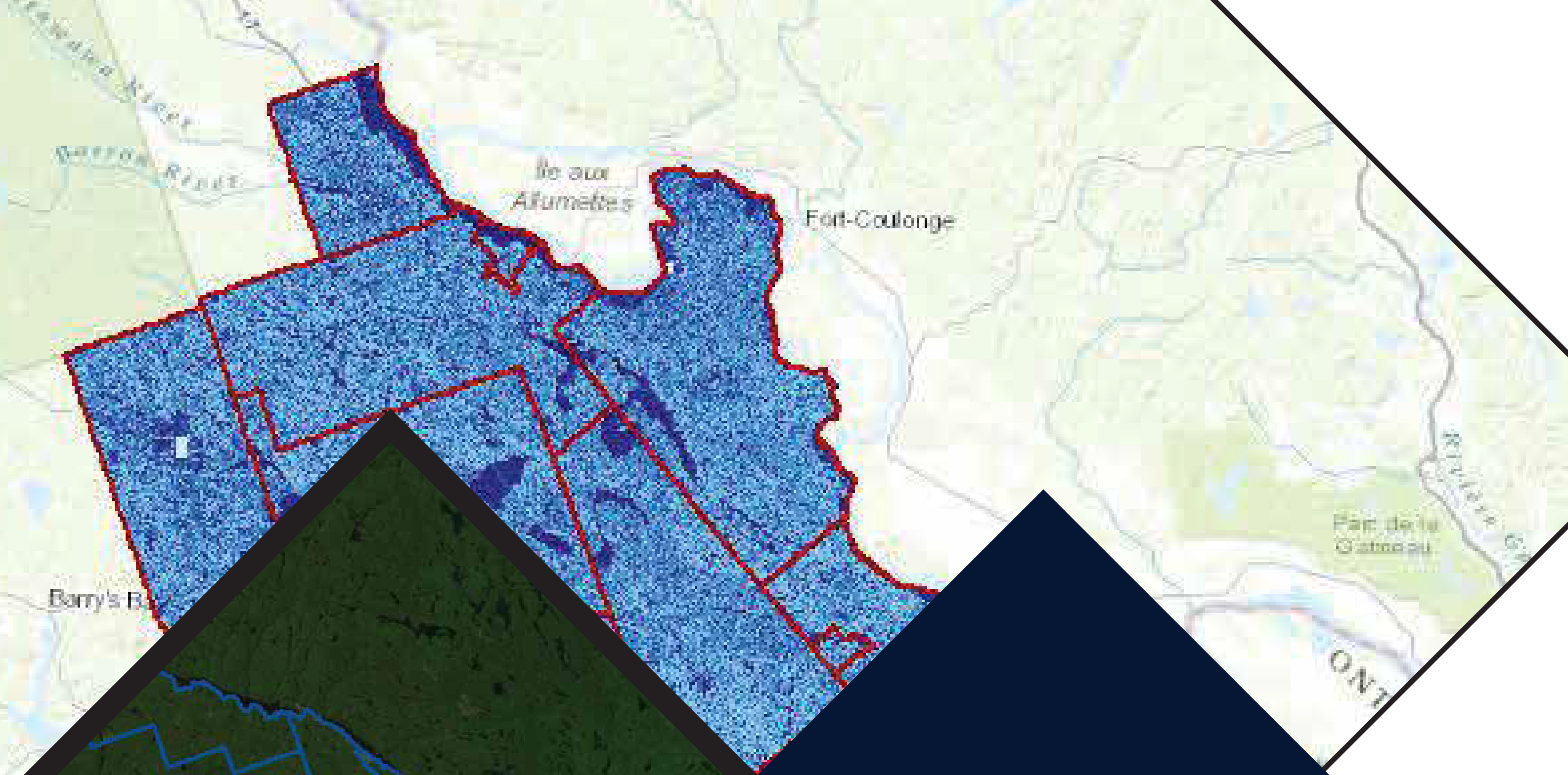

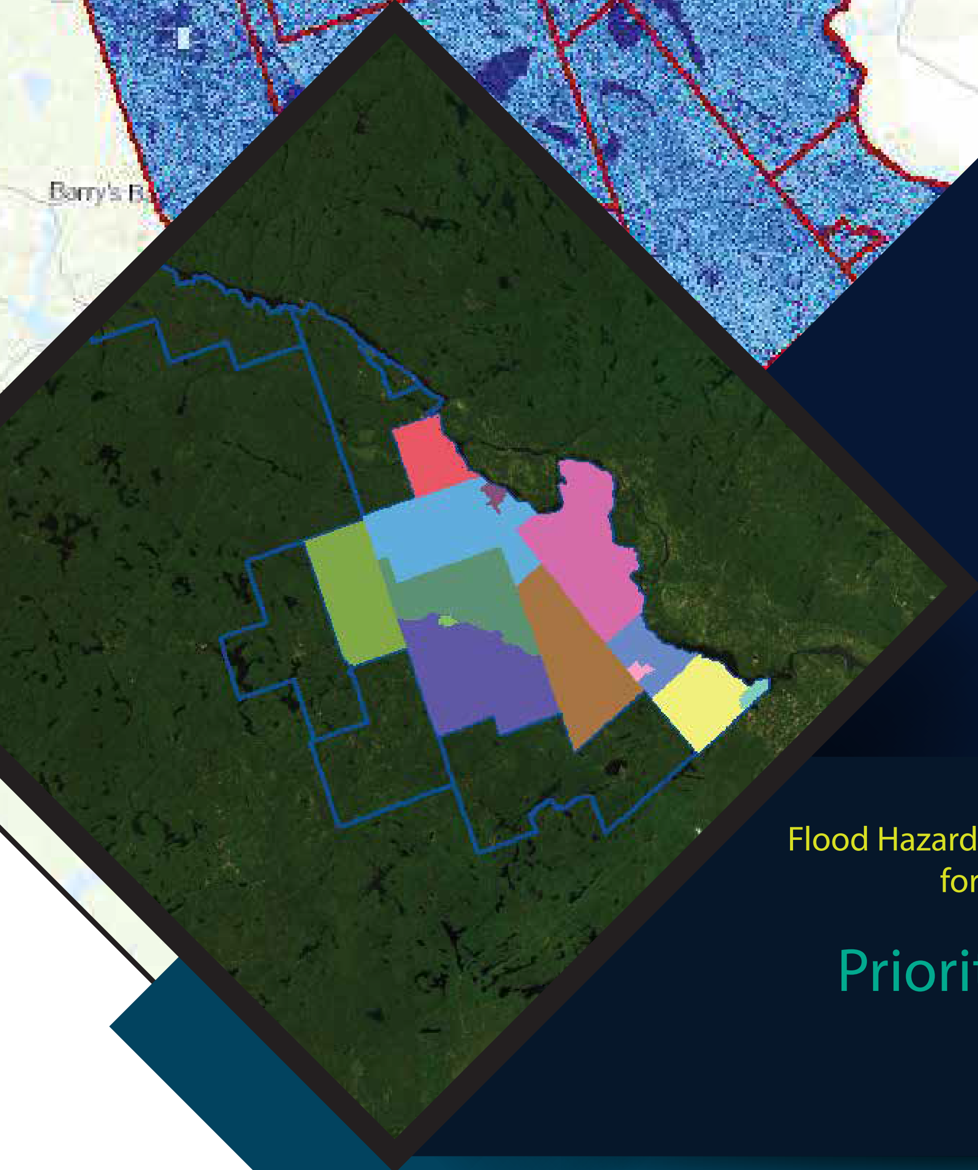

Flood Hazard Identification and Priority Setting
for the County of Renfrew

Priority Setting Report

February 2024

County of Renfrew
Ontario . Canada

AHYDTECH GEOMORPHIC
ADVANCED HYDROLOGY HYDRAULIC GEOMORPHOLOGY

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Priority Setting

1 Introduction

1.1 Project Background

The County of Renfrew stands on the west bank of Ottawa river in Eastern Ontario, consisting of seventeen (17) municipalities. The County is in the heart of Ottawa Valley, located south of the Ottawa river defining the interprovincial border between Québec and Ontario. The County covers approximately 3912 square kilometers of area, comprising forest cover and rural-agricultural land uses with distinct physiographic regions. The County is home to 106,365 people. The entire County falls within the Central Ottawa watershed of the Ottawa River watershed.

The government of Canada in Partnership with provincial and territorial governments, has taken the initiative to invest in Flood Hazard Identification and Mapping Program (FHIMP), under the National Adaptation Strategy to plan and prepare for future flood risk for the next five year. This program aims to complete flood hazard maps of higher risk areas in Canada for decision-making in support of land use planning, flood mitigation, adaptation to a changing climate, resilience building, and protection of lives and properties and make this flood hazard information accessible. The County of Renfrew has participated in the FHIMP to conduct a flood hazard identification and priority setting exercise for the jurisdiction. Among the seventeen (17) municipalities, the County has pre-identified thirteen (13) municipalities where flood hazards and future risks of potential flooding will be assessed along with prioritization of areas based on different criteria, analyzing the past and potential future flood hazard.

1.2 Study Area

The study area lies within the municipal boundaries of the County of Renfrew, which is the largest geographic County in the province of Ontario, Canada. The County has a total land area of 3912 square kilometers and a population of approximately 106,365 (2021 Census). The County stretches for more than 200 km along the shores of the Ottawa River from Arnprior in the east to the northern tip of Algonquin Park in the west and south to the communities of Hardwood Lake, Matawatchan and Calabogie. The County consists of 17 municipalities, including one city (Arnprior), four towns (Deep River, Laurentian Hills, Petawawa, and Renfrew) and 12 townships. The county seat is Pembroke, which is an independent municipality not part of the County. Among these 17 municipalities, this study will focus on 13 municipality/towns and the concerned study area has been shown in ***Figure 1-1.***

The County has more than 900 lakes and five major tributaries of Ottawa river naming-Petawawa River, Muskrat River, Indian River, Bonnechere River and Madawasaka River. Various water bodies occupy around 8.25% of the study area. Except for the major tributaries within the 13 selected municipalities, there are several other small and large rivers/creeks that discharge into Ottawa River and plays an integral part in the river-drainage network of the County of Renfrew such as- Dumoine River, Grants Creek, Mackey Creek, Harvey Creek, Perch Creek etc.

Approximately 62.4% of the land area is covered by dense vegetation and forest land. A large portion (around 16.0%) of the land within the area of concern is being used for agriculture purposes. In comparison to the extent of the study area, the percentage of imperviously built areas is very low (4.0%).

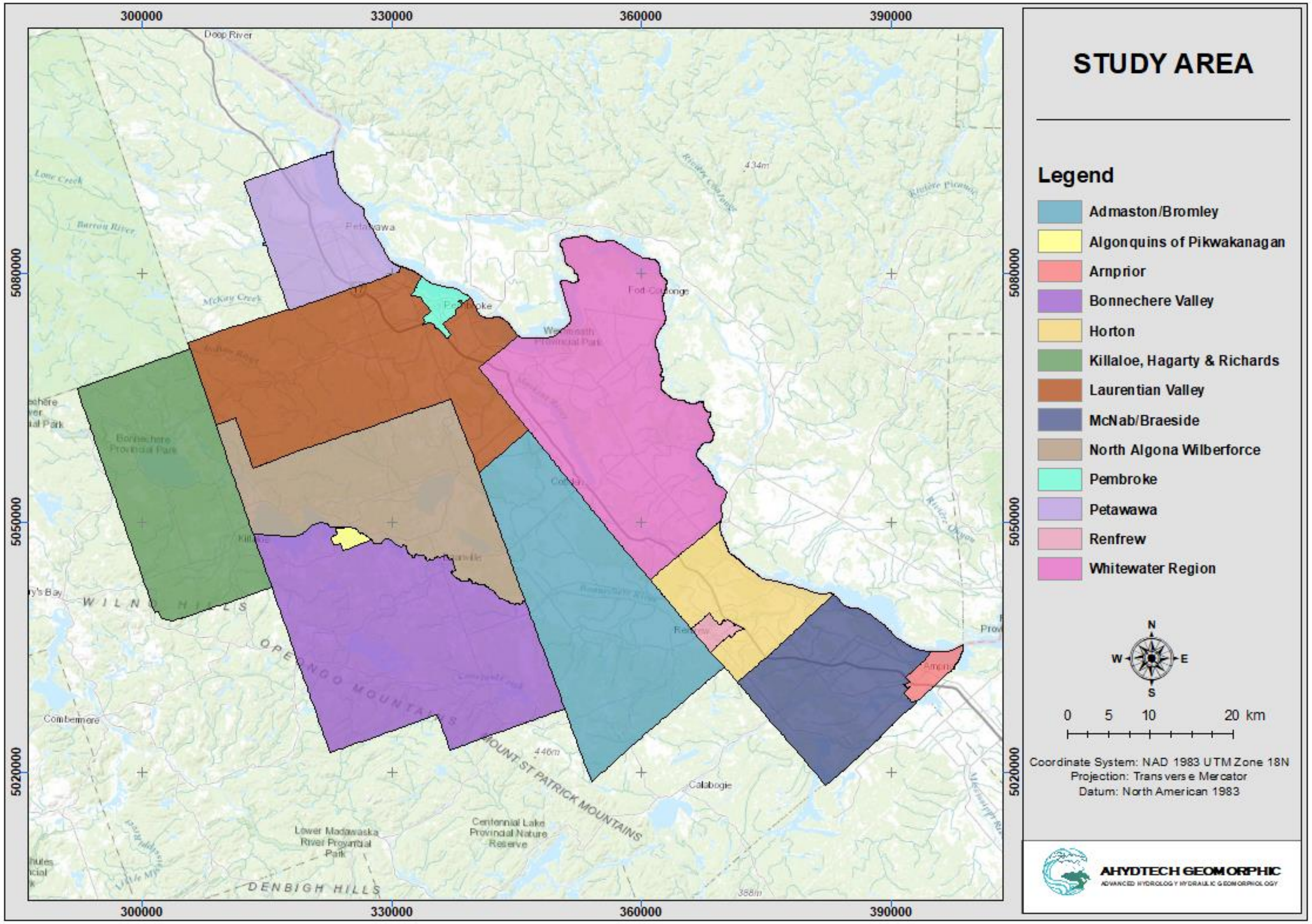

Figure 1-1: Map of Study Area

1.3 Objective of the study

The main objective of this study are as follows-

- Identifying and compiling the existing flood hazard mapping products within the study area,
- Identify shortfalls in current data and mapping products,
- Estimate Hazards in unmapped areas,
- Identify and prioritize areas for acquiring new mapping studies,
- Develop a plan to acquire data required for flood mapping and implement flood mapping across the County.

1.4 Scope of Work

The scope of work can be broadly classified into the following:

i. Collection and Review of background data and reports.

ii. Identify and compilation of existing mapping products and identify gaps in current mapping.

iii. Perform historical imagery analysis to assess flood locations and extents and Identify types of floods that frequently affect the study area and their origins.

iv. Perform geomorphic assessment of streams, lakes, associated rivers, and creeks.

v. Assess existing and future masterplans, demographic conditions, LULC, climate scenarios, infrastructure development information etc., of the study area.

vi. Perform flood hazard analysis along with the vulnerability and risk assessment using GIS techniques.

vii. Identify vulnerable locations and prioritize those areas based on multi-Criteria Analysis.

viii. Prepare a flood risk map.

ix. Create an inventory of existing flood mapping products, available data to perform hydrologic and hydraulic models, etc., for the identified highest priority areas.

x. Perform a data gap assessment for the priority areas, propose suitable approaches, data needs, and required field assessments to eliminate the data gaps and provide details of tasks to be performed.

xi. Prepare work plans, schedules and budgets for future hydrologic and hydraulic analysis required to update existing or generate new flood maps.

xii. Attend consultation workshops with local stakeholders, attend meetings with the County's technical committee, and prepare meeting agenda, presentations, minutes, and other required materials.

This report summarizes the analysis performed for flood hazard estimation and priority setting exercise.

2 Data Collection and Data Processing

Data is an essential component of any flood hazard identification project, as it provides the basis for understanding the risk and impact of flooding in each area. The flood hazard identification and priority setting exercise for the County of Renfrew has been designed having four folds- Flood Hazard Identification, Priority Setting based on multi-criteria Analysis, Data Inventory and Gaps Assessment and Priority Setting and Identification of Future Scope of Work. Each fold is completely driven on primary and secondary source data. Collecting relevant data from different primary and secondary sources and managing a database is an integral part of this study. Task-wise data has been identified and of data has been requested from the county officials and different town/township authorities (**Table 2-1**) as below:

Table 2-1: List of Data

Task Name	Data Type
Flood Hazard Identification	• Available Flood Hazard maps. • Relevant Reports of the previous Flood Hazard and Risk Analysis studies. • Previous Flood Hazard Modelling information (Hydrologic and Hydraulic Model) • Available Municipality/Town wise Flood reports. • Technical Reports on the Existing Official Plan Maps. • Relevant Flood Hazard study reports performed for the major rivers passing through the study area (Ottawa River, Barron River, Petawawa River, Madawaska River, Bonnechere River, Indian River and Muskrat River). • Epigraphic markings and Available Images captured during any previous flood events. • Available Historical Satellite Images relating to the major flood events. • LiDAR Data. • Available Watershed Study Reports.
Priority Setting based on Multi-Criteria Analysis	• Fine Resolution DEM of entire study area • GIS based Soil Type Data • Land Use and Land Cover Data (LULC) • Spatially distributed gridded Precipitation Data • Floodplain Area • Dissemination Area • Demographic Data (Age, Family Structure, Language, Income, Education, Renters, Population Density etc.) compatible with GIS Environment. • Environmental Data
Data Inventory and Gaps Assessment and Identification of future scope of work	• As built drawings of all bridges and culverts. • In-line hydraulic structure database and drawings. • Available topographic and bathymetric survey data. • Information regarding the previously developed hydrologic and hydraulic models.

3 Review of Existing Studies and Guidelines

The analysis of flood hazard identification, vulnerability assessment and risk assessment has been performed following established and standard practices. Several relevant documents have been reviewed before devising the analysis. Among them, following documents has been most helpful-

❖ **Name:** **Federal Flood Hazard Identification and Priority Setting Version 1.0**

Location: Canada

Description: This document outlines methods for determining where to conduct flood mapping and how to prioritize flood mapping projects. This document details the framework for flood hazard identification and priority setting works. The first step is to establish the purpose and preliminary approach of overall activities. Then identifying the existing types of hazards within the area of interest. Estimation of hazards comes next, which is the most crucial task. Risk assessment based on pre-identified flood hazard and prioritizing areas within higher risk are the final two steps. The guidelines set out for flood hazard estimation in unmapped areas and potential future flood locations; risk assessment and prioritization has been strictly followed during preparation of this deliverable.

❖ **Name:** **Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study**

Location: Don River Watershed, Toronto

Description: The document presents a method for assessing and mapping flood risk in the Don River Watershed within the Great Toronto Area (GTA) using geographic information systems (GIS) and multi-criteria analysis. Several factors that influence flood occurrence and severity, such as distance to streams, height above nearest drainage, slope, land use, soil type, and precipitation etc. have been prepared and analyzed. Analytic Hierarchy Process (AHP) has been used in the study to assign weights to these factors based on expert opinions and Engineering judgement. The result is a flood risk map that shows the spatial distribution of flood risk zones within the study area. Multiple scenarios were generated using different combinations of flood hazard parameters. Then the outcome of each scenario was compared with a base case scenario that used a floodplain map developed by the Toronto and Region Conservation Authority. Scenario-2 (S2) was the most similar to the base case, followed by S3 and S4. Social and economic vulnerability of the population were also assessed to determine the total flood vulnerability in the watershed under three scenarios. The study suggests that this method could be used for flood prediction, early warning, and management practices.

❖ **Name:** **Prioritizing Flood-Prone Areas Using Spatial Data in the Province of New Brunswick, Canada**

Location: New-Brunswick, Canada

Description: The document presents a method for assessing and mapping flood-prone areas at the provincial scale in New Brunswick, Canada. Geographic information system (GIS) and multi-criteria evaluation (MCE) techniques has been used to integrate several factors that influence flood occurrence and severity, such as distance to streams, height above nearest drainage, slope, land use, soil type, and precipitation. They also used the Analytic Hierarchy Process (AHP) to assign weights to these factors based on expert opinions and public institutions. The result is a flood-prone area map that shows the spatial distribution of flood risk zones in the study area. The outcome was validated by comparing it with a floodplain map developed by the Department of Environment and Local Government of New Brunswick. They found that their method was more accurate and comprehensive than the existing map. Social and economic vulnerability of the population has been analyzed to determine the total flood vulnerability in the province under three scenarios. This study suggested that the above-mentioned method could be used for flood prediction, early warning, and management practices.

- **Name: Flood Hazard Assessment and Mapping using GIS Integrated with Multi-criteria Decision Analysis in Upper Awash River Basin, Ethiopia**

Location: Upper Awash River basin, Ethiopia

Description: The study presents a method for assessing and mapping flood hazard in the upper Awash River basin in Ethiopia. Geographic information system (GIS) and multi-criteria decision analysis (MCDA) integrate several factors that influence flood occurrence and severity, such as soil, slope, elevation, drainage density, and land use land cover. They also used the analytic hierarchy process (AHP) to assign weights to these factors based on expert opinions and public institutions. The result is a flood hazard map that shows the spatial distribution of flood risk zones in the study area. The study concludes that about 43.28% and 13.09% of the area were vulnerable to high and very high flood risk zones, respectively.

4 Overall Approach

The overall approach of this study has been illustrated in **Figure 4-1**. The final product is the prioritized areas in terms of flood risk. The flood risk maps are a combination of flood hazard maps and vulnerability analysis.

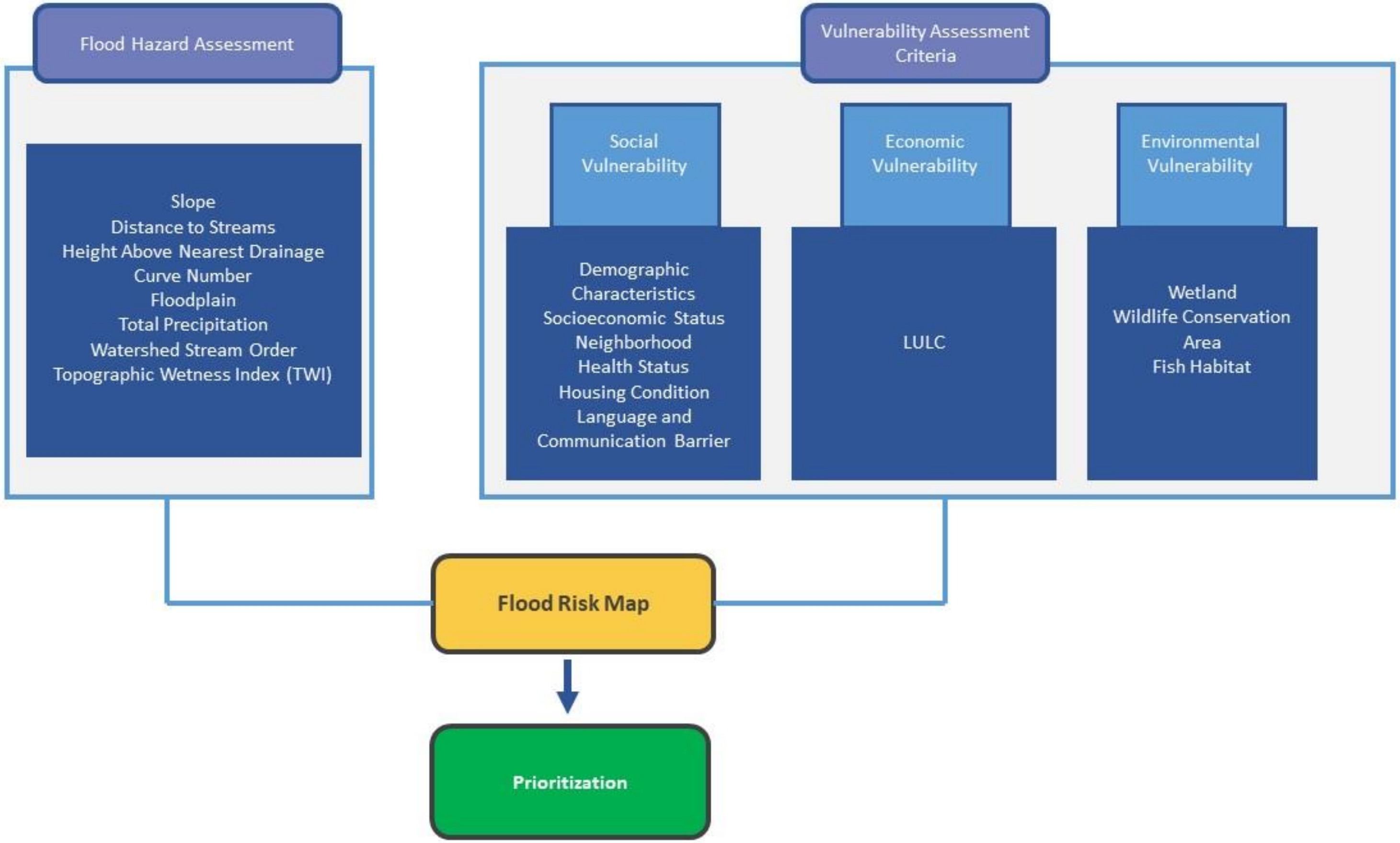

Figure 4-1: Overall Approach of Study

5 Flood Hazard Assessment

5.1 Flood Hazard Criteria Layers

Owing to climate change impact flood has become the most frequent and disastrous natural calamity all over Canada. Accurate flood risk assessment is a crucial part of flood management and for planning mitigation measures. In our area of interest, the most common type of flooding is the Fluvial and Lake flooding.

Floodplain mapping is the most common and appropriate measure of identifying areas within flooding hazard. Between the years 1981-1991, floodplain maps were prepared for Town of Petawawa, Township of Whitewater Region, Township of McNab/Braeside. In total, approximately 330 km of the Ottawa Riverbank was mapped. But the process of floodplain mapping is costly and time consuming. To utilize the time and effort, accurate flood risk mapping can be very beneficial. **Figure 5-1** shows the parameters which has been used in various combinations to replicate different scenarios for flood hazard estimation-

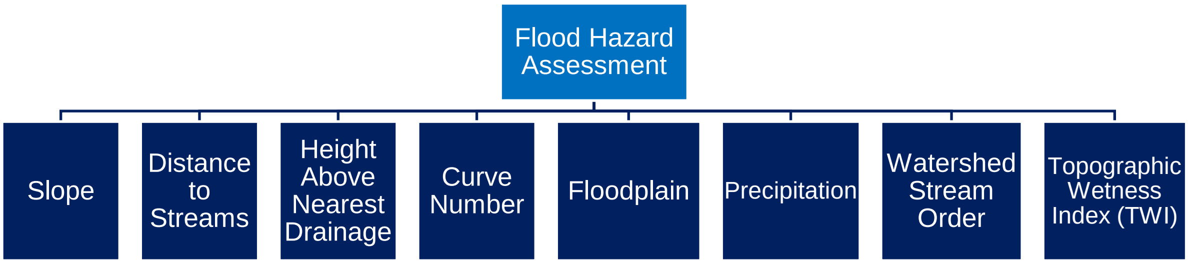

Figure 5-1: Parameters used in Flood Hazard Identification

Each parameter has been delineated and processed in ArcGIS environment having same resolution of 2m*2m. The values of each parameter have been divided into five classes starting from 1 to 5. Where class-1 denotes very low potential of causing flood hazard and class-5 denotes very high potential for causing flood hazard. A Multi-Criteria-Analysis (MCA) has been performed to calculate the weight of each parameter using Analytical Hierarchy Process (AHP). Details of each parameter, method of estimation and use in the hazard estimation process has been stated below-

5.1.1 Slope (S)

Slope is an essential indicator of flood-prone surface zones and in determining the speed and duration of flow. Water moves more slowly, collects for a longer period, and accumulates on flatter surfaces, making them more vulnerable to flooding than steeper surfaces (Wondim 2016; Gigovi ç et al. 2017; Rimba et al. 2017; Rincón, et al. 2018; Desalegn and Mulu 2020; Singh et al. 2020a). It significantly impacts the quantity of surface runoff generated by precipitation. Steep slope contributes more for storm runoff than mild slope. In areas having mild slope, flood water tends to accumulate in place and creates water logging. Fine resolution (2m*2m) Digital Elevation Model (DEM) has been used to derive the slope layer using *'Slope'* Spatial Analyst tools in ArcGIS. The slope layer has been reclassified based on slope values. The classification of slope values has been defined following extensive review of relevant flood hazard estimation studies. The slope layer has been reclassified in the following classes (**Table 5-1**):

Table 5-1: Classification of Slope Layer

Hazard Category	Hazard Value	Slope Values (Degree)
Very Low	1	80.93-23.26
Low	2	23.26-13.38
Moderate	3	13.38-7.01
High	4	7.01-2.55
Very High	5	2.55-0

Figure 5-2 illustrates the reclassified slope layer. This layer has been used in estimating flood hazard. Most of the area exhibits very high potential of flooding in terms of slope.

