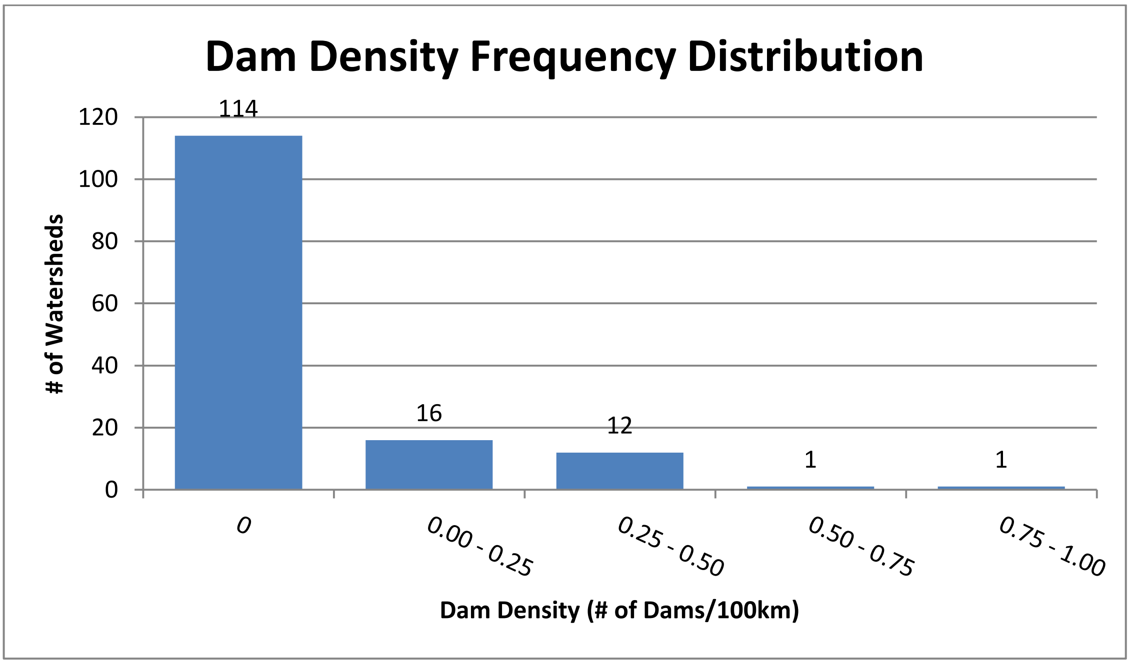


Figure 3.11 – Watersheds sorted by dam density

Dam density is a simple way of identifying potential risks however in terms of quantifying risks, it is less than ideal. For example, the Mactaquac Dam, located on the Saint John River, is by New Brunswick standards, a huge dam. It generates hydroelectricity with a capacity of 670 megawatts and supplies power to approximately 12% of the provinces homes and businesses (NB Power, 2015). The potential watershed risk associated with this dam is enormous compared do many of the other dams in the province. The simple measure of dam density is unable to take these differences into account. So, although dam density does provide valuable information and is the best measurement possible with the data that is available, it doesn't necessarily capture the magnitude of the risks associated with individual dams. Dam density results are shown for all watersheds in Figure 3.12.

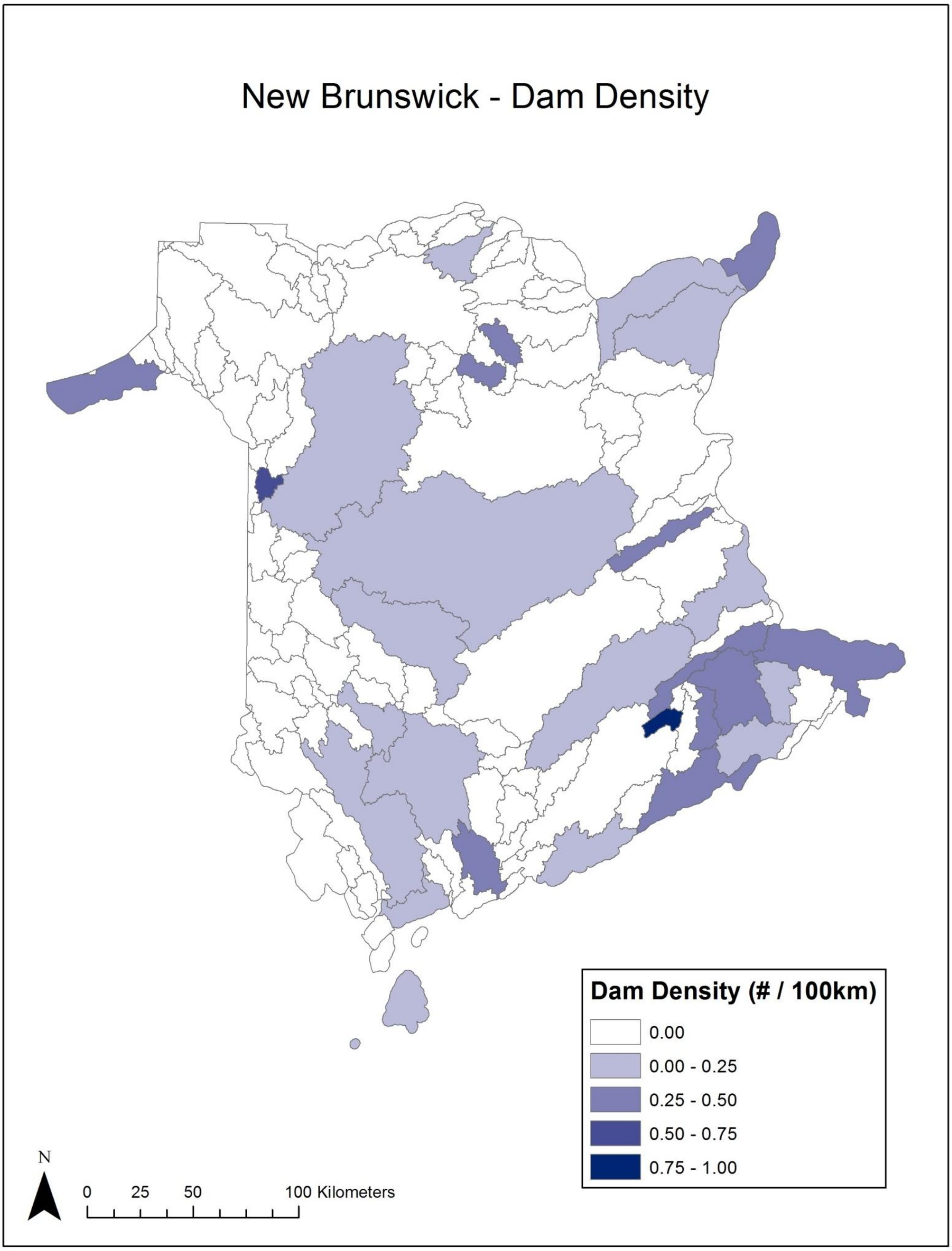


Figure 3.12 – Map of watersheds according to dam density

3.8 Average Watershed Slope Results

The average watershed slope in New Brunswick ranged between 0.06% and 14.4% with a provincial average of 3.99%. 114 or 79% of the province's watersheds have an average slope equal or lesser than 6%. All watersheds are sorted according to average watershed slope in Figure 3.13.

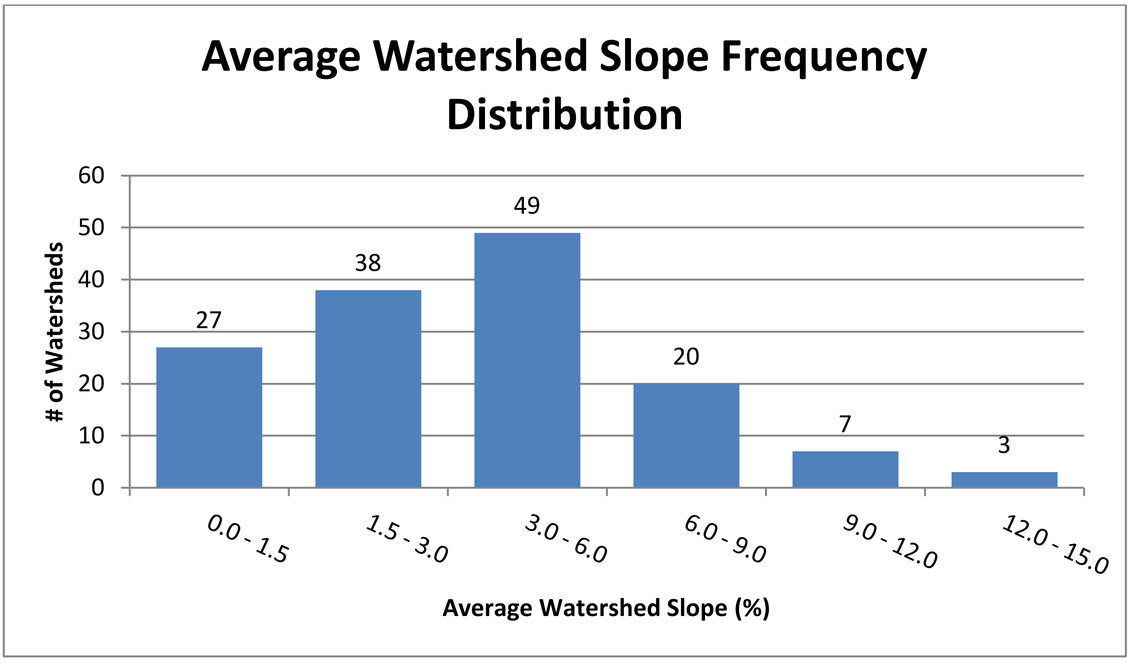


Figure 3.13 – Watersheds sorted by average watershed slope

The frequency and spatial distribution of the average watershed slope is explained with knowledge of four primary geological features of the province. The spatial distribution is shown in Figure 3.14. Northern New Brunswick contains the northern end of the Appalachian Mountain Range which stretches as far south as Alabama and Georgia in the United States. There are nine watersheds in the province with an average slope above 10% and they are all found in the part of the province covered in the Appalachians. These average slope values are not very large by international or even national standards. New Brunswick's highest point is only 832m. Much of the eastern and central parts of the province make up what is known as the New Brunswick Lowlands. There are eight watersheds which have an average slope below 0.5% all of which are found on the northeastern coast bordering the Northumberland Strait. The region with the second highest grouping of higher sloped watersheds is along the southeastern coast bordering the Bay of Fundy.

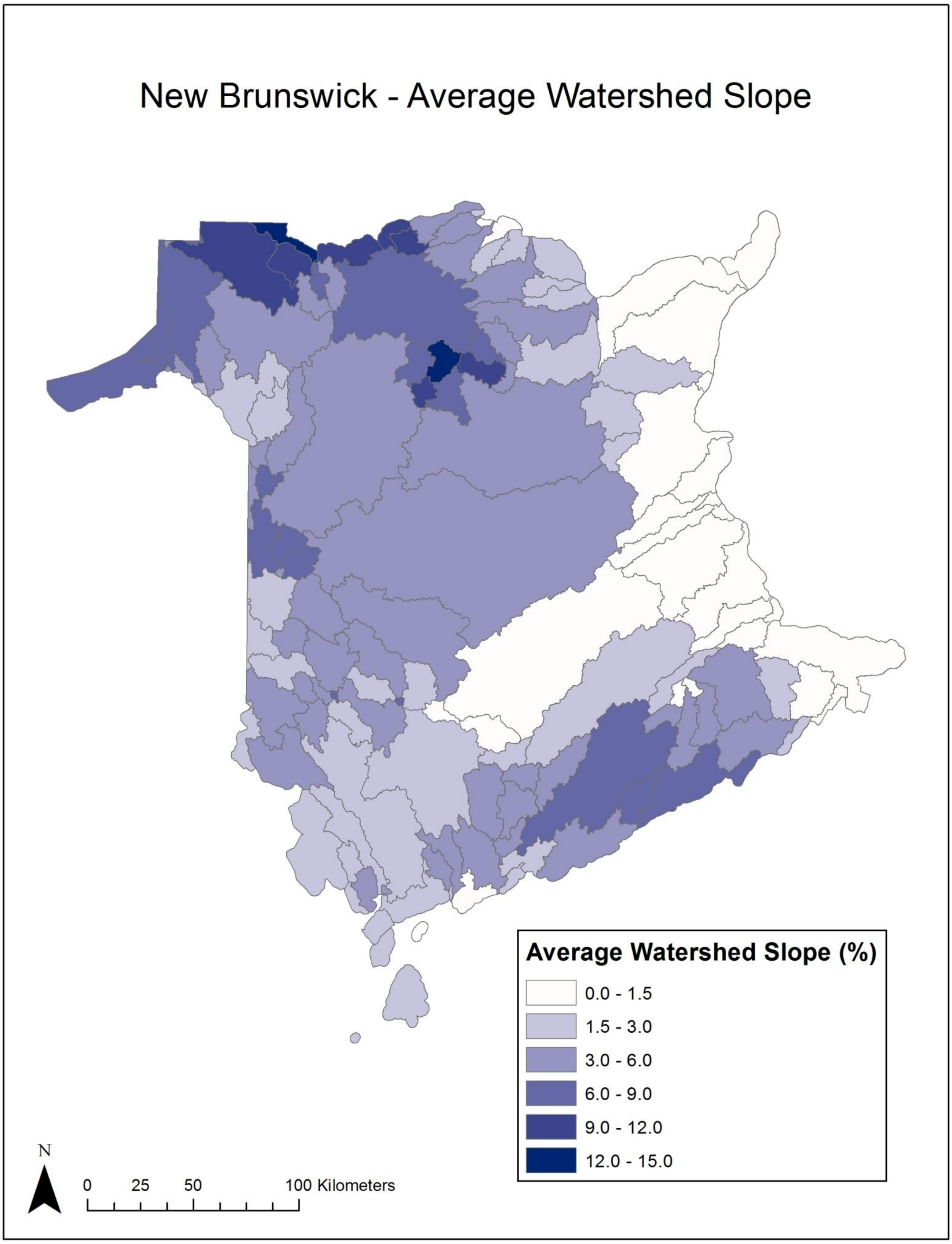


Figure 3.14 – Map of watersheds according to average watershed slope

3.9 Drainage Density Results

Drainage density in the province ranged from 0.0 to 1.77 km/km^2 with an average drainage density of 1.14 km.km^2. The watershed with a drainage density value of 0 km/km^2 is a small island watershed containing no known streams.

