

Flood Hazard Identification and Priority Setting  
for the County of Renfrew

# Final Hazard Identification Report

November 2023



County of  
**Renfrew**  
Ontario . Canada



**AHYDTECH GEOMORPHIC**  
ADVANCED HYDROLOGY HYDRAULIC GEOMORPHOLOGY

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## Abbreviations and Acronyms

DEM	Digital Elevation Model
ECCC	Environment and Climate Change Canada
FDRP	Flood Damage Reduction Program
FHIMP	Flood Hazard Identification and Mapping Program
GIS	Geographic Information System
GRD	Ground Range Detected
LiDAR	Light Detection and Ranging
LULC	Land Use Land Cover
NFHD	National Flood Hazard Database
NRCan	Natural Resources Canada
ORRPB	Ottawa River Regulation Planning Board
SAR	Synthetic Aperture Radar



## 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 7,357.94 square kilometers of area, mainly 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 county is exposed to various types of flood hazards, such as riverine floods, flash floods, and urban floods. This area has experienced several major floods in recent years, such as in 2017 and 2019, which caused significant damage to homes, businesses, roads, bridges, and utilities. Flooding is a frequent phenomenon that affects the County as it is situated along the right bank of the Ottawa River that flows to the St Lawrence River downstream. Ottawa river is the largest tributary of the St. Lawrence River and consists of 15 Major tributaries. Two of the main tributaries on the Ontario side of the Ottawa river flowing within the study area are Madawaska and Petawawa Rivers. Very few studies have been undertaken to identify the flood hazard related issues in comparison to the frequent occurrence and hazardous impacts of flood within the study area.

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.

The pre-identified areas include- Town of Arnprior, Town of Renfrew, Town of Petawawa, City of Pembroke, First Nations of Algonquins of Pikwakanagan, Township of McNab/Braeside, Township of Horton, Township of Admaston/Bromley, Township of Whitewater Region, Township of Laurentian Valley, Township of Bonnechere Valley, Township of Killaloe, Hagarty & Richards, and Township of North Algona Wilberforce. The study area has been illustrated in Figure 1. The entire study area covers approximately 3890 square kilometers of area. The project will be a part of a multi-phase plan leading to updated flood hazard maps, including data acquisition and flood hazard modeling which will allow Renfrew to identify shortfalls in current mapping, identify and prioritize areas for acquiring new mapping, plan strategies for acquiring the data required, and prepare work plans for future analysis. The project will help to inform decision-making in support of land use planning, flood mitigation, adaptation to a changing climate, resilience building, and protection of lives and properties.

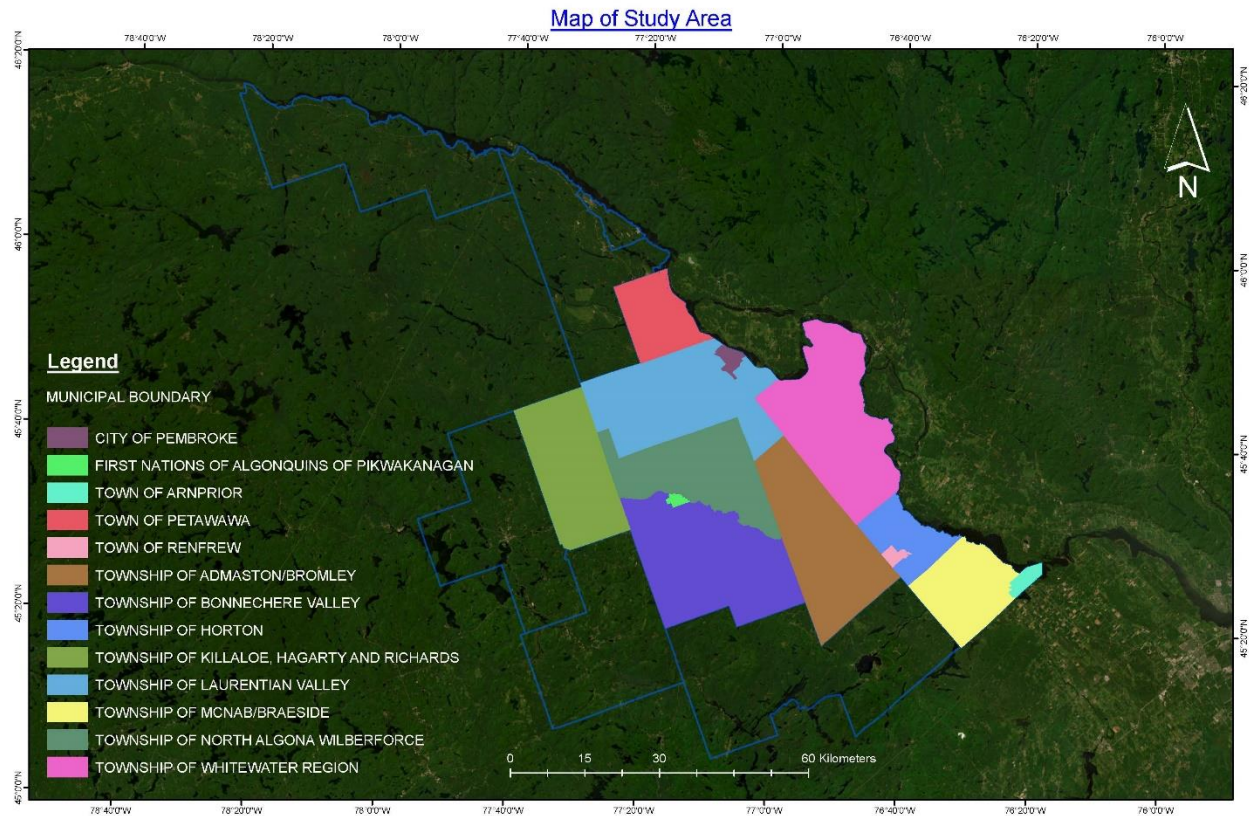


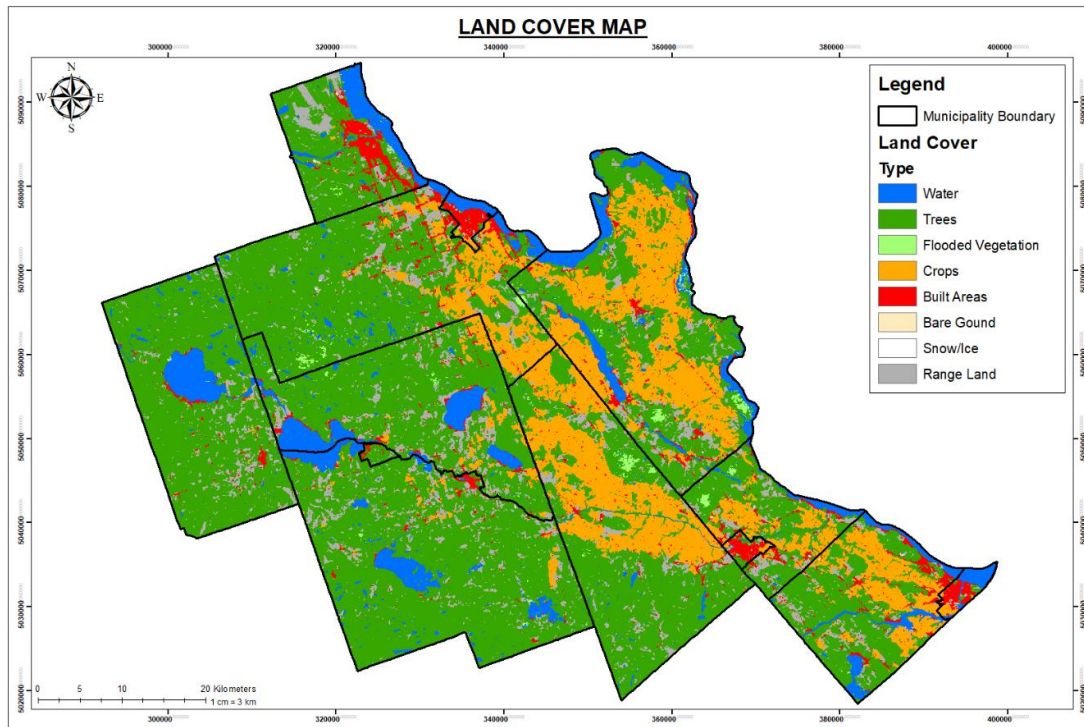
Figure 1-1: Map showing Municipalities within the Study area at the County of Renfrew

## 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 7,357.94 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 is in the primary region of Southern Ontario and the secondary region Eastern or Southeastern Ontario. It has a humid continental climate with four distinct seasons. The average annual temperature is 5.6 °C and the average annual precipitation is 1,016 mm. 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. 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, percentage

of impervious built area is very low (4.0%). Most of the built areas are situated on the right bank of Ottawa river. The various types of land use of the study area are illustrated in **Figure 1-2**.



*Figure 1-2: Land Cover map of Study Area*

Ottawa river is the largest tributary of the St. Lawrence River and consists of 15 Major tributaries. Only 35% of Ottawa river watershed is situated within Ontario. Rest of 65 is situated in Quebec. Over 60% of the Ottawa River basin has no storage reservoir to hold back spring runoff. The County of Renfrew lies within this area. The analysis of river systems and their connectivity is very important in any flood risk analysis study. The County of Renfrew encompasses a complex network of river/creek system that is a part of the Saint Lawrence River drainage basin in Ontario. **Figure 1-3** illustrates the major tributaries, and a brief description of the river network is given below-

**Petawawa River** flows from Algonquin Provincial Park to the Ottawa River through the town of Petawawa. The river heads north out of the lake over Big Trout Lake Dam, takes in the left tributary Tim River, flows over several rapids to reach Cedar Lake. It has several left and right bank tributaries- Jorgens Creek (left), Lac du Bois Dur Charlebois Creek (left), Barron River (right), Black Bay Creek (right), Centre Creek (left), Black Duck Creek (left), Lorne Creek (right), Military Creek (left), Cartier Creek (left), and Louie Creek (left) etc. The river flows for approximately 187 km and occupies a basin area of 4200 square kilometers.