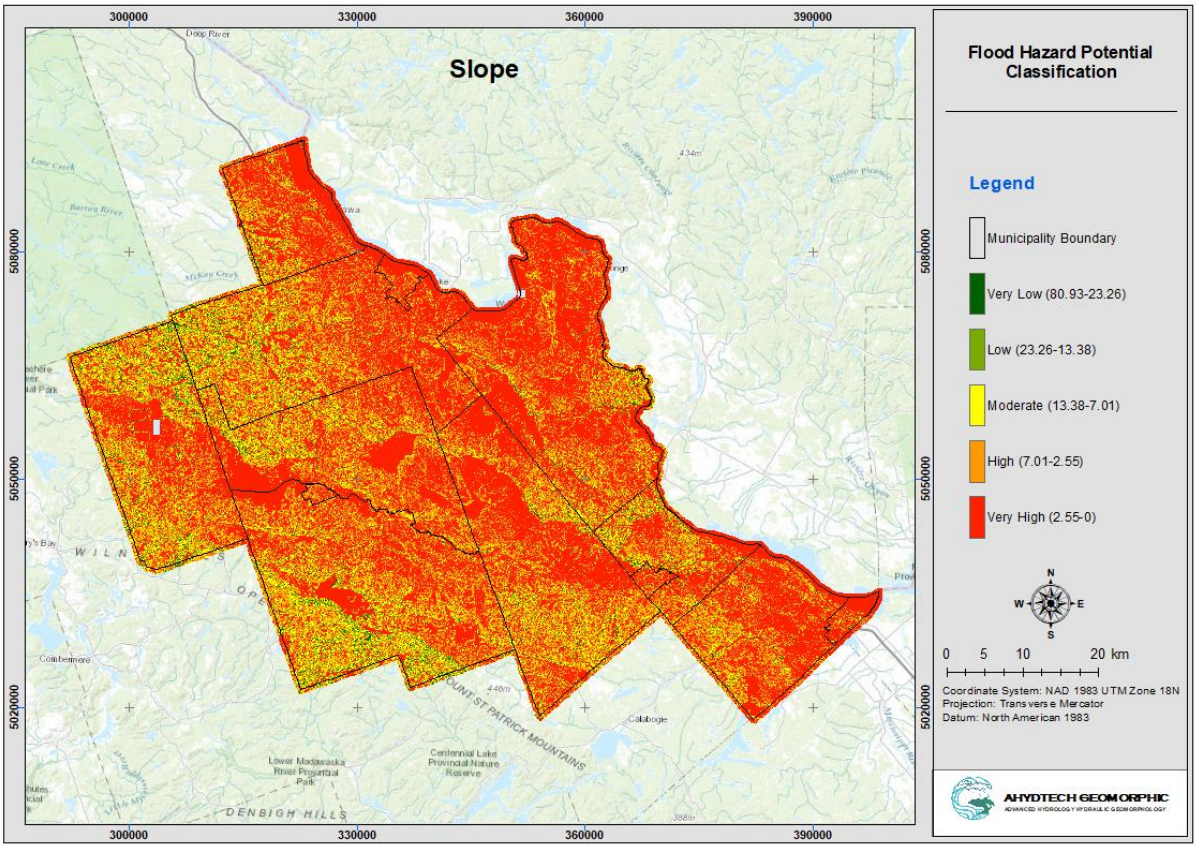

Figure 5-2: Classified map of Slope Layer

5.1.2 Distance to Streams (DS)

Distance to streams (DS) plays a significant role in determining areas susceptible to flooding. It is one of the primary criteria to evaluate flood hazard maps. The zones closest to rivers or any waterbody are highly flood-prone despite how deep the river is. The river may overflow and inundate the nearby areas during high intensity precipitation. '*Euclidean Distance'* Spatial Analyst tools in ArcGIS have been used to obtain these distances within the study area. The output layer has been reclassified for further hazard estimation analysis. The classes have been defined following extensive review of relevant flood hazard estimation studies. The values of DS layer have been divided in five classes (1 to 5) where class-1 denotes very low potential of causing flood hazard and class-5 denotes very high potential for causing flood hazard. The DS layer has been reclassified in the following classes (**:**

Table 5-2):

Table 5-2: Classification of Distance to Stream Layer(meters)

Hazard Category	Hazard Value	Distance to Steams(m)
Very Low	1	3066.96-934.38
Low	2	934.38-546.32
Moderate	3	546.32-304.50
High	4	304.50-134.34
Very High	5	134.34-0

Figure 5-3 illustrates the reclassified DS layer. The potential for flood hazard near the river and streams is very high.

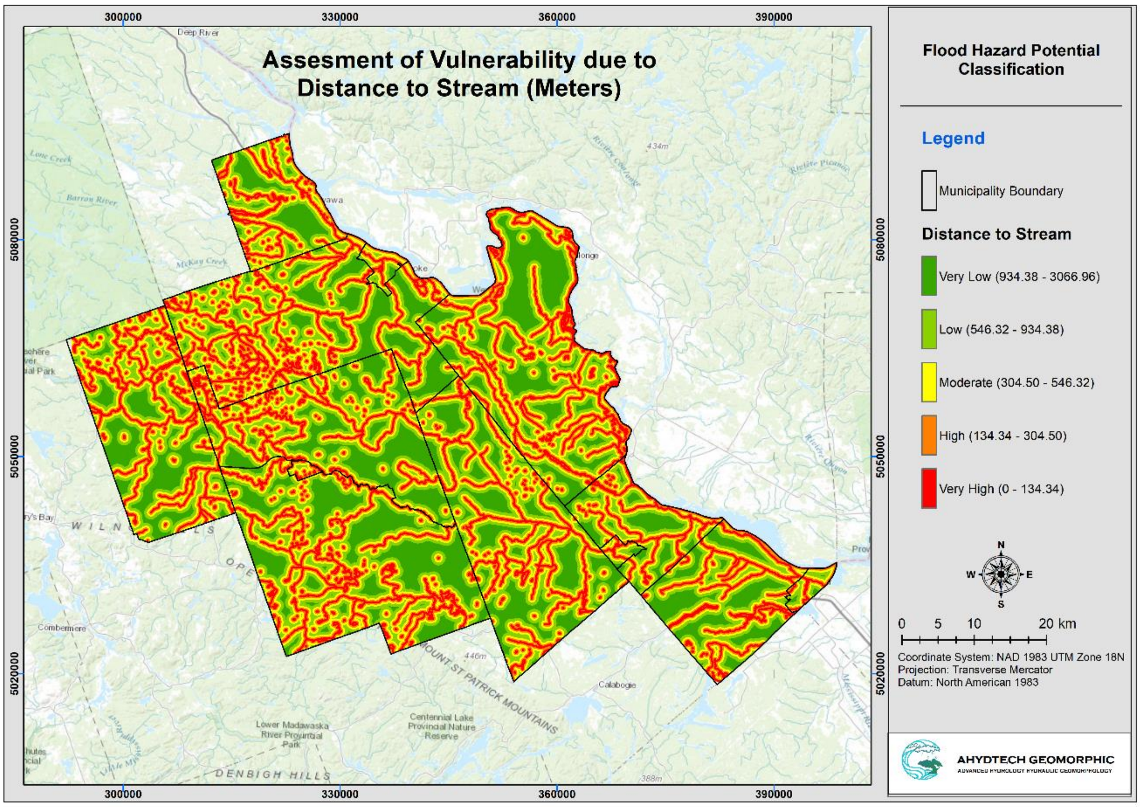

Figure 5-3: Classified map of Distance to Stream Layer (meters)

5.1.3 Height above Nearest Drainage (HAND)

HAND is an important indicator that influences the flood susceptibility of an area. Low-lying areas adjacent to streams will be more susceptible to floods than highly elevated areas. HAND is valuable in flood modeling and risk assessment because it helps to identify low-lying areas that are prone to flooding and areas that can act as natural floodplains, allowing for the safe discharge of excess water during floods. Locations with negative HAND values (lower than the nearest drainage) may require more immediate attention and flood risk management. The

HAND layer has been prepared using Topography tools developed by Dilts in ArcGIS utilizing DEM and Streams layer of the study area. The reclassified layer has been used for further analysis. The classification is provided below (**Table 5-3**):

Table 5-3: Classification of HAND Layer (meters)

Hazard Category	Hazard Value	HAND (m)
Very Low	1	287.609-8
Low	2	8-6
Moderate	3	6-4
High	4	4-2
Very High	5	2-0

Figure 5-4 illustrates different classes of HAND Layer. Most of the areas lie within very low hazard potential.

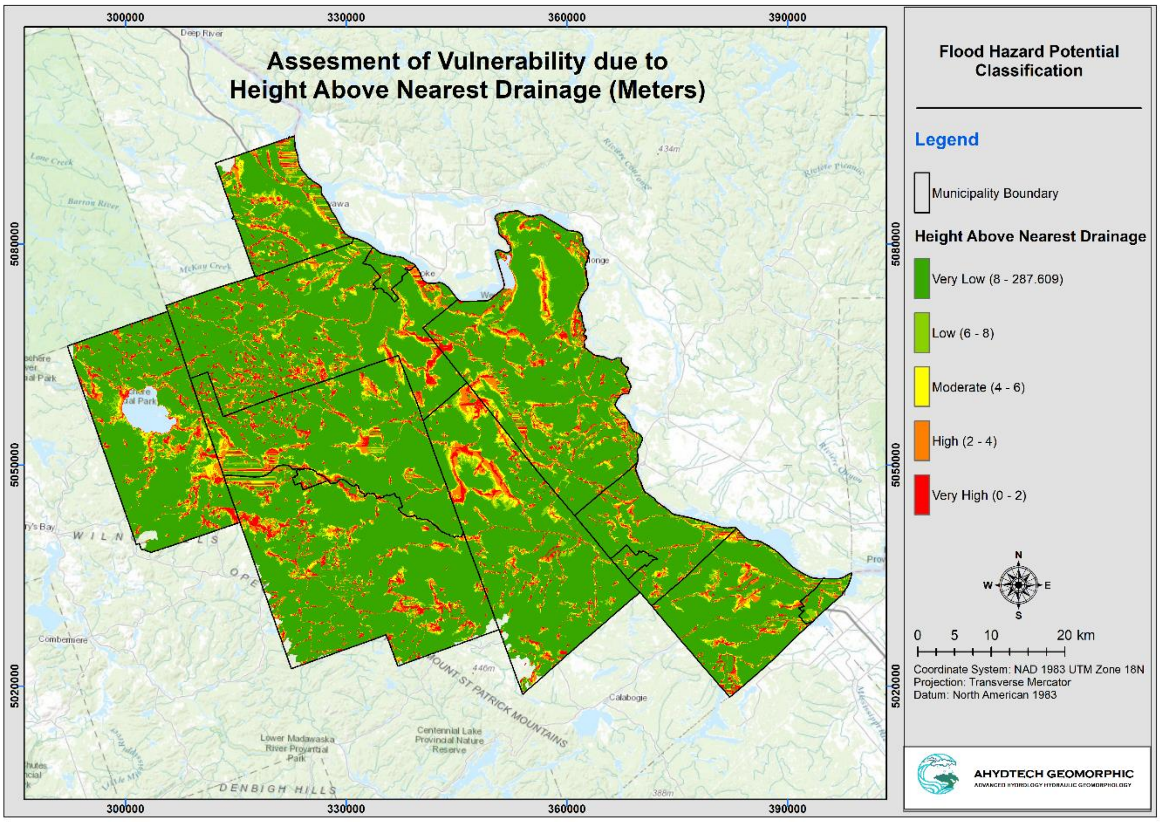

Figure 5-4: Classified map of HAND Layer (meters)

5.1.4 Curve Number (CN)

The Curve Number is a dimensionless parameter indicating the runoff response characteristic of a drainage basin. This parameter is related to land use, land treatment, hydrological condition, hydrological soil group, and antecedent soil moisture condition in the drainage basin. It is an empirical parameter used in hydrology to predict direct runoff or infiltration from excess rainfall. The values of CN ranges from 100 for impermeable surfaces to 30 for very permeable soils with low runoff potential. It is an important parameter to estimate flood hazard as higher CN value indicates very high potential for runoff generation resulting in low infiltration.

Curve Number map has been prepared utilizing the ESRI global land use land cover (LULC) map, derived from ESA Sentinel-2 imagery at 10m resolution and soil data from the Soil Survey Complex, prepared by the Ministry of Natural Resources. The LULC layer was developed by the Impact Observatory (IO) with the Environmental Systems Research Institute (ESRI) and in partnership with Microsoft AI for Earth. The Soil-database represents the soil layer as map units (polygon). Each of the map units has specified characteristics, including (but not limited to) soil complex numbers and the percentage of each soil complex, hydrologic soil group, soil texture and drainage, slope, etc.

For the study area CN value ranges between 34-100. Then the CN values have been classified using '*Reclassify*' too in ArcGIS for further analysis. The classification of CN values is listed below (**Table 5-4**):

Table 5-4: Classification of Curve Number

Hazard Category	Hazard Value	Curve Number
Very Low	1	34-49
Low	2	49-63
Moderate	3	63-79
High	4	79-89
Very High	5	89-100

Areas having higher CN values will contribute to higher runoff generation, hence has been classified in very high flood hazard potential class. **Figure 5-5** illustrates the spatial distribution of CN values within the study area. Floodplain of Ottawa river falls within the very high hazard potential zone.

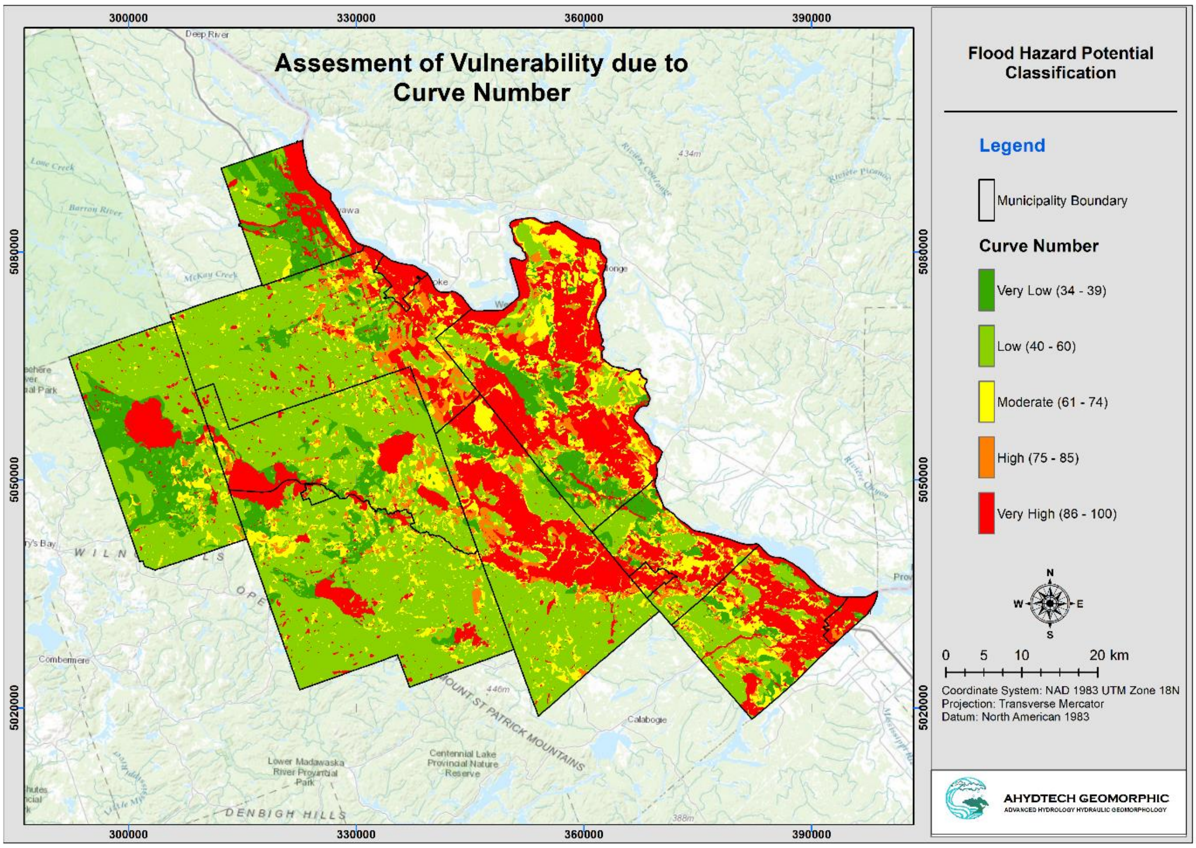

Figure 5-5: Classified Map of Curve Number Layer

5.1.5 Total Precipitation (TP)

Increased rainfall can cause flooding when streams become unable to convey the excess water. Since the volume of runoff is directly influenced by the quantity of precipitation, greater rainfall results in more runoff. Different regions within the Ottawa River watershed may experience different precipitation patterns due to local geographical features.

Spatial distribution of precipitation across the study area has been prepared to perform flood hazard estimation. Exploring source of precipitation data has been quite challenging. Because very few meteorological/rainfall gauging stations exist within the study area but most of the data collected by these stations has become outdated. Meteorological station within the study area were looked up in the Environment Canada (Historical Data - Climate - Environment and Climate Change Canada (weather.gc.ca)) website. From the thirteen municipalities, meteorological station recording daily total precipitation data were found in 6 locations, naming- Town of Arnprior, Town of Renfrew, Town of Petawawa, City of Pembroke, Township of McNab/Braeside, Township of Killaloe, Hagarty & Richards. However, among these six locations, meteorological stations in Pembroke and Petawawa are actively recording data till date. Remaining station data has become obsolete as they stopped recording data at least 10 years ago. Due to unavailability of continuous and up-to-date meteorological data, the rainfall distribution analysis has been performed using open access high-resolution NETCDF average historical monthly total precipitation data from Climate Research Unit (High-resolution gridded datasets (uea.ac.uk)).

The CRU TS dataset was developed and has been subsequently updated, improved, and maintained with support from several funders, principally the UK's Natural Environment Research Council (NERC) and the US Department of Energy. Long-term support is currently provided by the UK National Centre for Atmospheric Science (NCAS), a NERC collaborative center. The data set is gridded to 0.5x0.5-degree resolution, based on analysis of over 4000 individual weather station records. The precipitation data have been used to assess global precipitation variability. The gridded precipitation data has been prepared in mm per month unit.

For the analysis, gridded precipitation data for the study area from the year 2011-2020 has been used. The IDW tool was used to prepare precipitation-isohyet map interpolating the gridded precipitation data. The best results from IDW are obtained when sampling is sufficiently dense regarding the local variation. Hence using high resolution gridded dataset has been beneficial for the analysis. The precipitation layer has been classified into five classes using 'Natural Breaks (Jenks)' method. The defined classes have been listed below (**Table 5-5**):

Table 5-5: Classification of Total Precipitation (mm)

Hazard Category	Hazard Value	Total Precipitation (mm)
Very Low	1	799.7-815.33
Low	2	815.33-831.22
Moderate	3	831.22-843.40
High	4	843.40-855.32
Very High	5	855.32-867.5

The high value of total precipitation has been classified as very high hazard potential as potential of flood hazard is directly proportional to rainfall depth. Figure illustrates the spatial distribution of total monthly precipitation. Very high potential can be seen along **the White-Water Region and Bonnechere valley.**

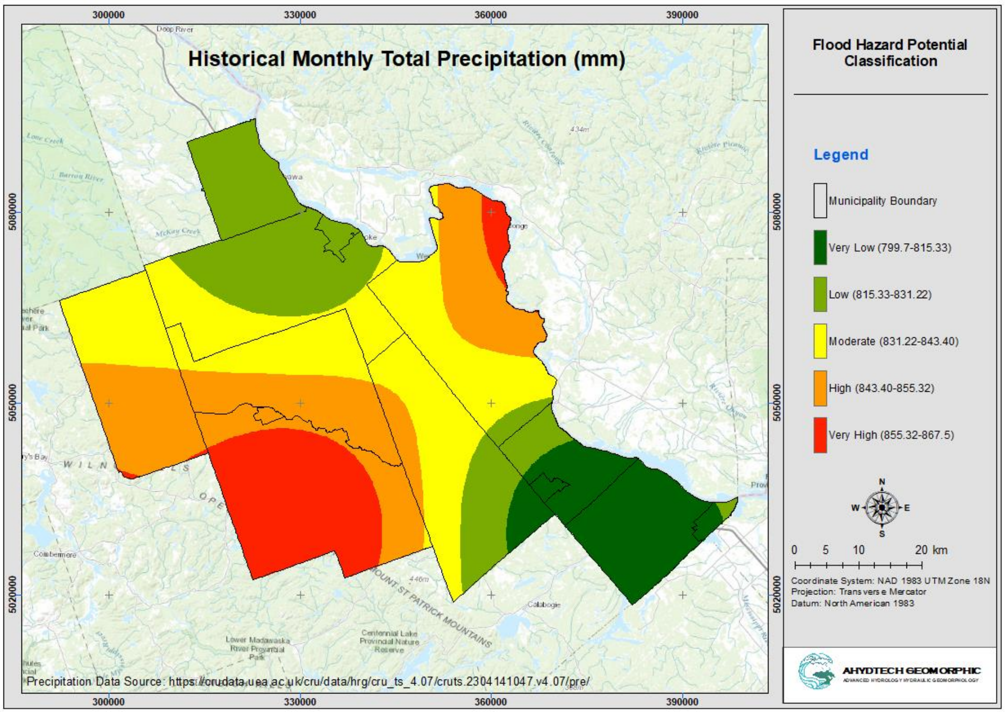

Figure 5-6: Classified map of Total Precipitation (mm)

5.1.6 Floodplain (FP)

Floodplain maps are very crucial for flood hazard analysis. These maps illustrate the areas surrounding rivers, streams, and other water bodies that are prone to flooding during various flood events, such as a 10-year, 50-year, or 100-year flood. The floodplain layer has been prepared combining flood maps in the jurisdiction provided by the County officials, past flood mapping reports and 2017 and 2019 flood extents from Floods in Canada - Cartographic Product Collection - Open Government Portal. The floodplains have been digitized using the maximum extent of all the sources. Then the areas within the floodplain have been classified as carrying very high hazard potential and attributed the hazard value of 5. The areas outside the floodplain have been termed as No Floodplain and classified to bear low flood hazard potential and attributed the hazard value of 2. **Figure 5-7** illustrates the classified floodplain layer.

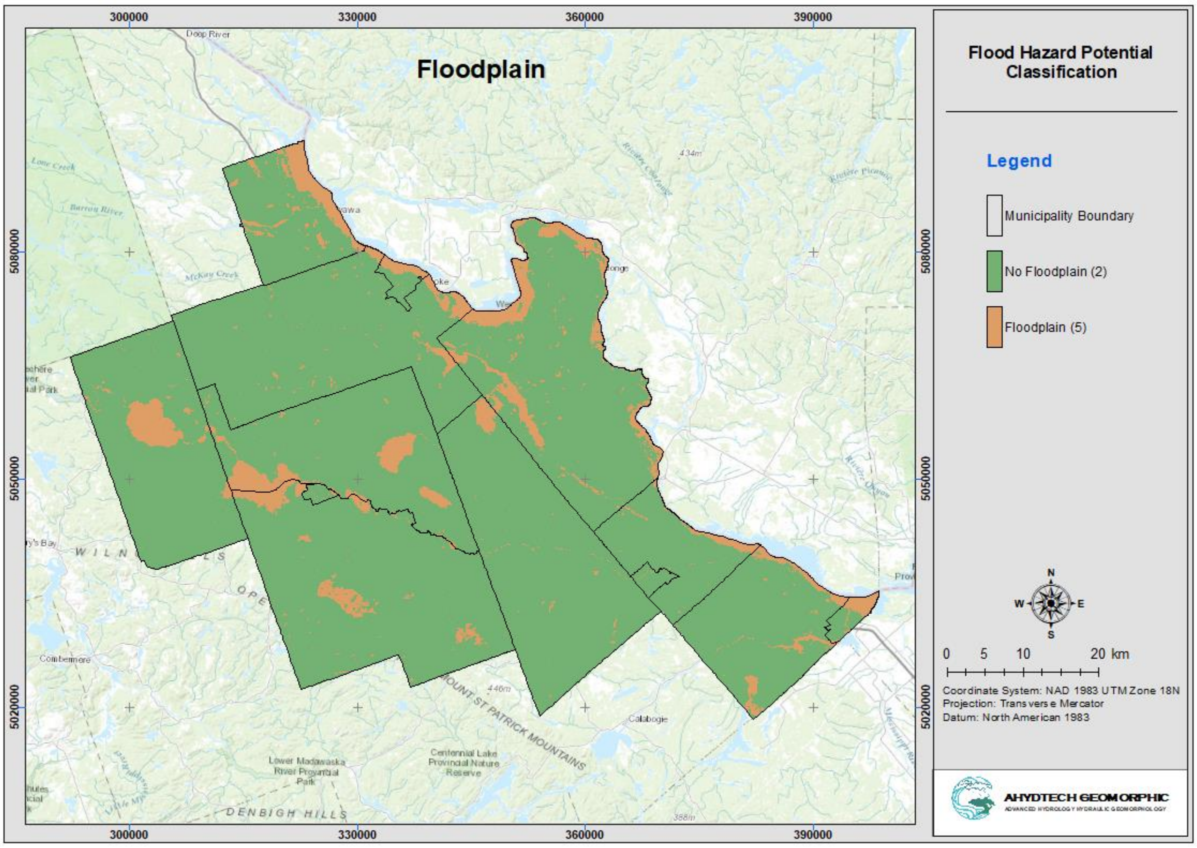

Figure 5-7: Classified map of Floodplain layer

5.1.7 Watershed Stream Order (WSO)

This is one of the crucial parameters that directly impacts flooding phenomena. Watershed information has been collected from Ontario GeoHub- Ontario Watershed Boundaries. Stream data has been collected from both Ontario Hydro Network (OHN) and Ontario Integrated Hydrology data. Ontario Integrated Hydrology Data provides stream order information and classes delineated using both Strahler and Shreve method. Since Strahler is the most widely used method, it has been taken to define watershed stream order. **Figure 5-8** shows the map illustrating streams from 4^{th} to 9^{th} order. Ottawa River falls in 9^{th} order stream according to the collected information and hence, decreases depending on the branching of this river system.

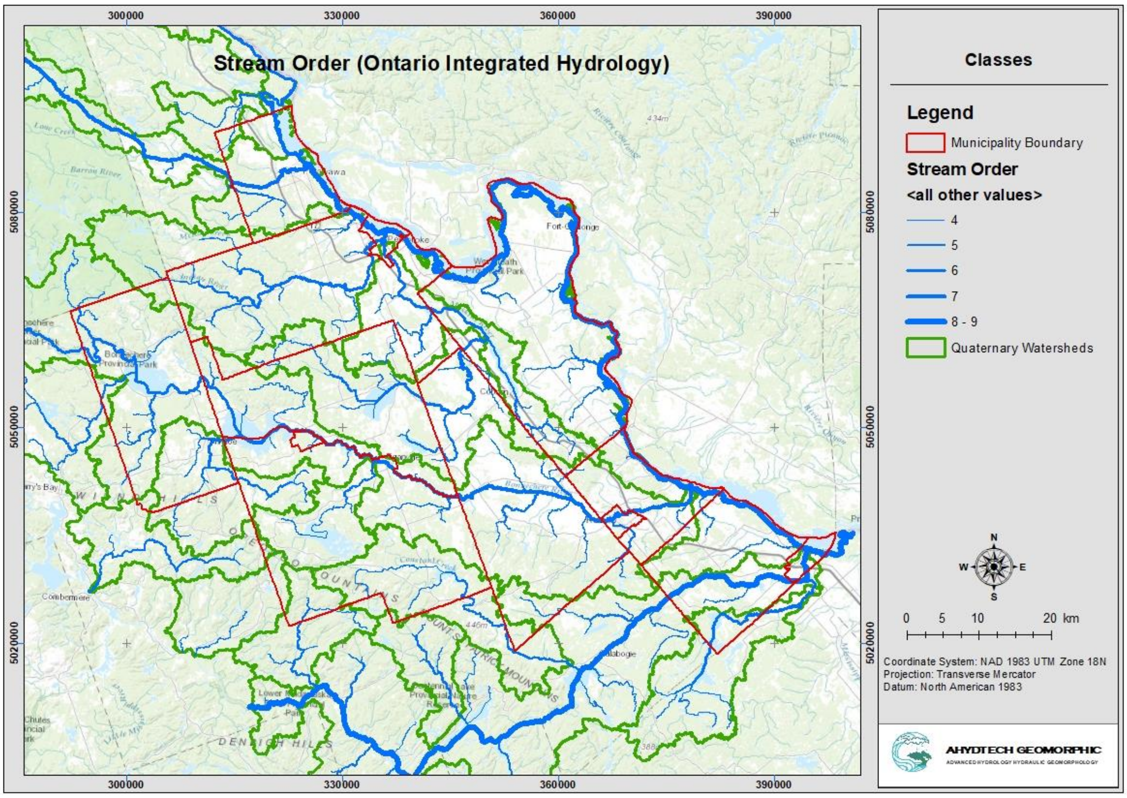

Figure 5-8:Ontario Integrated Hydrology (OIH) Stream Order

1st to 3rd order stream has not been considered to make the result conservative since they are the outermost tributaries and are not directly connected with the main streams located within the study area.