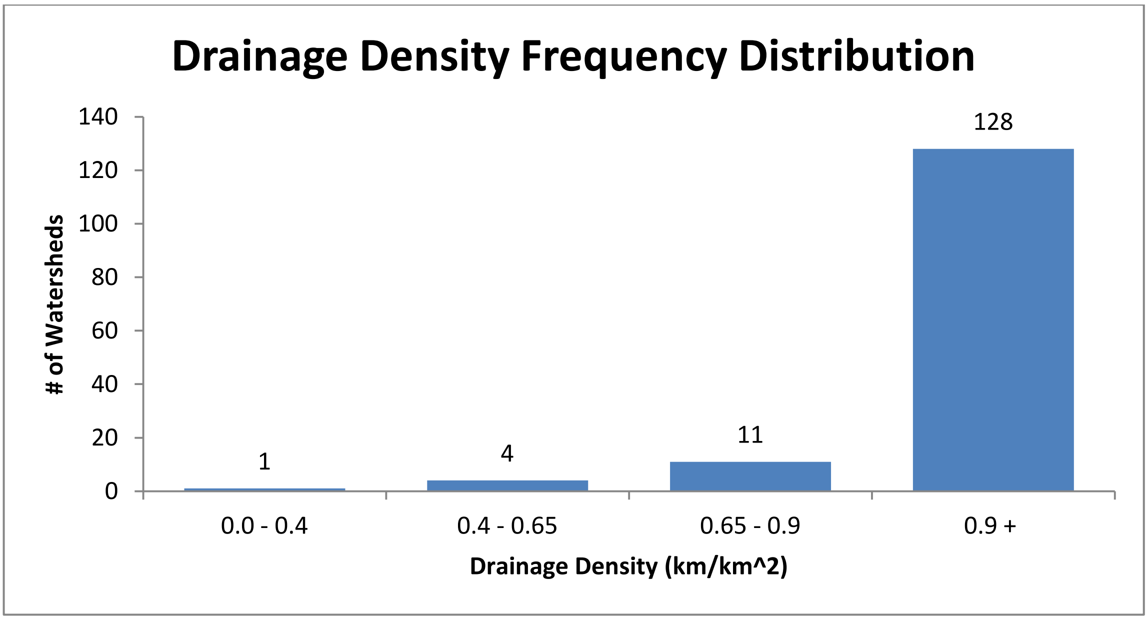


Figure 3.15 – Watersheds sorted by drainage density

From Figure 3.15 above it is shown that the vast majority of watersheds have a drainage density exceeding 0.9 km/km^2. 0.9 km/km^2 was the upper limit proposed by Ogden et al. (discussed in Methods) meaning that, according to their results, the differences in drainage density have little or no effect on the runoff characteristics of the watershed. So for this investigation, 128 of the 144 watersheds are treated the same as far as drainage density is concerned. These watersheds with lower drainage density are found throughout the province with once cluster found around the Miramichi area. The full spatial distribution is shown in Figure 3.16.

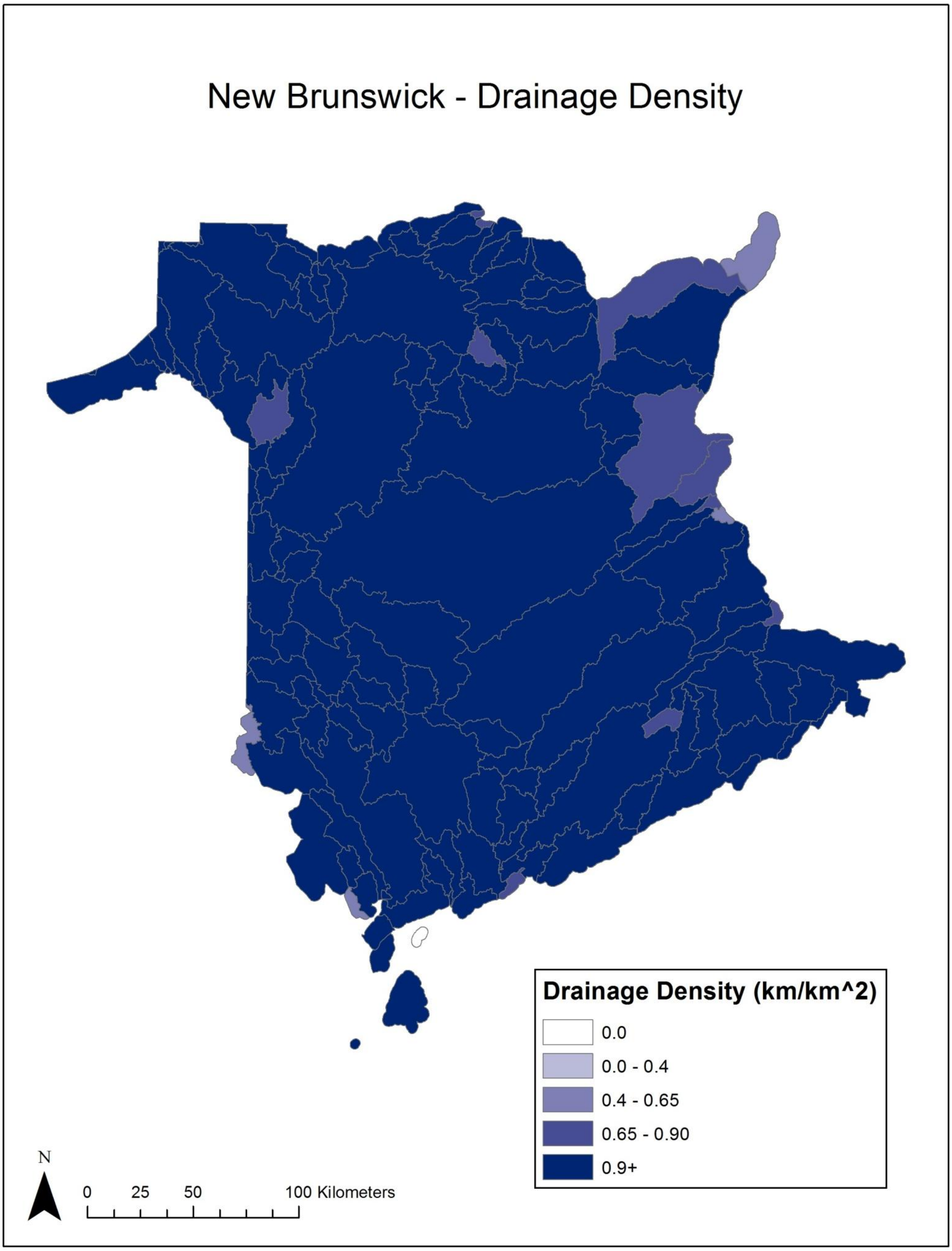


Figure 3.16 – Map of watersheds according to drainage density

3.10 Attribute-only Risk Rankings

Figure 3.17 displays the overall risk rankings for watersheds when only attributes are considered. The watershed with the ranking of one is the highest risk, and 144 has the lowest risk.

The attribute weighting scheme allows for a single watershed to have a maximum score of 110 in the attribute only rankings. When considering only attributes, no watershed had a score which exceeded 45. This is a very positive result as it means that within the scope of the attributes considered, not a single watershed approached the maximum risk. The average score was 15.7 and the median score was 13.3. Fifty percent of all scores were found between 9.4 and 19.1.

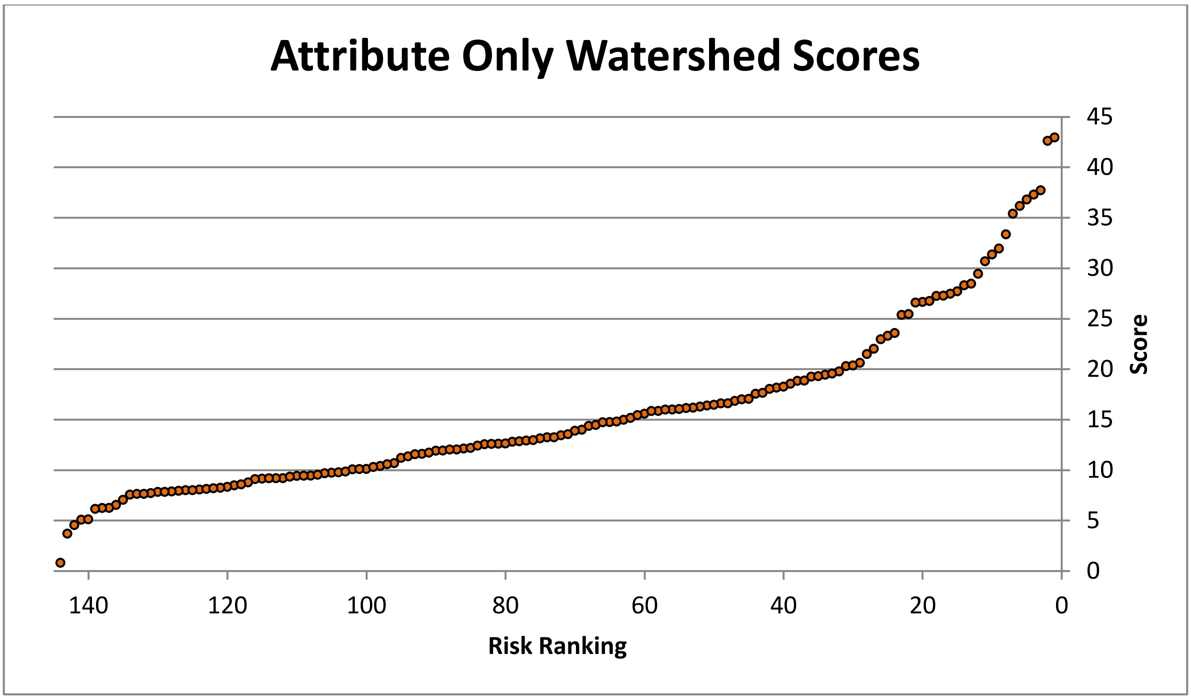


Figure 3.17 – Attribute-only scores and risk rankings

The ten watersheds with the highest risks scored between 31.4 and 43.0 and they were not clustered together in terms of location. Each of these watersheds had a combined agricultural and human land use percentage exceeding 5%. The only watershed without a high land use percentage was the Jemseg River Watershed which is a large watershed located in the central part of the province. The reason for this is this watershed contains fifteen mining extraction sites giving it the highest possible score for acid mine drainage risk.

There is one watershed that scores noticeably lower than the rest. It had a score of only 0.81. This watershed is contains the entirety of The Wolves Archipelago, a series of rocky islands situated to in the Bay of Fundy to the south of Blacks Harbour. The islands are currently uninhabited, with the occasional visitor for research purposes. Only two of the nine attributes in this assessment do not involve human activity in any way and those that do not have low risk multipliers (drainage density and watershed slope) and therefore the low score for this watershed is not surprising.

The ten watersheds with the lowest measured risk also were not clustered geographically. They are all areas in which there is very little human activity. Agricultural land use, human land use, mining sites, and road density all scored very low for each of these watersheds. The spatial distribution of watersheds according to attribute-only ranking is shown in Figure 3.18. Attribute-only scores are broken down into more detail in Appendix B.

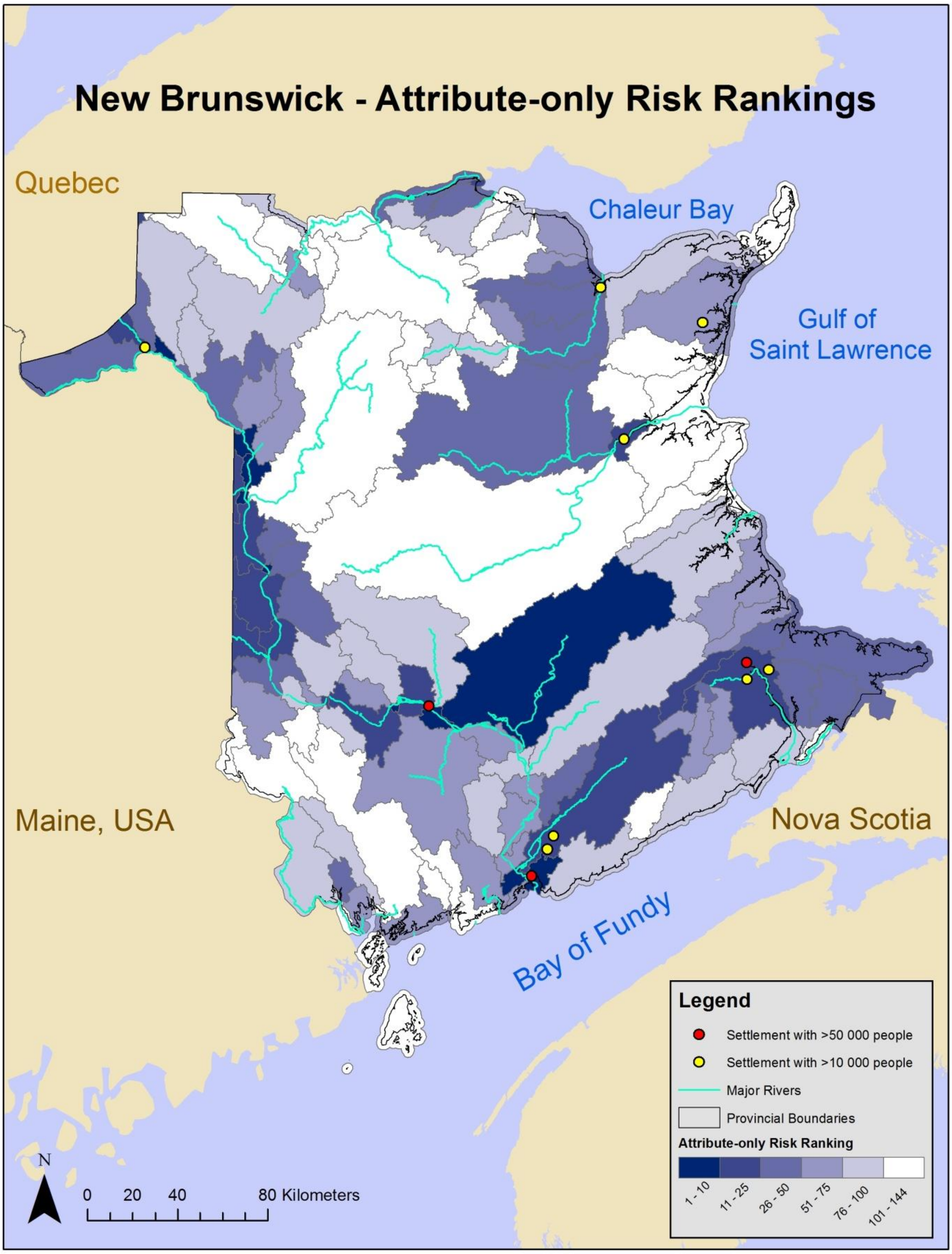


Figure 3.18 – Map of watersheds according to attribute-only rankings

3.11 Consumption-adjusted Risk Rankings

When adjusting the watershed scores with municipal water consumption data, the maximum score increased to 63.9 out of a maximum total of 220. Using this scoring system, the average score was 19.8 (an increase of 4.1) and the median score was 16.0 (an increase of 2.7). All scores are shown in Figure 3.19.