**Muskrat River** originates from the Edmunds Lake in White-water region and then flows northwest. It has four major tributaries naming- Indian River (Left), Mud Creek (Left), Snake River

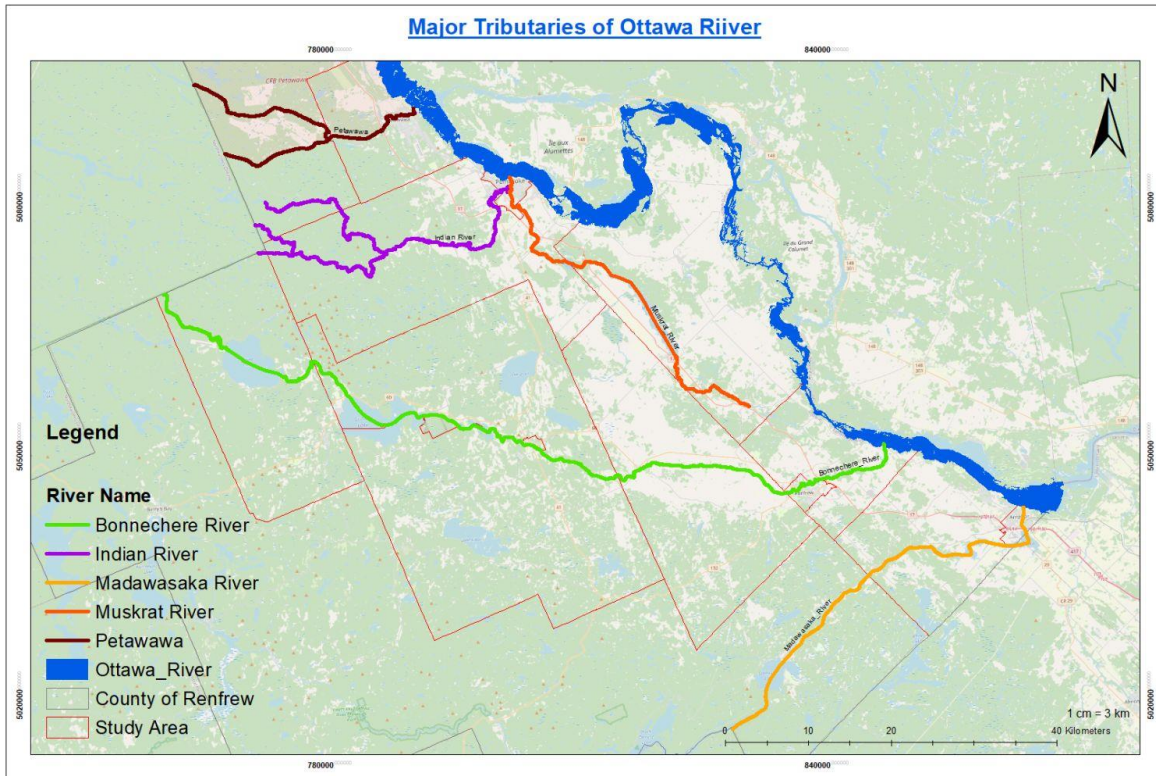


Figure 1-3: Map Showing Major Tributary Network of Ottawa River passing through the study area

(Left), and Buttermilk Creek (Right). Just before the river meets Muskrat Lake, the right tributary, Buttermilk creek joins Muskrat River.

**Indian River** originates from the wetlands of Laurentian valley and converges into Muskrat River within the city of Pembroke approximately 2 kilometers away from Ottawa river. The main tributaries of the Indian River are: O'Mearas Creek (left), Locksley Creek (right), Maves Creek (left), Crooked Lake Creek (right), Kelly Lake Creek (right), Gariepy Creek (right), Little Cranberry Creek (right), Turquoise Creek (left), Steer Creek (left), Walker Creek (left), Each of these tributaries contributes to the flow of the Indian River and can have an impact on flood conditions.

**Bonnechere river** connects Round Lake, Golden Lake, and Wilber Lake. It originates from the Algonquin Provincial Park and flows east towards Ottawa River through the township of Killaloe, Hagarty and Richards, Bonnechere Valley, Admaston/Bromley, Renfrew, and Horton. It's almost 145 km in length and occupies a basin area of 2400 square kilometers. There are several tributaries of the river originating from the lakes that the river connects. Two prominent tributaries of Bonnechere River are- Pine River (Left) and Sherwood River (Right).

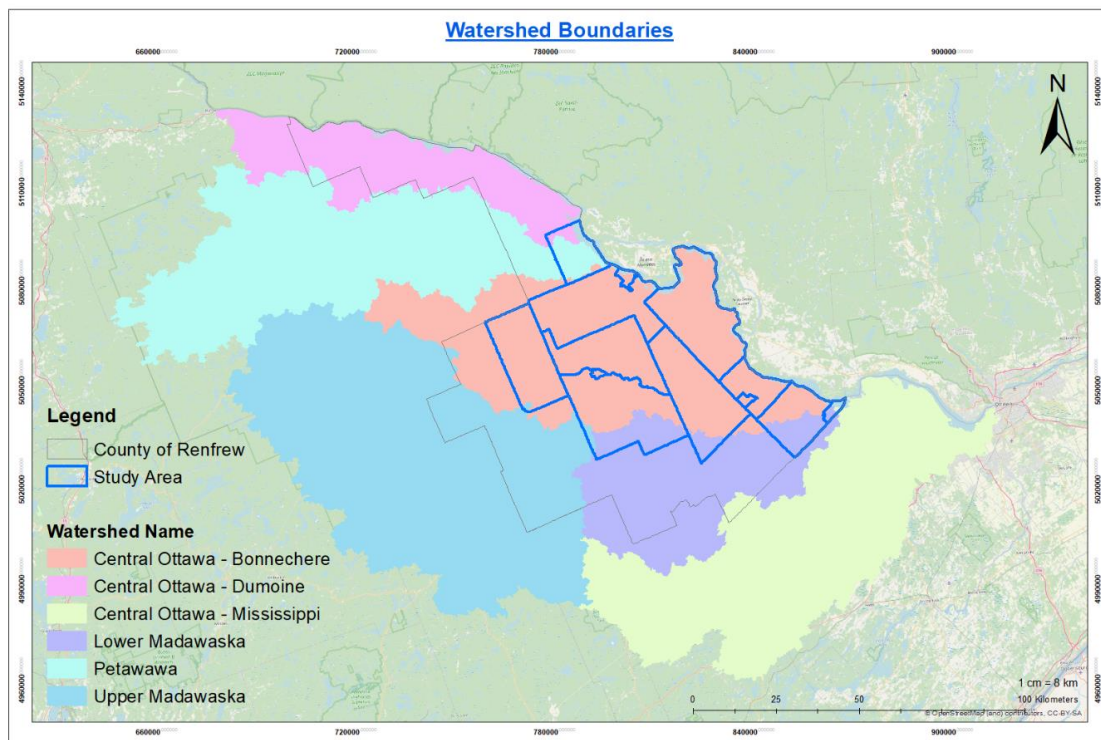
**Madawasaka River** originates far away from the boundaries of County of Renfrew at Source Lake, in the highlands of southern Algonquin Park. The lower portion of the river feeds into Centennial Lake, Black Donald Lake, Calabogie Lake, Madawaska Reservoir (Annprior Head Pond), Kamaniskeg Lake and then flows towards Ottawa river though the city of Annprior. The river is 230 km (143 mi) long and drains an area of 8,470 square kilometers.

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.

The entire province of Ontario has been divided into three major primary watershed which drains the water through Great Lakes - St. Lawrence, Southwestern Hudson Bay, and Nelson River system ([Ontario GeoHub \(gov.on.ca\)](http://Ontario.GeoHub.gov.on.ca)). The concerned study area lies within the primary watershed of St. Lawrence River system. The primary watershed of St. Lawrence River system is divided into seventeen secondary watersheds among which three watersheds are connected to Ottawa River naming- Upper Ottawa, Central Ottawa, and Lower Ottawa watershed. The county of Renfrew encompasses approximately 32.75% of the area of the Central Ottawa watershed.

**Figure 1-4** illustrates the tertiary watersheds within Central-Ottawa Watershed that drains through the study area. Broadly six watershed naming-Central Ottawa Dumoine, Petawawa, Central Ottawa Bonnechere, Upper Madawaska, Lower Madawaska, and Central Ottawa - Mississippi Watershed.



*Figure 1-4: Map of Watersheds Boundaries Concerning County of Renfrew*

### 1.3 Objectives 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.

The entire activities to be performed under this study has been categorized into four distinct yet interconnected tasks such as-

- i. Flood Hazard Identification
- ii. Priority Setting based on multi-criteria analysis
- iii. Data Inventory and Gaps Assessment
- iv. Priority Setting and Identification of Future Scope of Work

The purpose of this 'Draft Hazard Identification Report' is to identify and assess the flood hazards within the study area using various methods and data sources. The report will provide valuable information for flood risk management and planning in the county.

## 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 1: List of Data

Task Name	Data Type
Flood Hazard Identification	<ul style="list-style-type: none"> <li>• Available Flood Hazard maps.</li> <li>• Relevant Reports of the previous Flood Hazard and Risk Analysis studies.</li> <li>• Previous Flood Hazard Modelling information (Hydrologic and Hydraulic Model)</li> <li>• Available Municipality/Town wise Flood reports.</li> <li>• Technical Reports on the Existing Official Plan Maps.</li> <li>• 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).</li> <li>• Epigraphic markings and Available Images captured during any previous flood events.</li> <li>• Available Historical Satellite Images relating to the major flood events.</li> <li>• LiDAR Data.</li> <li>• Available Watershed Study Reports.</li> </ul>
Priority Setting based on Multi-Criteria Analysis	<ul style="list-style-type: none"> <li>• Fine Resolution DEM of entire study area</li> <li>• Soil Data</li> <li>• Land Use and Land Cover Data (LULC)</li> <li>• Precipitation Data (Snowmelt).</li> <li>• Demographic Data (Age, Family Structure, Language, Income, Education, Renters, Population Density etc.) compatible with GIS Environment. If GIS based data is not available, then the latest statistical data/reports.</li> </ul>
Data Inventory and Gaps Assessment and Identification of future scope of work	<ul style="list-style-type: none"> <li>• As built drawings of all bridges and culverts.</li> <li>• In-line hydraulic structure database and drawings.</li> <li>• Available topographic and bathymetric survey data.</li> <li>• Information regarding the previously developed hydrologic and hydraulic models.</li> </ul>

### 3. Review of Existing Studies and Guidelines

The following Policy Documents have been reviewed during the study-

#### Federal Flood Mapping Framework (Version 2.0)

The document provides guidelines for the development of flood maps in Canada, with a focus on identifying areas at risk of flooding. It covers various types of floods, including riverine, coastal, and urban floods, and highlights the factors that contribute to flooding. The guidelines outline different methods and technologies that can be used to map flood hazards, such as remote sensing, hydrological modeling, and historical data analysis. The document is intended to be used

by federal, provincial, and territorial governments, as well as other organizations involved in flood mapping. It emphasizes the importance of collaboration and data sharing among stakeholders to ensure accurate and up-to-date flood maps. The guidelines also highlight the need for ongoing monitoring and evaluation to improve the effectiveness of flood mapping efforts.

### **Bibliography of Best Practices and References for Flood Mitigation (Version 2.0)**

The document focuses on development of a national flood hazard database for Canada. It describes the methodology, data sources, and quality assessment of the database, which contains information on historical and potential flood events across the country. The document also presents some applications and analyses of the database, such as mapping flood frequency, estimating flood damages, and identifying flood risk areas.

Bibliography of Best Practices and References for Flood Mitigation provides a comprehensive overview of the flood hazard situation in Canada, as well as a reference for data and methods that can be used for your project. Some of the key points from the document are:

- The national flood hazard database (NFHD) was developed by Natural Resources Canada (NRCan) in collaboration with federal, provincial, and territorial partners, as well as academic and private sector experts.
- The NFHD contains information on more than 6,000 historical and potential flood events across Canada, covering the period from 1900 to 2015.
- The NFHD includes various types of data, such as flood location, date, duration, magnitude, frequency, cause, impact, mitigation measures, and references.
- The NFHD uses a standardized classification system for flood types, based on the main cause of flooding (e.g., rainfall, snowmelt, ice jam, storm surge, etc.).
- The NFHD also incorporates spatial data from various sources, such as digital elevation models, hydrographic networks, land cover maps, population and infrastructure data, and flood hazard maps.
- The NFHD underwent a rigorous quality assessment process, involving data validation, verification, and cross-checking by multiple sources and experts.
- The NFHD is intended to support various applications and analyses related to flood hazard assessment and management in Canada.

Bibliography of Best Practices and References for Flood Mitigation demonstrates some examples of such applications and analyses, such as:

- Mapping the spatial distribution and frequency of historical and potential flood events in Canada.
- Estimating the economic damages caused by historical and potential flood events in Canada.
- Identifying the areas with high flood risk in Canada, based on the combination of flood hazard, exposure, and vulnerability factors.
- The document also discusses some limitations and challenges of the NFHD, such as data gaps, inconsistencies, uncertainties, and accessibility issues.