Both Tertiary and Quaternary Watershed data has been collected from Ontario GeoHub. It has been observed that the majority of the study area falls within the Bonnechere River Watershed and Muskrat, Indian, Westmeath Watershed which are under Ontario tertiary watersheds. A total of seventeen quaternary watersheds contribute to the study area and among these, there are five watersheds that have very insignicfant portion located within the study area and do not directly impact flooding.

These seventeen watersheds have been classified based on the highest available stream order within those watersheds and have been categorized in five classes based on the risk associated. Watershed Stream Order (WSO) values have been classified into five classes listed below (**Table 5-6**):

Table 5-6: Classification of Watershed Stream Order

Hazard Category	Hazard Value	Watershed Stream Order (Strahler)
Very Low	1	4
Low	2	5
Moderate	3	6
High	4	7
Very High	5	8-9

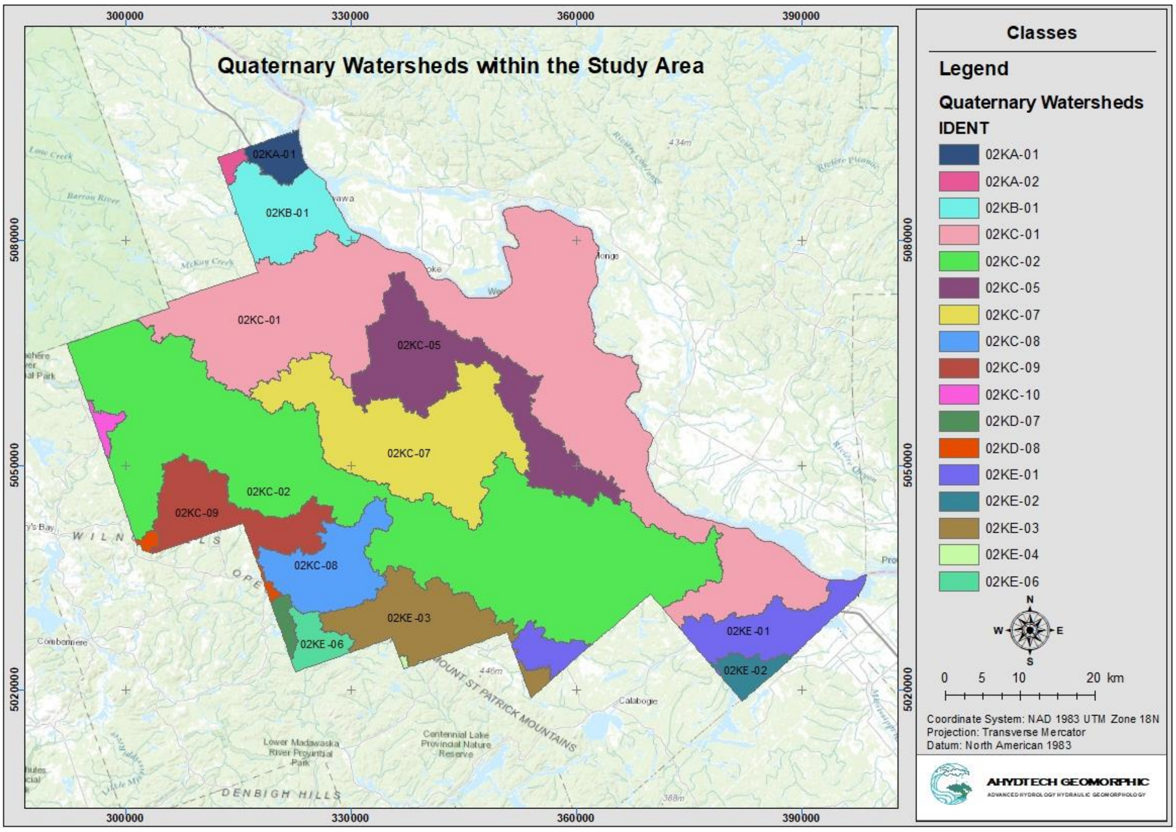

Figure 5-10: Tertiary Watersheds within the Study Area

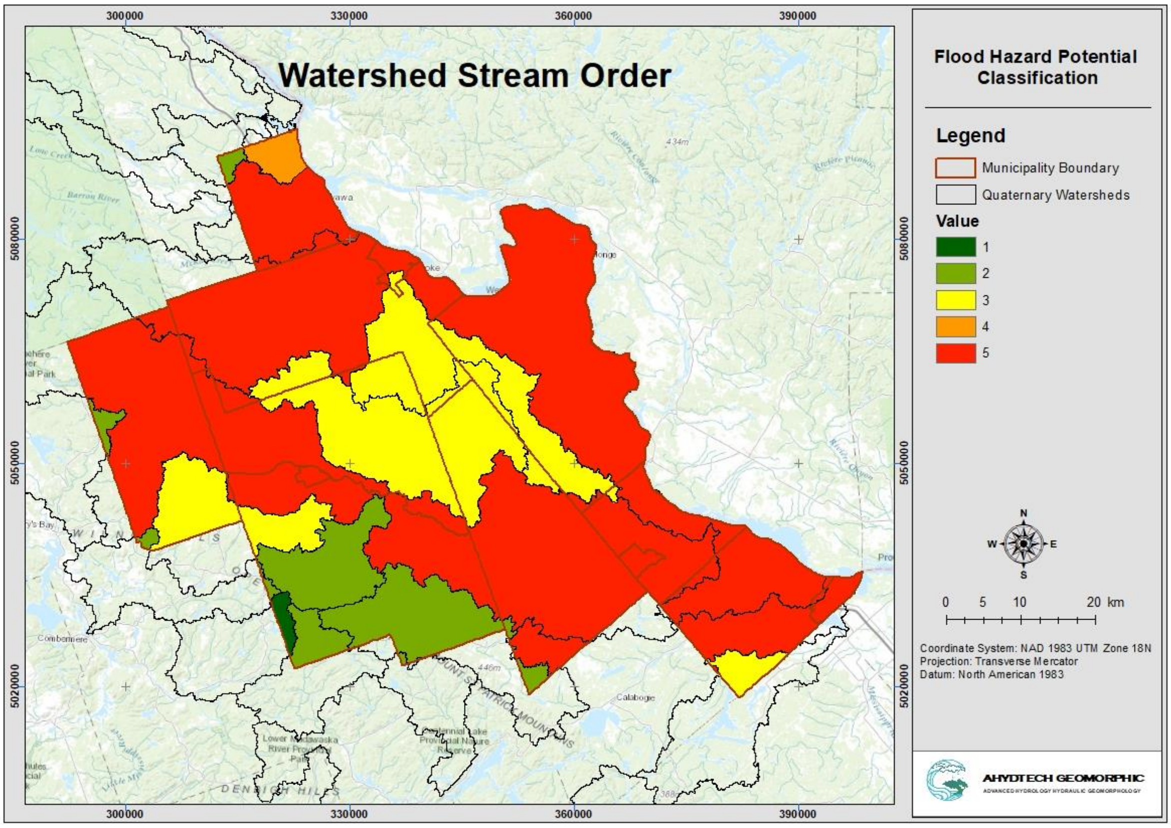

Figure 5-9:Classified Map of Watershed Stream Order (WSO)

Figure 5-9 illustrated the spatial distribution of classified WSO layer. Very High WSO denotes that in case of any flood event, the watershed will generate higher discharge due to the increased capacity of the streams and vice versa. Higher order streams typically have wider floodplains. During periods of heavy rainfall or snowmelt event, these watersheds experience a significant increase in discharge and hence becomes very high flooding potential zones.

5.1.8 Topographic Wetness Index (TWI)

TWI is widely used to quantify topographical control of hydrological processes. It is a unitless approximation of soil moisture as a function of local topography and upslope contributing area (Beven and Kirby, 1979) and has been used to assess rain-derived flooding risk in land use planning (Pourali et al., 2016). TWI provides insights into the wetness potential of the terrain, highlighting areas that are more prone to water accumulation and potential waterlogging.

TWI is calculated by using high resolution DEM raster layer in a GIS environment, then using several tools within the program to calculate the slope, flow direction, flow accumulation, tan of slope, and ultimately TWI using simple equations. TWI values are inversely proportional to slope. In mild sloped areas TWI values are higher than areas having steep slope. High TWI values denote high potential for causing flood. The TWI layer has been classified into five classes. The classes have been listed below (**Table 5-7**):

Table 5-7: Classification of Topographic Wetness Index

Hazard Category	Hazard Value	TWI
Very Low	1	-1-7
Low	2	8-9
Moderate	3	10-11
High	4	12-16
Very High	5	17-33

Figure 5-11 illustrates the spatial distribution of TWI values in the above stated classes. Maximum areas fall within very low hazard potential.

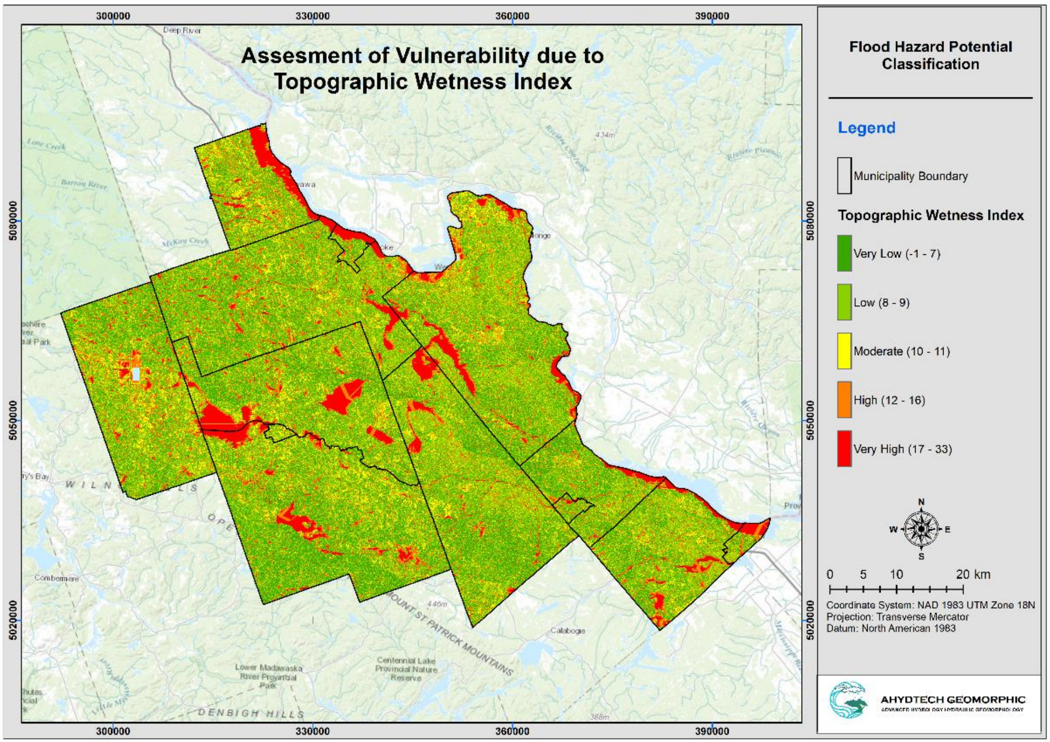

Figure 5-11: Classified Map of Topographic Wetness Index

5.2 Development of different Scenarios

Multiple scenarios have been prepared to understand the influence of these parameters in flood susceptibility. These scenarios help to determine the suitability of the criteria and to observe comparable differences between different combinations of criteria. Relative weights have been assigned on each criterion and multi-criteria analysis has been performed. The output results for each scenario have been analyzed and using ArcGIS, flood hazard maps for each scenario has been developed. The combination of parameters for different scenarios has been shown in **Table 5-8**:

Table 5-8: Combination of Scenarios

Scenario	Criteria
Scenario-1 (Base Scenario)	Flood Plain, Slope, Distance to Stream, Height above Nearest Drainage, Curve Number, Watershed Stream Order, Topographic Wetness Index, Total Precipitation
Scenario-2	Slope, Distance to Stream, Height above Nearest Drainage, Curve Number, Watershed Stream Order, Topographic Wetness Index, Total Precipitation
Scenario-3	Slope, Distance to Stream, Height above Nearest Drainage, Curve Number, Watershed Stream Order, Total Precipitation
Scenario-4	Slope, Distance to Stream, Curve Number, Watershed Stream Order, Total Precipitation, Topographic Wetness Index

5.3 Multi-Criteria Analysis (MCA)

Multi-Criteria-Analysis (MCA) is one of the best methods that can be used for prioritization, especially in data-scarce environments. GIS-based MCA has been performed for flood hazard assessment and vulnerability assessment. Several critical criteria have been identified for flood hazards and social and economic vulnerability assessment within the study area. Details of each criterion and indicator have been demonstrated in section 5.1.

One of the most common and effective methods for dealing with MCA is the Analytic Hierarchy Process (AHP). AHP was developed by Thomas L. Saaty in the 1980s. It is a widely used method for MCA. It involves assigning importance to the criteria that define the main goal. This is done by comparing the criteria two by two through pairwise comparisons. AHP converts these evaluations into numbers on a scale of relative importance ranging from 1 to 9 (

Table 5-9), which then is used to calculate weight of each criteria following simple equations.

Table 5-9: Saaty's Scale for Weight-Assignment

Intensity of Importance	Definition
1	Equal Importance
2	Equal to moderate Importance
3	Moderate Importance
4	Moderate to strong Importance
5	Strong Importance
6	Strong to very strong Importance
7	Very strong Importance
8	Very to extremely strong Importance
9	Extremely strong Importance

Since the AHP may have inconsistencies in establishing the values for the pairwise comparison matrix, it is important to calculate this level of inconsistency using the Consistency Index (CI). The CI value is calculated using the Average of Consistency Vector and total number of criteria to check the consistency level while performing MCA. For MCA having more than three criteria, CI must be less than 0.1.

5.3.1 Assigning Criteria Weights

In the flood hazard assessment multiple scenarios have been prepared combining various flood hazard criteria. The base scenario (Scenario-1) contains all the flood hazard parameters. As the first step of AHP, all these parameters were compared with each other in pairs of two and importance score was assigned to one from 1-9 (

Table 5-9) based on literature review and engineering judgement. **Table 5-10** shows the assigned importance score for the base scenario. Similar analysis is shown for the remaining three scenarios in **Appendix A**. Since all the parameters considered in this study are very crucial in terms of flood hazard, the importance score does not vary much and ranges between 1-3.

Using the assigned importance score an 8 by 8 comparison matrix (**Table 5-11**) and Normalization matrix (**Table 5-12**) has been prepared. The final weight of each parameter is the average of the normalized weights. The final weight of each parameter is shown in

Table 5-13**.**

Table 5-10: Assigned Importance Score for Base Scenario

Criteria		Weight	
A	**B**	**Importance (A/B)**	**Value**
Slope	Distance to Streams (DS)	B	2
	Height above Nearest Drainage (HAND)	B	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	3
	Floodplain (FP)	B	3
	Watershed Stream Order (WSO)	A	1
	Topographic Wetness Index (TWI)	A	2
Distance to Streams (DS)	Height above Nearest Drainage (HAND)	A	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Floodplain (FP)	B	1
	Watershed Stream Order (WSO)	A	1
	Topographic Wetness Index (TWI)	A	2
Height above Nearest Drainage (HAND)	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Floodplain (FP)	B	2
	Watershed Stream Order (WSO)	A	1
	Topographic Wetness Index (TWI)	A	2
Curve Number (CN)	Total Precipitation (TP)	B	3
	Floodplain (FP)	B	3
	Watershed Stream Order (WSO)	B	2
	Topographic Wetness Index (TWI)	A	1
Total Precipitation (TP)	Floodplain (FP)	A	1
	Watershed Stream Order	A	2
	Topographic Wetness Index (TWI)	A	3
Floodplain (FP)	Watershed Stream Order (WSO)	A	2
	Topographic Wetness Index (TWI)	A	3
Watershed Stream Order (WSO)	Topographic Wetness Index (TWI)	A	2

Table 5-11: Comparison Matrix for Base Scenario

Comparison Matrix								
Criteria	Slope	Distance to Streams (DS)	Height above Nearest Drainage (HAND)	Curve Number (CN)	Total Precipitation (TP)	Floodplain (FP)	Watershed Stream Order	Topographic Wetness Index (TWI)
Slope	1	0.5	1	2	0.33333333	0.33333333	1	2
Distance to Streams (DS)	2	1	1	2	0.5	1	1	2
Height above Nearest Drainage (HAND)	1	1	1	2	0.5	0.5	1	2
Curve Number (CN)	0.5	0.5	0.5	1	0.33333333	0.33333333	0.5	1
Total Precipitation (TP)	3	2	2	3	1	1	2	3
Floodplain (FP)	3	1	2	3	1	1	2	3
Watershed Stream Order	3	1	1	2	0.5	2	1	2
Topographic Wetness Index (TWI)	0.5	0.5	0.5	1	0.33333333	0.33333333	0.5	1
Sum	14	7.5	9	16	4.5	6.5	9	16

Table 5-12: Normalization Matrix for Base Scenario

Normalization								
Criteria	Slope	Distance to Streams (DS)	Height above Nearest Drainage (HAND)	Curve Number (CN)	Total Precipitation (TP)	Floodplain (FP)	Watershed Stream Order	Topographic Wetness Index (TWI)
Slope	0.071	0.067	0.111	0.125	0.074	0.051	0.111	0.125
Distance to Streams (DS)	0.143	0.133	0.111	0.125	0.111	0.154	0.111	0.125
Height above Nearest Drainage (HAND)	0.071	0.133	0.111	0.125	0.111	0.077	0.111	0.125
Curve Number (CN)	0.036	0.067	0.056	0.063	0.074	0.051	0.056	0.063
Total Precipitation (TP)	0.214	0.267	0.222	0.188	0.222	0.154	0.222	0.188
Floodplain (FP)	0.214	0.133	0.222	0.188	0.222	0.154	0.222	0.188
Watershed Stream Order	0.214	0.133	0.111	0.125	0.111	0.308	0.111	0.125
Topographic Wetness Index (TWI)	0.036	0.067	0.056	0.063	0.074	0.051	0.056	0.063
	1	1	1	1	1	1	1	1

Table 5-13: Final Weight of Each Flood Hazard Parameter for Base Scenario

Parameters	Weights	Percentage
Slope	0.09196	**9**
Distance to Streams (DS)	0.12667	**13**
Height above Nearest Drainage (HAND)	0.10813	**11**
Curve Number (CN)	0.05798	**6**
Total Precipitation (TP)	0.20956	**21**
Floodplain (FP)	0.19289	**19**
Watershed Stream Order (WSO)	0.15483	**15**
Topographic Wetness Index (TWI)	0.05798	**6**
Sum	**1**	**100**

Total precipitation and floodplain parameter have received the higher weight of 21% and 19% and Topographic Wetness Index and Curve Number has received equal and least weight of 6%. The summation of the weight of all the parameters is 100%.

5.3.2 Consistency Index

The barring value of Consistency index depends on the number of parameters used in the MCA. For 3*3 matrix or an analysis with 3 parameters CI should be less than 0.05. For 4*4 matrix CI value should be less than 0.09 for and 0.1 for larger matrix.

The consistence index calculated for base scenario is 0.088 which is under the acceptable limit of 0.1 indicating that the accuracy of the analysis is reasonable.

5.4 Flood Hazard Map

5.4.1 Flood Hazard Spatial Layers

Flood hazard maps have been prepared combining all the parameters within different scenarios and their respective weights by spatial overlay in ArcGIS interphase using 'Weighted Overlay Tool.' The Weighted Overlay tool in ArcGIS is a method for combining multiple raster layers to derive a suitability value for each cell. The algorithm involves assigning a weight and a scale to each input raster, reclassifying the raster values to a common suitability scale, and overlaying the rasters by multiplying and adding the weighted values. The algorithm can also exclude areas that are restricted from the analysis or contain No Data.

The weights calculated using MCA have been assigned to each parameter of different scenarios and a scale of 1 to 5 by an increment of 1 has been incorporated in the Weighted Overlay Toolbox. The output layer is a classified flood hazard raster which exhibits different classes of hazard between 1 to 5. **Figure 5-12** illustrates the flood hazard maps prepared for different scenarios. All the scenarios exhibit a similar pattern of flood hazard potential. Scenario 4 exhibits maximum high hazard area in comparison to the other three scenarios. But the location of very high and high hazard areas remains similar in all scenarios. For example, the portion land adjacent to the Ottawa Riverbank in Petawawa, Pembroke, Laurantian Valley and Whitewater region falls within moderate to high hazard in all scenarios, whereas Horton, MacNab/Braeside and southern portion of Admaston/Bromley always exhibit low hazard. Bonnechere valley faces less high hazard in scenario 1, than the other scenarios. Overall Moderate Hazard dominates in all the scenarios.

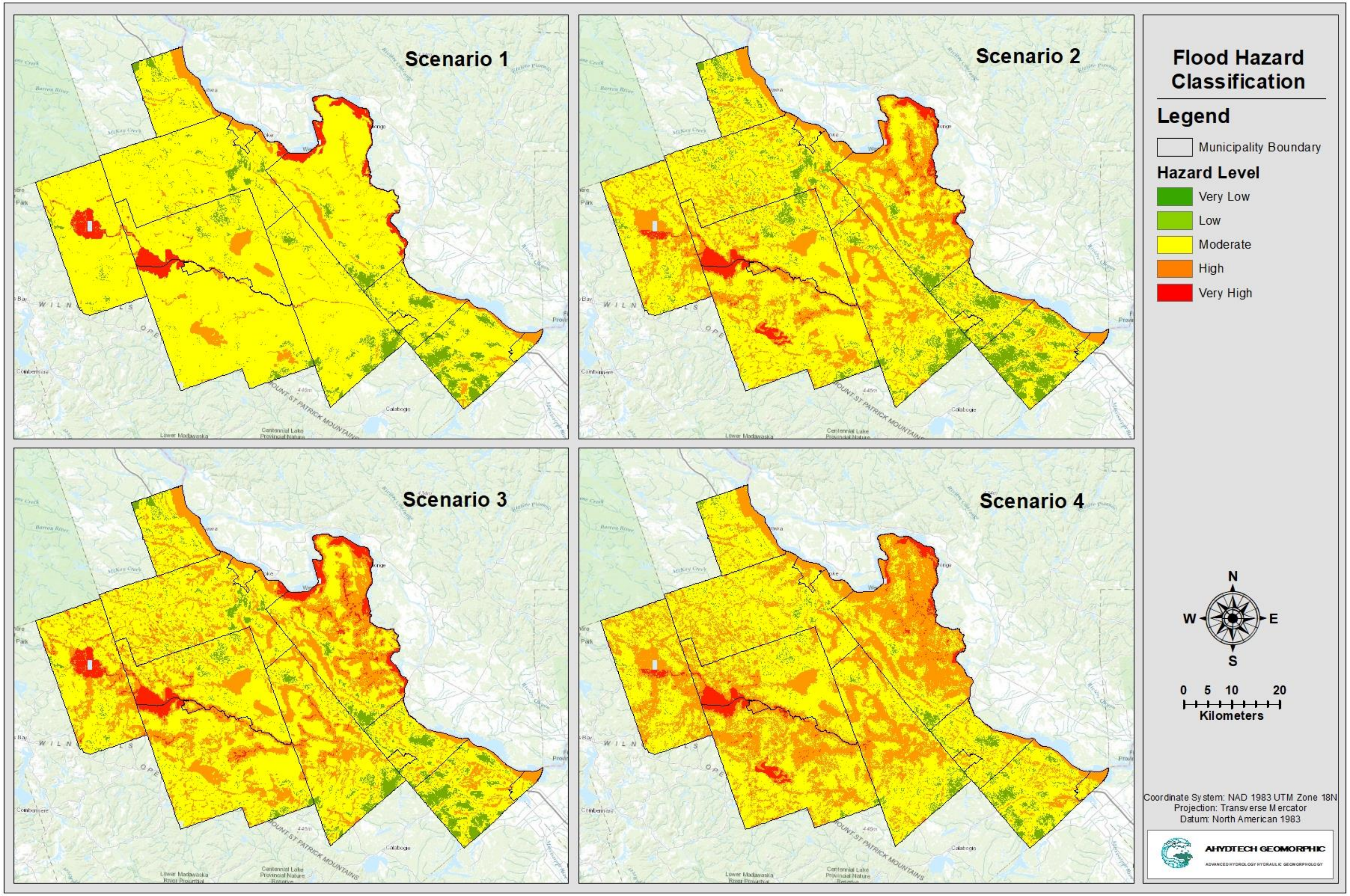

Figure 5-12: Flood Hazard Map for All Scenarios

5.4.2 Comparisons of Scenarios

Multiple scenarios were developed to identify the most appropriate combination of parameters that contribute to occurrence of flood within the study area. In this case, four (4) scenarios were developed, where the one having all the parameters has been considered as the base scenario. Two types of comparison exercise have been performed between these scenarios. (i) Initially the percentage of area acquired by each level of hazard has been compared which has been illustrated in **Figure 5-13**. (ii) In a later stage the Flood Risk maps generated for each flood hazard scenario and flood vulnerability have been performed.

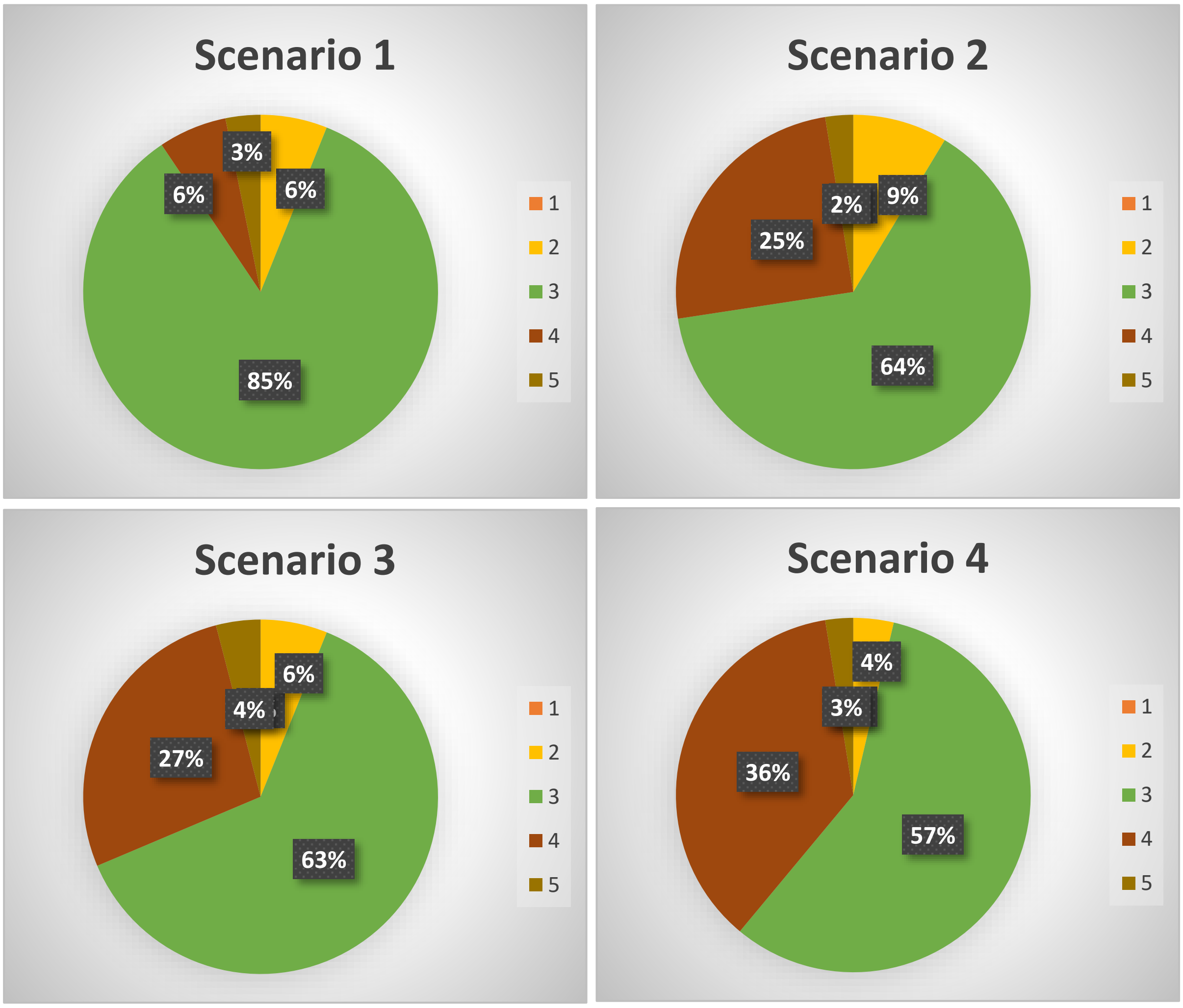

Figure 5-13: Chart of Hazard Level Percentage for Scenario 1 (a), Scenario 2 (b), Scenario 3 (c), Scenario 4 (d)

Scenarios 1, 2, 3 and 4 exhibit only 3%, 2%, 4% and 3% of very high hazard. Combining high and very high categories, scenario 4 shows maximum high hazard zones which is 39%. In scenario 1, the area within moderate flood hazard is 85% of the study area which is the highest for all the scenarios. Area within low hazard zone is quite similar for scenario 1, 2, 3 and 4 but significantly lower for scenario 4, as the percentage of high and very high zone occupies larger area. Therefore, scenario 4 exhibits the worst case of flooding hazard. **Table 5-14** shows the Flood hazard summery table for the entire study area for four (4) different scenarios.