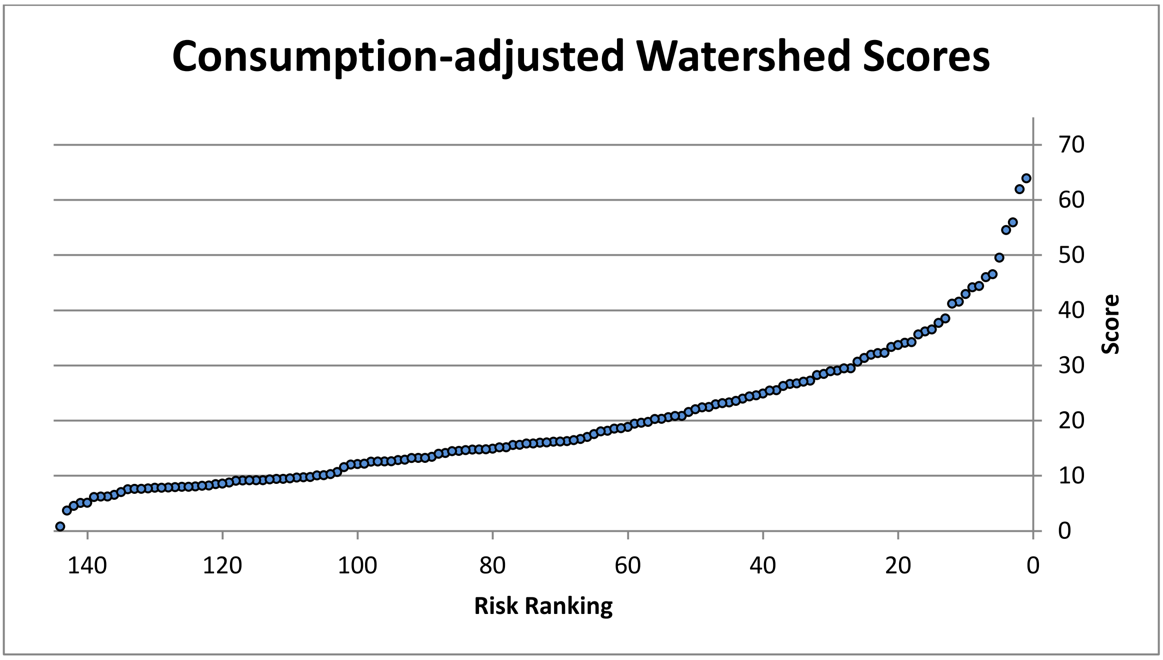


Figure 3.19 – Consumption-adjusted scores and risk rankings

Five of the top ten most at risk watersheds using this scoring system also scored in the top ten in the attribute-only rankings. All of the top ten watersheds using this scoring scheme scored in the top twenty three in the attribute-only rankings. This is somewhat logical as the watersheds with larger municipal water demand will also likely have a higher population which typically leads to a higher human land use score.

Three of the province's major settlements were represented in the top ten watersheds; one from Moncton, one from Miramichi, and two from the Fredericton area. Saint John, the largest settlement by population in the province sources its municipal water from outside of the city limits from watersheds with average attribute-only scores. Thus, the large amount of water abstracted was not sufficient to move the watersheds into the upper echelons of the risk scale. The spatial distribution of watersheds evaluated in terms of consumption-adjusted ranking is shown in Figure 3.20. Consumption-adjusted scores are broken down in more detail in Appendix C.

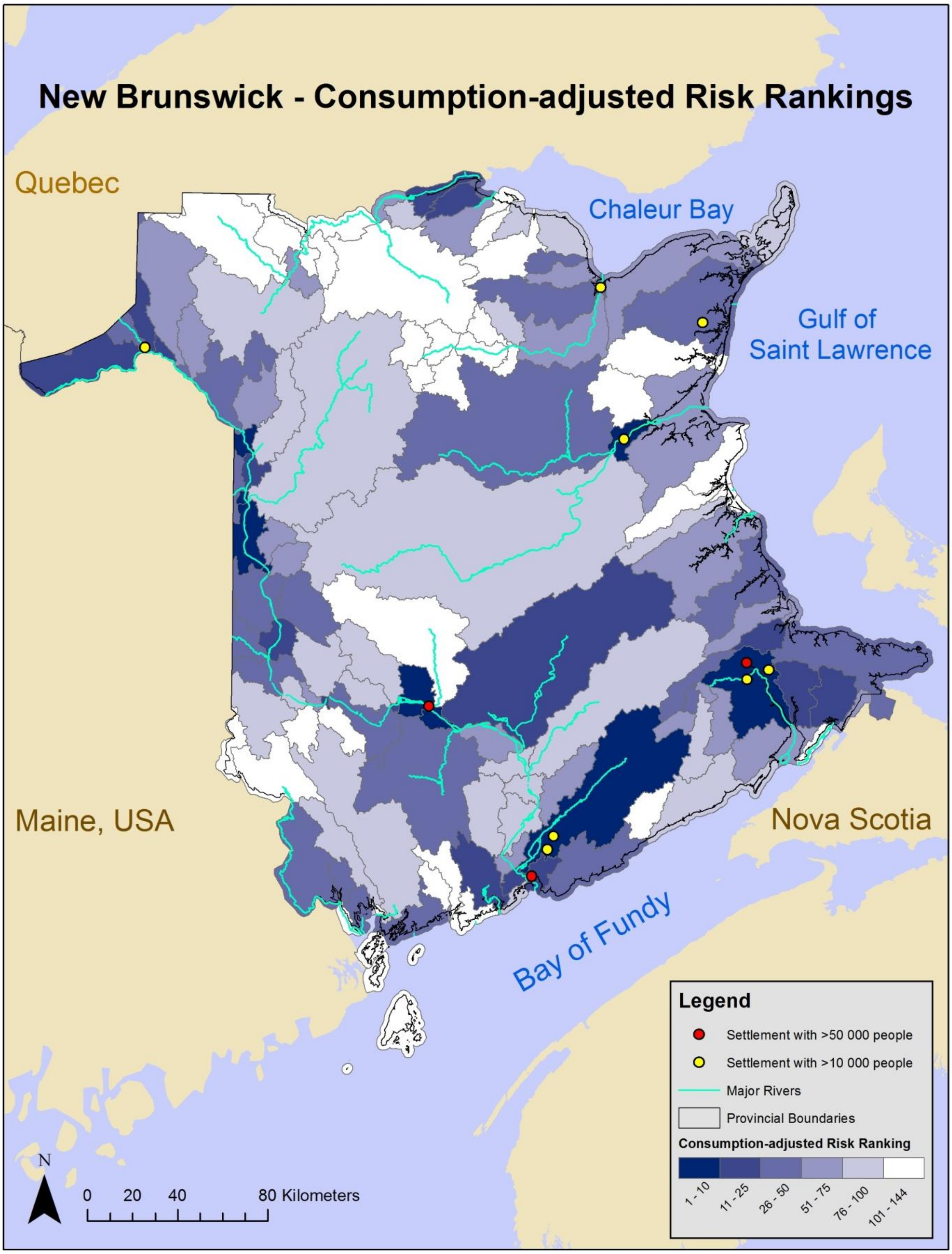


Figure 3.20 – Map of watersheds according to consumption adjusted rankings

4. CONCLUSION AND RECOMMENDATIONS

There are many watershed attributes that contribute to the overall water quality within in watershed. This risk assessment evaluated watersheds in New Brunswick based on nine attributes that have the potential to degrade water quality. The attributes were agricultural land use, human land use, acid mine drainage risk, road density, stream crossing density, length of stream behind dams, dam density, average watershed slope, and drainage density. The attributes were chosen based on the availability of data from national and provincial sources as well as through communication with representatives from the New Brunswick Environment and Local Government department. To obtain a final score, watershed attributes were assigned a risk multiplier to provide more significance to attributes with a higher perceived risk. Agricultural land use, human land use, and acid mine drainage risk were the attributes with the highest assigned risk in this assessment. In addition to the attribute-only score, watersheds were also evaluated with a water use component. The location of municipal abstraction sites as well as annual consumption data was used to assign a measure of importance to watersheds that New Brunswickers rely on for municipal water. Using this information, an additional scoring scheme named ‘consumption-adjusted’ was used to increase the risks associated with watersheds that New Brunswick relies upon for municipal water supply.

The results of the assessment were able to identify watersheds that had high risks relative to the province as a whole. Neither scoring scheme resulted in a score that exceeded fifty percent of the maximum potential score. In the attribute-only scoring scheme, more than half of all watersheds scored between ten and twenty points out of a possible one hundred and ten. This result is positive and also somewhat unsurprising. Seven of the nine attributes that were evaluated are based on human activity in one way or another. New Brunswick has a low population density, only 10.5 people per square kilometre which is lower than all European countries except Russia and Iceland. The results did not directly correlate with population density however as important human activities such as agriculture and mining often take place in the province in sparsely populated areas.

Watersheds that scored highly under both scoring schemes had certain similar characteristics. Most of these watersheds had high amounts of both agricultural and human land use or contained many mining extraction sites. Three areas stood out as scoring particularly highly; the area including and between Saint John and Moncton in the southeastern part of the province, Fredericton and its surrounding area in the south-central part of the province, and the length of the north-south border with Maine. Saint John, Fredericton, and Moncton are the province's three largest settlements. The area between Saint John and Moncton is a well known agricultural area, as is the north-south border with the USA. Also, although there are no major settlements along the north-south border, there are many smaller towns which receive a lot of traffic from those wishing to cross the border.

The results of the assessment can be used to better manage watersheds in the province. The number of monitoring sites in the province is far less than the number of watershed units assessed in this investigation. The results of this assessment could allow for a better selection of monitoring sites to better identify problems when they arise. For example, many monitoring sites are located near the end of a first order drainage basin. Samples collected at such a site will be representative of the entire drainage basin and there is the possibility that water quality degradation may go unnoticed due to dilution. For example, the Miramichi River Basin, a first level drainage basin contained five sub-units that were evaluated in this assessment. The rankings in terms of consumption-adjusted scoring were five, thirty four, sixty seven, ninety nine, and one hundred and thirty four. These results provide a clear priority in terms of watershed management.

The results that can be obtained from this type of assessment are not all that is needed in terms of watershed assessment and although useful they cannot completely replace traditional watershed assessment techniques involving water sampling and testing. First, the results of this assessment provide the reader with an understanding of the potential risks associated with one watershed relative to another, but not the actual magnitude of the risk. Essentially, this type of assessment provides information regarding relative risk but does not actually provide any information as to which watersheds could be considered as 'at risk'. For example, it is unclear based on the results whether or not a score of 30 should be concerning or 20, or any other number. It is possible that none of the watersheds are at risk and the differences in results are insignificant. The strengths of this type of assessment are that it provides a low-investment means of assessing watersheds on a regional scale. Watershed managers overseeing large areas would be well served in doing such an assessment as a starting point for prioritizing conservation and management efforts.

Another limitation associated with this investigation is its ability to properly assess trans-boundary watersheds. Certain watersheds in this investigation have outlets which flow into Maine, Nova Scotia, and Quebec and others receive water from the same destinations. The scores assigned to these watersheds therefore may not be representative of their completed watershed unit. This situation is not ideal however it is likely to present itself in many assessments of this type whose boundaries are administrative rather than hydrological. In situations where the data is available on both sides of the border, it is recommended that the watershed units be completed such that the administrative borders be completely contained by the study area rather than define its limits. In this investigation, the availability of data did not allow for this to be done.

A strength associated with this type of assessment is that once the framework is in place, it can be updated reasonably easily as new data becomes available. Much of the data used in this investigation was sourced from databases updated within the past year. Other data was much older but is scheduled to be updated within the next twelve months. For example, the agricultural land use and human land use data was taken from a study completed by Agriculture & Agri-Food Canada every fifteen years and last completed in 2001. The age of the data means that it does not perfectly reflect the current situation in terms of land use in the province. It was assumed that at a large scale, the changes in land use would not be large enough to impact the results of the assessment in a meaningful way. This assumption could be easily confirmed or denied by revisiting certain components of the assessment as new data becomes available. Further, as these types of investigations gather data from a variety of different sources, they identify information gaps and can provide guidance regarding which data should be sought in the future.

One of the key characteristics of this type of watershed assessment is that the attributes used to evaluate the watershed change from one assessment to the next based on the availability of the data. Through examining other assessments of similar nature, there are four types of information that was unavailable that if it had been available could have provided a more complete assessment.

Industrial and Agricultural Water Use

Water use in this assessment was only analyzed in terms of municipal withdrawals. Significant consumers such as power plants, farms and other industrial facilities were not included in the investigation. This does not mean that all industrial water use was missed as many industrial consumers would be connected to the municipal supply. In other assessments, water consumption was calculated based on permits given out by the governing bodies. It was not possible to obtain this sort of data for New Brunswick. Through personal communication with government employees, it was made clear that an industrial water consumption tracking system was in development but the current state of affairs meant that the dataset was incomplete in such a way that it was not usable. It is anticipated that if this assessment was to be reviewed in the next couple of years, data regarding significant non-municipal water consumers would be available.

Forestry

There was no information regarding forestry considered for this report. In similar assessments, forestry played a key role measuring attributes such as recent and planned harvesting and areas damaged by forest fires. For New Brunswick, there is no information regarding harvesting available and for the past decade, forest fires have been limited to only extremely minor fires. Much of New Brunswick is forested and having a means of measuring the state of forest could have been a useful addition. Forest harvesting can potentially contribute to water quality problems through erosion, sedimentation, surface runoff, increased risk of landslides, herbicide application, etc.

