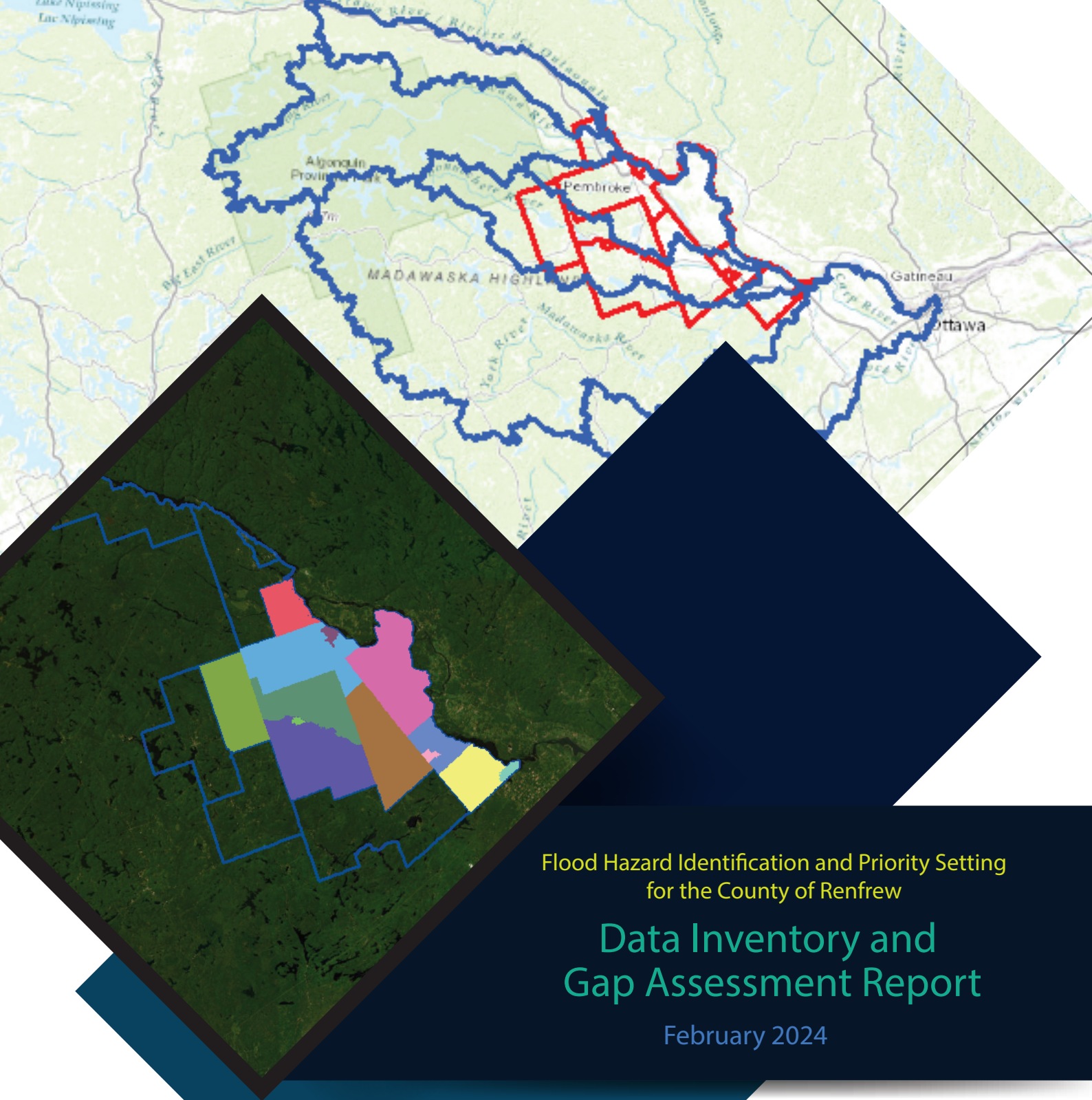

Flood Hazard Identification and Priority Setting
for the County of Renfrew

Data Inventory and Gap Assessment Report

February 2024

County of Renfrew
Ontario . Canada

AHYDTECH GEOMORPHIC
ADVANCED HYDROLOGY HYDRAULIC GEOMORPHOLOGY

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Abbreviations and Acronyms

DEM	Digital Elevation Model
DRAPE	Light Detection and Ranging
DTM	Digital Terrain Model
ECCC	Environment and Climate Change Canada
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
EWRG	Environmental Water Resources Group
GCS	Geographical Coordinate System
IDF	Intensity Duration Frequency
LiDAR	Light Detection and Ranging
LIO	Land Information Ontario
LULC	Land Use and Land Cover
OHN	Ontario Hydro Network
OLCC	Ontario Land Cover Compilation
OMNRF	Ontario Ministry of Natural Resources and Forestry
PET	Potential Evapotranspiration
SCOOP	South Central Ontario Orthophotography Project