Table 5-14: Flood Hazard summery for Four (4) different Scenarios

Class	Hazard Category	Scenario 1 (Number of Cells)	Scenario 2 (Number of Cells)	Scenario 3 (Number of Cells)	Scenario 4 (Number of Cells)
1	Very Low	1159	1369	1159	1069
2	Low	59356466	84221867	59449135	35875095
3	Moderate	825364069	624720325	610878730	560607928
4	High	60920839	242985254	266810870	355972141
5	Very High	31070778	24784496	39573423	24772436

6 Vulnerability Assessment

For flood risk identification, there is a necessity to perform vulnerability assessment by identifying the vulnerable assets in terms of people, environment and economy. Consequently, this requires comprehensive study of all valued assets that are susceptible to flood damage within the area of interest. The population density and dwelling characteristics and environmental parameters are also interrelated with probable estimates of vulnerability to flood risk. For this reason, vulnerable assets layer has been created in ArcGIS environment for social, economic and environmental vulnerability criteria. The guidelines set in ***Federal Flood Hazard Identification and Priority Setting Version 1.0*** has been followed to perform multi criteria analysis using these layers for the area to assess and classify the vulnerability of social, environmental and economic vulnerability within study area. Combining the output of social, economic and environmental vulnerability, a total vulnerability map was prepared.

6.1 Social Vulnerability Assessment

6.1.1 Social Vulnerability Criteria Layers

Social vulnerability assessment has been performed by accumulating spatially varied GIS based data of valued assets and performing multi criteria analysis using these layers. The selected criteria for assessing Socially valuable assets for all thirteen municipality are as follows-

- **Demographic characteristics**
  - Population Density.
  - Percentages of population for 0-4 years.
  - Percentages of population for 65 years and above.
- **Economic and social conditions of households**
  - Median income per household.
  - Percentage of households with annual income less than 20,000 CAD ($).
- **Language barriers**
  - Number of non-English speakers.
- **Educational statistics**
  - Percentage of people with highest degree as high school or less.

These layers will give us a comprehensive understanding of the socio-economic conditions of the concerned municipalities in the County of Renfrew. Most of the data have been extracted from Statistics Canada website (https://www.statcan.gc.ca/en/start). The vulnerable age group of 0-4 years and 65 years and more as well as other statistical parameters has been selected based on Federal Flood Hazard Identification and Priority Setting Version 1.0 and the Flood Risk Assessment and Ranking study performed by IBI Group for Toronto Region Conservation Authority. An overview of these dataset has been presented in a tabular format below (**Table 6-1).** Then these criteria layers have been reclassified into five classes ranging from 1 to 5, where Class 1 denotes very low vulnerability and Class 5 denotes very high vulnerability to flood.

Table 6-1: Social vulnerability criteria data

Name of Municipality	Area (sq km)	Total Population	Population Density (per sq km)	Population Aged 4 or Less (%)	Population Aged 65 or More (%)	Median Income Per Household (CAD $)	Households with Annual Income Less than 20,000 CAD $ (%)	Number of Non-English Speakers	People Aged 15+ with highest Degree of High School Education or Less (%)
Township of Bonnechere valley	640.25	3898	6.6	3.85	30.27	68000	4.61	185	33.28
Township of Killaloe, Hagarty and Richards	432.78	2410	6.2	3.73	30.08	63200	4.11	45	30.64
Town of Petawawa	169.96	18160	110.3	7.71	9.44	102000	1.55	1855	35.9
Town of Renfrew	13.50	8190	639.3	3.54	32.11	60400	7.85	230	37.39
Township of Horton	159.84	3182	20.1	4.40	22.78	90000	3.49	30	33.83
Town of Arnprior	14.13	9629	738.5	4.83	27.16	75500	5.46	410	31.44
Township of Adamston/Bromley	529.25	2995	5.8	5.01	19.87	85000	4.41	55	31.59
Township of Whitewater Region	552.45	7225	13.5	5.33	23.32	81000	4.13	140	32.36
Township of North Algona Wilberforce	426.63	3111	8.4	4.82	25.23	82000	2.7	85	30.84
City of Pembroke	6.61	14364	1002.8	4.77	26.56	63200	7.1	270	35.08
Township of McNab/Braeside	269.70	7591	29.7	5.14	22.00	99000	2.47	230	32.4
Township of Laurentian valley	551.84	9450	17.5	5.13	20.63	94000	2.29	535	30.36
First nations of Algonquins of Pikwakanagan	7.61	490	66.4	7.14	15.31	50000	13.51	10	40

Demographic Characteristics

I. Population Density Per Square Kilometer

The population density per square km data has been collected for the 13 municipalities from the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start). Population density is one of the most important criteria to understand the demographic condition of any location. In most cases, Population density often reflects the distinction between urban and rural areas. **Figure 6-1** illustrates the municipality-wise variation of population density, measured as the number of residents per square kilometer. Population density indicates how densely or sparsely populated an area is.

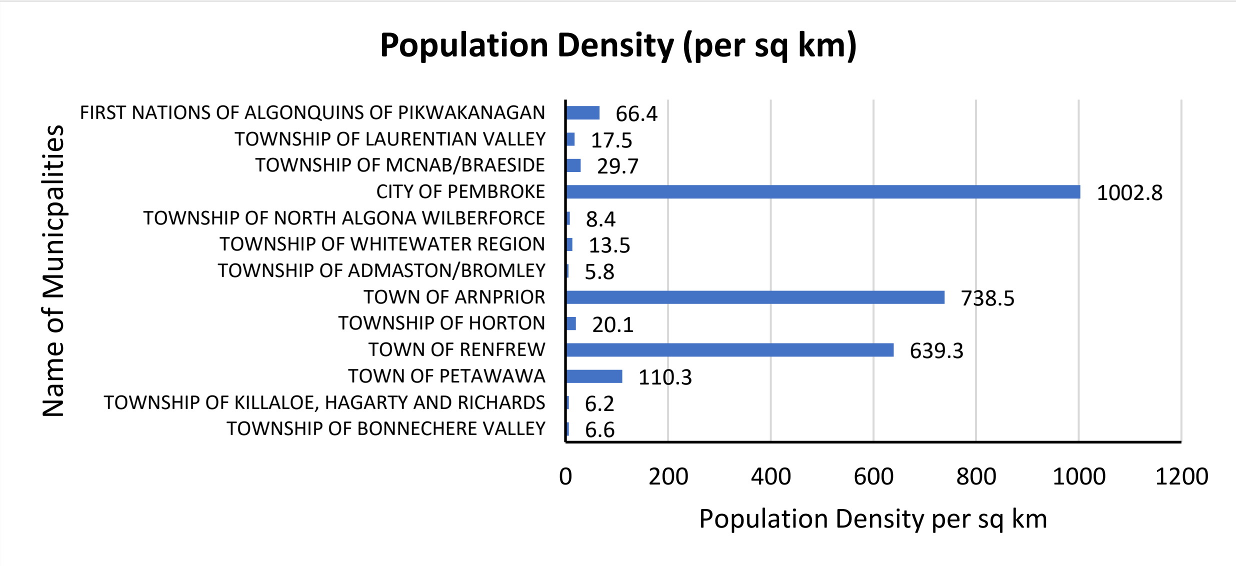

Figure 6-1: Population Density for 13 Municipalities

The dataset demonstrates a significant variation in population density across the municipalities, with values ranging from less than 10 residents per square kilometer to over 1,000 residents per square kilometer. Urban municipalities, such as the City of Pembroke, Town of Renfrew and the Town of Arnprior, have high population densities (per sqkm) (1002.8, 639.3 and 738.5, respectively), indicating a concentrated population. The City of Pembroke stands out with the highest population density among all listed municipalities, having 1002.8 persons per square kilometer. In contrast, more rural areas like the Township of Admaston/Bromley (5.8) and the Township of Killaloe, Hagarty, and Richards (6.2) have lower population densities, indicating more open spaces and fewer residents per square kilometer.

Most other municipalities listed, such as the Township of Horton, Township of Whitewater Region, and Township of McNab/Braeside, have population densities ranging from around 13.5 to 29.7 persons per square kilometer.

Population density raster dataset can help us demonstrate the spatial variation visually. Additionally, raster dataset for population density has been collected from https://data.humdata.org/dataset/worldpop-population-density-for-canada.

II. People 65 Years and Older

In this layer, the percentage of people with age 65 years and older has been demonstrated for the 13 municipalities. The tabular data has been collected from the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start). This age group is selected as it indicates a potentially vulnerable group of people. **Figure 6-2** illustrates the variation of Portion of population aged

65 or more that has been shown as a percentage of the total population of respective municipality.

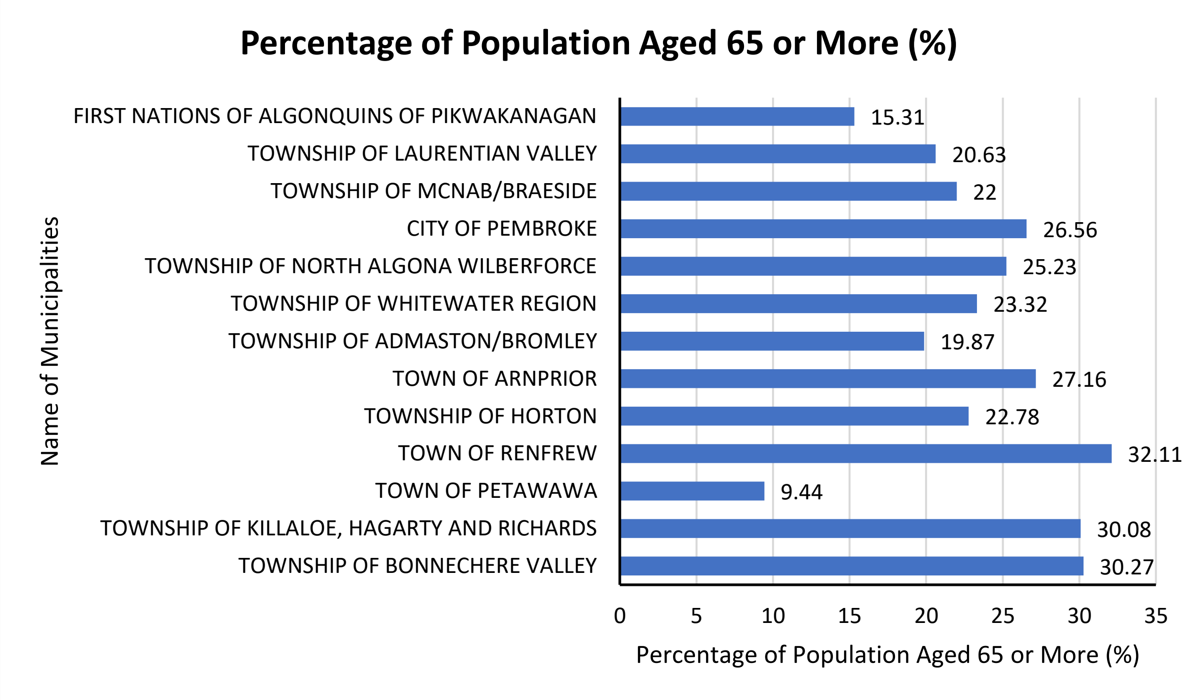

Figure 6-2: Percentage of Population Aged 65 or More for 13 Municipalities

For instance, the Township of Bonnechere Valley has 30.27% of its population aged 65 years or more, while the Township of Killaloe, Hagarty and Richards has a similar percentage at 30.08%. The Town of Petawawa has the lowest percentage of its people aged 65 years or older with only 9.44%. On the other hand, the Town of Renfrew has the highest percentage with 32.11% of its population aged 65 years or more. The First Nations of Algonquins of Pikwakanagan community has 15.31% of its population within this age group. Some municipalities, such as Township of Horton (22.78%), Township of Whitewater Region (23.32%), and Township of North Algona Wilberforce (25.23%), fall in the middle range in terms of aging population. This data is crucial for understanding the demographic structure of these municipalities and can be particularly useful for planning social services and policies targeted at older adults in time of flood.

III. Children 4 Years and Younger

The percentage of children aged 4 years and under has been demonstrated by this layer. The source of the data is the same as previous which is the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start). Again, this age group is selected as it indicates a potentially vulnerable group in comparison to the whole population. **Figure 6-3** represents the variation of people with 0-4 years age range which has been shown as percentage of total population of respective municipality.

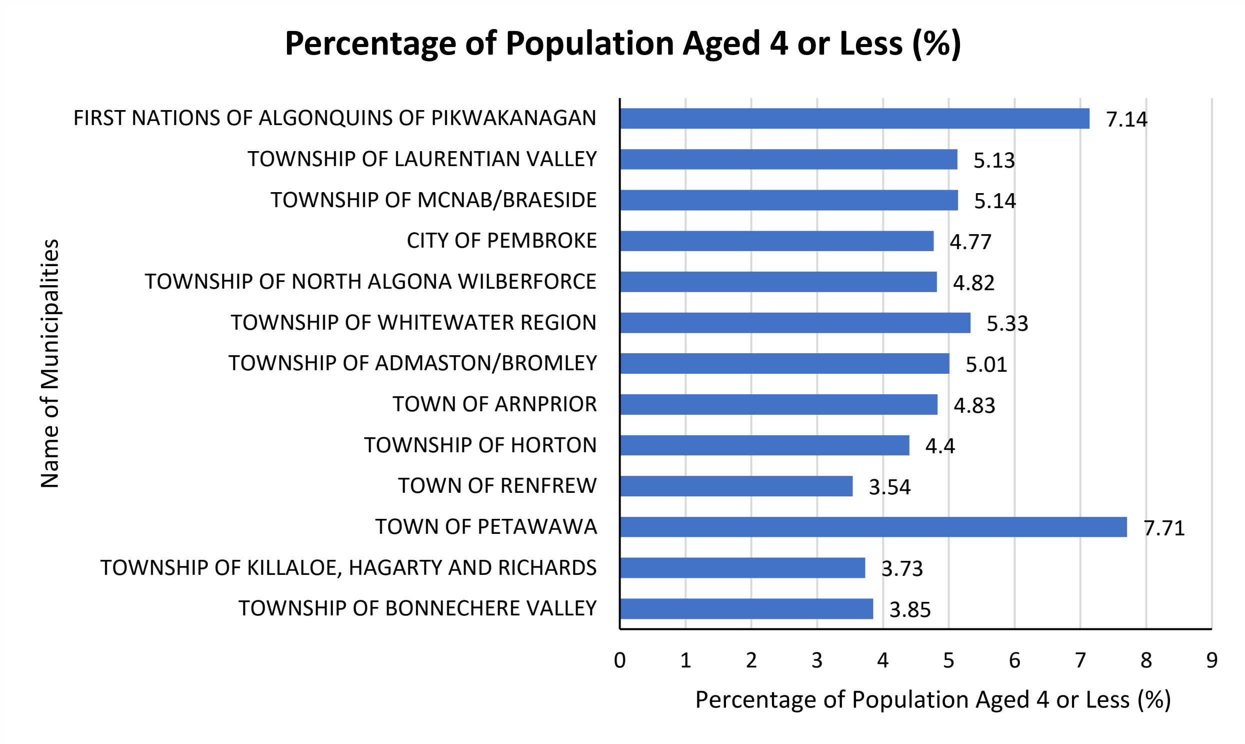

Figure 6-3: Percentage of Population Aged 4 or less for 13 Municipalities

The chart comprises 13 municipalities, each with a corresponding percentage that signifies the proportion of their population that is aged 4 or less. Children are the most vulnerable people in times of flood and any type of natural calamity. The Town of Petawawa has the highest percentage of the population aged 4 or less, that is 7.71%. The First Nations of Algonquins of Pikwakanagan community also has a relatively high percentage with 7.14% of its population within this age group, indicating a significant number of young children in this community. This suggests a higher number of young children in this municipality and needs special attention during peak flood season. The Town of Renfrew has the lowest percentage, with only 3.54% of its population falling into the 4 or less age group, indicating a smaller proportion of young children.

IV. Non-English-Speaking People

The number of non-English speakers for 13 municipalities is shown in this layer. The data is collected from the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start). The specific variable taken was 'First official language spoken' and from that the number of English speakers was subtracted from total speakers. **Figure 6-4** shows the variation of the number of non-English speakers in different municipalities. It offers insights into linguistic diversity and the presence of individuals who primarily speak languages other than English. The data shows significant variation in the number of non-English speakers across municipalities.

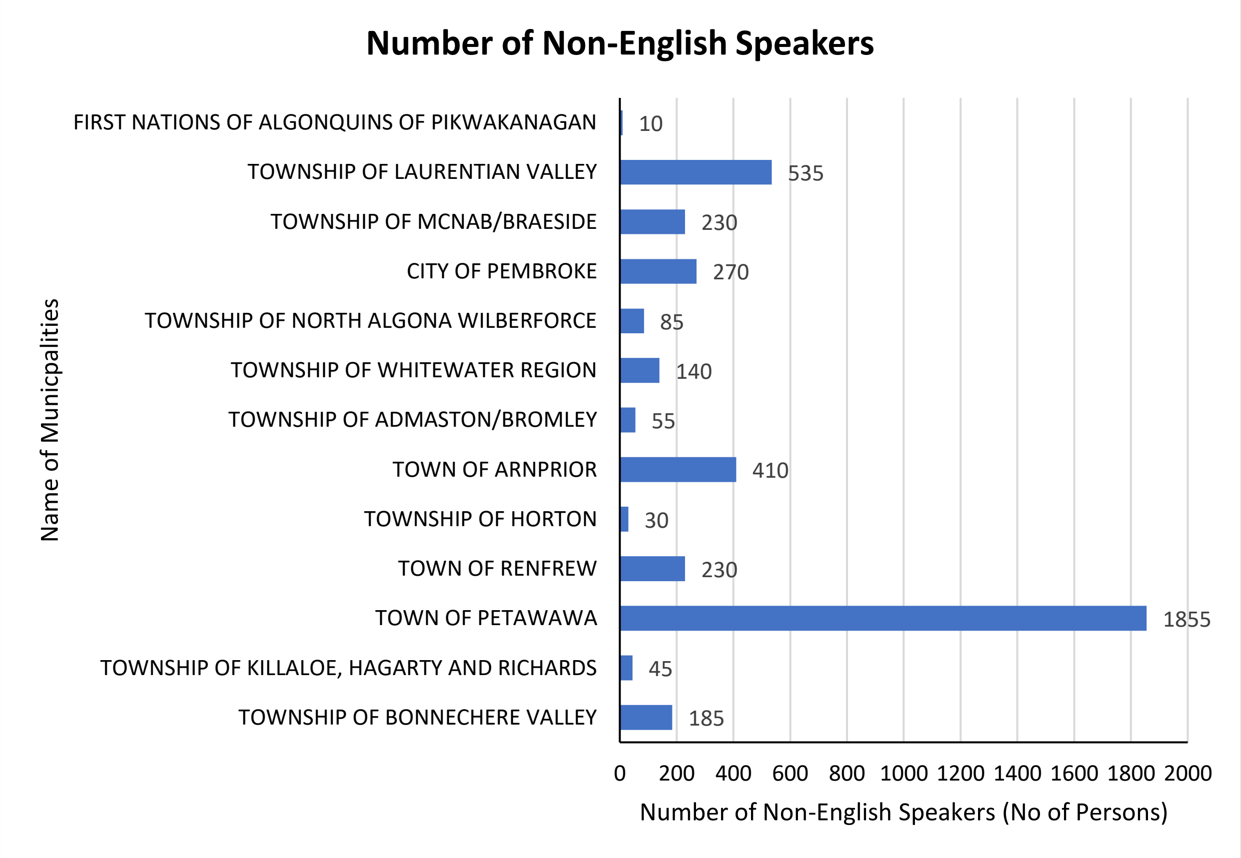

Figure 6-4: Number of Non-English Speakers for 13 Municipalities

For instance, the Town of Petawawa has the highest number of 1855, indicating a substantial population with languages other than English as their primary language. On the other hand, the First Nations of Algonquins of Pikwakanagan has the lowest number at 10, suggesting a smaller number of non-English speakers. Most other municipalities, such as the Township of Bonnechere Valley, Township of Whitewater Region, City of Pembroke, and Township of McNab/Braeside, have numbers ranging from around 140 to 270, suggesting a moderate number of non-English speakers in their populations.

V. Total Median Income Per Household

The median income per household of the 13 municipalities have been collected from the ‘Statistics Canada’ website (https://www.statcan.gc.ca/en/start). This variable will tell a summary about the socio-economic condition of the study area. **Figure 6-5** illustrates the municipality-wise variation of median income for each household.

The median income represents the midpoint of income levels, where half of the households earn more, and half earn less. This illustrates significant variability in median household incomes across the municipalities, with values ranging from 50,000 CAD $ to 102,000 CAD $.

There is often a difference between urban and rural areas in terms of median household income. For example, the Town of Petawawa, a more urban municipality, has the highest median income at 102,000 CAD $, while the First Nations of Algonquins of Pikwakanagan, which is also rural, has the lowest median income at 50,000 CAD $. The Township of Bonnechere Valley has a median household income of CAD $68,000. This is slightly higher than the Township of Killaloe, Hagarty and Richards, and the City of Pembroke, each with a median income of CAD $63,200.

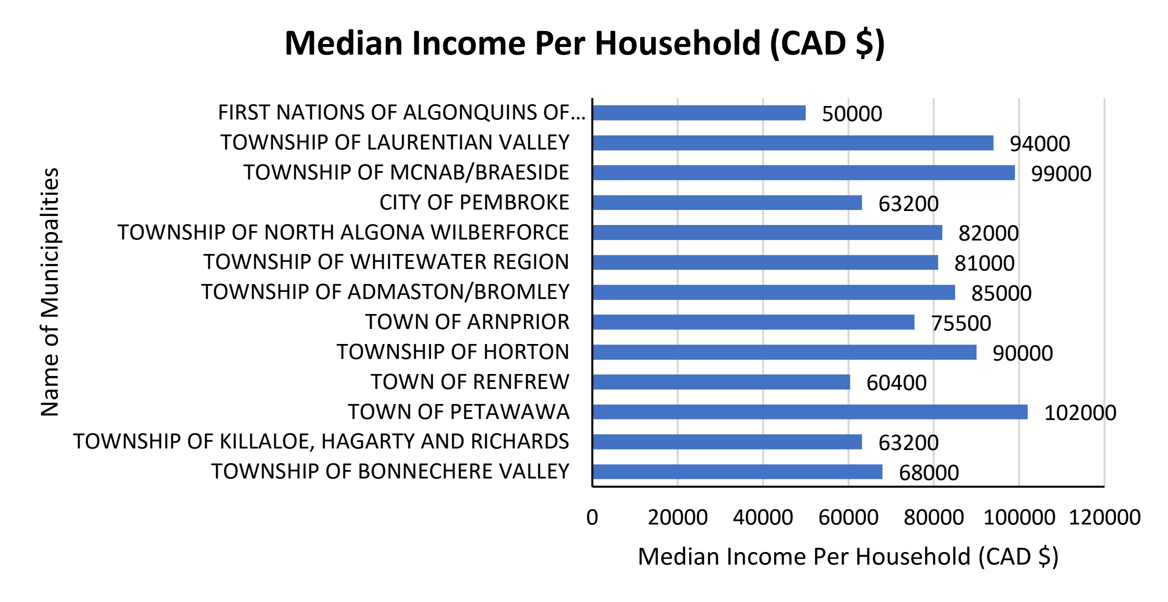

Figure 6-5: Median Income Per Household for 13 Municipalities

Median incomes of other municipalities range from around CAD $81,000 to CAD $99,000.

VI. Proportion of Household with Annual Income Less than CAD $20,000

The data for proportion or percentage of household with annual income less than CAD $20,000 has been calculated for 13 municipalities from the data gathered from the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start). **Figure 6-6** illustrates the municipality-wise variation of annual household incomes that is less than 20000 CAD $ which eventually indicates the condition of low earning community in each municipality.

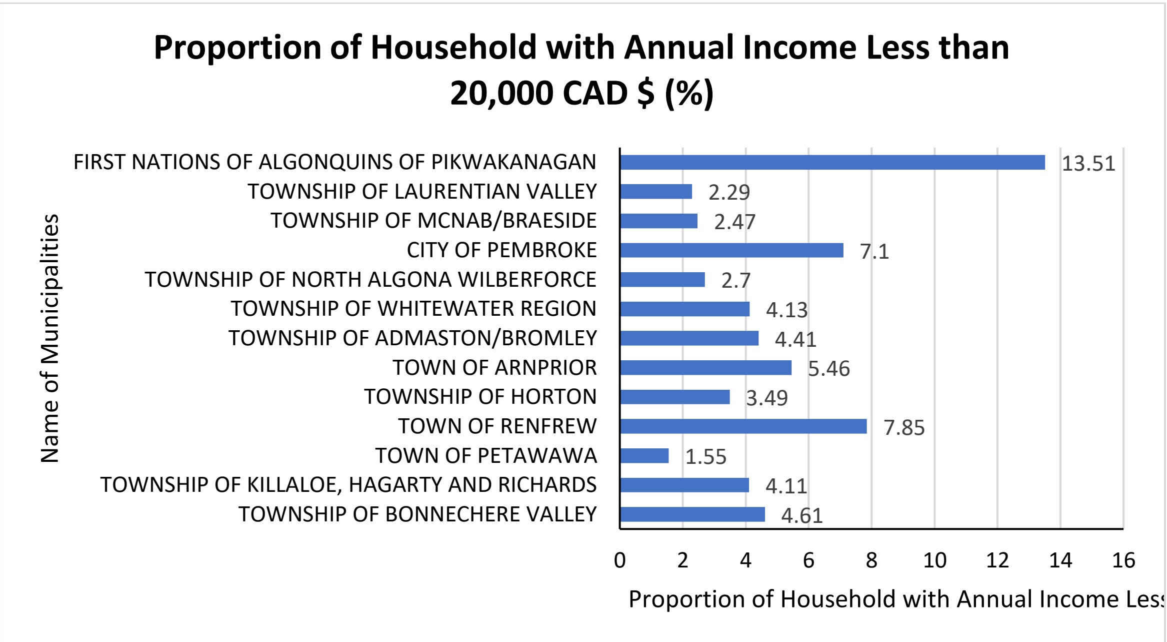

Figure 6-6: Percentage of Household with Annual Income Less than 20000 CAD for 13 Municipalities

The chart offers insights into the prevalence of lower-income households within each area. There are differences between urban and rural areas. For example, the Town of Petawawa, an urban municipality, has a relatively lower percentage (1.55%) of households with incomes below 20,000 CAD $ compared to some other municipalities. Conversely, the First Nations of Algonquins of Pikwakanagan, a rural community, has a much higher percentage (13.51%).

Most other municipalities listed, such as the Township of Bonnechere Valley, Township of Killaloe, Hagarty and Richards, Township of Horton, Township of Admaston/Bromley, and City of Pembroke, have proportions ranging from around 2.47% to 7.1%.

VII. High School Education or Less

The variable 'Highest certificate, diploma or degree' from the 'Statistics Canada' website (https://www.statcan.gc.ca/en/start) gives the total number of people with at best high school education or less. This data has been converted to percentage value for a comprehensive comparison of all the municipalities which can tell us about the education interest and situation. **Figure 6-7** illustrates the municipality-wise variation of the percentage of people aged 15 years or above having educational qualifications as a high-school degree or Diploma. The chart provides insights into the educational attainment of the population in each area.