Acid Rock Drainage

Acid rock drainage, caused by natural conditions, rather than mining activities poses significant risks to watersheds and this risk was not calculated as part of this assessment. How this could have been done would be to compare bedrock lithology with surficial geology to determine sites where sulphide bearing rocks were exposed to the atmosphere. This method was used in a watershed assessment of Nova Scotia as well as several project Environmental Site Assessment's in New Brunswick. In the EIAs, the authors consulted with local geology experts to determine which bedrock formations posed risks and which did not in their specific area. For this assessment, such information was not able to be obtained and would require a local geologist or geochemist to determine which bedrock units contained an ARD risk and which ones did not.

Fish

Some watershed assessments allocated additional risk to watersheds containing fish species at risk. This was a means to include the current state of fish species into the assessment rather than attempting to measure potential threats. If fish in the stream system were already at risk, then a loss of biodiversity was more in the balance compared with a stream network with only fish with no perceived danger. This sort of information was not available for New Brunswick in such a way that it could have been included in the assessment.

Overall, the assessment was able to rank the watersheds of New Brunswick based on a number of attributes known to have the potential to degrade water quality. The results can guide the decision making processes undertaken by watershed managers allowing them a low-investment means of identifying problematic areas within their jurisdiction. Overall, the results suggest that most New Brunswick watersheds do not have high risks associated with them; this is largely due to the low amount of human activity in these areas. The watersheds with higher relative risks are generally located in three specific areas of the province. The limitations of this sort of assessment do not permit it to be the full extent of a watershed risk assessment. This is due to the lack of knowledge regarding magnitude of risk as well as data availability and data representativeness. The assessment could be improved by including a wider range of watershed attributes. These attributes could be added once data becomes available, or their lack of availability could prompt watershed managers to initiate their own data collection process in order to better understand the risks associated with watersheds in the study area on a regional scale.

5. SUMMARY

This thesis provides a GIS-based watershed risk assessment of the Canadian province of New Brunswick. The assessment uses watershed attributes and municipal water use to develop an assessment scheme that allows all watershed units in the province to be scored and ranked based on overall relative risk to watershed quality. The results of the assessment identify single watersheds as well as areas composed of several watersheds whose estimated risk to water quality is high relative to much of the remainder of the province. The results could be useful to watershed managers in a variety of ways as the results assess the province on a regional scale which is currently not possible using traditional assessment techniques based on the extent of the water monitoring network.

The assessment used nine watershed attributes to assess each watershed in the province. The chosen attributes had all been shown to have an impact on watershed quality. A value for each attribute was assigned to each watershed using ArcGIS. Due to the difference in potential harm that each attribute provided, attributes were assigned a risk multiplier to ensure that this difference was accounted for. Final scores were calculated in two ways; one that considered only attributes and one that considered attributes and municipal water consumption. Municipal water consumption was used to increase the risks associated with watersheds that citizens rely on for municipal drinking water amongst other uses.

The results identified three primary areas of concern within the province: the area stretching between Moncton and Saint John, the greater Fredericton area, and the north-south border with Maine (USA). These areas all contained significant human or agricultural land use. Within these areas of concern, the results specify specific watersheds which contain the greatest risks in the entire province.

The results of the assessment can be valuable in three main ways. First, watershed managers could use the results to prioritize conservation and management efforts within the province. Watersheds shown to demonstrate substantive risk could receive greater attention and focus allowing for watersheds to be better managed. Second, the results can be used to direct monitoring efforts within the province. The current monitoring network is insufficient to provide a comprehensive outlook on the entire province. Using the results allows watershed managers site monitoring stations based on risks associated with a given watershed. Without such criteria, the monitoring network may but set up in a non-ideal way allowing for important findings to go unmonitored and unnoticed. Third, the assessment identifies information gaps spread across a variety of sources. Data for this assessment was produced by provincial and national organizations and by bringing this data together, gaps were observed. Specifically, data regarding forestry, fish, and non-municipal water use was either non-existent or insufficient to include in this investigation. Those in charge of data production could use these data gaps to help guide data collection and processing efforts in the future. If this data became available, the assessment could easily be revisited to include more attributes, providing readers with a more complete assessment of local watersheds.

6. REFERENCES

Agriculture and Agri-Food Canada. (2009, April 01). Landcover Classifications - Land Cover for Agricultural Regions of Canada, circa 2000 [XLS]. Ottawa: Agriculture and Agri-Food Canada.

Ahmed, S. E. (2014). The Ecological Implications of Roads. *Microsoft Research 2014*. Retrieved April 27, 2016, from http://research.microsoft.com/apps/pubs/default.aspx?id=228300

Bobrowsky, P.T. and Dominguez, M.J., 2012. Landslide Susceptibility Map of Canada; Geological Survey of Canada, Open File 7228, scale 1:6 million. Doi: 10.4095/291902

Bryant Watershed Project. (n.d.). Field and Slope Erosion. Retrieved May 1, 2016, from http://www.watersheds.org/earth/field.htm

Canadian Rivers Institute. (2003). Drainage System. In *NB Aquatic Data Warehouse Manual*.

Carroll, M. B. (2008). *<i>The Effects of Stream Crossings and Associated Road Approaches on Water Quality in the Virginia Piedmont</i>* (Unpublished master's thesis). Virginia Polytechnic Institute and State University. Retrieved May 1, 2016, from https://theses.lib.vt.edu/theses/available/etd-08112008-195801/unrestricted/MatthewCarrollThesisFinalwithETDreview.pdf

Coffin, A. W. (2007). From roadkill to road ecology: A review of the ecological effects of roads. *Journal of Transport Geography, 15*(5), 396-406. doi:10.1016/j.jtrangeo.2006.11.006

Deluca, W. V., Studds, C. E., Rockwood, L. L., & Marra, P. P. (2004). Influence of land use on the integrity of marsh bird communities of Chesapeake Bay, USA. *Wetlands, 24*(4), 837-847. doi:10.1672/0277-5212(2004)024[0837:ioluot]2.0.co;2

Efremova, M., & Izosimova, A. (2012). Contamination of agricultural soils with heavy metals. *Sustainable agriculture*, 250-252.

Environment Agency. (2002). *Scoping the environmental impacts of bridges and culverts*. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297112/geho0112bwak-e-e.pdf

Forman, R. T., & Alexander, L. E. (1998). Roads and Their Major Ecological Effects. *Annual Review of Ecology and Systematics, 29*, 207-231. Retrieved April 25, 2016, from http://www.edc.uri.edu/nrs/classes/nrs534/NRS_534_readings/FormanRoads.pdf

Fraser Institute. (2012). What is acid rock drainage? Retrieved from http://www.miningfacts.org/Environment/What-is-acid-rock-drainage/

Gay, S. W., & Knowlton, K. F. (2009). Ammonia Emissions and Animal Agriculture. *Virginia Cooperative Extension*.

Government of British Columbia. (2000). Water Quality - Urban Runoff. Retrieved March 24, 2016, from http://www.env.gov.bc.ca/wat/wq/nps/BMP_Compendium/Municipal/Urban_Runoff/Urban_Runoff.htm

Government of New Brunswick. (2012, June 26). Managing Pesticides and their application in NB. Retrieved March 23, 2016, from Managing Pesticides and their application in NB

Hascic, I., & Wu, J. (2006). Land Use and Watershed Health in the United States. *Land Economics, 82*(2), 214-239. doi:10.3368/le.82.2.214

Highland, L., & Bobrowsky, P. T. (2008). *The landslide handbook a guide to understanding landslides*. Reston, VA: U.S. Geological Survey.

International Rivers. (2014). Environmental Impacts of Dams. Retrieved from https://www.internationalrivers.org/environmental-impacts-of-dams

Jutras, P., Macrae, R., & Utting, J. (2007). Visean tectonostratigraphy and basin architecture beneath the Pennsylvanian New Brunswick Platform of eastern Canada. *Bulletin of Canadian Petroleum Geology, 55*(3), 217-236. doi:10.2113/gscpgbull.55.3.217

Knighton, D. (1998). *Fluvial forms and processes: A new perspective*. London: Arnold.

Morita, K., & Yokota, A. (2002). Population viability of stream-resident salmonids after habitat fragmentation: A case study with white-spotted charr (Salvelinus leucomaenis) by an individual based model. *Ecological Modelling, 155*(1), 85-94. doi:10.1016/s0304-3800(02)00128-x

Morita, K., & Yamamoto, S. (2002). Effects of Habitat Fragmentation by Damming on the Persistence of Stream-Dwelling Charr Populations. *Conservation Biology, 16*(5), 1318-1323. doi:10.1046/j.1523-1739.2002.01476.x

NB Power. (2015). Mactaquac Project. Retrieved April 16, 2016, from https://www.nbpower.com/en/about-us/projects/mactaquac-project

New Brunswick Department of Natural Resources. (2004, April 20). *Guidelines for Roads and Watercourse Crossings* [PDF]. Forest Management Branch - New Brunswick Department of Natural Resources.

Ongley, E. D. (1996). *Control of water pollution from agriculture*. Rome: Food and Agriculture Organization of the United Nations.

Ogden, F. L., Pradhan, N. R., Downer, C. W., & Zahner, J. A. (2011). Relative importance of impervious area, drainage density, width function, and subsurface storm drainage on flood runoff from an urbanized catchment. *Water Resources Research Water Resour. Res., 47*(12).

Radwell, A. J., & Kwak, T. J. (2005). Assessing Ecological Integrity of Ozark Rivers to Determine Suitability for Protective Status. *Environmental Management, 35*(6), 799-810. doi:10.1007/s00267-004-0136-4

Rex J. 2003. Omineca-Peace watershed prioritization project 2002/03 year end report. Rex Environmental Services. Prepared for Ministry of Environment. Unpublished.

Smith, C. (2016, January 25). Road salt supply secure this winter but future uncertain - New Brunswick - CBC News. Retrieved April 3, 2016, from http://www.cbc.ca/news/canada/new-brunswick/road-salt-supply-uncertain-1.3416104

Sterling, S. M., Garroway, K., Guan, Y., Ambrose, S. M., Horne, P., & Kennedy, G. W. (2014). A new watershed assessment framework for Nova Scotia: A high-level, integrated approach for regions without a dense network of monitoring stations. *Journal of Hydrology, 519*, 2596-2612. doi:10.1016/j.jhydrol.2014.07.063

The Canadian Press. (2009, December 15). Coal mining in Minto, N.B., comes to an end after hundreds of years. *The News (New Glasgow, NS)*. Retrieved from http://www.ngnews.ca/Business/2009-12-15/article-800147/Coal-mining-in-Minto-NB-comes-to-an-end-after-hundreds-of-years/1

TransCanada FoundLocally Inc. (2016). New Brunswick Trans-Canada Highway information. Retrieved April 29, 2016, from http://transcanadahighway.com/NewBrunswick

Waldman, J. (2013, April 4). Blocked Migration: Fish Ladders On U.S. Dams Are Not Effective. Retrieved May 04, 2016, from http://e360.yale.edu/feature/blocked_migration_fish_ladders_on_us_dams_are_not_effective/2636/

World Bank. (2016). Data retrieved March 2, 2009, from World Development Indicators Online (WDI) database.

7. APPENDICES

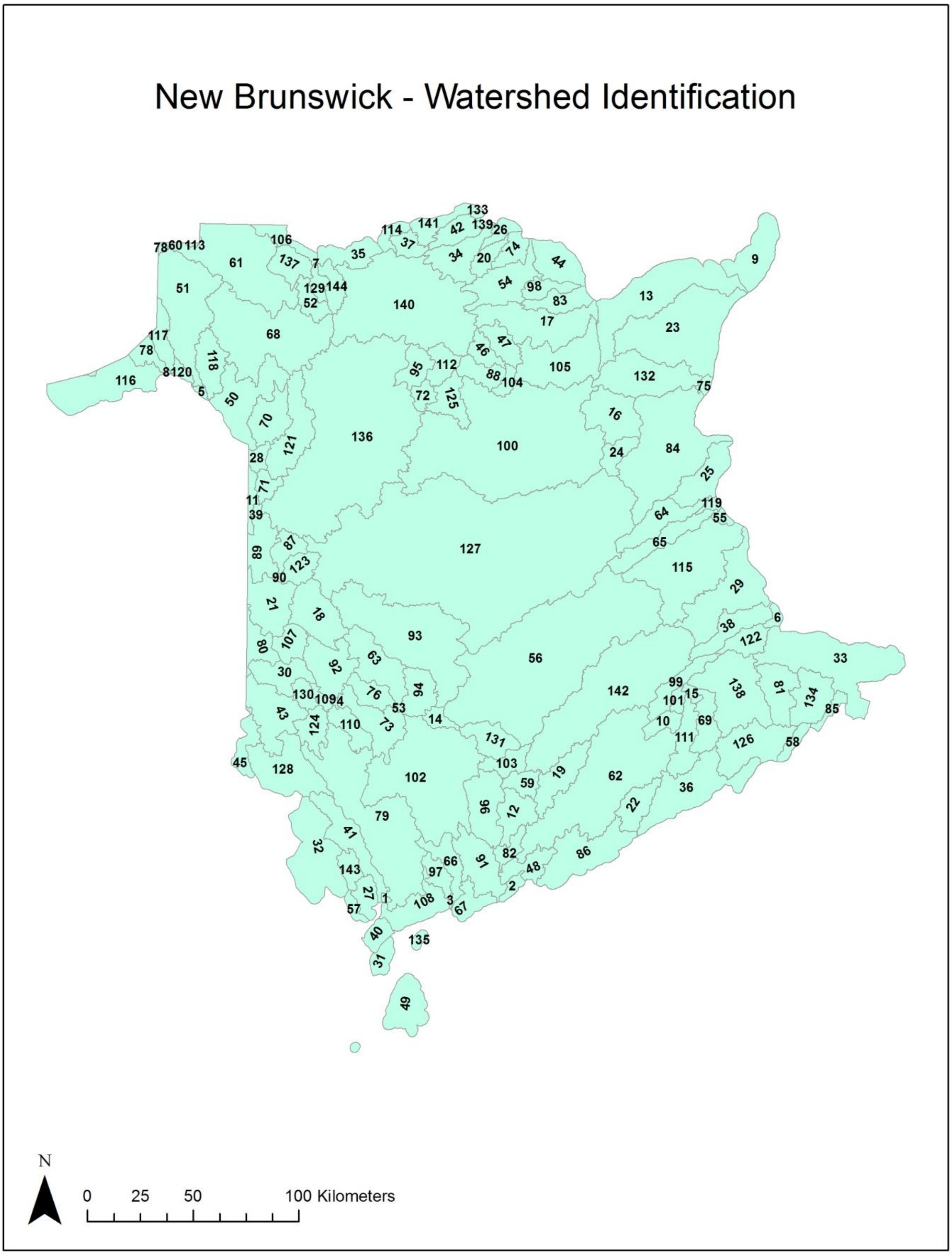
This section contains additional information regarding watershed identification, attribute results, and scoring results.