Bibliography of Best Practices and References for Flood Mitigation concludes by highlighting the benefits and potential of the NFHD for enhancing the understanding and management of flood hazard in Canada.



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## **Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation**

The document is a publication by Natural Resources Canada and Public Safety Canada that outlines the federal hydrologic and hydraulic procedures for floodplain delineation. The document is intended as a resource for practitioners who conduct hydrologic and hydraulic investigations before developing floodplain maps. Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation covers the following topics:

- The definition and types of floodplains and floods, and the factors that influence flood frequency and magnitude.
- The data sources and methods for estimating design flood flows, such as regional analysis, rainfall-runoff models, and hydrologic routing.
- The data sources and methods for estimating flood water levels, such as hydraulic models, empirical equations, and field measurements.
- The data sources and methods for mapping flood extents and depths, such as geographic information systems, remote sensing, and ground surveys.
- The considerations and challenges for floodplain delineation in different environments, such as urban areas, coastal zones, ice-affected rivers, and reservoirs.
- The quality assurance and quality control procedures for ensuring the accuracy and reliability of floodplain delineation results.

The Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation also provides examples of floodplain delineation applications in Canada and references to relevant standards, guidelines, and literature. The document aims to support flood mitigation efforts by providing consistent and scientifically sound procedures for floodplain delineation across Canada.

## **Federal Geomatics Guidelines for Flood Mapping (Version 1.0)**

The document is a publication by Natural Resources Canada and Public Safety Canada and is a part of the Federal Flood Mapping Guidelines Series. This document covers the Flood Mapping and Dissemination components of the Flood Mapping Framework. It contains information on the different types of flood maps and outlines technical specifications to consider when acquiring, managing, and disseminating these maps and their associated geospatial data. The document detailed the Geospatial Data Requirements for Flood Modelling. It also laid out different types of flood maps and their purpose for creation. Detailed information regarding developing Flood Risk and Awareness maps were included in the document.

## **Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure (Version 1.0)**

This document provides guidance on how to evaluate potential economic losses, with a focus on buildings and infrastructure, incurred as a result of flooding. This document focuses on describing the range of flooding hazards and the factors affecting flood damage. It also describes different methods available for estimating damage resulting from flooding - primarily riverine. The document provides guidance on how to develop and use stage-damage curves as well as considerations on their use, accuracy, and limitations and also guidance for future adjustments and regional indexing of stage-damage curves. It lists the flood types and damage influencing characteristics for each type of flood. The document detailed the damage reduction strategies along with different types of floods. The document also describes the tools for damage estimation and the stage-damage Curve. Future adjustments and regional indexing methods are also discussed in the document.

## **Case Studies on Climate Change in Floodplain Mapping (Volume 1.0)**

This collection of documents describes projects from across Canada where climate change has been incorporated into the floodplain mapping process. It will provide examples for practitioners to draw on and learn from others' experiences and will complement the climate change-related information and resources included in the "Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation" document. The case studies incorporating climate change into floodplain mapping are- Flood Mapping and Climate Change: City of Surrey Case Study, Flood Mapping and Climate Change Case Study: Integration of Climate Change in Flood Mapping in British Columbia's Lower Mainland – Fraser River and Coast and Flood Mapping and Climate Change: Waterford River Case Study Analysis.

## **4. Flood Hazard Identification**

### **4.1 Analysis of Historical Flood Events**

#### **4.1.1 Literature Review**

A significant background review has been conducted to identify and analyze the historical flood events experienced by the County of Renfrew. Different sources such as News portals, flood reports, available flood archive databases and mapping products have been extensively reviewed primarily to identify the types and causes of floods that inundated the study area.

Ontario typically experiences flooding caused by a variety of reasons such as snowmelt during spring, rainfall storms in the spring and summer, thunderstorms, tropical storms, hurricanes, and ice jams etc. However, the primary reason for flooding is the melting of snow during the spring season. In spring 2019, Ontario, Quebec and New Brunswick experienced exceptional flooding which broke all the previous records. Flooding along the Ottawa River was recognized as the most important weather event of the year.

When any extreme weather event such as high-intensity or long-duration rainfall events, rapid snowmelt, ice jams etc. occur, the land easily gets inundated near the Ottawa river. Four major rivers within the study area that drain into the Ottawa river are Petawawa River, Muskrat River, Bonnechere River, and Madawaska River. These tributaries have considerable impacts on flooding the adjacent lands and communities.

The County of Renfrew has a number of recorded flood events primarily caused by the Ottawa River flooding since it is located along the right bank of the river. The county has a very flat topography which made the county prone to flooding caused by the increase of Ottawa river water levels. Among its seventeen municipalities, municipalities that are located at the bank of Ottawa river are very susceptible to floods. Detail analyses have been performed on the historically available data related to the flood events previously occurred at the study area, located within the County of Renfrew which have been discussed in the following sections.

#### **4.1.2 Historical Imagery Analysis**

The most recent high magnitude flood within the study area occurred in 2017 and 2019. Along with literature review, existing satellite images from various sources were also reviewed for clear understanding of the historic flood scenario. The historical imagery analysis was configured in the following steps-



### ❖ Analysis using Google Earth Pro

Initially the 'Show Historical Imagery' tool within Google Earth Pro was explored to understand the extent of historical flood scenarios within the study area by shuffling between images from different acquisition dates at different times of the year. The study area was called on to the Google Earth Pro interphase as a layer shapefile. The observation from the initial analysis were not up to the mark as for most of the years, satellite images were only available for Dry season. Very few images were available for monsoon season, but the cloud coverage on the images were very high which made it quite difficult to visualize the flood extent accurately. But this analysis helped to identify the date range for the further analysis using Google Earth Engine.

### ❖ Analysis using Google Earth Engine

The analysis using Google Earth Engine was based on collecting Sentinel 1-grade image for two different time-ranges- one that represents the images before flood and one that represents an image after flood. The before and after time-range were determined for the catastrophic flood of 2019. The dates selected for Before Image Collection started from 2019-04-10 to 2019-04-22. The dates for After Image Collection started from 2019-04-22 to 2019-05-10.

The Sentinel-1 mission provides data from a dual-polarization C-band Synthetic Aperture Radar (SAR) instrument. This collection includes the S1 Ground Range Detected (GRD) scenes, processed using the Sentinel-1 Toolbox to generate a calibrated, ortho-corrected product. The collection is updated daily. New assets are ingested within two days after they become available. Each scene contains either 1 or 2 out of 4 possible polarization bands, depending on the instrument's polarization settings. The possible combinations are single band VV or HH, and dual band VV+VH and HH+HV:

VV: single co-polarization, vertical transmit/vertical receive;

HH: single co-polarization, horizontal transmit/horizontal receive;

VV + VH: dual-band cross-polarization, vertical transmit/horizontal receive;

HH + HV: dual-band cross-polarization, horizontal transmit/vertical receive.

This analysis was performed considering the 'VH' Transmitter Receiver Polarization. The selected images were clipped using the study area boundaries. The required codes to perform the analysis were written on the 'Code Editor' platform within Google Earth Engine. The before and after flooded vectors after the analysis are illustrated in **Figure 4-1**.

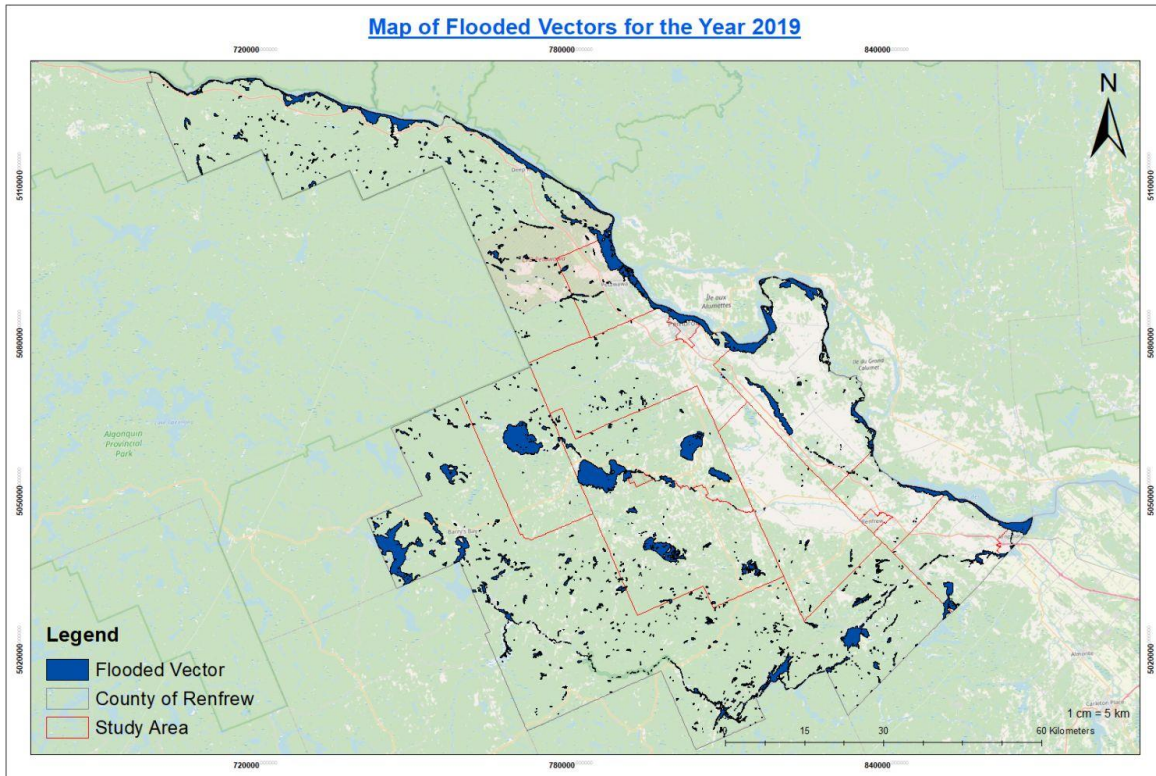


Figure 4-1: Outcome of Analysis for 2019 Flood using Google Earth Engine

The accumulated area of all the flooded vectors accounts for 443.85 square kilometers, where the entire area of County of Renfrew is 7646 square kilometers. A similar analysis can be performed for all severe flooding years.

❖ **Analysis using existing database ([Floods in Canada - Cartographic Product Collection - Open Government Portal](#))**

The Government of Canada has maintained an open access rich database focusing of flood hazard. Natural Resources Canada (NRC) monitors active and past floods throughout Canada using satellite imagery for emergency response. They have created a collection of cartographic products that includes flood extent polygons and their associated footprints. The dataset was created by analysis images from April to May for the years 2017 and 2019. The sensor type of images were Synthetic Aperture Radar and Optical Sensor. The flood data were classified in four classes depending on their severity and extent.