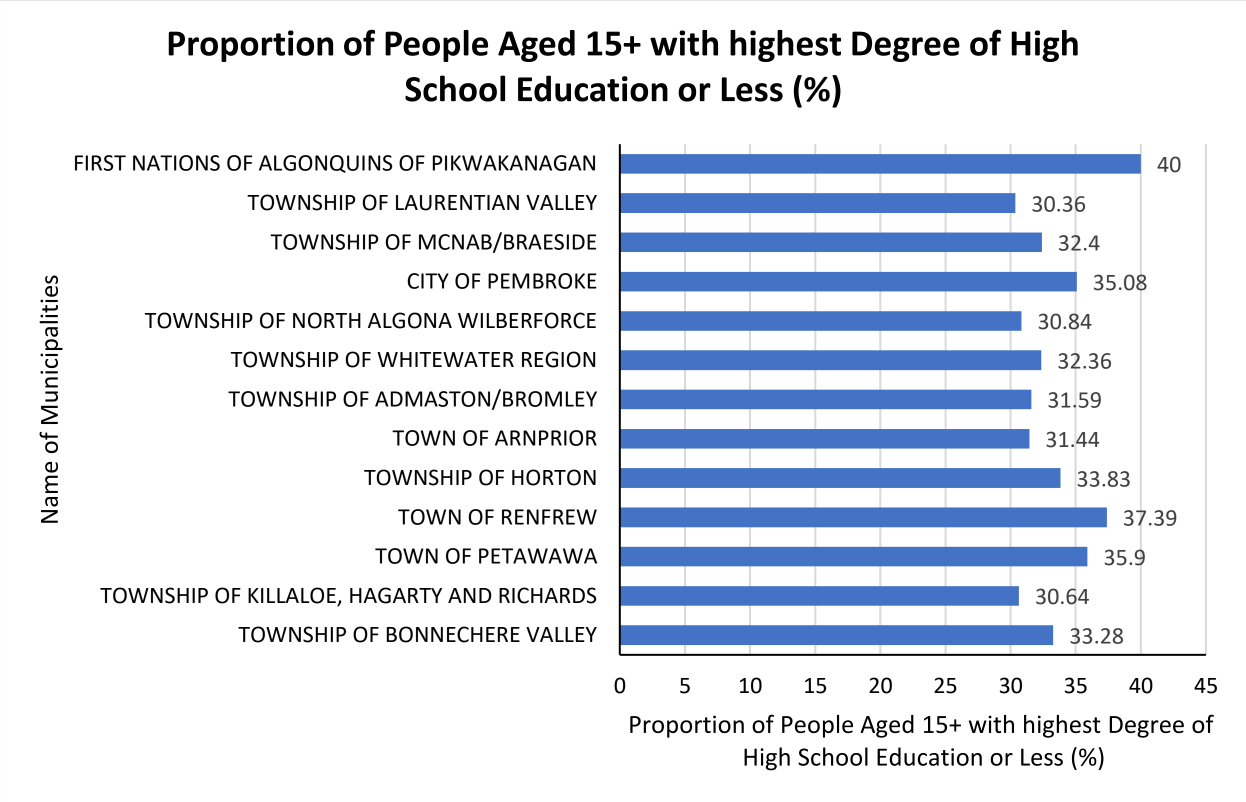

Figure 6-7: Percentage of 15+ Population with Highest Degree of High School Education or Less for 13 Municipalities

The First Nations of Algonquins of Pikwakanagan community stands out with the highest proportion among all listed municipalities, having 40% of its population aged 15 and above with a high school education or less.

On the other end of the spectrum, the Township of Laurentian Valley has the lowest proportion with only 30.36% of its population aged 15 and above having a high school education or less. The township of Killaloe, Hagarty and Richards, also has a low rate which is 30.64% of its population within this educational bracket. Most other municipalities listed, such as the Township of Bonnechere Valley, Township of Horton, Township of Whitewater Region, and City of Pembroke, have proportions ranging from around 32.4% to 35.08%.

6.1.2 Multi-Criteria Analysis (MCA)

Social vulnerability assessment has been performed by combining all the selected social parameters and a weightage calculated by performing Multi-Criteria-Assessment (MCA) in Analytical-Hierarchy-Process (AHP). Similar procedure, as explained in section 5.3, has been followed for all vulnerability assessments. The final weight calculated by MCA for all social vulnerability criteria is listed in Table 6-2: Final Weight of Each Social Vulnerability Criteria for Base Scenario**.** The calculation tables are attached in **Appendix B**.

Table 6-2: Final Weight of Each Social Vulnerability Criteria for Base Scenario

Parameters	Weights	Percentage
Population Density	0.217891952	**22**
Percentages of population for 0-4 years	0.182177666	**18**
Percentages of population for 65 years and above.	0.217891952	**22**
Median income per household.	0.168156502	**17**
Number of non-English speakers.	0.113707881	**11**
Percentage of people with highest degree as high school or less.	0.100174046	**10**
Sum	**1**	**100**

The population density and the percentage of people above 65-years criteria received most weight of 22%. The percentage of people with the highest degree as high school or less has received the least weightage. The summation of all the weight is 100%. These criteria wise weightages have been used in ArcGIS environment to prepare a comprehensive social vulnerability map.

6.1.3 Social Vulnerability Map

Preparation of the Social Vulnerability map requires reclassifying all the criteria layers. The reclassified rasters are than spatially overlayed in ArcGIS using 'Weighted Overlay Tool' and the weightage calculated using MCA. The reclassification has been done using the Natural Breaks (Jenks) methos and the classes are shown in **Table 6-3**. The outcome of Social Vulnerability assessment is the final social vulnerability map (**Figure 6-8**). Very high vulnerability has been observed in Pembroke and high vulnerability is observed in Petawawa, Renfrew and Arnprior.

Table 6-3: Defined Classed used for Reclassification of Social Vulnerability Criteria

Vulnerability Class	Value	Population Density (person/sqkm)	Population Aged below 4 Years	Population Aged above 65 Years	Median Income per Household (x 1000 CAD $)	Number of Non-English Speakers	Population having Highest Degree as High School or Less
Very Low	1	5.8-8.4	35-90	75-595	102-90	10-85	30-31
Low	2	8.4-20.1	90-150	595-785	90-82	85-140	31-33
Moderate	3	20.1-66.4	150-390	785-1180	82-68	140-270	33-35
High	4	66.4-110.3	390-685	1180-1950	68-63.2	270-535	35-37
Very High	5	110.3-1002.8	685-1400	1950-3815	63.2-50	535-1855	37-40

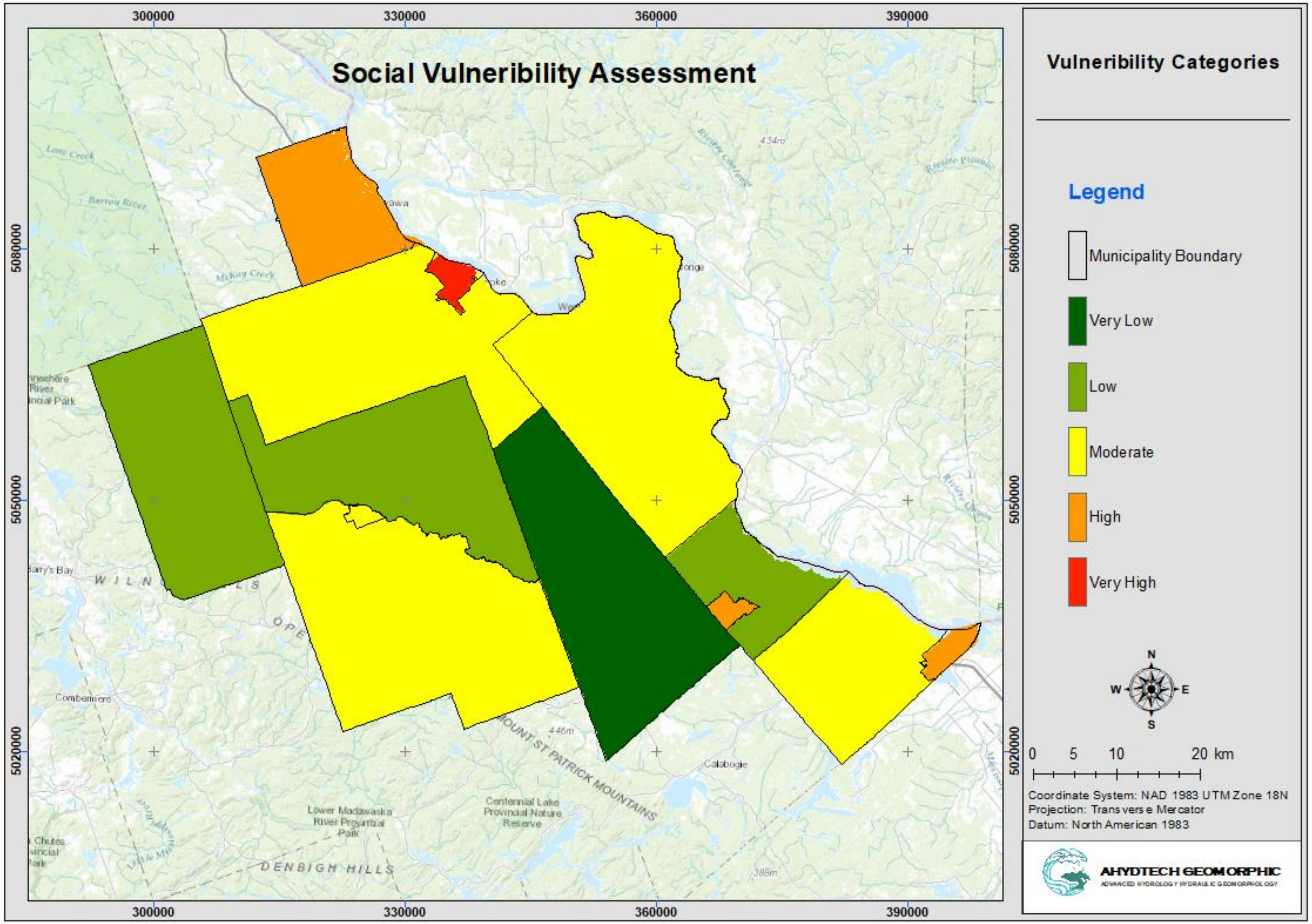

Figure 6-8: Social Vulnerability Map

6.2 Economic Vulnerability Assessment

Every year different types of floods takes its toll on the economy and living condition of people all around Canada. Hence, economic vulnerability assessment is very crucial while identifying flood risk of an area. To do so economically valued assets need to be identified first. In this study the land use type has been used as spatially varied criteria for potential economic vulnerability assessment. Land use incorporates all the economically valued assets such as- building footprints, residential areas, industrial areas and transportation networks. Since only one criterion has been used, no weightage for spatial overlay is required. The land use raster for different land use types has been reclassified as the following (**Table 6-4**) considering the economic loss that will be incurred to those assets in times of flood.

Table 6-4: Defined Classes for Economic Vulnerability

Vulnerability Class	Value	Land Use
Very High	5	Water Bodies and Wetland
High	4	Built Area
Moderate	3	Agriculture
Low	2	Bare Land
Very Low	1	Forest

Figure 6-9 illustrates the reclassified Land use raster and the economic vulnerability map. Most of the built-up area is formed in the urban areas near the Ottawa Riverbank or water bodies. Hence, the infrastructure becomes more susceptible to floods in these areas and falls within very high vulnerability zones. Moderate vulnerability zone dominates in White water region, Laurantian Valley and Admaston/Bromley.

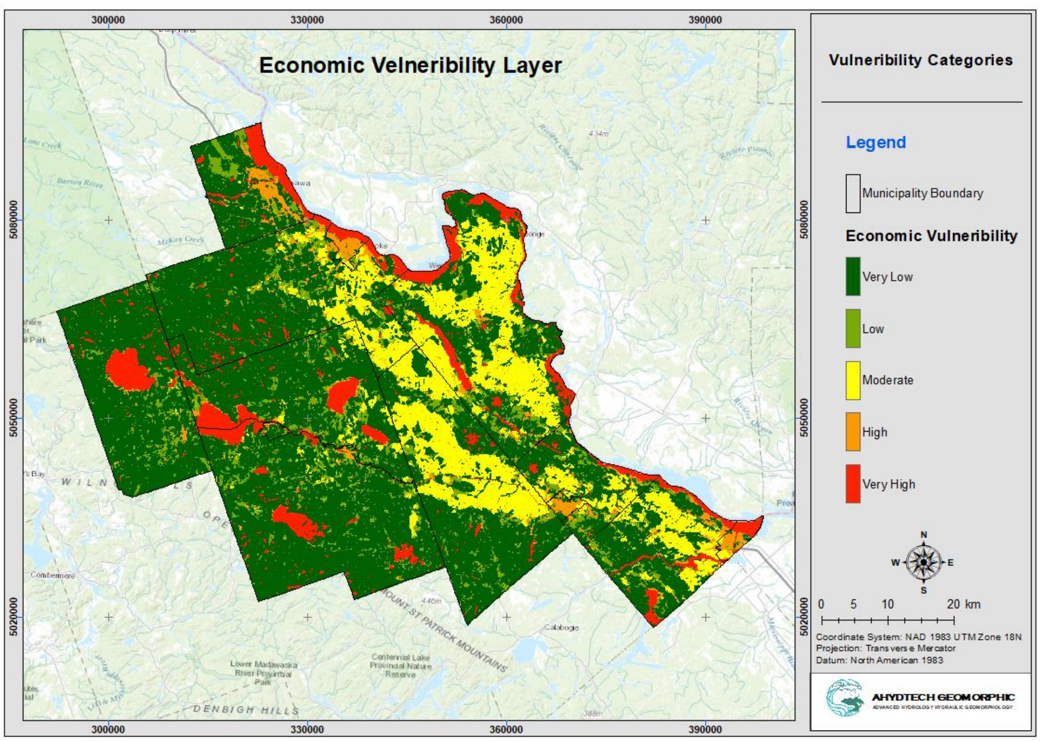

Figure 6-9: Economic Vulnerability Map

6.3 Environmental Vulnerability Assessment

One of the primary duties of city authorities in flood-prone areas is to manage floods with the goal of preserving people's safety, well-being, and environment. Reducing vulnerability and building resilience are important strategies for reaching this objective. Environmental vulnerability assessment is an integral part of any flood risk assessment. For assessing the vulnerability of environmental components to flood, multiple environmental criteria have been sought out. The final criteria layers, available for all the municipalities are as follows-

i. Wildlife Habitat
ii. Fish Habitat and
iii. Wetlands

Additionally, Areas of Natural and Scientific Interest (ANSI), Environmental Protection Area (EP), Significant Ecological Areas layers were explored. But data of these layers were not available for all municipalities. Each criteria raster was reclassified into five (5) classes using the 'Natural Break (Jenks)' method based on the percentage of area covered by each layer. Since only three criteria were used in the environmental vulnerability assessment, it was intended to assign equal weight to each criterion during spatial overlay, but for 'Weighted Overlay Tool' requires the sum of all weights to be 100. For which, 34% of weight was assigned to reclassified wetland raster and 33% of weight was assigned to other raster layers. **Figure 6-10** illustrates the environmental vulnerability map. Approximately 65% of the study area falls within very low environmental vulnerability.

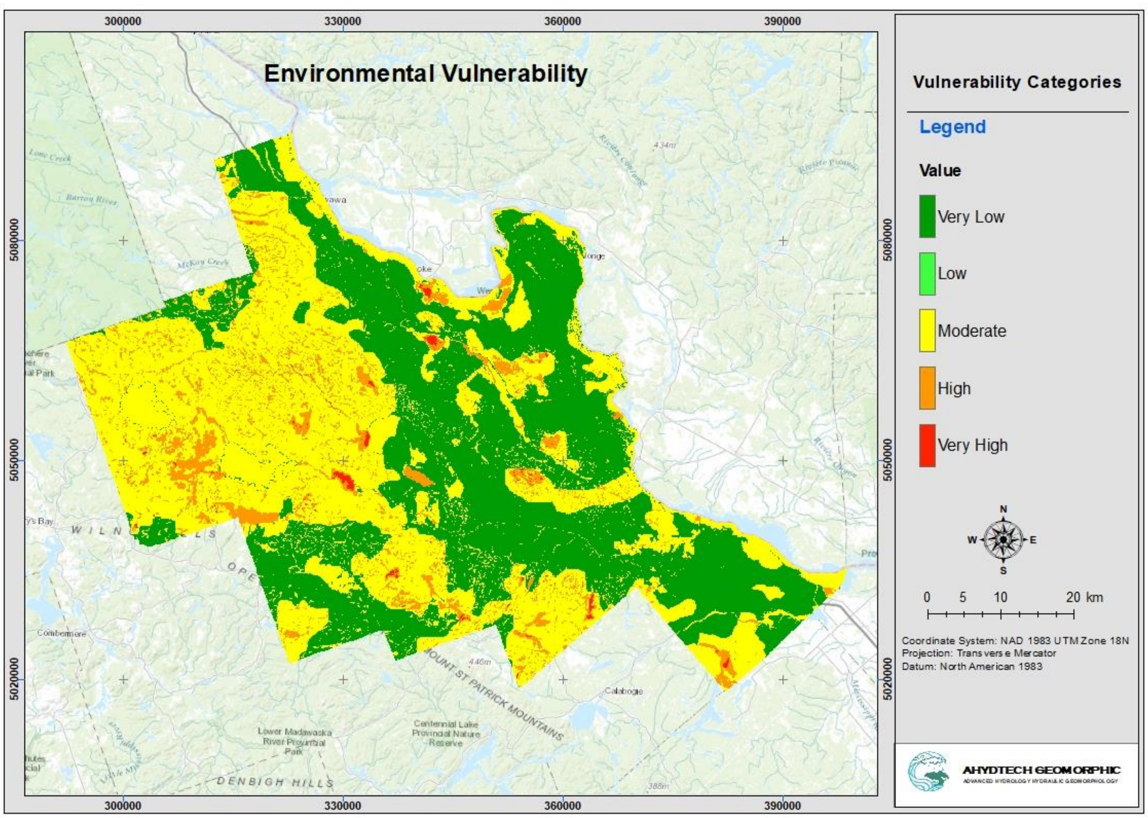

Figure 6-10: Map of Environmental Vulnerability

6.4 Total Vulnerability

All three vulnerability maps were used to produce the total vulnerability map (**Figure 6-11**), where 34% weight was assigned to social vulnerability, 33% of weight was assigned to Economic and 33% of weight to Environmental vulnerabilities. The areas along the Ottawa Riverbank show moderate to high vulnerability to flood.

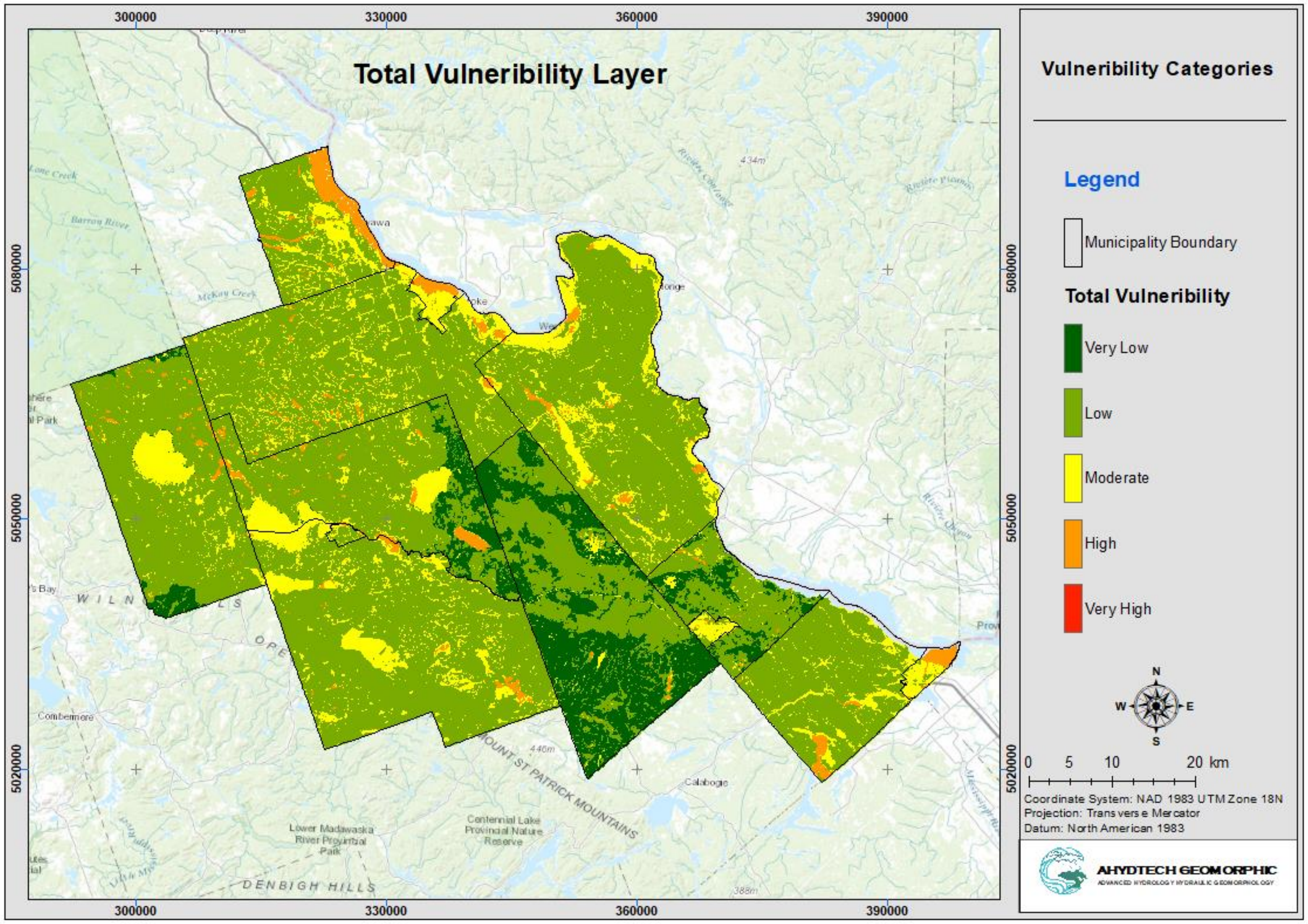

Figure 6-11: Map of Total Vulnerability

7 Flood Risk Assessment

7.1 Risk Map

Flood risk maps has been generated by spatial overlay between the total vulnerability map and the flood hazard map. Equal weight has been assigned to each layer while preparing the risk maps. Since there are four flood hazard scenarios, four risk maps have been generated.

Figure 7-1 to **Figure 7-4** illustrates the generated flood risk maps for all flood hazard scenarios. The output map layers show the spatial distribution of flood-prone areas, which needs to be prioritized for further site specific hydrologic and hydraulic assessments. Each map shows quaternary watershed boundaries that falls within the study area as well as the municipality boundaries. Prioritization has been made based on both the watershed and municipalities.

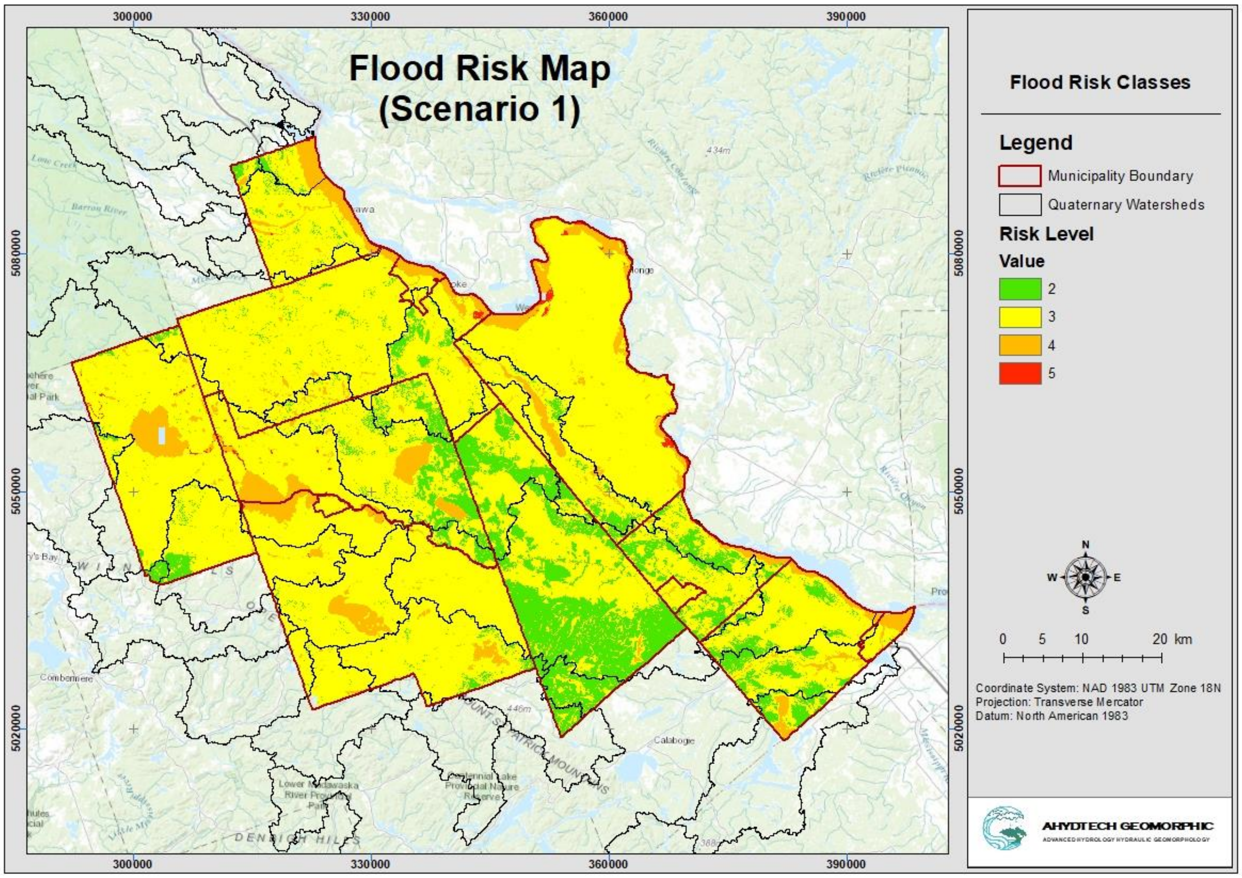

Figure 7-1: Flood Risk Map (Scenario 1)

Land adjacent to the Ottawa Riverbank shows high risk in all scenarios. Four levels of risk have been identified for risk scenario 1, 2, 3 and 4. Risk Maps have been used to prioritize areas that need immediate attention for flood mapping, management, and awareness. Risk maps are also used to identify the most suitable scenario of flood hazard for the study area. The suitable scenario can be identified by 'Risk Change' analysis.