Appendix A contains a map showing all New Brunswick Watersheds along with a reference number for each one.

Appendix B contains all of the numerical results for all watersheds in terms of attributes and water use.

Appendix B contains all of the scoring results for all attributes that were used to compute final scores and rankings for all watersheds.

6.1 Appendix A



Ref Num	Watershed Name	Ref Num	Watershed Name	Ref Num	Watershed Name
1	"East of Didgequash River" Composite	49	Grand Manan Island Composite	97	New River
2	"East of Musquash River" Composite	50	Grande Rivière Composite	98	Nigadoo River
3	"East of New River" Composite	51	Green River	99	North River
4	"East of Pokiok Stream" Composite	52	Hailes Brook Composite	100	Northwest Miramichi River
5	"North of Rivière Quisibis" Composite	53	Indian Brook Composite	101	O'Blenis Brook Composite
6	"South of Cocagne River" Composite	54	Jacquet River	102	Oromocto River
7	"South of Patapedia River" Composite	55	Jardine Lake Composite	103	Otnabog Stream Composite
8	"West of Rivière Iroquois" Composite	56	Jemseg River	104	Otter Brook Composite
9	Acadian Islands Composite	57	Johnson Cove Composite	105	Pabineau River Composite
10	Anagance River	58	Johnson Creek Composite	106	Patapedia River
11	Aroostook River	59	Jones Brook Composite	107	Phillips Creek Composite
12	Back Brook Composite	60	Kedgwick River	108	Pocologan River Composite
13	Baie de Caraquet Composite	61	Kedgwick River	109	Pokiok Reach Composite
14	Baker Brook Composite	62	Kennebecasis River	110	Pokiok Stream
15	Bannister Brook Composite	63	Keswick River	111	Pollett River
16	Bartibog River	64	Kouchibouguac River	112	Portage Brook Composite
17	Bathurst Harbour	65	Kouchibouguacis River	113	Québec
18	Becaguimec Stream	66	Lepreau River	114	Rafting Ground Brook Composite
19	Belleisle Creek	67	Little Lepreau River Composite	115	Richibucto River
20	Benjamin River	68	Little Main Restigouche River	116	Rivière Baker-Brook Composite
21	Big Presque Isle Stream Composite	69	Little River	117	Rivière Iroquois
22	Big Salmon River	70	Little River	118	Rivière Quisibis
23	Big Tracadie / Pokemouche Composite	71	Little River Composite	119	Ruisseau des Major Composite
24	Black Brook Composite	72	Little South Branch Nepisiguit River	120	Ruisseau Lavoie Composite
25	Black River Composite	73	Longs Creek Composite	121	Salmon River
26	Blackhead Brook Composite	74	Louison River Composite	122	Shediac River
27	Bocabec River Composite	75	Lufsbury Brook Composite	123	Shikatehawk Stream
28	Boutot Brook Composite	76	Mactaquac Stream	124	Shogomoc Stream
29	Buctouche River Composite	77	Madawaska River	125	South Branch Nepisiguit River
30	Bulls Creek Composite	78	Madawaska River	126	South Channel
31	Campobello Island Composite	79	Magaguadavic River	127	Southwest Miramichi River
32	Canoose Stream Composite	80	Meduxnekeag River	128	Spednic Lake
33	Cape Tormentine Peninsula Composite	81	Memramcook River	129	Stillwater Brook Composite
34	Charlo River	82	Milkish Creek Composite	130	Sullivan Creek Composite
35	Cheuters Brook Composite	83	Millstream River Composite	131	Swan Creek Composite
36	Chignecto Bay Composite	84	Miramichi Bay	132	Tabusintac River
37	Christopher Brook	85	Misaquash River Composite	133	Tait Brook Composite
38	Cocagne River	86	Mispec River Composite	134	Tantramar River
39	Curry Brook Composite	87	Monquart Stream	135	The Wolves Composite
40	Deer Island Composite	88	Moody Brook Composite	136	Tobique River
41	Digdeguash River	89	Muniac Stream Composite	137	Tracy Brook
42	Eel River	90	Murray Lake Composite	138	Turtle Creek Composite
43	Eel River	91	Musquash River	139	Upper Charlo Composite
44	Elmtree River Composite	92	Nackawic Stream	140	Upsalquitch River
45	Forest City Stream	93	Nashwaak River	141	Walker Brook Composite
46	Forty Four Mile Brook	94	Nashwaaksis Stream Composite	142	Washademoak Creek
47	Forty Mile Brook	95	Nepisiguit River Headwaters	143	Waweig River
48	Grand Bay Composite	96	Nerepis River	144	Whites Brook

6.2 Appendix B

Ref Num	Name	Area km^2	Road Density km/km^2	Drainage Density km/km^2	Stream Crossing Density #/km^2	Dam Density #/100km	% of Streams behind Dams	% Agricultural Land	% Human Land Use	% Non-Agri Human Land Use	Mining Extraction Sites	Watershed Slope (%)	Municipal GW (m3)	Municipal SW (m3)
1	"East of Didgequash River" Composite	14.78	0.40	1.07	0.07	0.00	0.00%	1.9%	2.6%	0.8%	0	5.56	0	0
2	"East of Musquash River" Composite	76.12	1.25	0.85	0.26	0.00	0.00%	1.9%	11.2%	9.3%	0	2.05	0	0
3	"East of New River" Composite	9.34	0.88	1.19	0.96	0.00	0.00%	0.0%	1.5%	1.5%	0	1.84	0	0
4	"East of Pokiok Stream" Composite	14.21	1.09	1.24	1.06	0.00	0.00%	19.3%	22.3%	3.0%	0	6.93	273916	0
5	"North of Rivière Quisibis" Composite	25.81	0.96	1.17	0.27	0.00	0.00%	26.7%	29.9%	3.2%	0	2.84	0	0
6	"South of Cocagne River" Composite	57.87	1.15	0.74	0.38	0.00	0.00%	18.4%	20.4%	1.9%	0	0.55	0	0
7	"South of Patapedia River" Composite	2.14	0.00	1.01	0.00	0.00	0.00%	0.0%	0.0%	0.0%	0	14.21	0	0
8	"West of Rivière Iroquois" Composite	5.59	4.20	1.35	0.54	0.00	0.00%	11.9%	48.3%	36.4%	0	3.54	0	0
9	Acadian Islands Composite	492.68	0.50	0.58	0.08	0.35	0.69%	4.3%	6.9%	2.5%	0	0.06	347124	0
10	Anagance River	138.87	0.57	0.87	0.17	0.83	4.20%	4.6%	6.7%	2.0%	0	4.09	0	0
11	Aroostook River	101.55	0.93	1.10	0.37	0.00	0.00%	34.0%	36.2%	2.1%	0	4.02	0	0
12	Back Brook Composite	313.12	0.63	1.28	0.28	0.00	0.00%	6.4%	7.2%	0.8%	0	5.22	0	0
13	Baie de Caraquet Composite	1179.68	0.53	0.82	0.19	0.10	2.54%	6.7%	10.0%	3.3%	0	0.87	2092977	0
14	Baker Brook Composite	105.56	2.76	1.16	0.65	0.00	0.00%	6.4%	38.2%	31.8%	0	1.37	4312481	0
15	Bannister Brook Composite	48.25	1.09	0.98	0.44	0.00	0.00%	14.7%	21.2%	6.4%	0	1.13	0	0
16	Bartibog River	514.43	0.29	0.91	0.09	0.00	0.00%	1.1%	1.3%	0.2%	0	1.81	0	0
17	Bathurst Harbour	798.51	0.49	1.21	0.14	0.00	0.00%	3.2%	7.7%	4.5%	1	3.18	0	4728381
18	Becaguimec Stream	526.21	0.42	1.44	0.32	0.00	0.00%	14.4%	15.4%	0.9%	0	5.01	185421	0
19	Belleisle Creek	395.58	0.85	1.23	0.52	0.00	0.00%	14.2%	15.5%	1.4%	0	5.41	0	0
20	Benjamin River	150.96	0.08	1.42	0.05	0.00	0.00%	0.2%	0.2%	0.0%	0	2.55	0	0
21	Big Presque Isle Stream Composite	500.65	0.97	1.19	0.53	0.00	0.00%	40.8%	43.6%	2.8%	0	2.80	0	0
22	Big Salmon River	281.50	0.38	1.11	0.15	0.00	0.00%	0.2%	0.2%	0.0%	0	7.62	0	0
23	Big Tracadie / Pokemouche Composite	1464.96	0.63	1.05	0.24	0.06	0.02%	12.9%	16.0%	3.1%	0	0.98	784077	0
24	Black Brook Composite	181.14	1.83	0.91	0.49	0.00	0.00%	9.5%	30.9%	21.4%	0	1.97	2174854	0
25	Black River Composite	420.75	0.16	0.75	0.07	0.00	0.00%	0.3%	0.7%	0.4%	0	0.28	0	0
26	Blackhead Brook Composite	117.80	0.23	0.95	0.11	0.00	0.00%	2.1%	2.6%	0.6%	0	1.40	0	0
27	Bocabec River Composite	173.66	0.93	1.11	0.42	0.00	0.00%	4.5%	7.4%	2.9%	0	3.77	0	536835
28	Boutot Brook Composite	99.20	1.67	1.11	0.67	0.00	0.00%	54.9%	64.2%	9.3%	0	3.18	101241	0
29	Buctouche River Composite	889.99	0.67	0.95	0.30	0.12	0.05%	13.6%	15.4%	1.8%	0	0.78	277957	0
30	Bulls Creek Composite	327.20	0.77	0.93	0.29	0.00	0.00%	18.6%	21.0%	2.4%	0	2.57	872850	0
31	Campobello Island Composite	138.35	0.47	1.02	0.19	0.00	0.00%	1.1%	2.2%	1.1%	0	1.76	0	0
32	Canoose Stream Composite	879.68	0.58	0.96	0.25	0.00	0.00%	6.9%	9.0%	2.0%	0	1.71	1932539	0
33	Cape Tormentine Peninsula Composite	1328.40	0.63	1.03	0.25	0.29	1.94%	13.8%	15.6%	1.8%	0	0.44	723968	0
34	Charlo River	401.70	0.24	1.47	0.13	0.17	26.90%	0.8%	1.2%	0.4%	0	3.92	0	1834732
35	Cheuters Brook Composite	284.09	0.03	1.19	0.01	0.00	0.00%	1.1%	1.1%	0.0%	0	10.64	0	0
36	Chignecto Bay Composite	824.49	0.29	1.10	0.13	0.33	4.19%	0.8%	1.1%	0.3%	0	6.63	27399	0
37	Christopher Brook	149.72	0.45	1.49	0.25	0.00	0.00%	2.7%	3.9%	1.2%	0	9.50	0	0
38	Cocagne River	355.38	0.60	0.98	0.25	0.00	0.00%	12.0%	13.2%	1.2%	0	1.29	161176	0
39	Curry Brook Composite	25.88	1.59	1.18	1.16	0.00	0.00%	26.4%	38.0%	11.6%	0	6.63	84886	0
40	Deer Island Composite	139.22	0.34	1.29	0.14	0.00	0.00%	0.8%	1.8%	1.0%	0	2.26	0	0
41	Digdeguash River	466.22	0.55	1.03	0.21	0.00	0.00%	6.2%	7.1%	0.9%	0	2.34	80504	0
42	Eel River	220.65	0.80	1.36	0.40	0.00	0.00%	9.9%	13.7%	3.8%	0	3.02	265910	198638
43	Eel River	584.84	0.48	1.05	0.17	0.00	0.00%	10.5%	11.2%	0.6%	0	3.21	0	0
44	Elmtree River Composite	381.37	0.66	1.02	0.30	0.00	0.00%	4.5%	9.9%	5.4%	0	1.72	0	0
45	Forest City Stream	208.44	0.20	0.64	0.06	0.00	0.00%	0.8%	1.1%	0.2%	0	1.97	0	0
46	Forty Four Mile Brook	165.12	0.14	0.89	0.04	0.00	0.00%	0.0%	0.0%	0.0%	0	7.97	0	0
47	Forty Mile Brook	221.59	0.23	1.00	0.05	0.45	7.51%	0.0%	0.1%	0.1%	1	4.36	0	0
48	Grand Bay Composite	244.04	2.40	1.23	0.68	0.00	0.00%	3.2%	30.0%	26.8%	0	2.46	0	0
49	Grand Manan Island Composite	442.06	0.25	1.02	0.09	0.22	0.06%	1.0%	2.5%	1.4%	0	2.09	0	0
50	Grande Rivière Composite	700.05	0.67	0.95	0.25	0.00	0.00%	14.2%	16.6%	2.5%	0	2.95	1128886	0