The outcome of the analysis, illustrating spatial distribution of flood for four different classes based on flood extent is shown in **Figure 4-2**. The Yellow polygon represents 'Class 0' flood, Light Blue Polygon represents 'Class 1', Blue polygon represents 'Class 2' flood and orange polygon represents 'Class 3' flood. The 'Class 0' flood occurred in 2017. The most severe flood in Canada occurred in 2019. The 2019 flood has been classified in three classes within the study area. According to **Floods in Canada – Product Specifications** publication by EGS, polygons of the flood layer has been classified according to type of flooded area mentioned as below in **Table 2**:

Table 2: Classification of Type of Flooded Area

Class	Type of flooded area
0	Unclassified
1	Permanent Water
2	Open Water
3	Flooded Vegetation
4	Urban Flood
5	River Ice
6	Unknown State

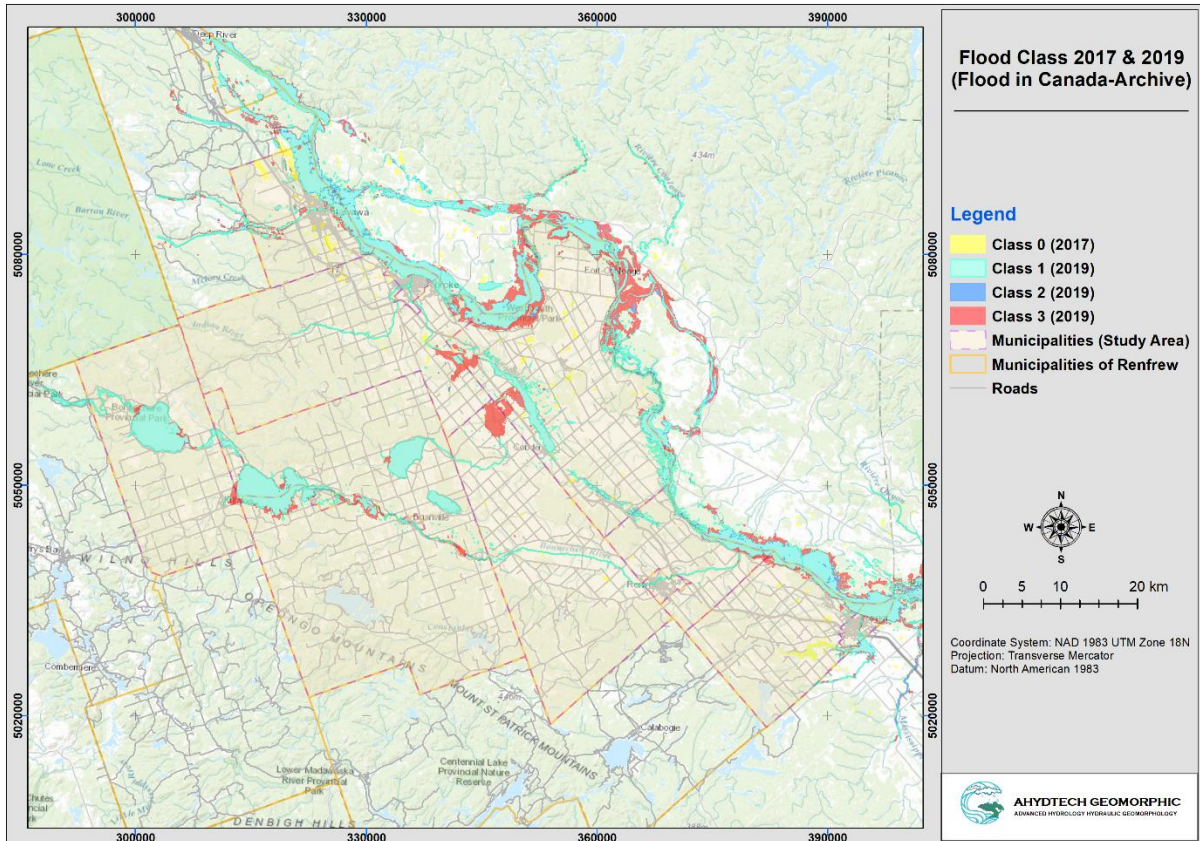


Figure 4-2: Historical Flood Analysis using Open Government Data Portal

Similar type of flood extent and severity can be observed by Comparison of **Figure 4-1** and **Figure 4-2**. Flooding is mainly observed around large waterbodies and lakes.

## 4.2 Identified Flood Types

According to the [Federal Flood Hazard Identification and Priority Setting Version 1.0](#), a wide variety of floods generally inundate different regions across Canada. Several types of floods such as Fluvial, Pluvial, Coastal, Lake flooding and Tsunami, may exist or occur depending on the geographical settings of different areas. The County of Renfrew is located in the Ottawa River watershed, which is shared by Ontario and Quebec. The Ottawa River experienced a number of significant flood events in its history, mainly due to heavy rainfall, snowmelt, ice jams and limited

storage capacity of the reservoirs upstream. A substantial number of flood events have inundated both banks of the river and have affected many municipalities through its associated tributaries.

After an extensive literature review and data analysis, it has been found that the historical floods the County has experienced were mostly due to heavy rainfall and snowmelt. Among several types of floodings, the County mostly faced fluvial or riverine flooding and lake flooding due to the increased river and overland flows during spring caused by increased rainfall and snowmelt within the Central Ottawa River Sub watershed.

According to the [Ottawa River Regulation Planning Board](#), significant flooding occurred along the Ottawa River back in 1920s, 1950s, 1970s and more recently in 2017 and 2019. Major flood events that affected the study area have been listed below in **Table 3**.

*Table 3: Identified Historical Flood Events Experienced by the County*

Year	Type	Reason	Maximum Water Level at Pembroke	Day	Maximum Water Level at Arnprior	Day
2023	Fluvial, Lake Flooding	Heavy Rain and Snowmelt	113.31	May 3	75.98	May 5
2019	Fluvial, Lake Flooding	Heavy Rain and Rapid Snowmelt	113.69	May 12	76.31	April 30
2017	Fluvial, Lake Flooding	Unusually heavy rainfall, coinciding with melting snow	113.03	May 4	75.95	May 6
1997	Lake Flooding	Spring Thaw	112.56	April 28	75.22	May 6
1985	Fluvial	Heavy Rain and Snowmelt	-	-	-	-
1979	Fluvial	Heavy Rain and Snowmelt	113.3	April 29	-	-
1976	Fluvial	Heavy Rain and Snowmelt	112.6	-	-	-
1974	Fluvial	Heavy Rain and Snowmelt	112.88	-	-	-
1967	Fluvial	Heavy Rain and Snowmelt	113.0	-	-	-
1960	Fluvial	Heavy Rain and Snowmelt	113.7	May 16	75.86	May 18
1957	Fluvial	Hurricane Audrey	112.852	July 7	74.94	July 7
1951	Fluvial	Heavy Rain, Rapid Snowmelt and Ice Jams	113.34	April 16	75.91	April 17
1947	Fluvial	Heavy Rain, Rapid Snowmelt and Ice Jams	113.59	June 18	75.7	June 20
1928	Fluvial	Heavy Rain and Spring Thaw	113.65	May 19	75.68	May 23
1909	Fluvial	Heavy Rain and Snowmelt	-	-	-	-

Some of these floods have very low impact in the study area such as 1974 and 1976 floods have disastrous impacts from Chats Lake down to the Montreal region.

Based on the information gathered from various sources, it is evident that historical flood events the study area had experienced was mostly fluvial/riverine flooding. **Table 3** shows that most of these fluvial floods occurred between April to June. According to a study on historical flood damages in Ontario conducted by [D. Shrubsole and R. Kreutzwiser](#), among 564 flood events occurred within Ontario between 1680 to 1989, 60% of the total events or 359 events occurred in February, March, April and May due to combination of spring melt, precipitation and/or ice jams. So, statistically this period of any given year has potential to cause flooding due to above-average snowfall during the winter, followed by warmer temperatures and heavy rains in the spring that leads to a significant volume of water flowing into the Ottawa river. As the City of Pembroke is located at the upstream section Ottawa River reach along the study area and Town of Arnprior is Located at downstream, water levels of these two stations have been taken to analyze the fluvial floods occurred in the study area. **Figure 4-3** and **Figure 4-4** shows the observed water level at Pembroke and Chats Lake at Arnprior from January to December for the year 2017, 2019 and 2023. The figures also manifest that historically all the fluvial floods the county has experienced was occurred between April to June.