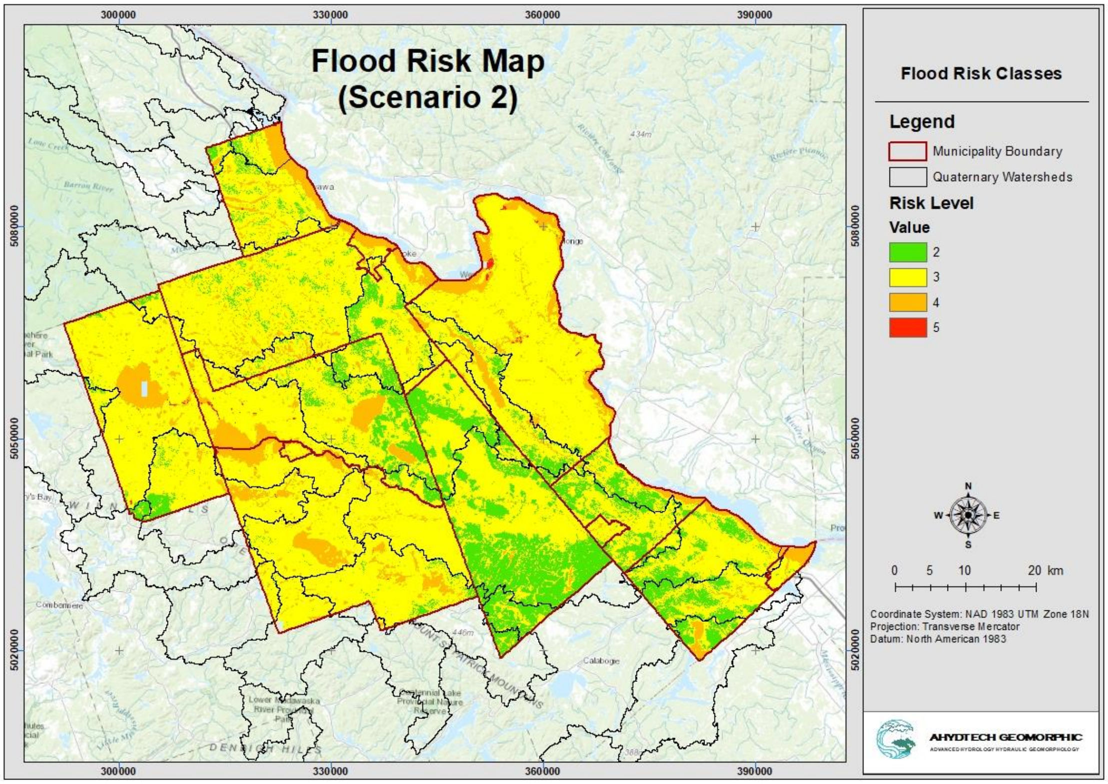

Figure 7-2: Flood Risk Map (Scenario 2)

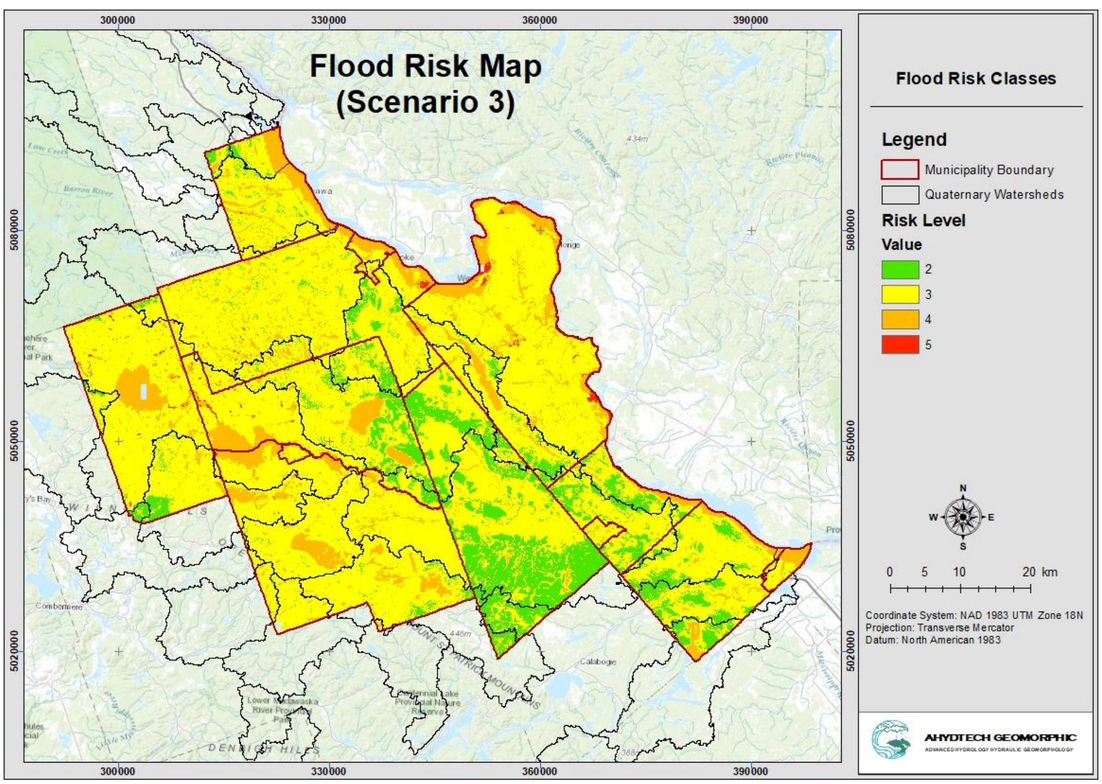

Figure 7-3: Flood Risk Map (Scenario 3)

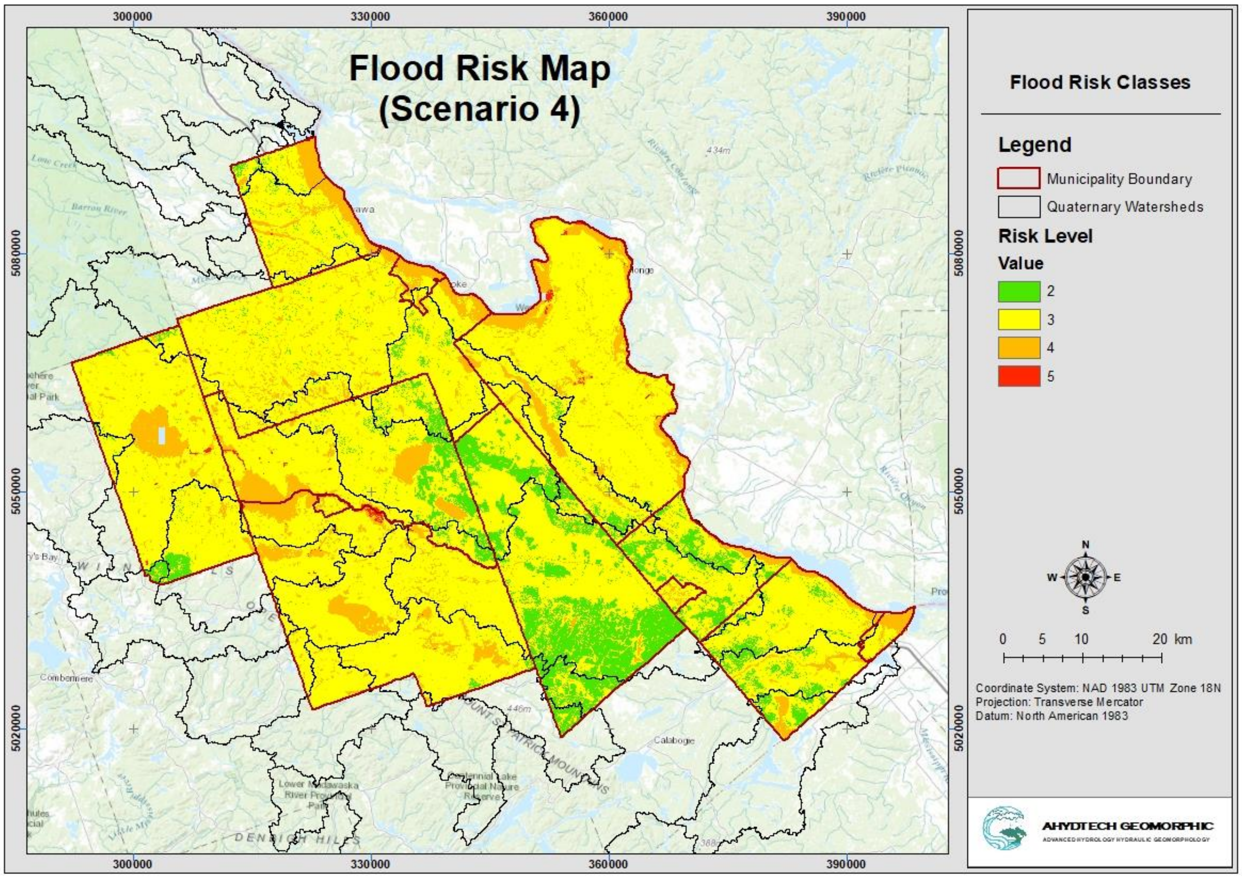

Figure 7-4: Flood Risk Map (Scenario 4)

7.2 Risk Change Analysis

Risk change analysis has been performed to identify the most suitable combination of flood hazard scenarios. It is a simple GIS based statistical analysis where Scenario 1 has been considered the base for analysis and the difference in risk level for other scenarios have been calculated. Since there are five levels of risk, the risk change value will range between -4 to 4. Following equation has been followed for calculating the risk change-

$RC = RS_1 - RS_n$;

where RC denotes risk change, RS1 denotes the risk level of Base Scenario and RS_n denotes risk level of Scenario 2, 3 and 4. RC value close to 0 indicates maximum similarities to base scenario.

Figure 7-5 indicates flood risk change for different risk scenarios with respect to the base scenario (S1). It can be observed that all three scenarios have more than 90% similarities to the base scenario. Yet scenario 3, has maximum percentage of area (94.56%) that has zero difference with base scenario. This demonstrates that even though there are some differences in flood hazard parameters in different risk scenarios, all the risk map shows almost similar results in case of identifying flood risk zones. Since, Scenario 4 have shown worst case in terms of flood hazard, it has been taken to prioritize the flood risk areas within the study area.

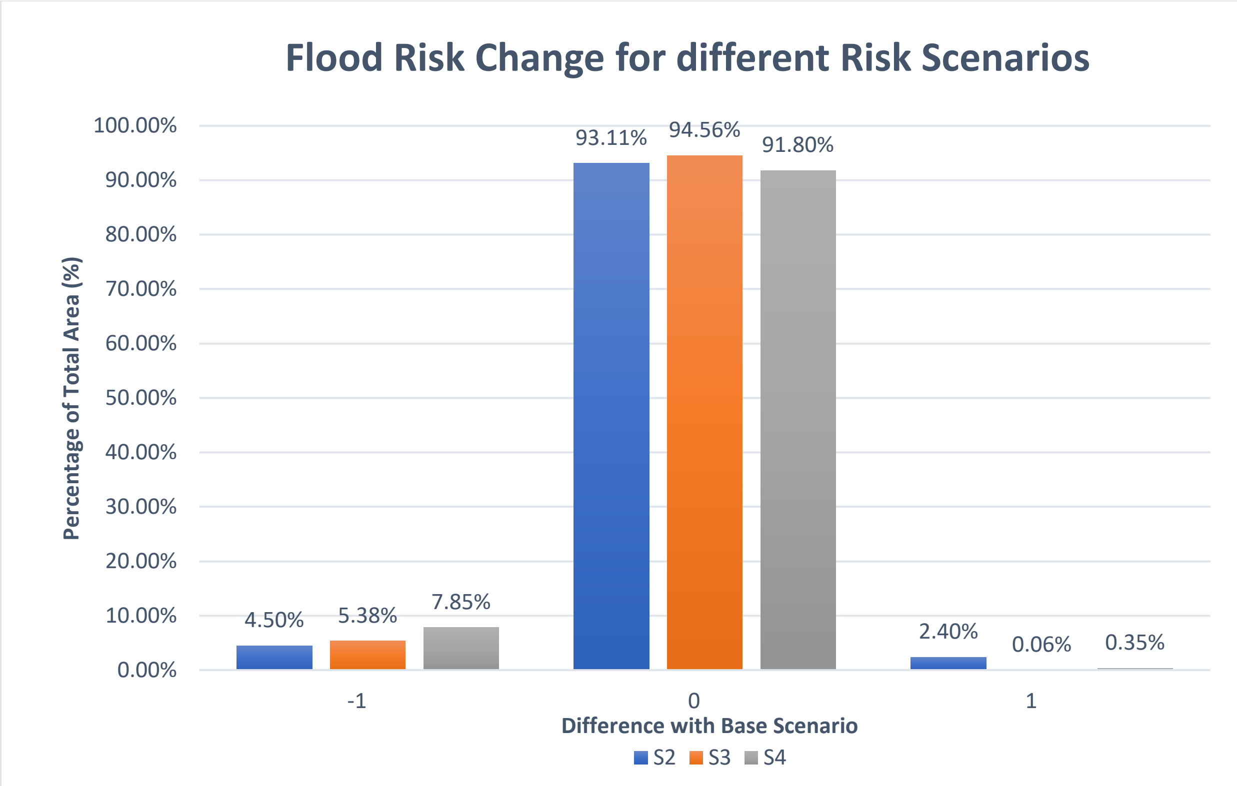

Figure 7-5: Outcome of Risk Change analysis

8 Prioritization

The main purpose of this study is to prioritize areas within flood risk for more site specific hydrologic and hydraulic assessment for floodplain map preparation. To achieve the goal of this project, flood hazard and vulnerability assessment has been performed using different hydrological parameters accountable for occurrence of flood in any area and social, economic and environmental parameters that are vulnerable to flood insecurity. The outcome of the flood hazard and vulnerability is flood risk map that is the basis of prioritization of areas within the study extent.

The criteria used for defining the prioritized area is the Quaternary Watersheds and Municipality boundaries. There are thirteen (13) municipalities, and seventeen (17) quaternary watersheds fall within the study area.

The prioritization exercise is a GIS based analysis that has been performed in two ways using '*Zonal Statistics'* and '*Frequency'* tool. Prioritization has been performed for four risk scenarios using these tools. The zonal statistics tool calculates from the values of raster cells falling within zones defined by another raster or vector dataset. Zonal statistics summarize the values of a particular group of cells. In this case zonal statistics tool calculates the statistics (minimum, maximum, mean etc.) of risk levels within a watershed or watershed segment separately for each risk scenario. On the other hand, Frequency tool reads a table and a set of fields and creates a new table containing unique field values and the number of occurrences of each unique field value. In this case the frequency tool reads the attribute table of each risk raster and creates a unique table summarizing the number of times a certain risk level occurred within a single entity (watershed or segments of watersheds in different municipalities). The first 12 nos. of watershed, 20 nos. of municipality-watershed segments, and 10 nos. of high-priority municipalities for both types of analysis have been shown here. The rank of all the 13 municipalities, 12 quaternary watersheds, and 43 segments of watersheds have been listed**.**

8.1 Watershed based Prioritization

A watershed is a natural hydrological entity that collects rainwater into streams and rivers, eventually draining through a single outlet. It is a self-contained system where water flows from higher to lower elevations. In flood mapping exercises, hydrologic models are developed for a watershed because, for any hydrological process, a watershed is considered as an ideal unit. Hence, watershed boundary has been considered to prioritize the areas.

Watershed-based prioritization refers to prioritizing the areas of flood risk within the 13 municipalities of the County of Renfrew according to the contributing watershed area. The County of Renfrew falls primarily within -the Ottawa River Watershed and, secondarily- the Central Ottawa River Watershed as per the Ontario Watershed Boundaries. Six (6) tertiary watersheds and seventeen (17) Quaternary watersheds intersect the study area boundary. Among the six tertiary watersheds, more than 90% of the study area is covered by only two watersheds. Hence, tertiary watersheds have not been considered for prioritization; instead, seventeen quaternary watersheds have been taken to prioritize the areas identifying. most flood prone zones based on flood risks for future extensive floodplain mapping studies **Figure 5-10** shows the portions of seventeen quaternary watersheds inside the study area boundary. Watershed based prioritization has been done using both Frequency and Zonal Statistics tools in ArcGIS.

Figure 8-1 shows distribution of high and very high flood risks among the 17 quaternary watersheds and **Figure 8-2** shows number of cells with High and Very High Risk in per Square Kilometer of Watershed Area.

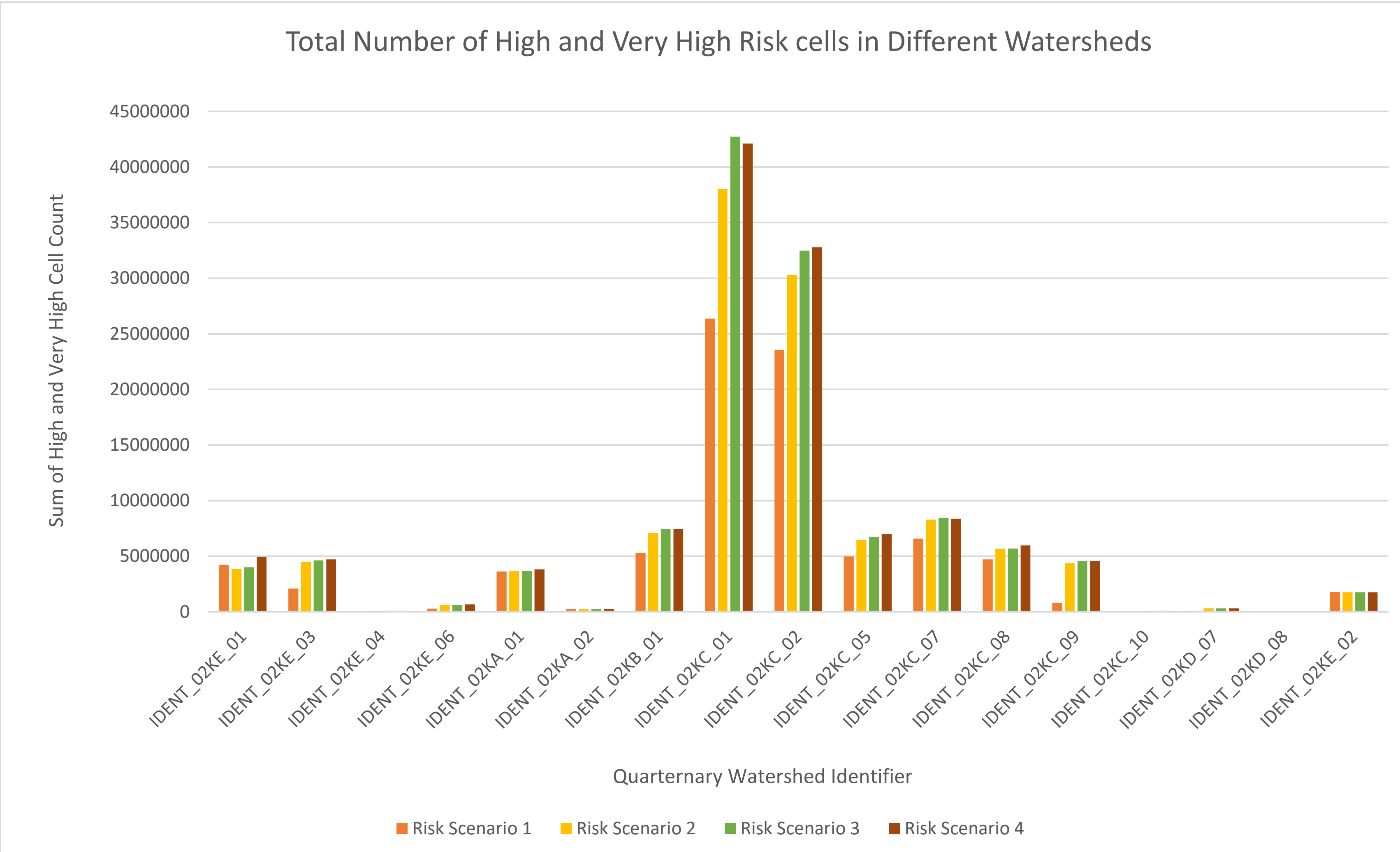

Figure 8-1: Total Number of High and Very High-Risk cells in Different Watersheds for four (4) Risk Scenarios

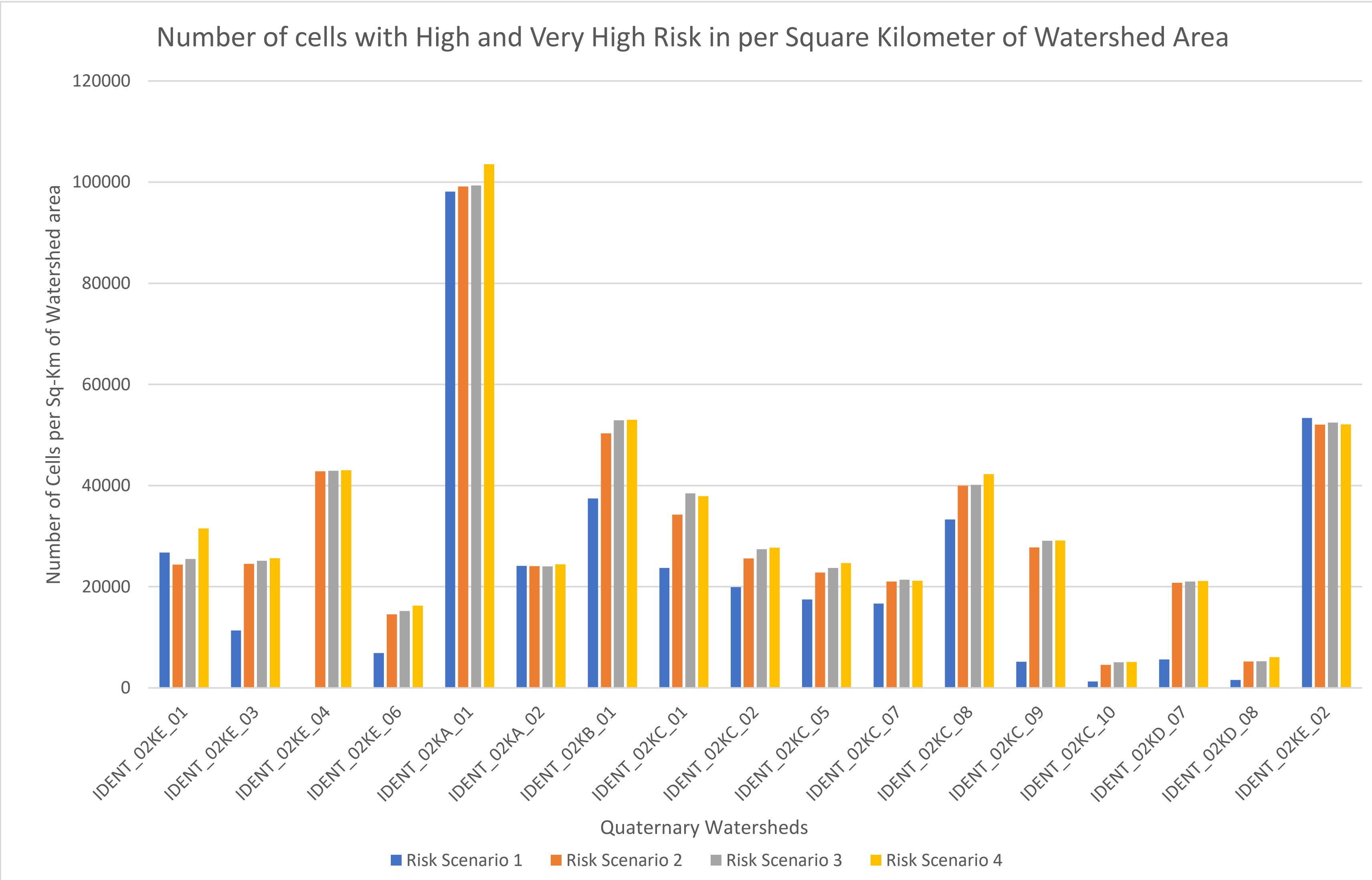

Figure 8-2: Number of cells with High and Very High Risk in per Square Kilometer of Watershed Area for different Risk Scenarios

Analyzing flow direction from stream order data collected from OIH and watershed area, it has been observed that five (5) quaternary watersheds do not have any direct impact on the study area and more than 90% of these quaternary watersheds fall outside of the study area. Quantities of high and very high-risk cells within these watersheds are also very insignificant compared to the others. Therefore, 02KD_07, 02KA_02, 02KE_04, 02KC_10 and 02KD_08 watersheds have been excluded from the priority list and the remaining twelve (12) watersheds have been ranked based on the frequency of high and very high-risk cells. Frequency tool counts the number of grids within a watershed. Summarizing the findings from **Figure 8-1** and **Figure 8-2,** a list has been prepared prioritizing the high-risk zones for four scenarios.

Table 8-1: Prioritization list of Quaternary Watersheds for all risk scenarios using Frequency Tool

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Quaternary Watershed	Frequency	Quaternary Watershed	Frequency	Quaternary Watershed	Frequency	Quaternary Watershed	Frequency
1	02KC_01	26367640	02KC_01	38042756	02KC_01	42724637	02KC_01	42111244
2	02KC_02	23560862	02KC_02	30305329	02KC_02	32469305	02KC_02	32782528
3	02KC_07	6580480	02KC_07	8294826	02KC_07	8451640	02KC_07	8366560
4	02KB_01	5273952	02KB_01	7084033	02KB_01	7443776	02KB_01	7458347
5	02KC_05	4960042	02KC_05	6466939	02KC_05	6725861	02KC_05	6997124
6	02KC_08	4706338	02KC_08	5655258	02KC_08	5677625	02KC_08	5972432
7	02KE_01	4211490	02KE_03	4503138	02KE_03	4613735	02KE_01	4957861
8	02KA_01	3620092	02KC_09	4352363	02KC_09	4557454	02KE_03	4702569
9	02KE_03	2087589	02KE_01	3839434	02KE_01	4010345	02KC_09	4565403
10	02KE_02	1791585	02KA_01	3656403	02KA_01	3663806	02KA_01	3819223
11	02KC_09	813374	02KE_02	1747796	02KE_02	1761555	02KE_02	1749357
12	02KE_06	279009	02KE_06	590441	02KE_06	616112	02KE_06	659872

In every scenario, 02KC_01, Muskrat, Indian, Westmeath Watershed near Ottawa river has ranked 1st, 02KC_02, Bonnechere River Watershed ranked 2nd and 02KC_07, Muskrat, Indian, Westmeath Watershed along the Township of Admaston/Bromley and Township of North Algona Wilberforce ranked 3rd among the twelve quaternary watersheds.

Prioritization has also been performed based on the mean risk of a watershed using 'Zonal Statistics' tool in ArcGIS for the twelve (12) watersheds mentioned above. The mean risk of each watershed was calculated which has been shown in **Figure 8-4**. **Table 8-1** shows the rank of 12 watersheds according to the mean risk value for different risk scenarios.