Ref Num	Name	Area km^2	Road Density km/km^2	Drainage Density km/km^2	Stream Crossing Density #/km^2	Dam Density #/100km	% of Streams behind Dams	% Agricultural Land	% Human Land Use	% Non-Agri Human Land Use	Mining Extraction Sites	Watershed Slope (%)	Municipal GW (m3)	Municipal SW (m3)
51	Green River	1074.50	0.37	1.32	0.24	0.00	0.00%	1.5%	1.9%	0.4%	0	8.37	0	116112
52	Hailes Brook Composite	182.23	0.58	1.15	0.26	0.00	0.00%	6.9%	9.1%	2.2%	0	4.67	288956	0
53	Indian Brook Composite	13.06	1.48	1.31	1.23	0.00	0.00%	18.4%	35.2%	16.8%	0	6.02	0	0
54	Jacquet River	513.24	0.16	1.33	0.07	0.00	0.00%	0.4%	0.7%	0.3%	0	5.61	0	0
55	Jardine Lake Composite	51.78	0.00	0.57	0.00	0.00	0.00%	2.8%	2.8%	0.0%	0	0.10	0	0
56	Jemseg River	3949.81	0.31	1.02	0.15	0.00	0.00%	1.9%	2.7%	0.8%	15	0.93	0	0
57	Johnson Cove Composite	73.51	0.26	0.60	0.11	0.00	0.00%	6.8%	8.2%	1.4%	0	1.54	0	0
58	Johnson Creek Composite	103.72	0.30	0.97	0.13	0.00	0.00%	4.6%	5.1%	0.6%	0	1.84	0	0
59	Jones Brook Composite	166.60	0.56	1.47	0.42	0.00	0.00%	9.0%	9.6%	0.7%	0	4.44	0	0
60	Kedgwick River	8.54	0.00	1.10	0.00	0.00	0.00%	0.0%	0.0%	0.0%	0	3.73	0	0
61	Kedgwick River	1273.87	0.23	1.30	0.11	0.00	0.00%	0.0%	0.0%	0.0%	0	10.05	0	0
62	Kennebecasis River	2145.12	1.00	1.21	0.47	0.00	0.00%	14.9%	19.6%	4.8%	1	6.22	2135035	0
63	Keswick River	522.24	0.33	1.16	0.19	0.00	0.00%	8.4%	9.1%	0.7%	0	4.55	0	0
64	Kouchibouguac River	390.93	0.39	1.06	0.17	0.00	0.00%	5.2%	6.3%	1.1%	0	0.49	0	0
65	Kouchibouguacis River	362.50	0.37	1.06	0.16	0.26	1.25%	5.7%	6.9%	1.2%	0	0.59	20710	0
66	Lepreau River	256.16	0.25	1.46	0.12	0.00	0.00%	0.0%	0.4%	0.4%	0	3.58	0	0
67	Little Lepreau River Composite	203.99	0.44	1.29	0.24	0.00	0.00%	0.7%	2.1%	1.3%	0	1.42	0	0
68	Little Main Restigouche River	1582.26	0.25	1.20	0.12	0.00	0.00%	4.3%	4.7%	0.4%	0	5.65	0	856056
69	Little River	276.14	0.52	1.23	0.33	0.30	0.58%	7.9%	8.8%	0.9%	0	5.98	0	0
70	Little River	383.24	0.26	0.89	0.09	0.00	0.00%	18.0%	18.9%	0.9%	0	1.81	978730	0
71	Little River Composite	127.32	0.95	1.29	0.60	0.61	36.90%	26.3%	28.2%	1.9%	0	6.41	0	0
72	Little South Branch Nepisiguit River	120.81	0.13	1.04	0.03	0.00	0.00%	0.0%	0.0%	0.0%	0	10.64	0	0
73	Longs Creek Composite	475.18	0.66	1.34	0.46	0.16	0.44%	12.4%	13.8%	1.4%	1	4.03	0	0
74	Louison River Composite	179.58	0.58	1.08	0.30	0.00	0.00%	4.5%	6.2%	1.8%	0	2.21	0	0
75	Lufsbury Brook Composite	47.32	0.00	0.92	0.00	0.00	0.00%	0.0%	0.0%	0.0%	0	0.31	0	0
76	Mactaquac Stream	220.66	0.46	1.20	0.24	0.00	0.00%	12.4%	13.2%	0.8%	0	2.77	0	0
77	Madawaska River	8.54	0.00	1.10	0.00	0.00	0.00%	0.0%	0.0%	0.0%	0	3.73	0	0
78	Madawaska River	164.09	1.52	1.07	0.56	0.00	0.00%	13.1%	24.0%	10.9%	0	8.97	0	0
79	Magaguadavic River	1871.17	0.33	1.23	0.15	0.09	1.56%	2.8%	3.4%	0.6%	0	2.54	623490	0
80	Meduxnekeag River	228.54	1.17	1.06	0.53	0.00	0.00%	32.4%	37.4%	5.1%	0	1.95	0	0
81	Memramcook River	396.40	0.77	1.16	0.48	0.22	1.01%	18.5%	20.9%	2.4%	0	2.08	289285	0
82	Milkish Creek Composite	135.83	1.10	1.13	0.38	0.00	0.00%	3.6%	9.6%	5.9%	0	3.58	0	0
83	Millstream River Composite	249.53	0.77	1.26	0.36	0.00	0.00%	5.9%	15.5%	9.7%	0	2.12	0	0
84	Miramichi Bay	1663.97	0.33	0.73	0.12	0.00	0.00%	4.0%	6.0%	2.1%	0	0.57	No Data	0
85	Misaquash River Composite	85.67	0.35	1.77	0.27	0.00	0.00%	26.8%	27.9%	1.1%	0	0.47	0	0
86	Mispec River Composite	718.92	0.51	1.04	0.22	0.13	0.16%	2.5%	4.8%	2.3%	0	3.95	0	38146600
87	Monquart Stream	190.14	0.50	1.37	0.32	0.00	0.00%	18.6%	19.4%	0.8%	0	6.28	0	0
88	Moody Brook Composite	215.92	0.23	1.14	0.08	0.41	0.40%	0.0%	0.0%	0.0%	0	10.32	0	0
89	Muniac Stream Composite	352.77	1.01	1.48	0.73	0.00	0.00%	29.9%	33.2%	3.3%	0	6.62	562051	0
90	Murray Lake Composite	14.88	1.32	1.19	0.34	0.00	0.00%	54.2%	59.9%	5.6%	0	3.77	165820	0
91	Musquash River	481.31	0.29	1.59	0.16	0.39	73.83%	0.2%	1.5%	1.4%	0	3.81	0	38146600
92	Nackawic Stream	479.13	0.39	1.06	0.15	0.00	0.00%	9.7%	10.4%	0.7%	0	3.21	0	0
93	Nashwaak River	1706.88	0.37	1.13	0.17	0.05	0.52%	3.4%	4.5%	1.1%	0	3.53	0	0
94	Nashwaaksis Stream Composite	305.24	1.55	1.12	0.52	0.00	0.00%	7.3%	24.7%	17.5%	0	2.91	4154750	0
95	Nepisiguit River Headwaters	227.67	0.07	1.25	0.04	0.00	0.00%	0.0%	0.0%	0.0%	0	8.46	0	0
96	Nerepis River	503.03	0.64	1.56	0.44	0.00	0.00%	2.1%	2.6%	0.5%	0	4.65	0	0
97	New River	160.25	0.19	1.60	0.10	0.00	0.00%	0.5%	0.6%	0.2%	0	4.05	0	0
98	Nigadoo River	168.25	0.39	1.44	0.15	0.00	0.00%	2.4%	5.6%	3.2%	1	2.40	294243	0
99	North River	265.65	0.80	1.25	0.45	0.30	7.17%	31.0%	33.0%	2.0%	0	2.19	0	0
100	Northwest Miramichi River	3873.72	0.25	1.10	0.09	0.00	0.00%	0.7%	1.1%	0.4%	4	3.82	271857	0

Ref Num	Name	Area km^2	Road Density km/km^2	Drainage Density km/km^2	Stream Crossing Density #/km^2	Dam Density #/100km	% of Streams behind Dams	% Agricultural Land	% Human Land Use	% Non-Agri Human Land Use	Mining Extraction Sites	Watershed Slope (%)	Municipal GW (m3)	Municipal SW (m3)
101	O'Blenis Brook Composite	66.73	1.42	1.04	0.66	0.00	0.00%	19.5%	26.4%	6.9%	0	1.31	0	0
102	Oromocto River	2022.32	0.49	1.37	0.25	0.04	23.45%	4.1%	5.9%	1.8%	0	2.04	47315	1527793
103	Otnabog Stream Composite	201.42	0.42	1.66	0.31	0.00	0.00%	8.4%	9.0%	0.6%	0	2.24	0	0
104	Otter Brook Composite	87.47	0.14	1.34	0.05	0.00	0.00%	0.0%	0.0%	0.0%	0	5.89	0	0
105	Pabineau River Composite	794.47	0.34	1.19	0.14	0.00	0.00%	0.3%	2.0%	1.7%	3	2.16	0	0
106	Patapedia River	175.40	0.04	1.10	0.03	0.00	0.00%	0.0%	0.0%	0.0%	0	14.40	0	0
107	Phillips Creek Composite	218.68	0.87	0.93	0.42	0.00	0.00%	32.3%	37.2%	4.9%	0	3.78	185421	0
108	Pocologan River Composite	388.25	0.59	1.44	0.36	0.18	1.21%	5.7%	8.5%	2.8%	0	1.93	No Data	0
109	Pokiok Reach Composite	61.21	0.59	1.03	0.42	0.00	0.00%	9.9%	10.8%	0.9%	0	4.77	0	0
110	Pokiok Stream	226.26	0.48	1.14	0.18	0.00	0.00%	8.0%	8.3%	0.3%	0	1.80	0	0
111	Pollett River	314.03	0.53	1.00	0.25	0.00	0.00%	7.2%	7.8%	0.7%	0	5.37	0	0
112	Portage Brook Composite	206.83	0.15	1.21	0.07	0.00	0.00%	0.0%	0.0%	0.0%	0	13.19	0	0
113	Québec	22.33	0.00	1.11	0.00	0.00	0.00%	0.0%	0.0%	0.0%	0	8.13	0	0
114	Rafting Ground Brook Composite	113.19	0.34	1.39	0.36	0.00	0.00%	4.4%	6.2%	1.8%	1	11.74	0	0
115	Richibucto River	1348.28	0.55	1.08	0.28	0.00	0.00%	6.9%	8.6%	1.7%	0	0.71	199677	0
116	Rivière Baker-Brook Composite	771.74	0.53	1.14	0.29	0.34	0.52%	12.5%	14.6%	2.0%	0	8.22	2344315	0
117	Rivière Iroquois	205.27	0.81	1.13	0.38	0.00	0.00%	11.8%	16.0%	4.2%	0	7.21	1603112	0
118	Rivière Quisibis	329.87	0.39	1.28	0.19	0.00	0.00%	5.9%	6.8%	0.9%	0	5.33	144071	0
119	Ruisseau des Major Composite	46.64	0.32	0.77	0.06	0.00	0.00%	0.9%	2.4%	1.4%	0	0.21	0	0
120	Ruisseau Lavoie Composite	56.89	1.73	1.44	1.14	0.00	0.00%	27.5%	41.0%	13.5%	0	4.52	0	0
121	Salmon River	573.16	0.27	1.34	0.17	0.00	0.00%	14.8%	15.5%	0.7%	0	3.93	0	0
122	Shediac River	220.74	0.75	1.16	0.33	0.39	4.79%	17.1%	19.0%	1.8%	0	1.20	0	1387129
123	Shikatehawk Stream	201.44	0.54	1.25	0.31	0.00	0.00%	11.6%	12.4%	0.9%	0	7.55	0	0
124	Shogomoc Stream	242.11	0.18	1.30	0.07	0.00	0.00%	1.1%	1.4%	0.3%	0	3.98	0	0
125	South Branch Nepisiguit River	274.99	0.22	1.06	0.15	0.00	0.00%	0.0%	0.0%	0.0%	0	7.51	0	0
126	South Channel	592.99	0.31	1.25	0.22	0.14	0.01%	5.0%	6.6%	1.6%	0	5.51	0	57706
127	Southwest Miramichi River	7770.00	0.26	1.03	0.10	0.01	0.23%	1.1%	1.5%	0.4%	0	3.01	242824	0
128	Spednic Lake	683.72	0.27	1.10	0.09	0.00	0.00%	0.4%	1.0%	0.6%	0	3.28	0	0
129	Stillwater Brook Composite	99.86	0.04	1.22	0.01	0.00	0.00%	0.5%	0.5%	0.0%	0	6.76	0	0
130	Sullivan Creek Composite	121.50	0.64	0.96	0.30	0.00	0.00%	4.2%	5.2%	1.0%	0	4.74	0	0
131	Swan Creek Composite	299.54	1.03	1.42	0.41	0.00	0.00%	7.8%	11.5%	3.8%	0	0.98	0	0
132	Tabusintac River	711.59	0.37	1.08	0.15	0.00	0.00%	2.2%	2.6%	0.4%	0	1.86	0	0
133	Tait Brook Composite	18.44	1.82	0.78	0.27	0.00	0.00%	1.1%	25.7%	24.6%	0	2.57	0	0
134	Tantramar River	410.42	0.73	1.25	0.33	0.00	0.00%	24.3%	29.0%	4.6%	0	0.88	1065811	0
135	The Wolves Composite	47.25	0.00	0.00	0.00	0.00	0.00%	1.5%	1.5%	0.0%	0	0.55	0	0
136	Tobique River	4331.31	0.25	1.27	0.13	0.11	1.90%	1.6%	2.0%	0.4%	0	5.54	448317	0
137	Tracy Brook	255.65	0.13	1.51	0.06	0.00	0.00%	0.0%	0.0%	0.0%	0	10.32	0	0
138	Turtle Creek Composite	906.90	1.65	1.19	0.52	0.37	2.73%	11.9%	24.1%	12.3%	0	3.06	118324	22583089
139	Upper Charlo Composite	23.64	1.02	0.90	0.38	0.00	0.00%	8.0%	18.1%	10.1%	0	0.52	68253	0
140	Upsalquitch River	2358.17	0.18	1.48	0.09	0.00	0.00%	0.1%	0.3%	0.1%	0	7.07	0	0
141	Walker Brook Composite	227.49	0.97	0.98	0.38	0.00	0.00%	1.9%	12.8%	10.9%	0	5.50	402074	2552409
142	Washademoak Creek	2163.93	0.42	1.06	0.21	0.04	0.19%	4.4%	5.0%	0.6%	0	1.65	68253	0
143	Waweig River	143.79	0.89	1.37	0.54	0.00	0.00%	15.2%	16.6%	1.4%	0	2.97	0	536835
144	Whites Brook	186.41	0.26	1.13	0.10	0.00	0.00%	0.6%	0.9%	0.3%	0	4.30	0	0