Data Inventory and Gaps Assessment

1. Objectives

Performing data inventory and gap assessments for flood-prone areas involves identifying and analyzing the existing data related to floods and understanding the information gaps that must be addressed. The study of flood hazard delineation heavily depends on data from various sources. Data availability can limit the types of analysis that can be performed. Every stage of the analysis, from assessing the design event to analyzing hydraulic flow, and considering effects of ice, wind, and waves, along with other flood hazard factors, is informed by data. The quality of the data used directly influences the quality of the results. Hence, it is essential to prepare data inventory and assess gaps soon after prioritizing flood-prone areas where floodplain mapping will be required. The main goal is to assemble all types of technical data inputs prior to the commencement of future floodplain mapping assignments.

AHYDTECH has prepared the inventory based on the information and data provided by the County Authority, different open-source databases and different flood mapping stakeholders of the region.

2. Review of Existing Guidelines

To assess the data requirements for hydrologic and hydraulic assessments, AHYDTECH extensively reviewed the ***Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation Guidelines, Version 2.0*** by Natural Resources Canada. It provides an overview of the technical procedures for flood delineation studies and data requirements.

The document demonstrated the detailed procedure to perform any hydrologic and hydraulic assessments across Canada. It offers technical advice on hydraulic and hydrologic methods for creating flood hazard maps in a Canadian context. The document-

- Outlines the expected process from professionals who offer technical services in flood hazard delineation, including quality control and technical evaluation.
- Explains various forms of flooding that take place in Canada, such as riverine (fluvial), lakeshore (coastal), and ice-related floods, either individually or in combination.
- Offers advice for professionals on conducting hydrologic and hydraulic analyses as part of the process of flood mapping and discuss the data requirements.
- Provides guidance on strategies and factors to consider when integrating climate change into flood hazard studies.

3. Data Requirements

Several types of data are required to perform floodplain mapping and develop hydrologic and hydraulic models. Data required to develop hydraulic and hydrologic analysis have been listed below-

Table 3-1: Data Requirements for Hydrologic and Hydraulic Assessments

Data Required for Hydrologic Modeling		Data Required for Hydraulic Modeling	
Serial		Serial	
1	Digital Elevation Model	1	Digital Elevation Model
2	Water Course Shapefiles	2	Water Course Shapefiles
3	LULC	3	Topography Data
4	Soil Data	4	Bathymetry Data of the Watercourses

Data Required for Hydrologic Modeling		Data Required for Hydraulic Modeling	
5	Available Hydrometric Gage Stations	5	Dimensions of Available Hydraulic Structures
6	Discharge Data	6	Available Hydrometric Gage Stations
7	Roughness Co-efficient	7	Discharge Data
8	IDF Curve (For Event-Based Model)	8	Water Level Data for Different Return Periods
9	Time series (Hourly) Precipitation data (For Continuous)	9	LIDAR Data
10	Time series (Hourly) Temperature data (For Continuous Model)	10	Hydraulic Co-efficient
11	Time series (Hourly) Dew Point Temperature data (For Continuous Model)	11	Available Dams and Reservoirs
12	Snowmelt Data	12	Rating Curve
13	Evapotranspiration Data	13	Levee Breach Dimensions
14	Solar Radiation	14	Debris Blockage Information
15	Relative Humidity		
16	Windspeed		

Other data that might assist in determining flood hazards and floodplain mapping are-

- Available flood maps
- Historical Aerial/ Satellite Images
- Contour Elevation Mapping
- Historical water course shapefiles

All types of required data listed above have been explicitly assessed and an inventory has been prepared for future flood mapping exercise for the identified prioritized area, categorizing further into the following classes and discussed elaborately. A generalized inventory for other areas has also been

4. Summary of Prioritization

As a part of ***Task 4: Priority Setting*** under this study, prioritization exercise has been performed for the study area based on quaternary watershed areas as well as municipality and watershed segments. Priority lists have been prepared for both watersheds and municipalities. ***Table 4-1*** shows the list of municipalities and watersheds ranked based on maximum numbers of high-risk cells per square kilometers of the municipalities and watersheds respectively.