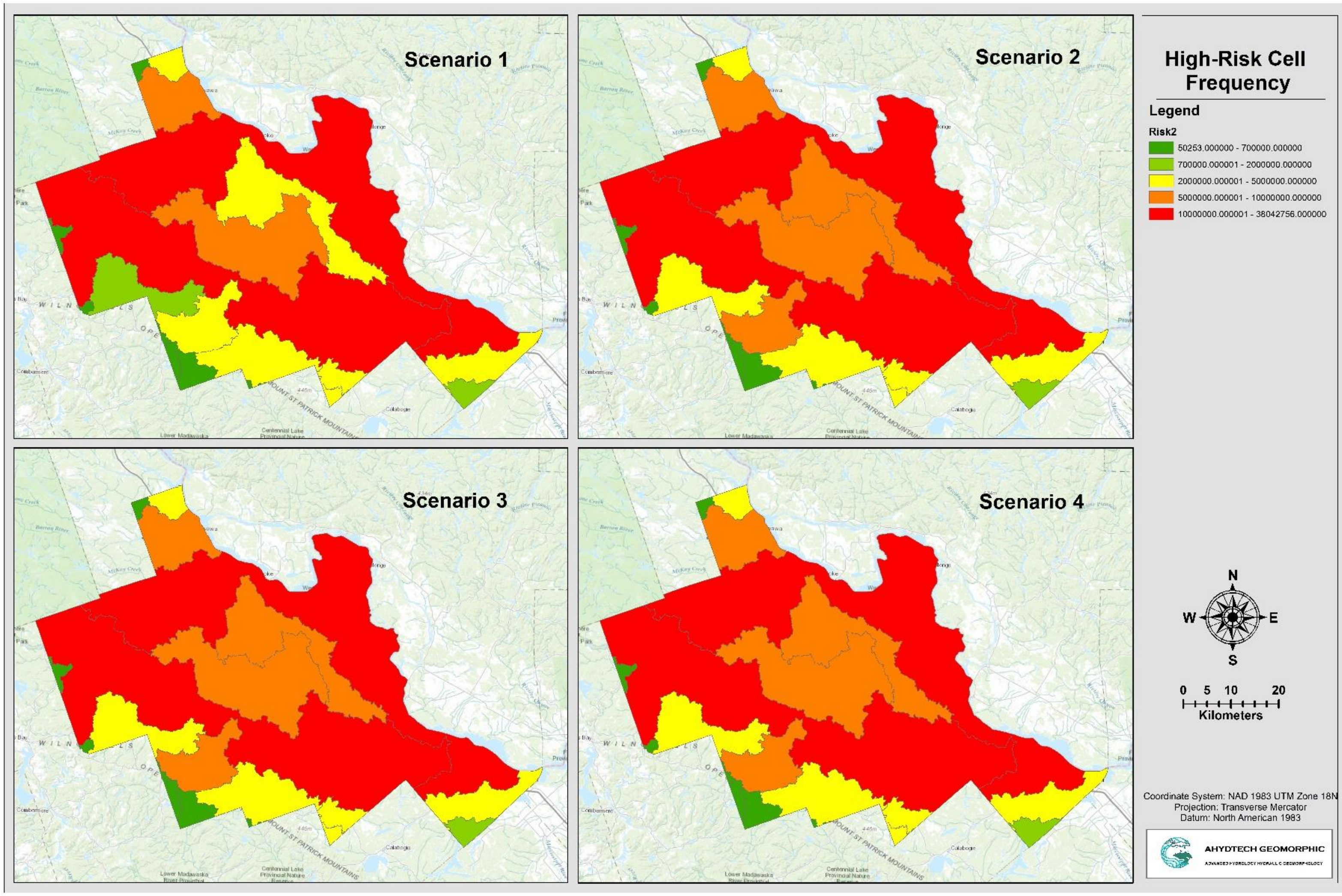

Figure 8-3: Frequency of High-Risk Cells in the Quaternary Watersheds

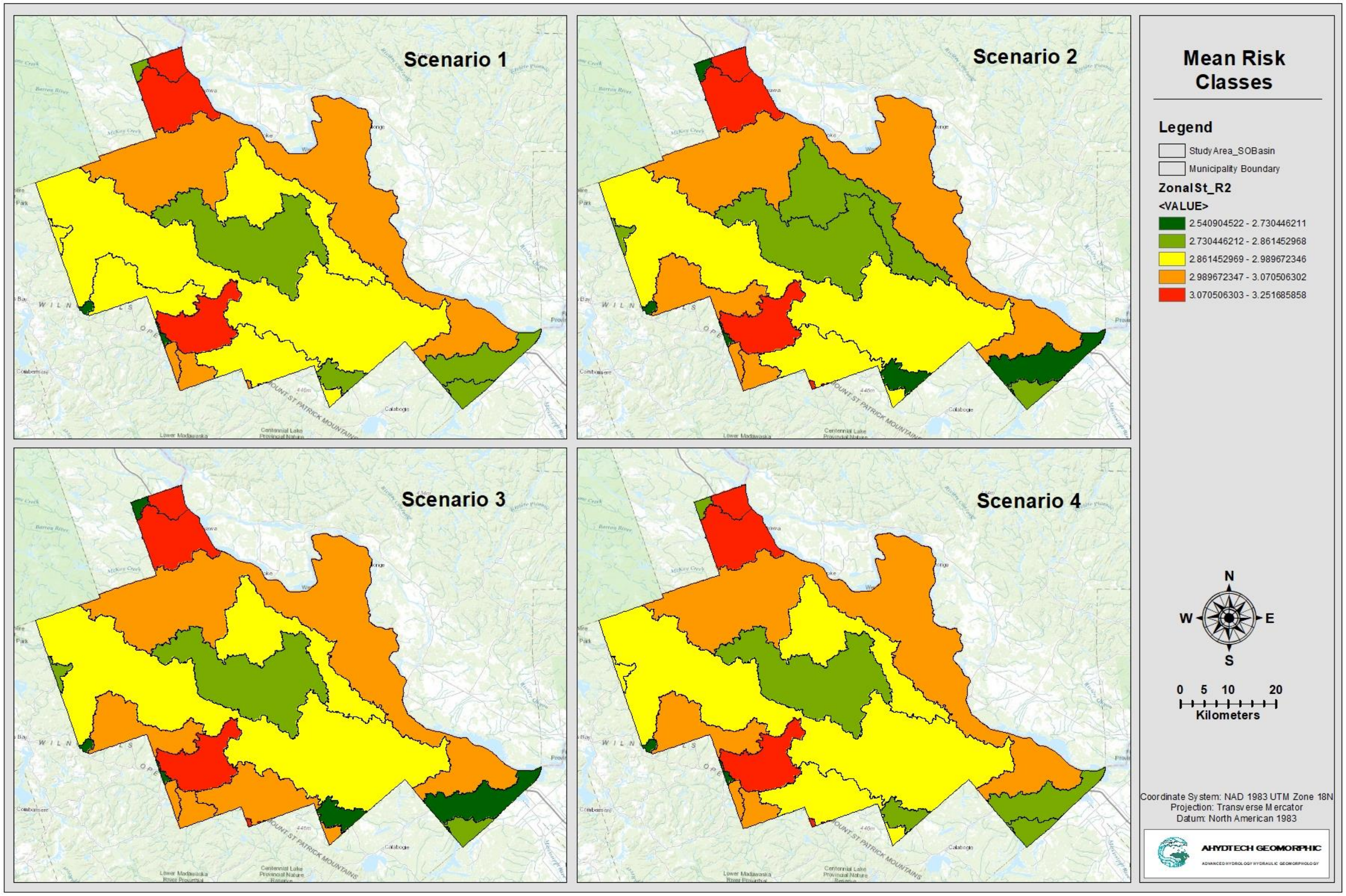

Figure 8-4: Mean Risk of the Quaternary Watersheds

Table 8-2: Prioritization list of Quaternary Watersheds for all risk scenarios using Zonal Statistics Tool

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Quaternary Watershed	Mean Risk	Quaternary Watershed	Mean Risk	Quaternary Watershed	Mean Risk	Quaternary Watershed	Mean Risk
1	02KA_01	3.276	02KA_01	3.25	02KA_01	3.28	02KA_01	3.37
2	02KC_08	3.12	02KE_01	3.17	02KB_01	3.17	02KB_01	3.18
3	02KB_01	3.11	02KC_08	3.15	02KC_08	3.15	02KC_08	3.17
4	02KC_01	3.054	02KB_01	3.11	02KC_01	3.11	02KC_01	3.12
5	02KE_06	3.023	02KC_01	3.069	02KE_06	3.06	02KC_07	3.08
6	02KC_09	2.95	02KE_06	3.058	02KC_09	3.04	02KE_06	3.06
7	02KE_03	2.93	02KC_09	3.03	02KE_03	2.99	02KC_09	3.05
8	02KC_02	2.89	02KE_03	2.99	02KC_02	2.94	02KE_03	3.02
9	02KC_05	2.87	02KC_02	2.92	02KC_07	2.86	02KC_02	2.96
10	02KC_07	2.81	02KC_05	2.86	02KC_05	2.85	02KC_05	2.96
11	02KE_02	2.77	02KC_07	2.84	02KE_02	2.77	02KE_02	2.88
12	02KE_01	2.75	02KE_02	2.73	02KE_01	2.76	02KE_01	2.85

It is evident that the two-prioritization list is different from each other which is certain because the Frequency tool calculates number of each type of risk within an area from which only high and very high-risk cell counts have been considered to prioritize the areas. On the other hand, 'Zonal Statistics' calculated mean risk of each watershed utilizing all types of risk (Category 1 to 5). Hence, considering **Table 8-2** for future flood mapping exercise will be slight underestimation for some municipalities even if they have a high number of high-risk cells. Prioritization list from **Table 8-1** on the other hand provides a more conservative output. Therefore, it is recommended to follow **Table 8-1** for future reference.

8.2 Municipality and Watershed based Prioritization

A total of 49 segments have been found combining the seventeen 17 quaternary watersheds and thirteen (13) municipality boundaries within the study extent. **Figure 8-5** shows the segments of watersheds in different municipalities of the study area.

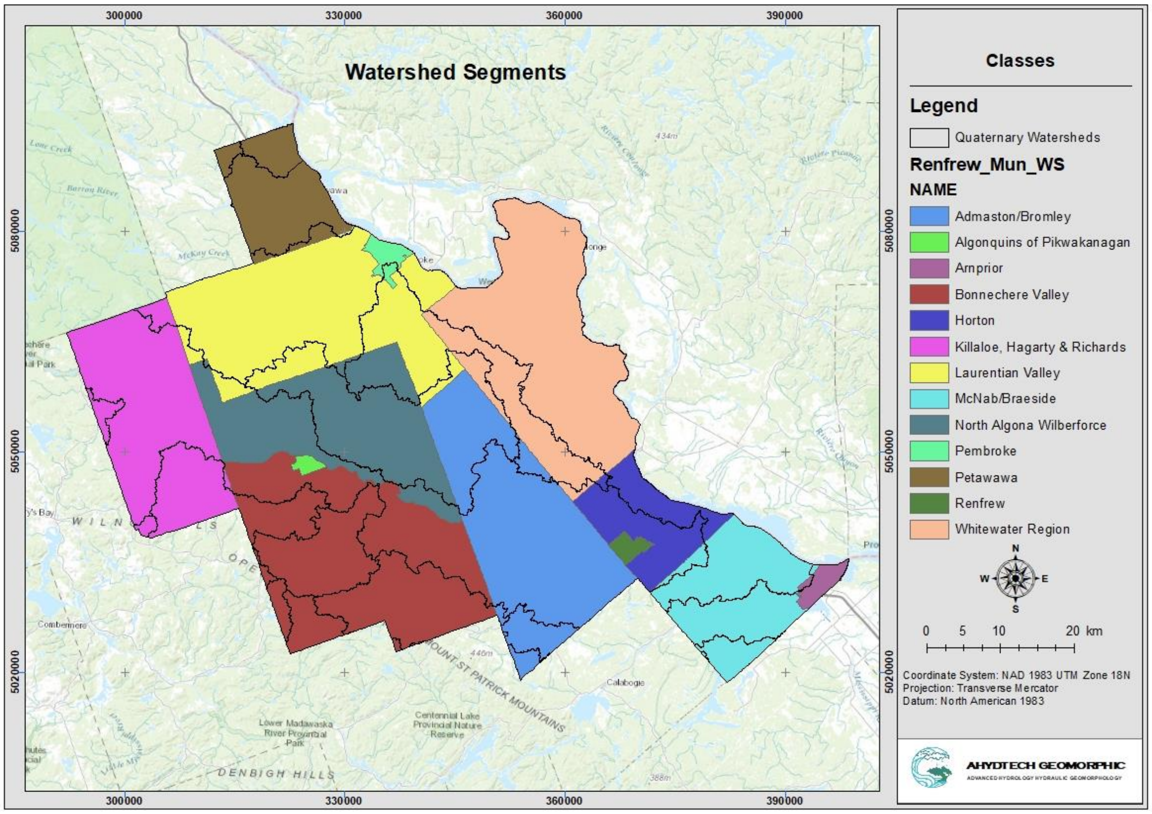

Figure 8-5: Segments of Quaternary Watersheds in different Municipalities of the Study Area

Watersheds have been categorized based on the field- “IDENT” and segments within each municipality have been named using the CSDNAME and IDENT like CSDNAME-IDENT (e.g., Horton-02KC-02).

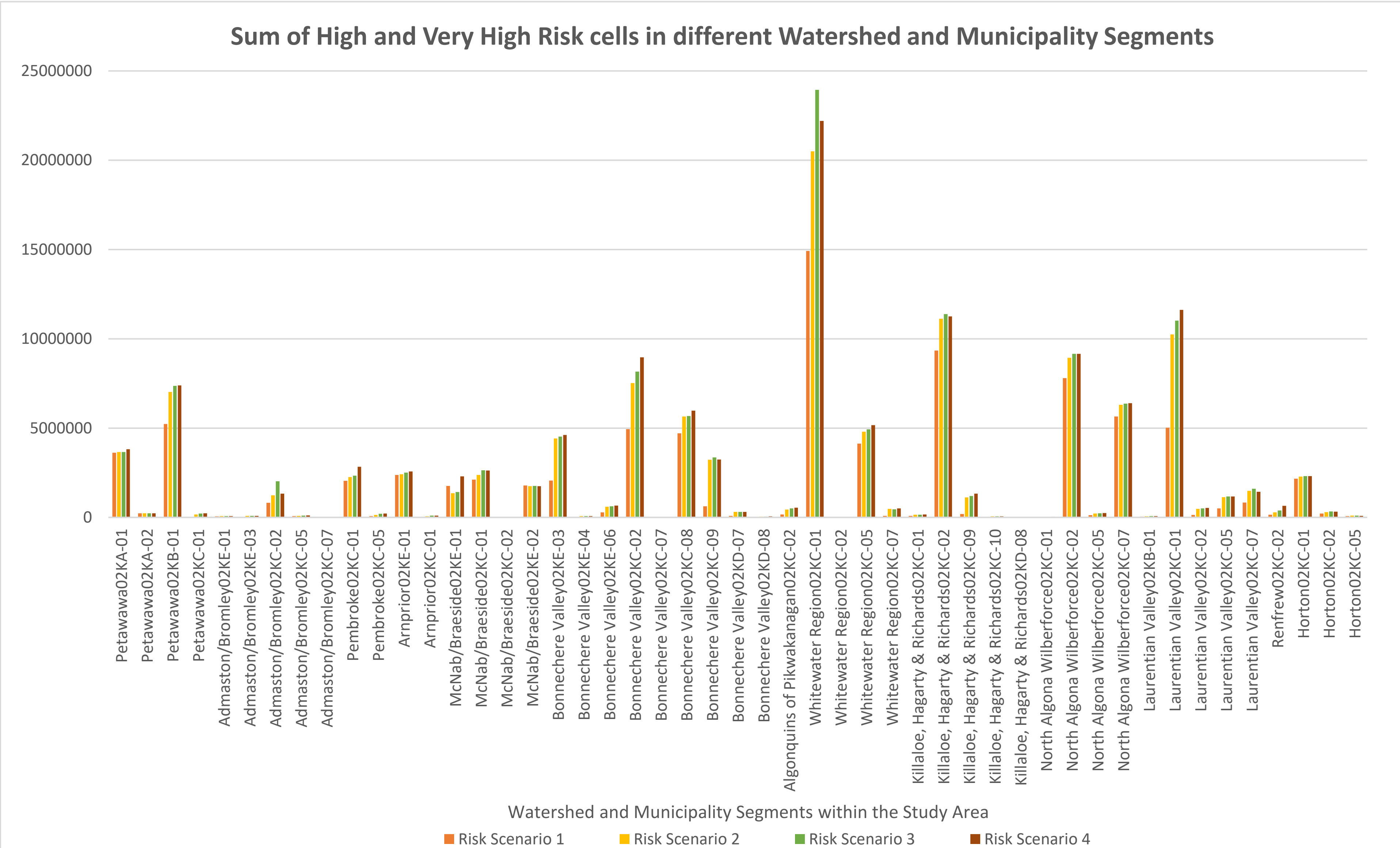

Figure 8-6: Total Number of High and Very High-Risk cells in Different 49 Municipality-Watershed segments for four (4) Risk Scenarios

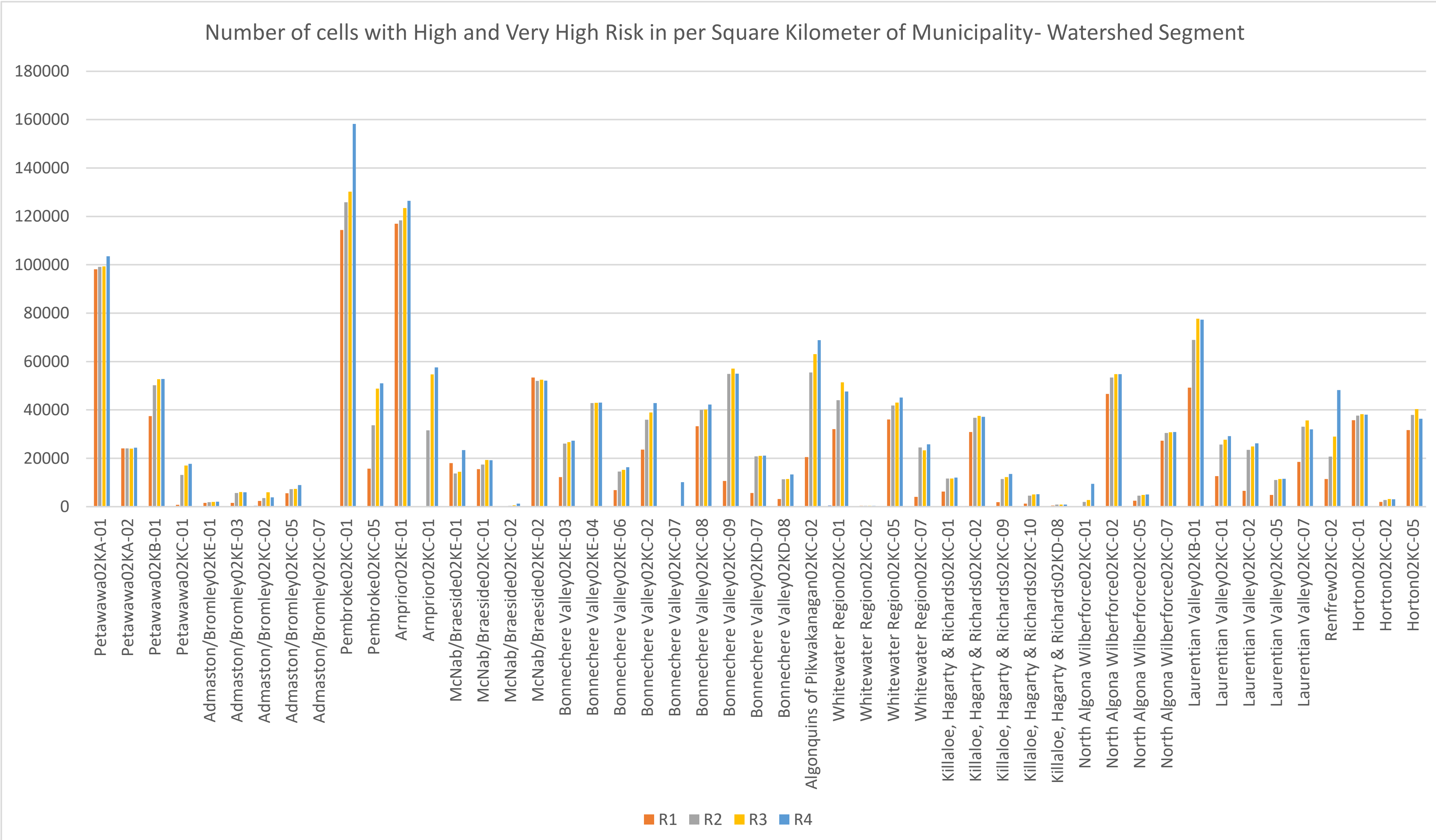

Figure 8-7: Number of cells with High and Very High Risk in per Square Kilometer of Municipality-Watershed Segment

Table 8-3: Prioritization list of Municipality-Watershed segments for all risk scenarios using Frequency Tool

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**
1	Arnprior02KE-01	116952.386	Pembroke02KC-01	125814.1835	Pembroke02KC-01	130217.25	Pembroke02KC-01	158239.2041
2	Pembroke02KC-01	114438.6697	Arnprior02KE-01	118432.9544	Arnprior02KE-01	123448.2376	Arnprior02KE-01	126500.2651
3	Petawawa02KA-01	98133.24676	Petawawa02KA-01	99117.56327	Petawawa02KA-01	99318.24337	Petawawa02KA-01	103531.2785
4	McNab/Braeside02KE-02	53355.5664	Laurentian Valley02KB-01	68935.99804	Laurentian Valley02KB-01	77673.31424	Laurentian Valley02KB-01	77275.09876
5	Laurentian Valley02KB-01	49212.61938	Algonquins of Pikwakanagan02KC-02	55503.61351	Algonquins of Pikwakanagan02KC-02	63098.07842	Algonquins of Pikwakanagan02KC-02	68873.93601
6	North Algona Wilberforce02KC-02	46627.98237	Bonnechere Valley02KC-09	54865.70256	Bonnechere Valley02KC-09	57112.49221	Arnprior02KC-01	57627.45986
7	Petawawa02KB-01	37401.88469	North Algona Wilberforce02KC-02	53382.09226	North Algona Wilberforce02KC-02	54752.8065	Bonnechere Valley02KC-09	55009.03915
8	Whitewater Region02KC-05	36056.61877	McNab/Braeside02KE-02	52051.47706	Arnprior02KC-01	54664.37349	North Algona Wilberforce02KC-02	54752.17295
9	Horton02KC-01	35756.58132	Petawawa02KB-01	50219.60532	Petawawa02KB-01	52734.6819	Petawawa02KB-01	52841.60612
10	Bonnechere Valley02KC-08	33295.18646	Whitewater Region02KC-01	43995.44608	McNab/Braeside02KE-02	52461.2367	McNab/Braeside02KE-02	52097.96552
11	Whitewater Region02KC-01	32032.24955	Whitewater Region02KC-05	41861.62488	Whitewater Region02KC-01	51396.33917	Pembroke02KC-05	51039.71972
12	Horton02KC-05	31675.99255	Bonnechere Valley02KC-08	40008.36098	Pembroke02KC-05	48861.80472	Renfrew02KC-02	48252.3363
13	Killaloe, Hagarty & Richards02KC-02	30841.33554	Horton02KC-05	37906.93678	Whitewater Region02KC-05	43019.21631	Whitewater Region02KC-01	47659.98997
14	North Algona Wilberforce02KC-07	27322.24139	Horton02KC-01	37678.97675	Horton02KC-05	40295.30745	Whitewater Region02KC-05	45086.85731

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	Frequency (Category 4 and 5)	Segment Name	Frequency (Category 4 and 5)	Segment Name	Frequency (Category 4 and 5)	Segment Name	Frequency (Category 4 and 5)
15	Bonnechere Valley02KC-02	23575.92626	Killaloe, Hagarty & Richards02KC-02	36707.51586	Bonnechere Valley02KC-08	40166.59726	Bonnechere Valley02KC-02	42823.70423
16	Algonquins of Pikwakanagan02KC-02	20467.44319	Bonnechere Valley02KC-02	35924.9338	Bonnechere Valley02KC-02	38982.96663	Bonnechere Valley02KC-08	42252.2218
17	Laurentian Valley02KC-07	18476.68304	Pembroke02KC-05	33649.49087	Horton02KC-01	38197.11543	Horton02KC-01	38009.66358
18	McNab/Braeside02KE-01	17980.23617	Laurentian Valley02KC-07	33093.60804	Killaloe, Hagarty & Richards02KC-02	37566.76365	Killaloe, Hagarty & Richards02KC-02	37158.29742
19	Pembroke02KC-05	15718.30359	Arnprior02KC-01	31519.67224	Laurentian Valley02KC-07	35623.14135	Horton02KC-05	36313.04139
20	McNab/Braeside02KC-01	15513.70472	North Algona Wilberforce02KC-07	30460.6414	North Algona Wilberforce02KC-07	30764.27335	Laurentian Valley02KC-07	31943.74333
21	Laurentian Valley02KC-01	12584.59437	Bonnechere Valley02KE-03	26102.80453	Renfrew02KC-02	28962.20092	North Algona Wilberforce02KC-07	30908.40575
22	Bonnechere Valley02KE-03	12186.33276	Laurentian Valley02KC-01	25698.7841	Laurentian Valley02KC-01	27632.03368	Laurentian Valley02KC-01	29149.30317
23	Renfrew02KC-02	11428.30023	Whitewater Region02KC-07	24443.12066	Bonnechere Valley02KE-03	26724.99964	Bonnechere Valley02KE-03	27253.30199
24	Bonnechere Valley02KC-09	10652.51892	Laurentian Valley02KC-02	23502.41978	Laurentian Valley02KC-02	24940.33736	Laurentian Valley02KC-02	26154.29514
25	Bonnechere Valley02KE-06	6881.721671	Renfrew02KC-02	20673.52484	Whitewater Region02KC-07	23327.07512	Whitewater Region02KC-07	25821.91211
26	Laurentian Valley02KC-02	6546.547701	McNab/Braeside02KC-01	17436.20773	McNab/Braeside02KC-01	19350.54134	McNab/Braeside02KE-01	23431.68962
27	Killaloe, Hagarty & Richards02KC-01	6250.088157	Bonnechere Valley02KE-06	14563.15253	Petawawa02KC-01	17046.65202	McNab/Braeside02KC-01	19241.69163
28	Admaston/Bromley02KC-05	5565.55163	McNab/Braeside02KE-01	13773.18621	Bonnechere Valley02KE-06	15196.3245	Petawawa02KC-01	17752.24087
29	Laurentian Valley02KC-05	4887.339671	Petawawa02KC-01	13177.89536	McNab/Braeside02KE-01	14429.38985	Bonnechere Valley02KE-06	16275.65936
30	Whitewater Region02KC-07	4087.374006	Killaloe, Hagarty & Richards02KC-01	11655.08968	Killaloe, Hagarty & Richards02KC-09	12200.08152	Killaloe, Hagarty & Richards02KC-09	13546.84164

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**	**Segment Name**	**Frequency (Category 4 and 5)**
31	North Algona Wilberforce02KC-05	2492.075685	Killaloe, Hagarty & Richards02KC-09	11456.52322	Killaloe, Hagarty & Richards02KC-01	11673.84566	Killaloe, Hagarty & Richards02KC-01	12043.24703
32	Admaston/Bromley02KC-02	2389.827048	Laurentian Valley02KC-05	11076.00382	Laurentian Valley02KC-05	11453.14122	Laurentian Valley02KC-05	11500.83348
33	Horton02KC-02	2002.832893	Admaston/Bromley02KC-05	7220.477055	Admaston/Bromley02KC-05	7352.71467	Bonnechere Valley02KC-07	10118.55487
34	Killaloe, Hagarty & Richards02KC-09	1900.850461	Admaston/Bromley02KE-03	5650.849557	Admaston/Bromley02KE-03	6017.995351	North Algona Wilberforce02KC-01	9412.533951
35	Admaston/Bromley02KE-01	1607.437387	North Algona Wilberforce02KC-05	4546.914025	Admaston/Bromley02KC-02	5940.978346	Admaston/Bromley02KC-05	8966.141265
36	Admaston/Bromley02KE-03	1586.566302	Admaston/Bromley02KC-02	3608.68099	North Algona Wilberforce02KC-05	4872.814796	Admaston/Bromley02KE-03	5967.848956
37	Petawawa02KC-01	808.58641	Horton02KC-02	2810.457533	Horton02KC-02	3136.632141	North Algona Wilberforce02KC-05	5077.76915
38	Whitewater Region02KC-02	414.0585349	North Algona Wilberforce02KC-01	1990.822191	North Algona Wilberforce02KC-01	2763.15809	Admaston/Bromley02KC-02	3886.270257
39	Admaston/Bromley02KC-07	127.6446072	Admaston/Bromley02KE-01	1900.894174	Admaston/Bromley02KE-01	2011.131	Horton02KC-02	3102.631405
40	North Algona Wilberforce02KC-01	7.187978527	Whitewater Region02KC-02	365.2394063	McNab/Braeside02KC-02	586.3894925	Admaston/Bromley02KE-01	2021.594069
41	Arnprior02KC-01	0	McNab/Braeside02KC-02	325.9673058	Whitewater Region02KC-02	372.6526814	McNab/Braeside02KC-02	1259.521259
42	Bonnechere Valley02KC-07	0	Admaston/Bromley02KC-07	196.7813668	Admaston/Bromley02KC-07	214.1001455	Whitewater Region02KC-02	395.7965645
43	McNab/Braeside02KC-02	0	Bonnechere Valley02KC-07	36.95600757	Bonnechere Valley02KC-07	88.69441816	Admaston/Bromley02KC-07	204.9605833

Using Zonal Statistics tool, a list has also been prepared shown in **Table 8-4**.