6.3 Appendix C

Ref Num	Name	Road Density	Drainage Density	Stream Crossing Density	Dam Density	% of Streams behind Dams	Agricultural Land Use	Human Land Use	Acid Rock Drainage Risk	Watershed Slope	**Total Score**	**Attribute-only Rank**	GW	SW	Consumption Multiplier	**Adjusted Total**	**Consumption Adjusted Rankings**
1	"East of Didgequash River" Composite	0.90	5.00	0.54	0.00	0.00	0.77	0.39	0.00	1.85	**9.45**	**108**	0.00	0.00	1.00	**9.45**	**111**
2	"East of Musquash River" Composite	2.77	3.75	2.10	0.00	0.00	0.81	4.64	0.00	0.68	**14.76**	**65**	0.00	0.00	1.00	**14.76**	**83**
3	"East of New River" Composite	1.95	5.00	7.71	0.00	0.00	0.00	0.73	0.00	0.61	**16.00**	**56**	0.00	0.00	1.00	**16.00**	**73**
4	"East of Pokiok Stream" Composite	2.42	5.00	8.45	0.00	0.00	8.02	1.51	0.00	2.31	**27.71**	**15**	0.50	0.00	1.50	**41.57**	**11**
5	"North of Rivière Quisibis" Composite	2.13	5.00	2.17	0.00	0.00	11.13	1.58	0.00	0.95	**22.97**	**26**	0.00	0.00	1.00	**22.97**	**47**
6	"South of Cocagne River" Composite	2.55	3.75	3.04	0.00	0.00	7.68	0.96	0.00	0.18	**18.17**	**41**	0.00	0.00	1.00	**18.17**	**63**
7	"South of Patapedia River" Composite	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	4.74	**9.74**	**105**	0.00	0.00	1.00	**9.74**	**108**
8	"West of Rivière Iroquois" Composite	9.33	5.00	4.30	0.00	0.00	4.95	18.20	0.00	1.18	**42.95**	**1**	0.00	0.00	1.00	**42.95**	**10**
9	Acadian Islands Composite	1.11	2.50	0.63	2.05	0.05	1.81	1.26	0.00	0.02	**9.42**	**110**	0.50	0.00	1.50	**14.13**	**87**
10	Anagance River	1.26	3.75	1.38	4.87	0.28	1.94	1.02	0.00	1.36	**15.86**	**58**	0.00	0.00	1.00	**15.86**	**74**
11	Aroostook River	2.07	5.00	2.99	0.00	0.00	14.19	1.06	0.00	1.34	**26.66**	**20**	0.00	0.00	1.00	**26.66**	**36**
12	Back Brook Composite	1.39	5.00	2.25	0.00	0.00	2.67	0.39	0.00	1.74	**13.45**	**72**	0.00	0.00	1.00	**13.45**	**89**
13	Baie de Caraquet Composite	1.17	3.75	1.50	0.61	0.17	2.78	1.66	0.00	0.29	**11.92**	**90**	0.75	0.00	1.75	**20.86**	**52**
14	Baker Brook Composite	6.14	5.00	5.23	0.00	0.00	2.68	15.90	0.00	0.46	**35.40**	**7**	0.75	0.00	1.75	**61.95**	**2**
15	Bannister Brook Composite	2.42	5.00	3.48	0.00	0.00	6.13	3.22	0.00	0.38	**20.63**	**29**	0.00	0.00	1.00	**20.63**	**54**
16	Bartibog River	0.65	5.00	0.75	0.00	0.00	0.46	0.11	0.00	0.60	**7.57**	**134**	0.00	0.00	1.00	**7.57**	**134**
17	Bathurst Harbour	1.10	5.00	1.11	0.00	0.00	1.35	2.24	5.00	1.06	**16.85**	**47**	0.00	0.75	1.75	**29.49**	**27**
18	Becaguimec Stream	0.94	5.00	2.52	0.00	0.00	6.01	0.47	0.00	1.67	**16.61**	**49**	0.50	0.00	1.50	**24.91**	**40**
19	Belleisle Creek	1.88	5.00	4.17	0.00	0.00	5.91	0.68	0.00	1.80	**19.45**	**34**	0.00	0.00	1.00	**19.45**	**59**
20	Benjamin River	0.19	5.00	0.42	0.00	0.00	0.07	0.02	0.00	0.85	**6.55**	**136**	0.00	0.00	1.00	**6.55**	**136**
21	Big Presque Isle Stream Composite	2.15	5.00	4.22	0.00	0.00	16.99	1.39	0.00	0.93	**30.69**	**11**	0.00	0.00	1.00	**30.69**	**26**
22	Big Salmon River	0.86	5.00	1.22	0.00	0.00	0.07	0.00	0.00	2.54	**9.69**	**106**	0.00	0.00	1.00	**9.69**	**109**
23	Big Tracadie / Pokemouche Composite	1.39	5.00	1.96	0.38	0.00	5.37	1.57	0.00	0.33	**15.99**	**57**	0.50	0.00	1.50	**23.99**	**43**
24	Black Brook Composite	4.07	5.00	3.93	0.00	0.00	3.95	10.71	0.00	0.66	**28.31**	**14**	0.75	0.00	1.75	**49.54**	**5**
25	Black River Composite	0.36	3.75	0.57	0.00	0.00	0.13	0.18	0.00	0.09	**5.08**	**141**	0.00	0.00	1.00	**5.08**	**141**
26	Blackhead Brook Composite	0.51	5.00	0.88	0.00	0.00	0.86	0.29	0.00	0.47	**8.01**	**126**	0.00	0.00	1.00	**8.01**	**126**
27	Bocabec River Composite	2.06	5.00	3.36	0.00	0.00	1.86	1.44	0.00	1.26	**14.98**	**63**	0.00	0.50	1.50	**22.48**	**48**
28	Boutot Brook Composite	3.72	5.00	5.32	0.00	0.00	22.88	4.64	0.00	1.06	**42.62**	**2**	0.50	0.00	1.50	**63.93**	**1**
29	Buctouche River Composite	1.49	5.00	2.39	0.69	0.00	5.66	0.90	0.00	0.26	**16.39**	**51**	0.50	0.00	1.50	**24.59**	**41**
30	Bulls Creek Composite	1.70	5.00	2.32	0.00	0.00	7.76	1.20	0.00	0.86	**18.84**	**38**	0.50	0.00	1.50	**28.26**	**32**
31	Campobello Island Composite	1.05	5.00	1.50	0.00	0.00	0.48	0.54	0.00	0.59	**9.15**	**115**	0.00	0.00	1.00	**9.15**	**117**
32	Canoose Stream Composite	1.30	5.00	2.04	0.00	0.00	2.88	1.02	0.00	0.57	**12.81**	**79**	0.75	0.00	1.75	**22.41**	**49**
33	Cape Tormentine Peninsula Composite	1.40	5.00	1.96	1.73	0.13	5.76	0.88	0.00	0.15	**17.01**	**46**	0.50	0.00	1.50	**25.52**	**38**
34	Charlo River	0.54	5.00	1.06	1.00	1.79	0.32	0.19	0.00	1.31	**11.21**	**95**	0.00	0.75	1.75	**19.62**	**58**
35	Cheuters Brook Composite	0.07	5.00	0.11	0.00	0.00	0.45	0.02	0.00	3.55	**9.20**	**112**	0.00	0.00	1.00	**9.20**	**114**
36	Chignecto Bay Composite	0.64	5.00	1.07	1.94	0.28	0.32	0.14	0.00	2.21	**11.61**	**92**	0.25	0.00	1.25	**14.51**	**85**
37	Christopher Brook	1.00	5.00	1.98	0.00	0.00	1.13	0.58	0.00	3.17	**12.85**	**78**	0.00	0.00	1.00	**12.85**	**94**
38	Cocagne River	1.33	5.00	2.00	0.00	0.00	5.01	0.60	0.00	0.43	**14.38**	**68**	0.50	0.00	1.50	**21.57**	**51**
39	Curry Brook Composite	3.54	5.00	9.27	0.00	0.00	10.98	5.80	0.00	2.21	**36.81**	**5**	0.25	0.00	1.25	**46.01**	**7**
40	Deer Island Composite	0.75	5.00	1.15	0.00	0.00	0.34	0.49	0.00	0.75	**8.49**	**119**	0.00	0.00	1.00	**8.49**	**121**
41	Digdeguash River	1.23	5.00	1.66	0.00	0.00	2.58	0.47	0.00	0.78	**11.73**	**91**	0.25	0.00	1.25	**14.66**	**84**
42	Eel River	1.78	5.00	3.23	0.00	0.00	4.14	1.90	0.00	1.01	**17.06**	**45**	0.50	0.50	2.00	**34.11**	**19**
43	Eel River	1.08	5.00	1.40	0.00	0.00	4.39	0.31	0.00	1.07	**13.25**	**74**	0.00	0.00	1.00	**13.25**	**91**
44	Elmtree River Composite	1.47	5.00	2.37	0.00	0.00	1.87	2.72	0.00	0.57	**14.00**	**69**	0.00	0.00	1.00	**14.00**	**88**
45	Forest City Stream	0.44	2.50	0.50	0.00	0.00	0.35	0.11	0.00	0.66	**4.55**	**142**	0.00	0.00	1.00	**4.55**	**142**
46	Forty Four Mile Brook	0.31	3.75	0.34	0.00	0.00	0.00	0.00	0.00	2.66	**7.05**	**135**	0.00	0.00	1.00	**7.05**	**135**
47	Forty Mile Brook	0.51	5.00	0.43	2.65	0.50	0.00	0.03	5.00	1.45	**15.58**	**60**	0.00	0.00	1.00	**15.58**	**77**
48	Grand Bay Composite	5.32	5.00	5.47	0.00	0.00	1.35	13.39	0.00	0.82	**31.36**	**10**	0.00	0.00	1.00	**31.36**	**25**
49	Grand Manan Island Composite	0.55	5.00	0.74	1.30	0.00	0.43	0.71	0.00	0.70	**9.44**	**109**	0.00	0.00	1.00	**9.44**	**112**
50	Grande Rivière Composite	1.49	5.00	2.01	0.00	0.00	5.90	1.23	0.00	0.98	**16.62**	**48**	0.75	0.00	1.75	**29.08**	**29**