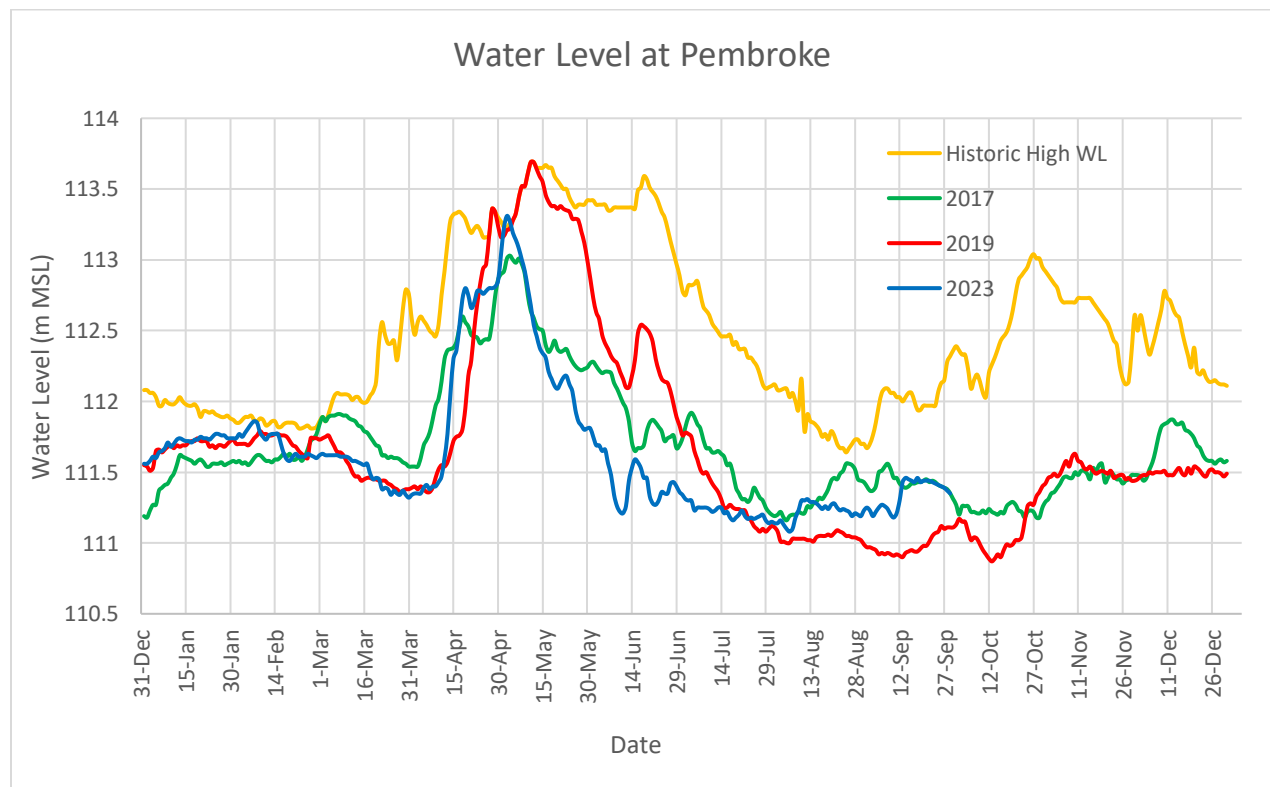


Figure 4-3: Water Level of Ottawa River at Pembroke

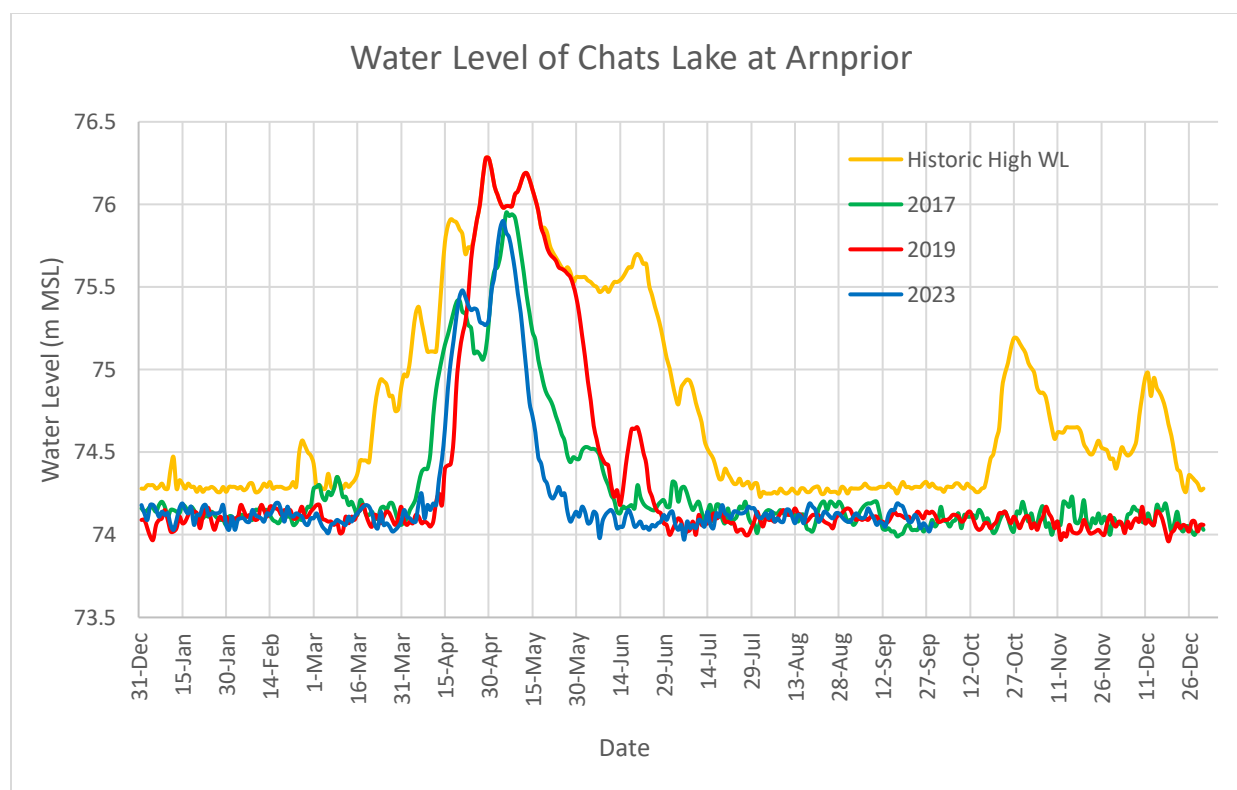


Figure 4-4: Water Level of Ottawa River at Chats Lake at Arnprior

Flood Frequency analyses were carried out under FDRP in 1991 for Pembroke gauge near Allumette Lake to prepare floodplain mapping and compute regulatory flood elevation. A freeboard allowance of 0.16m was added to the 1 in 100-year flood level and regulatory flood elevation for the south west mainland shoreline of Allumette Lake was set to be 113.89 meters GSC. The results of frequency analysis have been tabulated below:

Table 4: Outputs of Frequency Analysis conducted by FDRP in 1991

Return Period (Years)	Flood Elevation (m GSC) Lognormal Distribution	Flood Elevation (m GSC) Wakeby Distribution
2	112.61	112.61
5	112.96	112.95
10	113.17	113.18
20	113.35	113.39
50	113.58	113.64
100	113.73	113.82

From **Table 4** and **Figure 4-3** it can be observed that the 2019 peak near Pembroke station exceeded the 1-in 50-Year flood elevation.

#### 4.2.1 Summary of major Fluvial/ Riverine Floods:

##### ❖ 2019 Flood:

The 2019 Ottawa River flood had a significant and widespread impact on the County of Renfrew. The county declared a state of emergency due to increased water levels along Ottawa River and

its tributaries- Bonnechere, Madawaska and Petawawa Rivers. A news report stated that 478km of Ottawa River shoreline, 81km of Petawawa River shoreline, 678km of Madawaska River shoreline, and 364km of Bonnechere River shoreline were affected by the flood. The water level surpassed all the previous records along this reach of the Ottawa River. According to ORRPB, in Petawawa River, 2019 peak flow was approximately 690 m<sup>3</sup>/s which was 46% higher than the historic peak of 1985. And in Madawaska River, peak discharge was around 760 m<sup>3</sup>/s which was around 700 m<sup>3</sup>/s during 2017 flood. The return period of the 2019 flood was estimated to be 1:100-year flood. It was considered even worse depending on the location and local impacts such as in the Township of Whitewater Region, it was referred as a 500-year flood.

AHYDTECH has collected historical flood discharge and water level data from the ECCC ([Environment and Climate Change Canada](#)) hydrometric gage stations located within the County of Renfrew. The table below shows the Peak Water Level and Peak Discharge of 2019 found for different Hydrometric Gage stations located along different Ottawa River tributaries passing through the study area.

*Table 5: Peak Water Level and Discharge during 2019 Flood at the Tributaries of Ottawa River passing through the study area*

River	Station	2019 Flood	
		Peak Water Level (m)	Peak Discharge (m <sup>3</sup> /s)
Petawawa River	02KB001	5.382	639 (April-28)
Indian River	02KC018	5.888	101 (April-21)
Muskrat River	02KC015	4.678	63.1 (April-24)
Bonnechere River	02KC009	8.232	267 (April-20)
Madawaska River	02KE002	Unavailable	Unavailable

#### ❖ 2017 Flood:

In 2017, the County of Renfrew experienced another significant flooding. Until 2019 flood, this was reported to be the most catastrophic flood the county has experienced before. Although the snow conditions of the Ottawa river were not likely to cause any flood events that year, a considerably higher precipitation caused flooding along the river. People living along the Ottawa River floodplain as well as its tributaries- Bonnechere and Madawaska rivers were affected the most. The following **Table 6** shows the Peak Water Level and Peak Discharge of 2017 found for different Hydrometric Gage stations located along different Ottawa River tributaries passing through the study area.

*Table 6: Peak Water Level and Discharge during 2017 Flood at the Tributaries of Ottawa River passing through the study area*

River	Station	2017 Flood	
		Peak Water Level (m)	Peak Discharge (m <sup>3</sup> /s)
Petawawa River	02KB001	4.523	439 (April-18)
Indian River	02KC018	5.911	102 (April-12)
Muskrat River	02KC015	4.5	49.3 (May-9)
Bonnechere River	02KC009	8.107	248 (May-7)
Madawaska River	02KE002	Unavailable	Unavailable

### 4.2.2 Lake flooding

County of Renfrew has a substantial number of large lakes such as Golden Lake, Round Lake, Lac des Chats, Lake Doré etc. During 2019 flood event, it has been observed that water levels of these lakes increased significantly and caused flooding in surrounded areas. Some of the historical records shows that temporary inundation by water of normally dry lands were caused by a thaw period. The thaw period is often accompanied by precipitation that adds to the surface runoff produced by melting snow. The thaw can also cause ice jams and flooding due to rising water tables. **Figure 4-5** shows the Golden Lake flooding during 2019 flood.



*Figure 4-5: Flooding near Golden Lake in 2019*

### 4.2.3 Pluvial Flood

Analyzing the recent flood events from available data sources and historical images, it has been observed that some of the roads and private properties were inundated temporarily due to heavy rainfall and snowmelt events that also caused riverine and lake flooding in 2017 and 2019. **Figure 4-6** shows urban flooding near Pembroke Airport in 2017.



Figure 4-6: Pluvial Flooding near Pembroke Airport in 2017

### 4.3 Identified Historical Flood Locations

Among the thirteen (13) municipalities within the study area at the County of Renfrew, the municipalities that were inundated mostly during the previous floods and faced frequent flooding phenomena are located along the right bank of the Ottawa River such as the Town of Petawawa, City of Pembroke, Township of Laurentian Valley, Township of Whitewater Region etc. The County mostly experienced riverine floodings due to increased discharge of the Ottawa River caused by freshet during spring season.

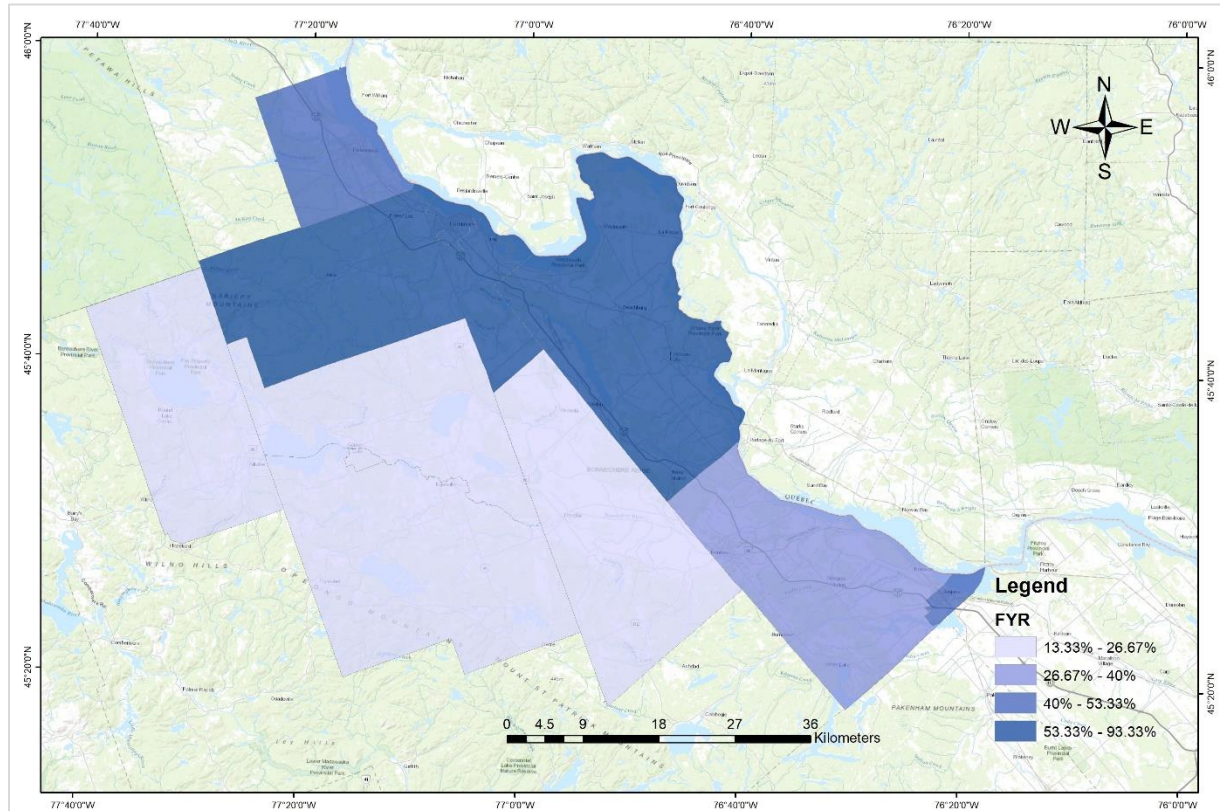
After gathering information regarding historical flood events that inundated the study area, the following **Table 7** has been prepared. It illustrates the municipalities that were inundated during the fifteen (15) flood events previously mentioned in **Table 3**. The red cells of the table represent the municipalities that experienced flooding during the year mentioned in the first row and white cells represent the municipalities that didn't experience any flooding during that event.