Table 8-4: Prioritization list of Municipality-Watershed segments for all risk scenarios using Zonal Statistics Tool

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	**Mean Risk**	**Segment Name**	**Mean Risk**	**Segment Name**	**Mean Risk**	**Segment Name**	**Mean Risk**
1	Pembroke02KC-01	3.46	Pembroke02KC-01	3.50	Pembroke02KC-01	3.52	Pembroke02KC-01	3.64
2	Arnprior02KE-01	3.46	Arnprior02KE-01	3.46	Arnprior02KE-01	3.48	Arnprior02KE-01	3.50
3	Petawawa02KA-01	3.28	Laurentian Valley02KB-01	3.27	Laurentian Valley02KB-01	3.31	Petawawa02KA-01	3.37
4	Laurentian Valley02KB-01	3.19	Petawawa02KA-01	3.25	Algonquins of Pikwakanagan02KC-02	3.28	Laurentian Valley02KB-01	3.31
5	Whitewater Region02KC-01	3.14	Algonquins of Pikwakanagan02KC-02	3.25	Petawawa02KA-01	3.28	Algonquins of Pikwakanagan02KC-02	3.30
6	North Algona Wilberforce02KC-02	3.14	Bonnechere Valley02KC-09	3.22	Bonnechere Valley02KC-09	3.23	Bonnechere Valley02KC-09	3.23
7	Bonnechere Valley02KC-08	3.12	Whitewater Region02KC-01	3.18	Whitewater Region02KC-01	3.22	Arnprior02KC-01	3.22
8	Killaloe, Hagarty & Richards02KC-02	3.12	North Algona Wilberforce02KC-02	3.17	Arnprior02KC-01	3.20	Whitewater Region02KC-01	3.20
9	Algonquins of Pikwakanagan02KC-02	3.11	Bonnechere Valley02KC-08	3.15	North Algona Wilberforce02KC-02	3.19	North Algona Wilberforce02KC-02	3.20
10	Petawawa02KB-01	3.11	Bonnechere Valley02KC-02	3.15	Pembroke02KC-05	3.17	Pembroke02KC-05	3.19
11	Bonnechere Valley02KC-02	3.10	Killaloe, Hagarty & Richards02KC-02	3.14	Petawawa02KB-01	3.17	Petawawa02KB-01	3.18
12	Bonnechere Valley02KC-09	3.04	Petawawa02KB-01	3.12	Bonnechere Valley02KC-02	3.16	Bonnechere Valley02KC-02	3.18
13	Pembroke02KC-05	3.04	Pembroke02KC-05	3.11	Killaloe, Hagarty & Richards02KC-02	3.15	Bonnechere Valley02KC-08	3.17
14	Laurentian Valley02KC-01	3.03	Arnprior02KC-01	3.09	Bonnechere Valley02KC-08	3.15	Renfrew02KC-02	3.16
15	Laurentian Valley02KC-07	3.03	Laurentian Valley02KC-02	3.09	Laurentian Valley02KC-02	3.10	Killaloe, Hagarty & Richards02KC-02	3.14
16	Laurentian Valley02KC-02	3.02	Whitewater Region02KC-07	3.09	Laurentian Valley02KC-07	3.09	Laurentian Valley02KC-07	3.11

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	Mean Risk	Segment Name	Mean Risk	Segment Name	Mean Risk	Segment Name	Mean Risk
17	Bonnechere Valley02KE-06	3.02	Bonnechere Valley02KE-06	3.06	Laurentian Valley02KC-01	3.09	Laurentian Valley02KC-02	3.10
18	Whitewater Region02KC-07	3.01	Laurentian Valley02KC-07	3.06	Whitewater Region02KC-07	3.09	Laurentian Valley02KC-01	3.10
19	Whitewater Region02KC-05	3.01	Bonnechere Valley02KE-03	3.05	Renfrew02KC-02	3.07	Whitewater Region02KC-07	3.10
20	Renfrew02KC-02	3.00	Laurentian Valley02KC-01	3.05	Bonnechere Valley02KE-06	3.06	Whitewater Region02KC-05	3.10
21	North Algona Wilberforce02KC-01	3.00	Renfrew02KC-02	3.00	Petawawa02KC-01	3.05	Bonnechere Valley02KE-03	3.09
22	Bonnechere Valley02KE-03	2.99	North Algona Wilberforce02KC-01	3.00	Bonnechere Valley02KE-03	3.05	Bonnechere Valley02KE-06	3.07
23	Petawawa02KC-01	2.99	Petawawa02KC-01	3.00	Whitewater Region02KC-05	3.04	Petawawa02KC-01	3.06
24	Bonnechere Valley02KC-07	2.98	Whitewater Region02KC-05	3.00	North Algona Wilberforce02KC-01	3.01	North Algona Wilberforce02KC-01	3.04
25	Arnprior02KC-01	2.98	Bonnechere Valley02KC-07	2.99	Bonnechere Valley02KC-07	2.99	Bonnechere Valley02KC-07	3.03
26	McNab/Braeside02KC-01	2.89	Killaloe, Hagarty & Richards02KC-09	2.92	Killaloe, Hagarty & Richards02KC-09	2.93	Laurentian Valley02KC-05	2.98
27	Killaloe, Hagarty & Richards02KC-09	2.89	North Algona Wilberforce02KC-07	2.89	North Algona Wilberforce02KC-07	2.91	McNab/Braeside02KC-01	2.96
28	North Algona Wilberforce02KC-07	2.88	Killaloe, Hagarty & Richards02KC-01	2.86	McNab/Braeside02KC-01	2.91	Horton02KC-05	2.95
29	Laurentian Valley02KC-05	2.86	Laurentian Valley02KC-05	2.85	Laurentian Valley02KC-05	2.89	Killaloe, Hagarty & Richards02KC-09	2.95
30	Horton02KC-05	2.83	McNab/Braeside02KC-01	2.83	Killaloe, Hagarty & Richards02KC-01	2.86	North Algona Wilberforce02KC-07	2.95
31	Killaloe, Hagarty & Richards02KC-01	2.82	Horton02KC-01	2.79	Horton02KC-05	2.86	McNab/Braeside02KE-01	2.91
32	Horton02KC-01	2.82	Horton02KC-05	2.76	Horton02KC-01	2.85	Killaloe, Hagarty & Richards02KC-01	2.90
33	McNab/Braeside02KE-01	2.80	McNab/Braeside02KE-02	2.73	McNab/Braeside02KE-01	2.78	McNab/Braeside02KE-02	2.89

Rank	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Segment Name	Mean Risk	Segment Name	Mean Risk	Segment Name	Mean Risk	Segment Name	Mean Risk
34	McNab/Braeside02KE-02	2.77	McNab/Braeside02KE-01	2.68	McNab/Braeside02KE-02	2.77	Horton02KC-01	2.86
35	McNab/Braeside02KC-02	2.76	McNab/Braeside02KC-02	2.65	McNab/Braeside02KC-02	2.76	McNab/Braeside02KC-02	2.84
36	Horton02KC-02	2.70	Horton02KC-02	2.65	Horton02KC-02	2.72	North Algona Wilberforce02KC-05	2.76
37	North Algona Wilberforce02KC-05	2.68	Admaston/Bromley02KC-07	2.65	North Algona Wilberforce02KC-05	2.72	Horton02KC-02	2.73
38	Admaston/Bromley02KC-07	2.57	North Algona Wilberforce02KC-05	2.63	Admaston/Bromley02KC-07	2.65	Whitewater Region02KC-02	2.71
39	Admaston/Bromley02KC-05	2.52	Admaston/Bromley02KC-05	2.55	Admaston/Bromley02KC-05	2.60	Admaston/Bromley02KC-07	2.67
40	Whitewater Region02KC-02	2.50	Admaston/Bromley02KC-02	2.53	Admaston/Bromley02KC-02	2.56	Admaston/Bromley02KC-02	2.59
41	Admaston/Bromley02KC-02	2.48	Whitewater Region02KC-02	2.44	Whitewater Region02KC-02	2.50	Admaston/Bromley02KC-05	2.58
42	Admaston/Bromley02KE-01	2.25	Admaston/Bromley02KE-01	2.31	Admaston/Bromley02KE-01	2.34	Admaston/Bromley02KE-01	2.36
43	Admaston/Bromley02KE-03	2.16	Admaston/Bromley02KE-03	2.20	Admaston/Bromley02KE-03	2.21	Admaston/Bromley02KE-03	2.21

Table 8-3 and **Table 8-4** show Frequency of High-Risk Cells in 43 Municipality-Watershed Segments and Mean Risk of those segments respectively. Since, Frequencies of high-risk cells have demonstrated more conservative results, based on this a list of 20 priority segments have been prepared. According to this list, prioritization of Municipalities has also been prepared.

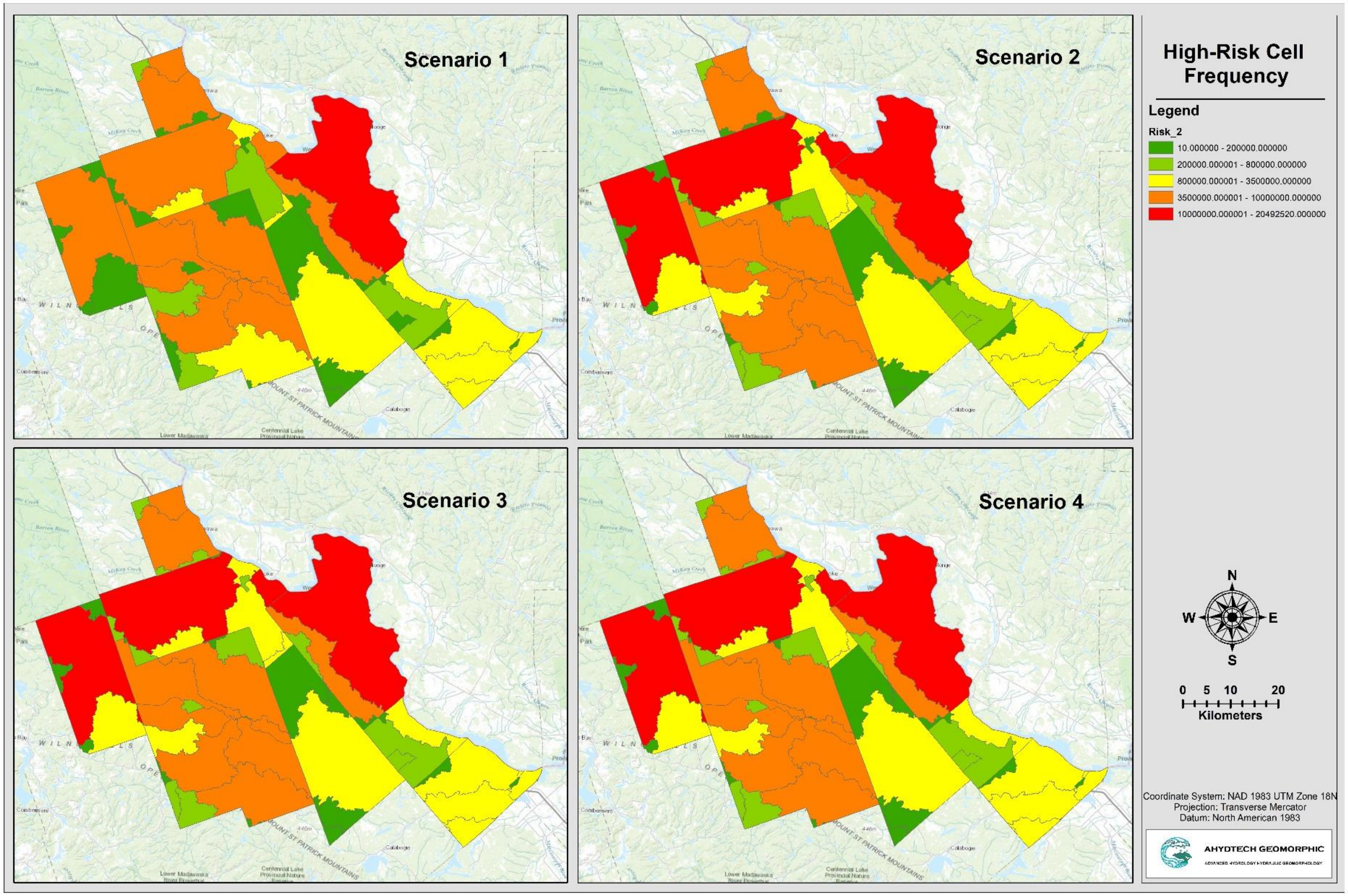

Figure 8-8: Frequency of High-Risk Cells in the Municipality-Watershed Segments

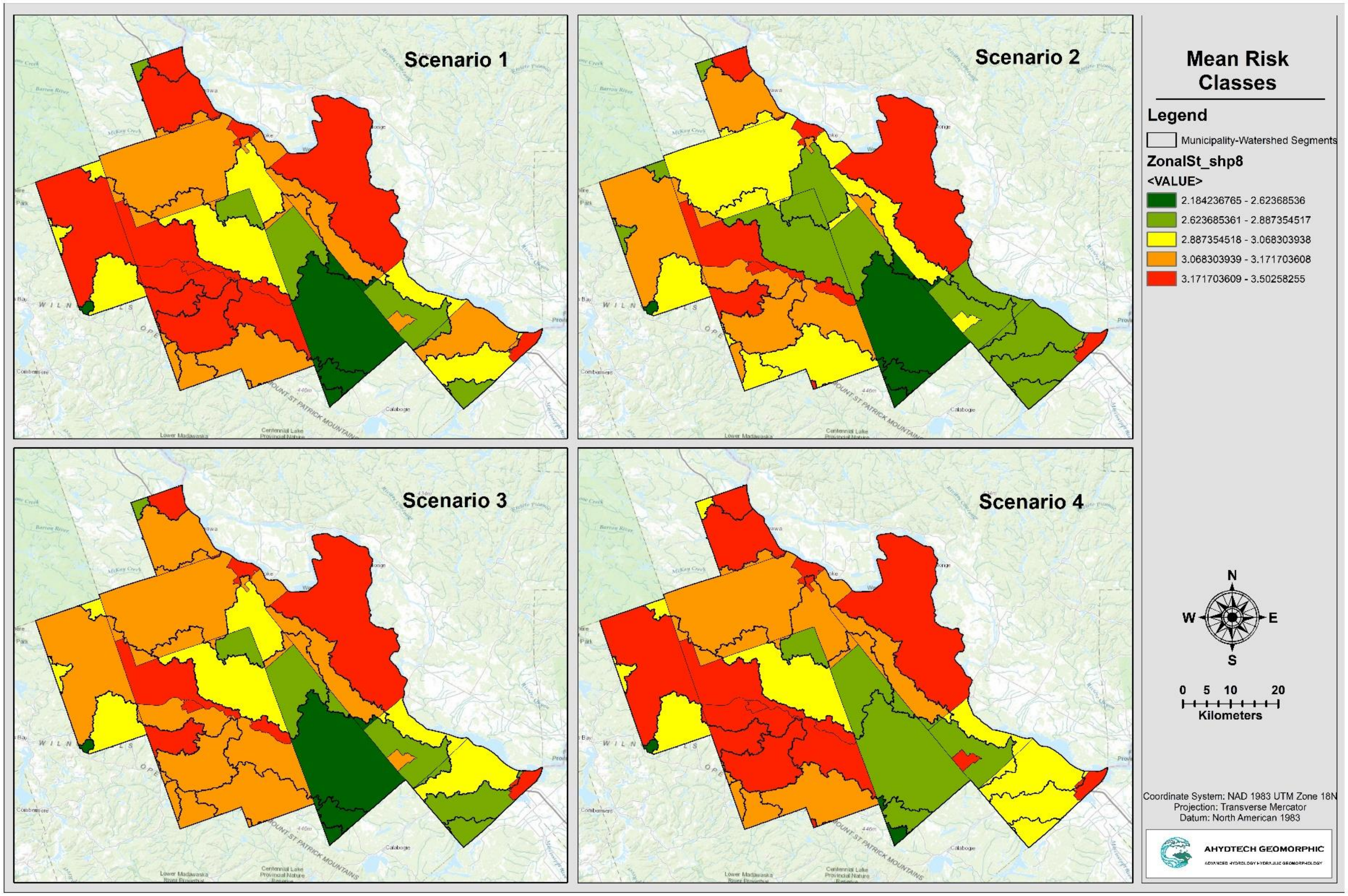

Figure 8-9 Mean Risk of the Municipality-Watershed Segments

For both watershed and municipality-watershed based prioritization, results from **Table 8-1** and

Table 8-3 of the Scenario 4 has been summarized and a final priority list of the thirteen (13) municipalities has been prepared estimating the frequency of high-risk cells per square kilometers of municipalities/watershed which has been tabulated below:

Table 8-5: Outputs of Prioritization- Rank of Municipalities and Quaternary Watersheds

Numbers of High-Risk cells in per Square Kilometers of Municipalities/Watershed			
Priority List of the Municipalities		Priority List of the Watersheds	
Rank	**Municipality Name**	**Rank**	**Watershed Identifier**
1	City of Pembroke/ Muskrat, Indian, Westmeath Watershed (02KC)	1	02KC-01
2	Town of Arnprior	2	02KE-01
3	Town of Petawawa	3	02KA-01
4	Township of Laurentian Valley	4	02KB-01
5	Algonquins of Pikwakanagan	5	02KC-02
6	Township of Bonnechere Valley	6	02KC-09
7	Township of North Algona Wilberforce	7	02KC-05
8	Township of McNab/Braeside	8	02KC-08
9	Town of Renfrew	9	02KC-07
10	Township of Whitewater Region	10	02KE-03
11	Township of Horton	11	02KE-02
12	Township of Killaloe, Hagarty & Richards	12	02KE-06
13	Township of Admaston/Bromley		

9 Conclusions

Flooding has become a greater hazard across Canada and the risk is increasing in an alarming rate. In such a condition comprehensive flood hazard and risk analysis study is a soft measure of mitigating flood insecurity. In this study a comprehensive flood risk assessment and prioritization of areas within flood risk has been performed.

Flood risk assessment is a combination of flood hazard assessment and vulnerability assessment. For the flood hazard assessment eight (8) hydrological parameters contributing to the occurrence of floods have been prepared and analyzed. Weight of each hazard parameter has been prepared by Multi-Criteria-Analysis following Analytical Hierarchy Process (AHP) method. Then the weight has been assigned to reclassify hazard parameters within weighted overlay tool to prepare a flood hazard parameter. This analysis has been performed four times for four (4) different scenarios. The scenarios have been developed by combining different hydrological parameters. The scenario containing all the hydrological parameters has been considered the base scenario. Scenario 4 shows the worst hazard condition among all other scenarios. The highest percentage of high (36%) and very high (3%) hazard has been observed for scenario 4.

The vulnerability assessment has been performed combining social, economic and environmental criteria that are susceptible to flood damage. In social vulnerability six demographic and statistical criteria have been used. Economic vulnerability has been determined from the land use data. Environmental vulnerability has been determined from three criteria naming- Wild-life habitat, Fish habitat and Wetland. A total vulnerability map has been prepared from spatially overlaying the social, economic and environmental vulnerability in Weighted Overlay Tool.

Then risk maps are prepared by assigning equal weights to flood hazard and vulnerability for all hazard scenarios. Comparing the change in risk values of three scenarios with the base scenario demonstrates that all the scenarios show more than 90% similarity with the base scenario shows almost identical results even if there are significant changes in parameters.

Scenario 4 has been considered for prioritization as it shows maximum number of high-risk cells which is the combination of Slope, Distance to Stream, Curve Number, Watershed Stream Order, Total Precipitation, Topographic Wetness Index. It has 91.8% similarities with the base scenario.

The final step is to prioritize areas with high risk of flooding. For prioritization, quaternary watershed boundaries have been considered as the basis. Prioritization has been performed in two methods, using two different GIS based tools which are Zonal Statistics and Frequency tool. Frequency tool analysis only accounts for the areas within high-risk level where the Zonal statistical analysis averages all the risk levels within an area. As the Frequency tool resulted in more conservative outputs based on high and very high-risk cells, considering those results prioritization has been made.

Muskrat, Indian, Westmeath Watershed (02KC) / City of Pembroke-02KC01 has ranked 1st for all scenarios and this area has the maximum numbers of high-risk cells per square kilometers of area. Town of Arnprior-02KE01 has ranked 2nd and Town of Petawawa-02KA01 has ranked 3rd. Therefore, for the further steps, the highest priority area- the City of Pembroke and Muskrat, Indian, Westmeath watershed (02KC) must be considered.

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Appendix A

Weight Calculation by Multi-Criteria Analysis of Flood Hazard Parameters

Scenario 2

Table 1: Assigned Importance Score for Base Scenario 2

Criteria		Weight	
A	**B**	**Importance (A/B)**	**Value**
Slope	Distance to Streams (DS)	B	2
	Height above Nearest Drainage (HAND)	A	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	3
	Watershed Stream Order	B	2
	Topographic Wetness Index (TWI)	A	2
Distance to Streams (DS)	Height above Nearest Drainage (HAND)	A	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
	Topographic Wetness Index (TWI)	A	2
Height above Nearest Drainage (HAND)	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
	Topographic Wetness Index (TWI)	A	2
Curve Number (CN)	Total Precipitation (TP)	B	2
	Watershed Stream Order	B	2
	Topographic Wetness Index (TWI)	A	1
Total Precipitation (TP)	Watershed Stream Order	A	2
	Topographic Wetness Index (TWI)	A	3
Watershed Stream Order	Topographic Wetness Index (TWI)	A	2

Table 2: Comparison Matrix for Base Scenario 2

Comparison Matrix							
Criteria	**Slope**	**Distance to Streams (DS)**	**Height above Nearest Drainage (HAND)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**	**Topographic Wetness Index (TWI)**
Slope	1	0.5	1	2	0.333333333	0.5	2
Distance to Streams (DS)	2	1	1	2	0.5	1	2
Height above Nearest Drainage (HAND)	1	1	1	2	0.5	1	2

Curve Number (CN)	0.5	0.5	0.5	1	0.5	0.5	1
Total Precipitation (TP)	3	2	2	2	1	2	3
Watershed Stream Order	2	1	1	2	0.5	1	2
Topographic Wetness Index (TWI)	0.5	0.5	0.5	1	0.333333333	0.5	1
Sum	**10**	**6.5**	**7**	**12**	**3.666666667**	**6.5**	**13**

Table 3: Normalization Matrix for Base Scenario 2

Normalization							
Criteria	**Slope**	**Distance to Streams (DS)**	**Height above Nearest Drainage (HAND)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**	**Topographic Wetness Index (TWI)**
Slope	0.10	0.08	0.14	0.17	0.09	0.08	0.15
Distance to Streams (DS)	0.20	0.15	0.14	0.17	0.14	0.15	0.15
Height above Nearest Drainage (HAND)	0.10	0.15	0.14	0.17	0.14	0.15	0.15
Curve Number (CN)	0.05	0.08	0.07	0.08	0.14	0.08	0.08
Total Precipitation (TP)	0.30	0.31	0.29	0.17	0.27	0.31	0.23
Watershed Stream Order	0.20	0.15	0.14	0.17	0.14	0.15	0.15
Topographic Wetness Index (TWI)	0.05	0.08	0.07	0.08	0.09	0.08	0.08
Sum	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table 4: Final Weight of Each Parameter for Base Scenario 2

Parameters	Weights	Percentage
Slope	0.115446458	12
Distance to Streams (DS)	0.158203701	16
Height above Nearest Drainage (HAND)	0.143917987	14
Curve Number (CN)	0.081699253	8

Parameters	Weights	Percentage
Total Precipitation (TP)	0.267323153	26
Watershed Stream Order	0.158203701	16
Topographic Wetness Index (TWI)	0.075205747	8
Sum	1	**100**

Scenario 3

Criteria		Weight	
A	B	Importance (A/B)	Value
Slope	Distance to Streams (DS)	B	2
	Height above Nearest Drainage (HAND)	A	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
Distance to Streams (DS)	Height above Nearest Drainage (HAND)	A	1
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
Height above Nearest Drainage (HAND)	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
Curve Number (CN)	Total Precipitation (TP)	B	2
	Watershed Stream Order	B	2
Total Precipitation (TP)	Watershed Stream Order	A	1

Table 5: Assigned Importance Score for Base Scenario 3

Table 6: Comparison Matrix for Base Scenario 3

Comparison Matrix						
Criteria	**Slope**	**Distance to Streams (DS)**	**Height above Nearest Drainage (HAND)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**
Slope	1	0.5	1	2	0.5	1
Distance to Streams (DS)	2	1	1	2	0.5	1

Height above Nearest Drainage (HAND)	1	1	1	2	0.5	1
Curve Number (CN)	0.5	0.5	0.5	1	0.5	0.5
Total Precipitation (TP)	2	2	2	2	1	1
Watershed Stream Order	1	1	1	2	1	1
Sum	**7.5**	**6**	**6.5**	**11**	**4**	**5.5**

Table 7: Normalization Matrix for Base Scenario 3

Normalization						
Criteria	**Slope**	**Distance to Streams (DS)**	**Height above Nearest Drainage (HAND)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**
Slope	0.13	0.08	0.15	0.18	0.13	0.18
Distance to Streams (DS)	0.27	0.17	0.15	0.18	0.13	0.18
Height above Nearest Drainage (HAND)	0.13	0.17	0.15	0.18	0.13	0.18
Curve Number (CN)	0.07	0.08	0.08	0.09	0.13	0.09
Total Precipitation (TP)	0.27	0.33	0.31	0.18	0.25	0.18
Watershed Stream Order	0.13	0.17	0.15	0.18	0.25	0.18
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 8: Final Weight of Each Parameter for Base Scenario 3

Parameters	Weights	Percentage
Slope	0.143191531	14
Distance to Streams (DS)	0.179302642	18
Height above Nearest Drainage (HAND)	0.15708042	16
Curve Number (CN)	0.088956876	9
Total Precipitation (TP)	0.253554779	25
Watershed Stream Order	0.177913753	18
Sum	1	100

Scenario 4

Table 9: Assigned Importance Score for Base Scenario 4

Criteria		Weight	
A	B	Importance (A/B)	Value
Slope	Distance to Streams (DS)	B	2
	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
	Topographic Wetness Index (TWI)	A	2
Distance to Streams(DS)	Curve Number (CN)	A	2
	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
	Topographic Wetness Index (TWI)	A	2
Curve Number (CN)	Total Precipitation (TP)	B	2
	Watershed Stream Order	A	1
	Topographic Wetness Index (TWI)	A	1
Total Precipitation (TP)	Watershed Stream Order	A	2
	Topographic Wetness Index (TWI)	A	2
Watershed Stream Order	Topographic Wetness Index (TWI)	A	2

Table 10: Comparison Matrix for Base Scenario 4

Comparison Matrix						
Criteria	**Slope**	**Distance to Streams (DS)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**	**Topographic Wetness Index (TWI)**
Slope	1	0.5	2	0.5	1	2
Distance to Streams (DS)	2	1	2	0.5	1	2
Curve Number (CN)	0.5	0.5	1	0.5	1	1
Total Precipitation (TP)	2	2	2	1	2	2
Watershed Stream Order	1	1	1	0.5	1	2
Topographic Wetness Index (TWI)	0.5	0.5	1	0.5	0.5	1
Sum	**7**	**5.5**	**9**	**3.5**	**6.5**	**10**

Table 11: Normalization Matrix for Base Scenario 4

Normalization						
Criteria	**Slope**	**Distance to Streams (DS)**	**Curve Number (CN)**	**Total Precipitation (TP)**	**Watershed Stream Order**	**Topographic Wetness Index (TWI)**
Slope	0.14	0.09	0.22	0.14	0.15	0.20
Distance to Streams (DS)	0.29	0.18	0.22	0.14	0.15	0.20
Curve Number (CN)	0.07	0.09	0.11	0.14	0.15	0.10
Total Precipitation (TP)	0.29	0.36	0.22	0.29	0.31	0.20
Watershed Stream Order	0.14	0.18	0.11	0.14	0.15	0.20
Topographic Wetness Index (TWI)	0.07	0.09	0.11	0.14	0.08	0.10
Sum	**1**	**1**	**1**	**1**	**1**	**1**

Table 12: Final Weight of Each Parameter for Base Scenario 4

Parameters	**Weights**	**Percentage**
Slope	0.158781959	16
Distance to Streams (DS)	0.197742998	20
Curve Number (CN)	0.111692012	11
Total Precipitation (TP)	0.277496577	27
Watershed Stream Order	0.155414955	16
Topographic Wetness Index (TWI)	0.098871499	10
Sum	1	**100**

Appendix B

Weight Calculation by Multi-Criteria Analysis of Social Vulnerability Parameters

Table 1 Assigned Importance Score for Base Scenario

Criteria		Weight	
A	B	Importance (A/B)	Value
Population Density	Percentages of population for 0-4 years	A	1
	Percentages of population for 65 years and above.	A	1
	Median income per household.	A	2
	Number of non-English speakers.	A	2
	Percentage of people with highest degree as high school or less.	A	2
Percentages of population for 0-4 years	Percentages of population for 65 years and above.	A	1
	Median income per household.	B	2
	Number of non-English speakers.	A	2
	Percentage of people with highest degree as high school or less.	A	2
Percentages of population for 65 years and above.	Median income per household.	A	2
	Number of non-English speakers.	A	2
	Percentage of people with highest degree as high school or less.	A	2
Median income per household.	Number of non-English speakers.	A	2
	Percentage of people with highest degree as high school or less.	A	1
Number of non-English speakers.	Percentage of people with highest degree as high school or less.	A	2

Table 2 Comparison Matrix for Base Scenario

Comparison Matrix						
Criteria	**Population Density**	**Percentages of population for 0-4 years**	**Percentages of population for 65 years and above.**	**Median income per household.**	**Number of non-English speakers.**	**Percentage of people with highest degree as high school or less.**
Population Density	1	1	1	2	2	2
Percentages of population for 0-4 years	1	1	1	0.5	2	2
Percentages of population for 65 years and above.	1	1	1	2	2	2
Median income per household.	0.5	2	0.5	1	2	1
Number of non-English speakers.	0.5	0.5	0.5	0.5	1	2
Percentage of people with highest degree as high school or less.	0.5	0.5	0.5	1	0.5	1
Sum	**4.5**	**6**	**4.5**	**7**	**9.5**	**10**

Table 3: Normalization Matrix for Base Scenario

Normalization						
Criteria	**Population Density**	**Percentages of population for 0-4 years**	**Percentages of population for 65 years and above.**	**Median income per household.**	**Number of non-English speakers.**	**Percentage of people with highest degree as high school or less.**
Population Density	0.222222222	0.166666667	0.222222222	0.285714286	0.210526316	0.2
Percentages of population for 0-4 years	0.222222222	0.166666667	0.222222222	0.071428571	0.210526316	0.2
Percentages of population for 65 years and above.	0.222222222	0.166666667	0.222222222	0.285714286	0.210526316	0.2
Median income per household.	0.111111111	0.333333333	0.111111111	0.142857143	0.210526316	0.1
Number of non-English speakers.	0.111111111	0.083333333	0.111111111	0.071428571	0.105263158	0.2
Percentage of people with highest degree as high school or less.	0.111111111	0.083333333	0.111111111	0.142857143	0.052631579	0.1

Table 4: Final Weight of Each Parameter for Base Scenario

Parameters	**Weights**	**%**	**Rounded Weightage**
Population Density	0.217891952	21.7892	22
Percentages of population for 0-4 years	0.182177666	18.21777	18
Percentages of population for 65 years and above.	0.217891952	21.7892	22
Median income per household.	0.168156502	16.81565	17
Number of non-English speakers.	0.113707881	11.37079	11
Percentage of people with highest degree as high school or less.	0.100174046	10.0174	10
Sum	**1**	**100**	**100**