Ref Num	Name	Road Density	Drainage Density	Stream Crossing Density	Dam Density	% of Streams behind Dams	Agricultural Land Use	Human Land Use	Acid Rock Drainage Risk	Watershed Slope	**Total Score**	**Attribute-only Rank**	GW	SW	Consumption Multiplier	**Adjusted Total**	**Consumption Adjusted Rankings**
51	Green River	0.83	5.00	1.90	0.00	0.00	0.63	0.21	0.00	2.79	**11.36**	**94**	0.00	0.50	1.50	**17.04**	**66**
52	Hailes Brook Composite	1.28	5.00	2.11	0.00	0.00	2.87	1.08	0.00	1.56	**13.89**	**70**	0.50	0.00	1.50	**20.84**	**53**
53	Indian Brook Composite	3.30	5.00	9.80	0.00	0.00	7.66	8.40	0.00	2.01	**36.17**	**6**	0.00	0.00	1.00	**36.17**	**16**
54	Jacquet River	0.35	5.00	0.55	0.00	0.00	0.18	0.13	0.00	1.87	**8.08**	**124**	0.00	0.00	1.00	**8.08**	**124**
55	Jardine Lake Composite	0.00	2.50	0.00	0.00	0.00	1.17	0.00	0.00	0.03	**3.70**	**143**	0.00	0.00	1.00	**3.70**	**143**
56	Jemseg River	0.69	5.00	1.18	0.00	0.00	0.80	0.38	25.00	0.31	**33.36**	**8**	0.00	0.00	1.00	**33.36**	**21**
57	Johnson Cove Composite	0.59	2.50	0.87	0.00	0.00	2.83	0.71	0.00	0.51	**8.01**	**125**	0.00	0.00	1.00	**8.01**	**125**
58	Johnson Creek Composite	0.66	5.00	1.08	0.00	0.00	1.90	0.29	0.00	0.61	**9.54**	**107**	0.00	0.00	1.00	**9.54**	**110**
59	Jones Brook Composite	1.25	5.00	3.36	0.00	0.00	3.73	0.35	0.00	1.48	**15.17**	**62**	0.00	0.00	1.00	**15.17**	**78**
60	Kedgwick River	0.00	5.00	0.00	0.00	0.00	0.01	0.00	0.00	1.24	**6.25**	**137**	0.00	0.00	1.00	**6.25**	**137**
61	Kedgwick River	0.51	5.00	0.92	0.00	0.00	0.01	0.00	0.00	3.35	**9.78**	**104**	0.00	0.00	1.00	**9.78**	**107**
62	Kennebecasis River	2.21	5.00	3.73	0.00	0.00	6.20	2.38	5.00	2.07	**26.59**	**21**	0.75	0.00	1.75	**46.54**	**6**
63	Keswick River	0.74	5.00	1.50	0.00	0.00	3.51	0.34	0.00	1.52	**12.61**	**81**	0.00	0.00	1.00	**12.61**	**96**
64	Kouchibouguac River	0.87	5.00	1.35	0.00	0.00	2.16	0.54	0.00	0.16	**10.08**	**102**	0.00	0.00	1.00	**10.08**	**106**
65	Kouchibouguacis River	0.83	5.00	1.30	1.54	0.08	2.38	0.61	0.00	0.20	**11.94**	**89**	0.25	0.00	1.25	**14.92**	**80**
66	Lepreau River	0.56	5.00	1.00	0.00	0.00	0.01	0.19	0.00	1.19	**7.95**	**127**	0.00	0.00	1.00	**7.95**	**127**
67	Little Lepreau River Composite	0.98	5.00	1.92	0.00	0.00	0.30	0.67	0.00	0.47	**9.35**	**111**	0.00	0.00	1.00	**9.35**	**113**
68	Little Main Restigouche River	0.55	5.00	0.97	0.00	0.00	1.79	0.22	0.00	1.88	**10.41**	**98**	0.00	0.50	1.50	**15.62**	**76**
69	Little River	1.16	5.00	2.61	1.74	0.04	3.30	0.45	0.00	1.99	**16.29**	**52**	0.00	0.00	1.00	**16.29**	**69**
70	Little River	0.57	3.75	0.69	0.00	0.00	7.50	0.44	0.00	0.60	**13.56**	**71**	0.50	0.00	1.50	**20.34**	**55**
71	Little River Composite	2.10	5.00	4.78	3.59	2.46	10.96	0.93	0.00	2.14	**31.95**	**9**	0.00	0.00	1.00	**31.95**	**24**
72	Little South Branch Nepisiguit River	0.28	5.00	0.26	0.00	0.00	0.01	0.00	0.00	3.55	**9.11**	**116**	0.00	0.00	1.00	**9.11**	**118**
73	Longs Creek Composite	1.46	5.00	3.67	0.92	0.03	5.17	0.71	5.00	1.34	**23.30**	**25**	0.00	0.00	1.00	**23.30**	**45**
74	Louison River Composite	1.29	5.00	2.36	0.00	0.00	1.87	0.88	0.00	0.74	**12.14**	**86**	0.00	0.00	1.00	**12.14**	**100**
75	Lufsbury Brook Composite	0.00	5.00	0.00	0.00	0.00	0.02	0.00	0.00	0.10	**5.12**	**140**	0.00	0.00	1.00	**5.12**	**140**
76	Mactaquac Stream	1.02	5.00	1.96	0.00	0.00	5.18	0.39	0.00	0.92	**14.47**	**67**	0.00	0.00	1.00	**14.47**	**86**
77	Madawaska River	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	1.24	**6.24**	**138**	0.00	0.00	1.00	**6.24**	**138**
78	Madawaska River	3.37	5.00	4.49	0.00	0.00	5.48	5.43	0.00	2.99	**26.75**	**19**	0.00	0.00	1.00	**26.75**	**35**
79	Magaguadavic River	0.73	5.00	1.22	0.51	0.10	1.17	0.28	0.00	0.85	**9.85**	**103**	0.50	0.00	1.50	**14.78**	**82**
80	Meduxnekeag River	2.60	5.00	4.20	0.00	0.00	13.49	2.53	0.00	0.65	**28.47**	**13**	0.00	0.00	1.00	**28.47**	**31**
81	Memramcook River	1.71	5.00	3.83	1.27	0.07	7.70	1.21	0.00	0.69	**21.49**	**28**	0.50	0.00	1.50	**32.24**	**23**
82	Milkish Creek Composite	2.45	5.00	3.06	0.00	0.00	1.52	2.96	0.00	1.19	**16.18**	**53**	0.00	0.00	1.00	**16.18**	**71**
83	Millstream River Composite	1.72	5.00	2.85	0.00	0.00	2.44	4.84	0.00	0.71	**17.56**	**44**	0.00	0.00	1.00	**17.56**	**65**
84	Miramichi Bay	0.73	3.75	0.98	0.00	0.00	1.66	1.04	0.00	0.19	**8.34**	**120**	1.00	0.00	2.00	**16.68**	**67**
85	Misaquash River Composite	0.78	5.00	2.15	0.00	0.00	11.15	0.54	0.00	0.16	**19.77**	**32**	0.00	0.00	1.00	**19.77**	**57**
86	Mispec River Composite	1.13	5.00	1.77	0.79	0.01	1.03	1.15	0.00	1.32	**12.20**	**85**	0.00	1.00	2.00	**24.39**	**42**
87	Monquart Stream	1.11	5.00	2.52	0.00	0.00	7.73	0.41	0.00	2.09	**18.86**	**37**	0.00	0.00	1.00	**18.86**	**60**
88	Moody Brook Composite	0.52	5.00	0.67	2.39	0.03	0.00	0.00	0.00	3.44	**12.04**	**87**	0.00	0.00	1.00	**12.04**	**101**
89	Muniac Stream Composite	2.26	5.00	5.87	0.00	0.00	12.48	1.64	0.00	2.21	**29.45**	**12**	0.50	0.00	1.50	**44.17**	**9**
90	Murray Lake Composite	2.94	5.00	2.69	0.00	0.00	22.60	2.81	0.00	1.26	**37.29**	**4**	0.50	0.00	1.50	**55.94**	**3**
91	Musquash River	0.64	5.00	1.26	2.30	4.92	0.07	0.69	0.00	1.27	**16.15**	**54**	0.00	1.00	2.00	**32.29**	**22**
92	Nackawic Stream	0.87	5.00	1.24	0.00	0.00	4.04	0.34	0.00	1.07	**12.56**	**83**	0.00	0.00	1.00	**12.56**	**98**
93	Nashwaak River	0.83	5.00	1.40	0.31	0.03	1.41	0.53	0.00	1.18	**10.69**	**96**	0.00	0.00	1.00	**10.69**	**103**
94	Nashwaaksis Stream Composite	3.45	5.00	4.19	0.00	0.00	3.03	8.73	0.00	0.97	**25.38**	**23**	0.75	0.00	1.75	**44.41**	**8**
95	Nepisiguit River Headwaters	0.15	5.00	0.28	0.00	0.00	0.00	0.00	0.00	2.82	**8.25**	**121**	0.00	0.00	1.00	**8.25**	**122**
96	Nerepis River	1.42	5.00	3.50	0.00	0.00	0.88	0.25	0.00	1.55	**12.60**	**82**	0.00	0.00	1.00	**12.60**	**97**
97	New River	0.41	5.00	0.80	0.00	0.00	0.20	0.08	0.00	1.35	**7.84**	**130**	0.00	0.00	1.00	**7.84**	**130**
98	Nigadoo River	0.86	5.00	1.19	0.00	0.00	0.98	1.62	5.00	0.80	**15.45**	**61**	0.50	0.00	1.50	**23.17**	**46**
99	North River	1.79	5.00	3.58	1.78	0.48	12.91	0.99	0.00	0.73	**27.25**	**18**	0.00	0.00	1.00	**27.25**	**33**
100	Northwest Miramichi River	0.56	5.00	0.70	0.00	0.00	0.30	0.22	10.00	1.27	**18.04**	**42**	0.50	0.00	1.50	**27.06**	**34**

Ref Num	Name	Road Density	Drainage Density	Stream Crossing Density	Dam Density	% of Streams behind Dams	Agricultural Land Use	Human Land Use	Acid Rock Drainage Risk	Watershed Slope	**Total Score**	**Attribute-only Rank**	GW	SW	Consumption Multiplier	**Adjusted Total**	**Consumption Adjusted Rankings**
101	O'Blenis Brook Composite	3.15	5.00	5.27	0.00	0.00	8.13	3.46	0.00	0.44	**25.45**	**22**	0.00	0.00	1.00	**25.45**	**39**
102	Oromocto River	1.08	5.00	2.02	0.21	1.56	1.71	0.89	0.00	0.68	**13.14**	**75**	0.25	0.75	2.00	**26.29**	**37**
103	Otnabog Stream Composite	0.93	5.00	2.46	0.00	0.00	3.49	0.30	0.00	0.75	**12.92**	**77**	0.00	0.00	1.00	**12.92**	**93**
104	Otter Brook Composite	0.31	5.00	0.37	0.00	0.00	0.00	0.00	0.00	1.96	**7.64**	**133**	0.00	0.00	1.00	**7.64**	**133**
105	Pabineau River Composite	0.75	5.00	1.10	0.00	0.00	0.12	0.87	10.00	0.72	**18.55**	**39**	0.00	0.00	1.00	**18.55**	**62**
106	Patapedia River	0.09	5.00	0.23	0.00	0.00	0.00	0.00	0.00	4.80	**10.11**	**100**	0.00	0.00	1.00	**10.11**	**105**
107	Phillips Creek Composite	1.94	5.00	3.37	0.00	0.00	13.45	2.45	0.00	1.26	**27.47**	**16**	0.50	0.00	1.50	**41.21**	**12**
108	Pocologan River Composite	1.32	5.00	2.88	1.05	0.08	2.36	1.40	0.00	0.64	**14.74**	**66**	1.00	0.00	2.00	**29.47**	**28**
109	Pokiok Reach Composite	1.30	5.00	3.40	0.00	0.00	4.11	0.45	0.00	1.59	**15.85**	**59**	0.00	0.00	1.00	**15.85**	**75**
110	Pokiok Stream	1.07	5.00	1.41	0.00	0.00	3.32	0.17	0.00	0.60	**11.57**	**93**	0.00	0.00	1.00	**11.57**	**102**
111	Pollett River	1.17	5.00	1.96	0.00	0.00	2.99	0.34	0.00	1.79	**13.25**	**73**	0.00	0.00	1.00	**13.25**	**90**
112	Portage Brook Composite	0.33	5.00	0.58	0.00	0.00	0.00	0.00	0.00	4.40	**10.31**	**99**	0.00	0.00	1.00	**10.31**	**104**
113	Québec	0.00	5.00	0.00	0.00	0.00	0.01	0.00	0.00	2.71	**7.72**	**131**	0.00	0.00	1.00	**7.72**	**131**
114	Rafting Ground Brook Composite	0.75	5.00	2.90	0.00	0.00	1.85	0.89	5.00	3.91	**20.30**	**31**	0.00	0.00	1.00	**20.30**	**56**
115	Richibucto River	1.22	5.00	2.25	0.00	0.00	2.86	0.85	0.00	0.24	**12.42**	**84**	0.50	0.00	1.50	**18.63**	**61**
116	Rivière Baker-Brook Composite	1.18	5.00	2.34	2.01	0.03	5.23	1.02	0.00	2.74	**19.56**	**33**	0.75	0.00	1.75	**34.23**	**18**
117	Rivière Iroquois	1.80	5.00	3.04	0.00	0.00	4.91	2.10	0.00	2.40	**19.26**	**36**	0.75	0.00	1.75	**33.71**	**20**
118	Rivière Quisibis	0.87	5.00	1.50	0.00	0.00	2.45	0.44	0.00	1.78	**12.04**	**88**	0.50	0.00	1.50	**18.05**	**64**
119	Ruisseau des Major Composite	0.72	3.75	0.51	0.00	0.00	0.38	0.72	0.00	0.07	**6.16**	**139**	0.00	0.00	1.00	**6.16**	**139**
120	Ruisseau Lavoie Composite	3.85	5.00	9.14	0.00	0.00	11.47	6.75	0.00	1.51	**37.72**	**3**	0.00	0.00	1.00	**37.72**	**14**
121	Salmon River	0.60	5.00	1.37	0.00	0.00	6.17	0.37	0.00	1.31	**14.81**	**64**	0.00	0.00	1.00	**14.81**	**81**
122	Shediac River	1.68	5.00	2.61	2.30	0.32	7.14	0.92	0.00	0.40	**20.36**	**30**	0.00	0.75	1.75	**35.64**	**17**
123	Shikatehawk Stream	1.20	5.00	2.50	0.00	0.00	4.83	0.43	0.00	2.52	**16.47**	**50**	0.00	0.00	1.00	**16.47**	**68**
124	Shogomoc Stream	0.41	5.00	0.53	0.00	0.00	0.47	0.14	0.00	1.33	**7.88**	**128**	0.00	0.00	1.00	**7.88**	**128**
125	South Branch Nepisiguit River	0.50	5.00	1.19	0.00	0.00	0.00	0.00	0.00	2.50	**9.20**	**113**	0.00	0.00	1.00	**9.20**	**115**
126	South Channel	0.70	5.00	1.75	0.80	0.00	2.08	0.81	0.00	1.84	**12.97**	**76**	0.00	0.25	1.25	**16.21**	**70**
127	Southwest Miramichi River	0.57	5.00	0.79	0.07	0.02	0.45	0.22	0.00	1.00	**8.13**	**123**	0.50	0.00	1.50	**12.20**	**99**
128	Spednic Lake	0.59	5.00	0.70	0.00	0.00	0.15	0.31	0.00	1.09	**7.84**	**129**	0.00	0.00	1.00	**7.84**	**129**
129	Stillwater Brook Composite	0.09	5.00	0.08	0.00	0.00	0.21	0.01	0.00	2.25	**7.64**	**132**	0.00	0.00	1.00	**7.64**	**132**
130	Sullivan Creek Composite	1.43	5.00	2.37	0.00	0.00	1.77	0.49	0.00	1.58	**12.64**	**80**	0.00	0.00	1.00	**12.64**	**95**
131	Swan Creek Composite	2.29	5.00	3.31	0.00	0.00	3.24	1.89	0.00	0.33	**16.05**	**55**	0.00	0.00	1.00	**16.05**	**72**
132	Tabusintac River	0.83	5.00	1.20	0.00	0.00	0.93	0.19	0.00	0.62	**8.78**	**117**	0.00	0.00	1.00	**8.78**	**119**
133	Tait Brook Composite	4.04	3.75	2.17	0.00	0.00	0.45	12.31	0.00	0.86	**23.58**	**24**	0.00	0.00	1.00	**23.58**	**44**
134	Tantramar River	1.63	5.00	2.63	0.00	0.00	10.14	2.32	0.00	0.29	**22.01**	**27**	0.75	0.00	1.75	**38.52**	**13**
135	The Wolves Composite	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.18	**0.81**	**144**	0.00	0.00	1.00	**0.81**	**144**
136	Tobique River	0.55	5.00	1.08	0.64	0.13	0.65	0.22	0.00	1.85	**10.10**	**101**	0.50	0.00	1.50	**15.16**	**79**
137	Tracy Brook	0.28	5.00	0.47	0.00	0.00	0.00	0.00	0.00	3.44	**9.19**	**114**	0.00	0.00	1.00	**9.19**	**116**
138	Turtle Creek Composite	3.66	5.00	4.17	2.18	0.18	4.94	6.13	0.00	1.02	**27.28**	**17**	0.50	1.00	2.00	**54.55**	**4**
139	Upper Charlo Composite	2.28	3.75	3.05	0.00	0.00	3.33	5.07	0.00	0.17	**17.65**	**43**	0.25	0.00	1.25	**22.06**	**50**
140	Upsalquitch River	0.39	5.00	0.72	0.00	0.00	0.06	0.07	0.00	2.36	**8.59**	**118**	0.00	0.00	1.00	**8.59**	**120**
141	Walker Brook Composite	2.16	5.00	3.02	0.00	0.00	0.79	5.46	0.00	1.83	**18.26**	**40**	0.50	0.75	2.00	**36.53**	**15**
142	Washademoak Creek	0.93	5.00	1.68	0.26	0.01	1.85	0.30	0.00	0.55	**10.58**	**97**	0.25	0.00	1.25	**13.23**	**92**
143	Waweig River	1.99	5.00	4.28	0.00	0.00	6.33	0.71	0.00	0.99	**19.31**	**35**	0.00	0.50	1.50	**28.96**	**30**
144	Whites Brook	0.58	5.00	0.77	0.00	0.00	0.26	0.15	0.00	1.43	**8.20**	**122**	0.00	0.00	1.00	**8.20**	**123**