Table 7: Municipality-wise Historic Flood Events experienced by the Study Area

Municipalities/ Flood Years	2023	2019	2017	1997	1985	1979	1976	1974	1967	1960	1957	1951	1947	1928	1909
Town of Arnprior															
Town of Renfrew															
Town of Petawawa															
City of Pembroke															
First Nations of Algonquins of Pikwakanagan															
Township of McNab/Braeside															
Township of Horton															
Township of Admaston/Bromley															
Township of Whitewater Region															
Township of Laurentian Valley															
Township of Bonnechere Valley															
Township of Killaloe, Hagarty & Richards															
Township of North Algona Wilberforce															

*This table has been prepared based on the available information from different open sources data and reports on Ottawa river flooding and its impacts on shoreline municipalities as well as from historical imageries, news portals and archives, photographs etc. There is a probability that some areas that have not been recognized as flooded during a particular year's flood event, were actually flooded during that event or some of the areas that have been recognized as flooded had less impacts compared to the unrecognized areas. The reason behind this uncertainty is lack of information and data unavailability.*

Analyzing available information an approximation of spatial distribution and frequency of flooding in different municipalities within the study area has been projected. Among the 15 major flood events experienced by the study area between 1909 to 2023, not all the thirteen municipalities were inundated by a single event. **Figure 4-7** shows the frequency of flooding within the 13 municipalities under the study area.

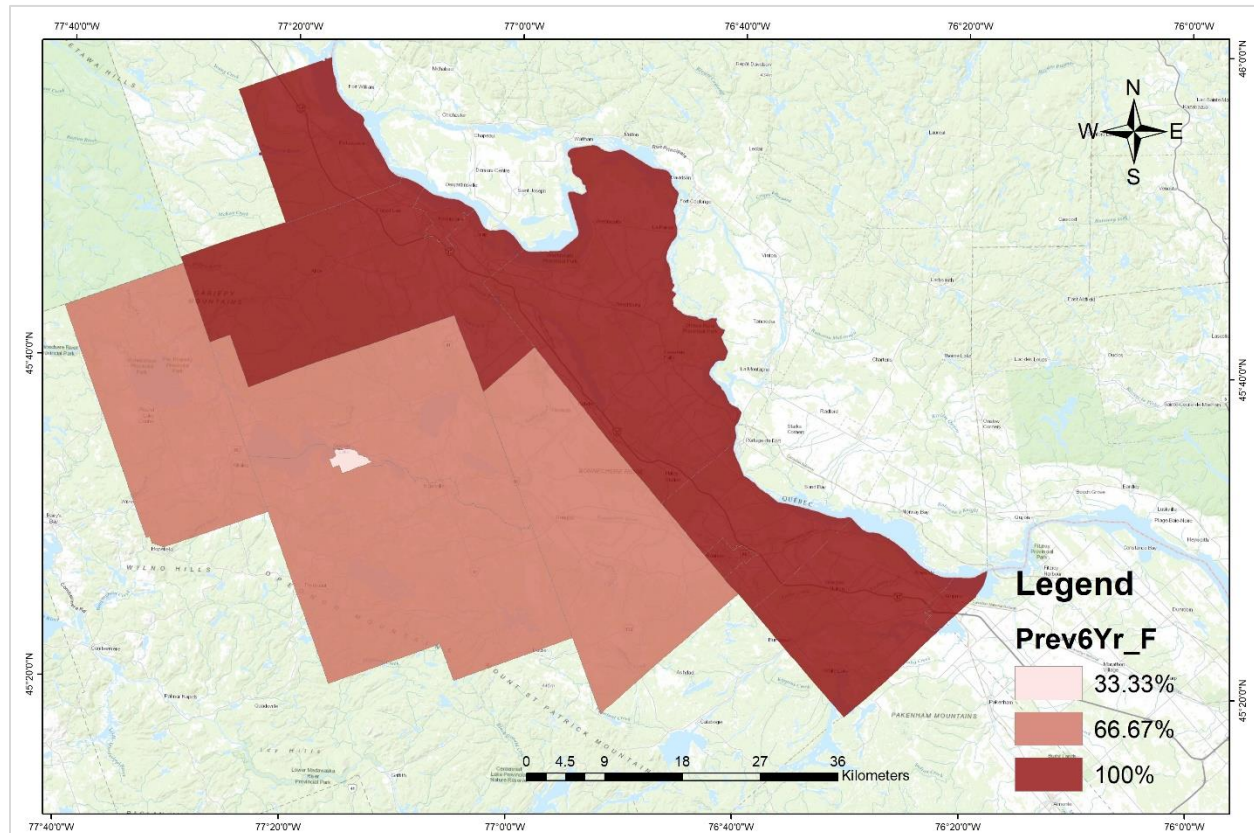


*Figure 4-7: Percent (%) of Historic Flood Events experienced by the Municipalities within the Study Area*

The figure shows that municipalities that are at close proximity of the Ottawa river and located on the west bank of Ottawa River have experienced more than 40% of the total floods experienced by the study area. The City of Pembroke, Township of Laurentian Valley and Township of Whitewater Region were the worst-hit areas and observed to be flooded approximately 54 to 94% of the time the county has experienced flooding during the past 104 years. On the other hand, municipalities that are situated at a distant away from the river have suffered less compared to the municipalities adjacent to Ottawa River. Such areas are Township of Bonnechere Valley, Township of Killaloe, Hagarty & Richards, Township of North Algona Wilberforce, Township of Admaston/Bromley and First Nations of Algonquins of Pikwakanagan.

AHYDTECH have also analyzed the frequency of flooding for different municipalities for the last six (6) years. It has been observed that the county has experienced three unprecedented and catastrophic flooding during the last 6 years which were 2017, 2019 and 2023 floods. Hence, separate analysis has been conducted to identify the municipalities that were affected by these floods. **Figure 4-8** shows that municipalities located at the bank of Ottawa river have experienced all the three spring floods occurred in 2017, 2019 and 2023. The 2019 flood event was extremely devastating that affected all the 13 municipalities located within the study area which can also be

observed from **Table 7**. According to the data presented in **Table 7**, which have been listed through reviewing literatures and **Figure 4-8**, it can be observed that except the First Nations of Algonquins of Pikwakanagan, all the municipalities of the study area were affected by 2017 and 2019 floods.



*Figure 4-8: Percent (%) of Past 6 Years Major Flood Events experienced by the Municipalities within the Study Area*

#### 4.4 Compilation of Severity, Frequency, Area Estimates

Assessing the flood history of the County of Renfrew, it has been found that the County has experienced mostly Fluvial flooding due to the Ottawa River flowing along the North-eastern side of the Study area. During spring the County faces lake flooding as well as urban flooding due to excessive rainfall. Extreme rainfall events sometimes cause urban flooding resulting in the blockage of roads and waterlogging in urban areas although no historical data was found regarding pluvial flooding. Due to climate change, both the frequency and the severity of the flooding has increased significantly.

Among the floods the county has experienced during the past six (6) years, it has been found that the 2019 flood was the most severe and devastating which affected all the municipalities of the study area. Severe damages were caused by previous floodings that inundated the study area. Depending on the collected information on the flooding histories of the County of Renfrew and nearby areas with similar geography, a matrix shown in **Table 8** has been prepared.

Table 8: Flood Impact Matrix of the Study Area

Flood Type	Severity/Consequences			Frequency			Area		
	High	Moderate	Minor	High	Moderate	Minor	High	Moderate	Minor
Coastal	-	-	-	-	-	-	-	-	-
Fluvial									
Lake Flooding									
Pluvial									
Tsunami	-	-	-	-	-	-	-	-	-
Groundwater Flooding	-	-	-	-	-	-	-	-	-
Flash Floods	-	-		-	-		-	-	

Lake flooding, Pluvial flooding and Flash Flooding are very rare phenomena for the study area. Although the historical information provides evidence that the study area was mostly affected by fluvial flooding; there are some locations where pluvial and flash floods occur occasionally. In terms of severity and inundation area, these events have not been reported so often as the fluvial flooding. According to some reports and news portals, flash floods were reported on roads which forced temporary closure of several roads due to sudden and intense rainfall events. Again, satellite images of 2019 floods showed inundation in some areas that were independent of any overflowing waterbody.

#### 4.5 Identified Additional Factors that contribute to flooding.

A number of factors have been identified that have contribution to flooding within the study area.

##### ❖ Limited Storage Capacity of Upstream Reservoirs:

No reservoir has the capacity to store an infinite amount of water. When the water level in a reservoir reaches its maximum capacity, excess water is typically released downstream to prevent the reservoir from overflowing. The Ottawa River generally tends to experience two flow peaks- one generated by snowmelt and rainfall in lower section of the watershed and another occurs when the primary reservoirs in the upper portion of the watershed become filled with water. According to [an Independent Review of the 2019 Flood Events](#), the upper reservoirs experienced a significant amount of snowmelt, which resulted in the second peak surpassing the first. Consequently, the upper reservoirs became full and had to pass their flow downstream to prevent flooding at the upstream areas.

##### ❖ Land Use Change and Development within Floodway:

According to the Official Plan of Renfrew County, municipalities along the Ottawa River bank are subject to flooding and some parts of the river such as the Township of Laurentian Valley are subject to flooding by the 1 in 100-year flood and are considered to be within the flood plain of the Ottawa River. The official plan demonstrates that development is strongly prohibited within the floodplain where the FDRP floodplain mapping is unavailable and one-zone approach is applicable. For the location for which FDRP maps are available; within the floodway, as delineated by FDRP maps, no development and site alteration are permitted. However, analyzing the FDRP flood maps and the extent of 2019 flood from [Floods in Canada - Cartographic Product Collection - Open Government Portal](#), some developed areas were observed within the floodplain provided

by FDRP. For some areas near Town of Petawata and Township of McNab/Braeside, 2019 floodline extend over the FDRP floodlines and some areas within the permitted development zone also experienced flooding. Alteration and development within floodplain make the consequences and severity even worse, since it obstructs flow and increase water level.

❖ **Climate Change**

Climate change is having a significant impact on the frequency of flooding. Along the Ottawa River, frequency of flood events has increased substantially due to increased precipitation, changes in snowmelt and streamflow. Changes in the timing of snowmelt and the amount of snowpack that accumulates in winter, sudden increase in temperatures, intensity of precipitation have changed the pattern and severity of flooding.

## 5. Estimation of Hazard

### 5.1 Compilation of Existing Flood Hazard Mapping

After compiling all the previous flood mapping products prepared under national Flood Damage Reduction Program (FDRP) of Canada Water Act provided by the County, it has been observed that study was conducted for three municipalities located along the Ottawa Riverbank. These are Town of Petawawa, Township of Whitewater Region and Township of McNab/ Braeside. Details of the provided maps have been tabulated below.

*Table 9: Information on Existing Flood Maps*

Location	Length Covered	Year
Town of Petawawa	188.88km Floodline	1981
Township of Whitewater Region	137.78km Floodway Boundary	1985, 1989, 1991
Township of McNab/Braeside	3.1km Fillline (Protected)	1983

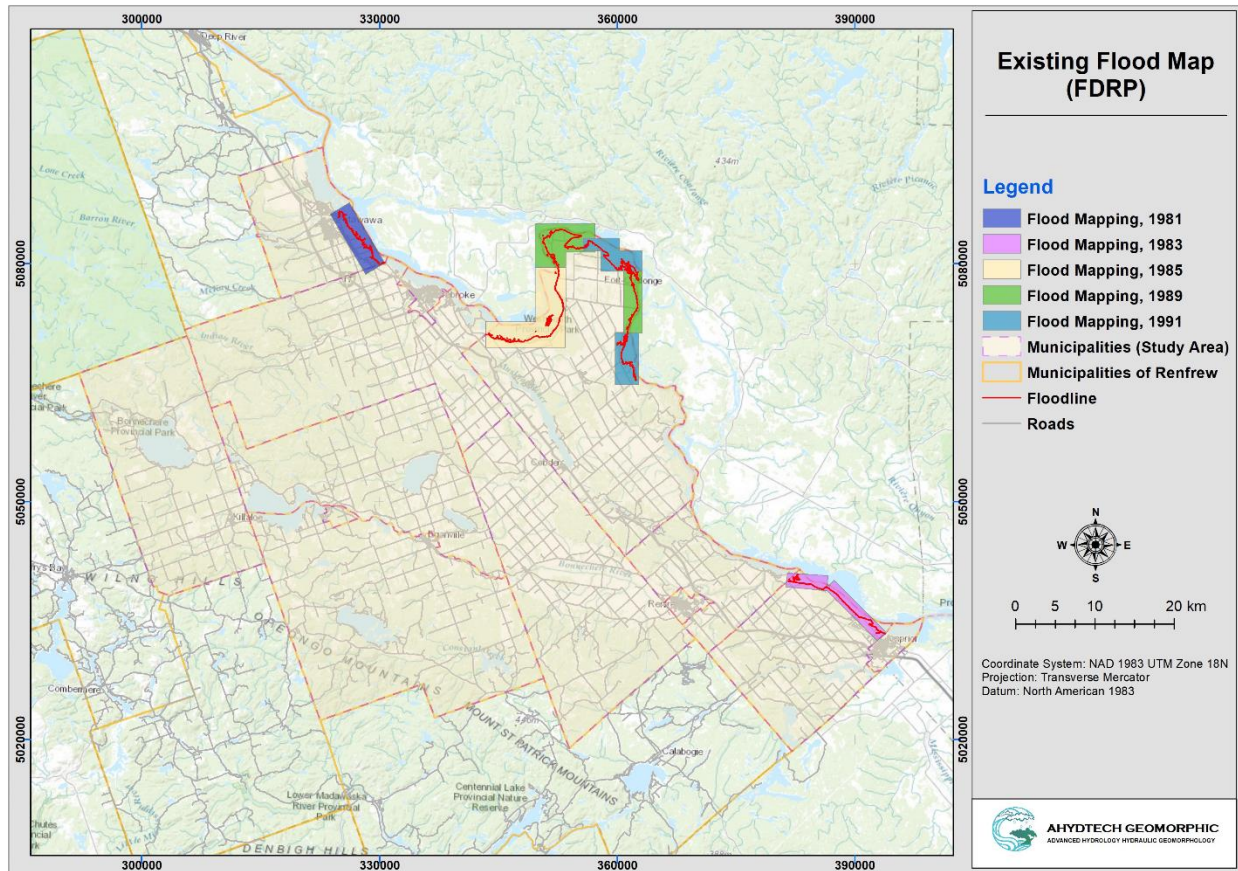


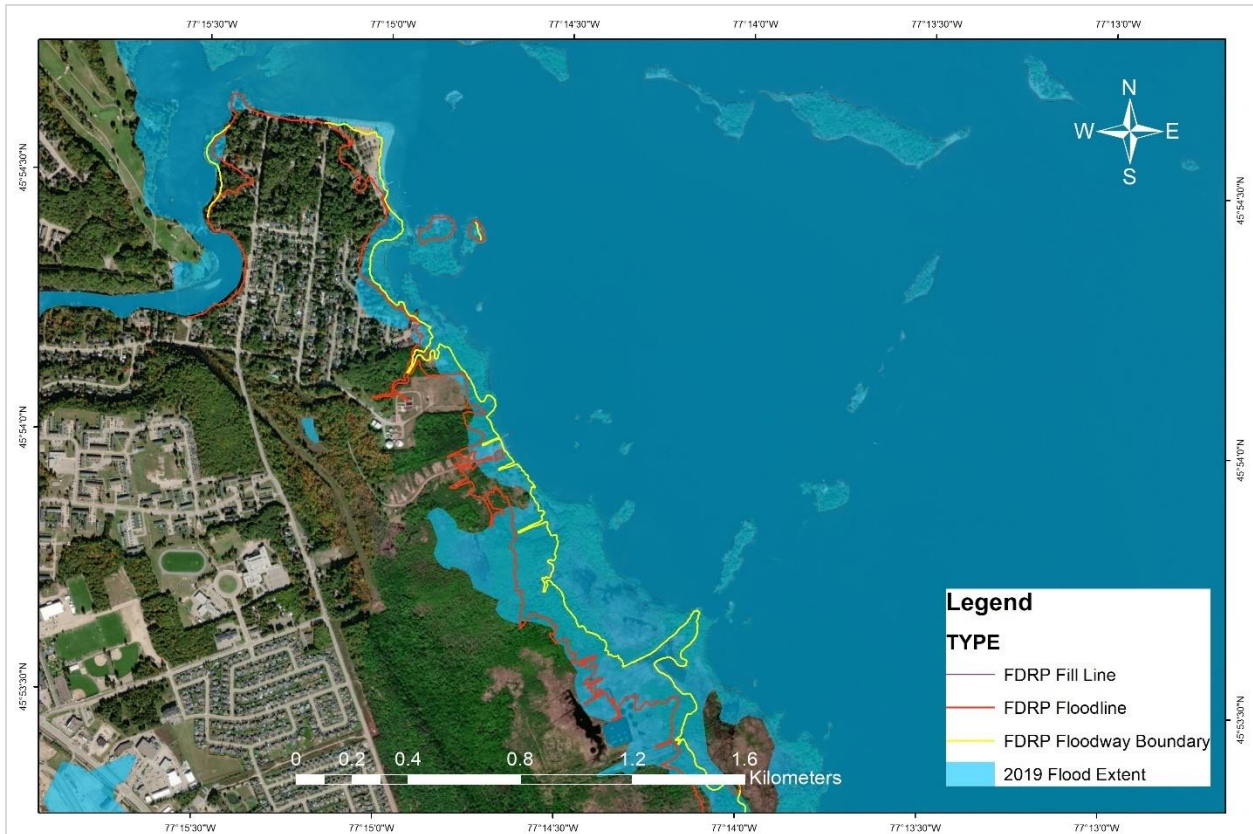
Figure 5-1: Compilation of Existing Flood maps prepared under FDRP

**Figure 5-1** illustrates the FDRP maps prepared for the three municipalities along the Ottawa River. It also demonstrates the gaps and absence of floodplain maps at different municipalities within the study area despite experiencing frequent flooding and being very prone to floods.

## 5.2 Preliminary Estimation of Hazards in Unmapped Areas

Primarily identifying the flood types and locations of the areas that experience frequent flooding, it has been found that most of the flood prone areas have not been mapped previously. Only a portion of the Ottawa riverbank that falls within the study area were mapped back in 1980s and early 1990s. For example, Even being very susceptible to flooding and experiencing major historical flood events, no floodplain maps were found and known to be delineated for Town of Arnprior, Town of Renfrew, Township of Horton, City of Pembroke etc. In some of the areas for which floodplain maps were generated, recent floods exceeded the floodlines delineated in the past. The following **Figure 5-2** shows some of the discrepancies found in FDRP maps with recent flood extent.

This figure demonstrates that the FDRP maps no longer applicable since the flood frequency, severity and extents have changed. The maps have outdated and not applicable for application in flood mitigation strategies as well as planning and development purposes. Hence, new limit should be set following an advanced and new approach.



*Figure 5-2: 2019 Flood exceeding the FDRP Floodlines*

After assessing different criteria that contribute to identify flooding within an area, a flood hazard map has been prepared. To prioritize the flood prone areas within the study area, a GIS-based Multi Criteria Analysis has been performed as a part of Task 4 under this assignment. Major factors that help to identify flood prone areas within any area are- Total Precipitation, Floodplains, Slope, Distance to Streams, Height Above Nearest Drainage, Curve Number, Drainage Density and Topographic Wetness Index. Considering these factors, AHYDTECH performed Multi-Criteria Analysis using Analytical Hierarchy Process (AHP) where pairwise comparison between the criteria were made to determine the weights of each criterion. Details of the analysis has been discussed in the **Priority Setting report**. **Figure 5-3** shows the flood hazard map of the study area classified in five (5) different classes from low to high hazard-prone zones.

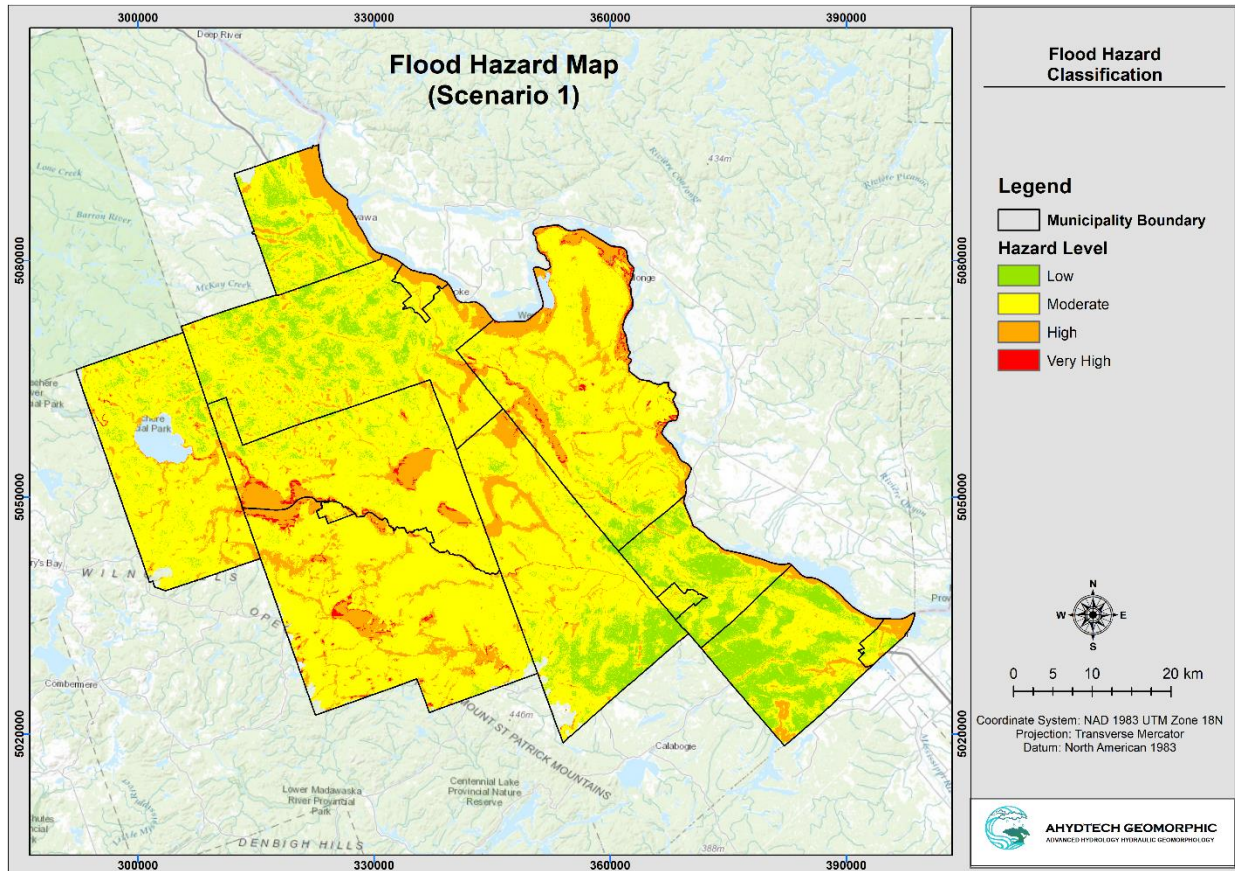


Figure 5-3: Flood Hazard Map of the Study Area

The figure illustrates that most of the areas within the study area are under moderate to high risk of flooding. This demonstrates that despite being under the risk of flooding, only a very insignificant portion of the area has been mapped previously that has been shown in **Figure 5-1** and those maps are not compatible with the recent flooding severity and extents.

### 5.3 Identify Potential Future Flood Locations

Historical analysis of major flood events has accompanied identifying the most frequently inundated locations during previous floods which have been shown in **Figure 4-7** and **Figure 4-8**.

**Figure 5-3** of the previous section illustrates the flood hazard map that has multiple classes of areas based on previous and probable future floods. Within those classified areas, there are some areas which have not experienced any flooding but falls within the moderate to high risk flood zones demonstrating the potential future flood locations within the study area.

For Identifying potential future flood locations, flood risks need to be assessed considering 3 following major changes: (i) Changes in Land use (ii) Future changes in climate (iii) Changes in Sea Level When estimating flood hazards and damages for the purpose of prioritizing mapping, estimation of non-stationarity effects including changing land use, climate, and sea level needs to be considered.

Brief assessment of these changes for identifying potential future flood locations has been described in following sections:

**(a) Changes in Land use**

The impacts of future land use changes on potential future flood locations in County of Renfrew are complex and uncertain, but some general trends can be identified based on the available information. Some of the possible impacts are:

- Changes in land use transform the landscape and can contribute to the loss of natural land, such as forests or wetlands, which can reduce the capacity of the land to absorb and store water and increase the runoff and erosion of soil.
- Loss of natural land can also disrupt the ecosystem services that support human wellbeing, resulting in a decline in air and water quality, an increase in air and water temperatures and an increased risk of flooding.
- As cities grow outward, urban expansion often encroaches on surrounding areas, including agricultural land, forests and other natural areas. When cropland is lost to urban growth, there can be additional pressure to convert natural areas to cropland to increase agricultural capacity.
- Urbanization also increases the amount of impervious surfaces, such as asphalt or concrete, which prevent water from infiltrating into the ground and increase the volume and speed of surface runoff<sup>1</sup>. This can overwhelm the drainage systems and cause urban flooding.
- The interaction between land-use change, flooding and human activities can create feedback loops that increase the vulnerability and exposure of people and assets to flood hazards. For example, land-use change can alter the hydrological regime and increase the flood risk, which can lead to the implementation of flood protection measures, such as dams or levees, which can in turn induce further land-use change and increase the potential consequences of flooding.

These impacts are not evenly distributed across County of Renfrew, as different regions have different physical, social and economic characteristics that influence their exposure and sensitivity to flooding. Therefore, it is important to assess the current and future flood risk at the local and regional scales, taking into account the multiple factors and uncertainties involved.

Based on these considerations, Municipalities will adopt an approach for assessing the relative impact of such land use changes on economic flood damages and associated risk. This spatially explicit approach integrates a reference situation, a flood damage model, and a rainfall-runoff model considering runoff re-infiltration and propagation to determine relative flood risk mitigation or increment related to the implementation of land use change scenarios. After the flood hazard assessment and prioritization is completed for the municipalities, detail study for municipal scale quantitative flood hazard mapping study will be undertaken and potential future flood locations will be prioritized.

**(b) Future changes in climate**

The historical record may not reflect the future climate patterns, which are expected to change significantly. According to recent publications, the effects of floods may expand to new areas and intensify in existing areas due to the changing precipitation patterns under climate change. This section provides a description of the components needed to incorporate climate change

considerations either qualitatively or quantitatively while undertaking municipal scale floodplain mapping study in future.

### Climate Change Information and Data

#### *b.1 Global Climate Models and General Circulation Models*

GCMs and ESMs are numerical models that simulate the global climate system and its response to greenhouse gas emissions. They include physical processes in different parts of the Earth, such as the atmosphere, ocean, ice, and land. Some models also include biogeochemical cycles, especially the carbon cycle. They generally have a horizontal resolution of 100 to 250 square kilometers (km<sup>2</sup>) with periods of simulation that can reach thousands of years.

#### *b.2 Ensembles*

GCMs are numerical models that try to mimic the real climate system and its response to greenhouse gas emissions. They have different assumptions and methods to represent complex physical processes that are not well captured by the model resolution. There are many GCMs that have projected future climate, but they have high uncertainty. Therefore, it is better to use a group of GCMs to project future climate variables.

The Pacific Climate Impacts Consortium (PCIC 2017) uses an ensemble of 12 different GCMs to conduct statistical downscaling for projecting future climate variables. Other scenarios are available in Canada (e.g. through the Canadian Centre for Climate Services (at ECCC) and the Ouranos consortium) and internationally (e.g. Coupled Model Inter-comparison Project (CMIP)). In addition, most providers have model ensembles driven by different GHG emission scenarios.

#### *b.3 Downscaling GCMs*

##### *Dynamical Downscaling by Regional Climate Models*

Dynamical downscaling is a method that uses a high-resolution climate model, called an RCM, to simulate the climate over a smaller area. The RCM is driven by a GCM, which is a lower-resolution climate model that covers the whole globe. Dynamical downscaling can capture more local details and interactions, but it can also inherit errors and biases from the GCM. Sometimes, dynamical downscaling may not be more accurate than using GCM data. The benefits and costs of dynamical downscaling should be evaluated before doing a climate change assessment. There are many RCMs that are developed and used by different institutions around the world. Most of them are part of the Coordinated Regional Climate Downscaling Experiment (CORDEX) project.

##### *Statistical Post-Processing and Downscaling*

GCMs and RCMs are climate models that have biases at local or basin scales. They need post-processing to produce reliable estimations. There are different methods for post-processing, such as bias correction and downscaling. Statistical downscaling is a method that uses climate model projections and local or regional observations to provide more spatial detail and other variables for flood mapping. There are different methods for statistical downscaling, such as regressions, weather generators and machine learning algorithms. Statistical downscaling is faster and cheaper than dynamical downscaling, but it does not capture physical processes and assumes stationary statistical relationships. Statistical downscaling may not always be more accurate than

using climate model data. The benefits and costs of statistical downscaling should be evaluated before doing a climate change assessment.

*b.4 Representative Concentration Pathways*

Projections of future climate change require projections of external drivers of change such as greenhouse gas and aerosol concentrations that are used as inputs to GCMs. Representative Concentration Pathways (RCPs) are standardized scenarios of radiative forcing and accompanying greenhouse gas, atmospheric aerosol, and land use change time series referred to as RCP2.6 (low radiative forcing pathway), RCP4.5 and RCP6.0 (moderate radiative forcing pathways), and RCP8.5 (high radiative forcing pathway).

Summary of Practices for Consideration of Climate Change in Hydrologic Analysis

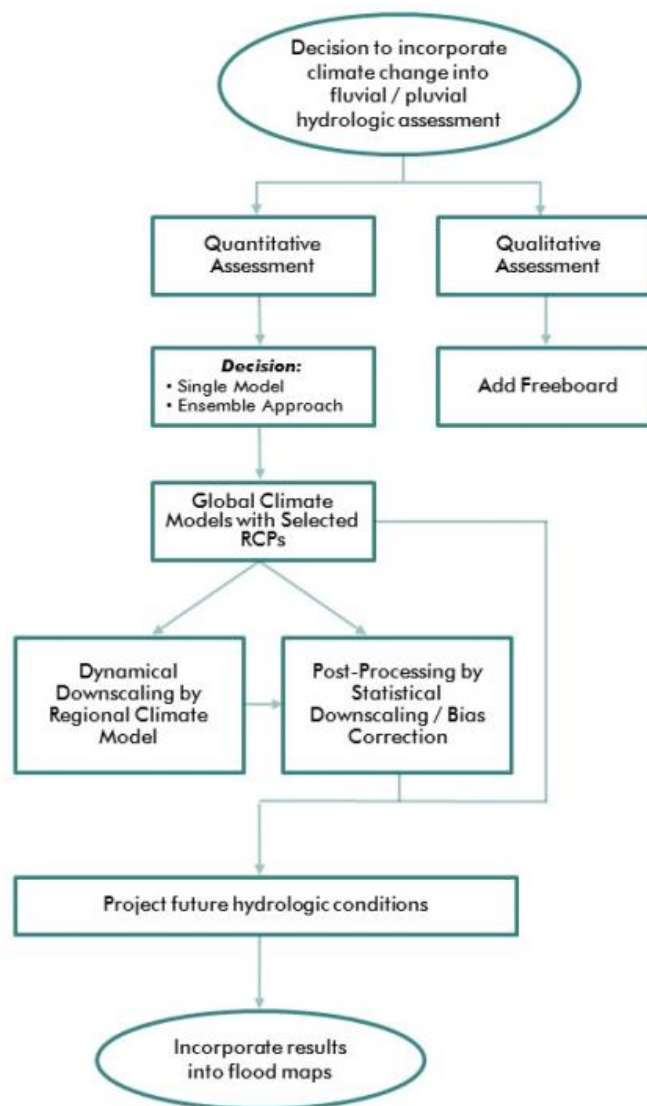


Figure 5-4: Climate Change Analysis Procedures (Source: Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation)



### (c) Changes in Sea Level

Projections for sea level change are relatively simple to incorporate into future coastal flooding projections. However, coastal flooding is due to several different factors (briefly described in Section 9.0), and an assessment of projected changes in climate variables may be completed using GCM outputs (directly or downscaled) as described in previous sections. In coastal cases, where a given flood probability is estimated over a long period into the future, the practitioner may use cumulative probabilistic techniques to account for increasing flood probabilities due to gradually increasing sea level.

Relative sea level (RSL) refers to the relative sea-level change that is experienced on the coastline and is a combination of global sea-level rise and vertical land motion. Incorporating projections of RSL change in flood mapping is essential for developing long-term adaptation strategies. Flood mapping that accounts for RSL should use up-to-date scenarios from national and international scientific reports.

***Based on these findings and considering additional factors related to flood hazard, potential future flood location will be identified while performing municipal tier floodplain mapping study project in future. The outputs will assist determining the potential future flood locations to prioritize for undertaking future studies and mapping.***

## 6. Conclusions

After assessing all the relevant data provided by the County and from various open-source data portals, newspapers, flood database and archives, reports etc. flood types that regularly inundate the study area have been identified. Through historical data analysis, municipalities where frequent flood event occurred have also been identified. Historical image analyses have also been conducted to identify the 2019 flood extents. Assessing the outcomes, it has been found that-

- The study area mostly experienced fluvial flooding caused by heavy rainfall and snowmelt.
- Municipalities that are located along the bank of Ottawa River have faced frequent flooding phenomena,
- Frequency of flooding has increased significantly and within the past 6 years, the county has experienced three major flood events occurred 2017, 2019 and 2023.
- After compiling FDRP prepared floodplain maps for three municipalities within the study area it has been observed that maximum portion of the study area that experienced frequent flooding have never been mapped.
- FDRP provided maps have become outdated and do not seem to be applicable for future flood mitigation strategies as well as planning and development. Hence, the entire study area is needed to be mapped following a new and precise approach.



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