Table 4-1: Prioritization of the 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

Numbers of High-Risk cells in per Square Kilometers of Municipalities/Watershed			
Priority List of the Municipalities		Priority List of the Watersheds	
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		

Since, the county authority have mentioned that Data Inventory and Gaps assessment as well as Priority Setting and Scope of Work tasks have to be performed for the highest priority area identified, AHYDTECH has prepared a comprehensive data inventory for the Muskrat, Indian, Westmeath watershed and City of Pembroke from the priority list shown in ***Table 4-1.***

5. Data Inventory

In the context of flood hazard identification and mapping, data inventory is typically referred to as a comprehensive collection of data that is used to assess and map potential floods. AHYDTECH prepared a complete inventory of all the available datasets for the City of Pembroke and watershed 02KC-01, a significant portion of Muskrat, Indian, Westmeath watershed where further technical flood hazard studies are required. According to the ***Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation Guidelines, Version 2.0,*** types of required data include-

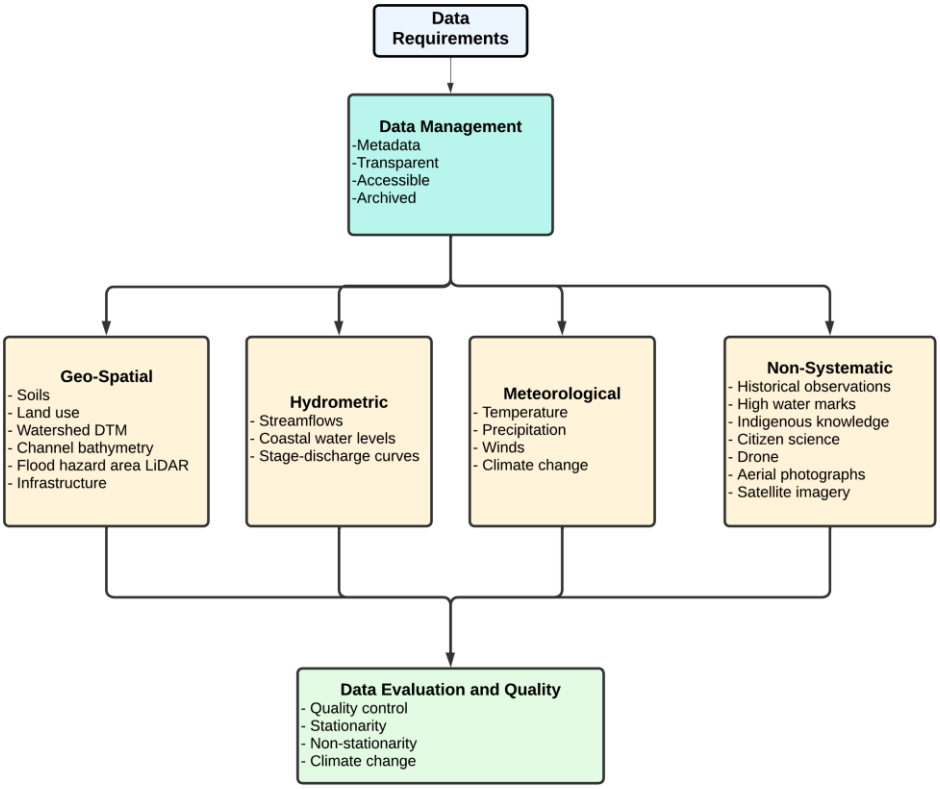

Figure 5-1: Data Requirements for Flood Hazard Delineation (FHIMP)

Availability of each dataset within the City of Pembroke and Muskrat, Indian, Westmeath Watershed have been discussed elaborately.

5.1 Geospatial Data

Geospatial data refers to the information that describes objects, events, or other features with a location on or near the surface of the earth. These data typically combine location information (usually coordinates on the earth) and attribute information (the characteristics of the object, event or phenomena concerned) with temporal information (the time or life span at which the location and attributes exist). To perform hydrotechnical assessments, various sets of geospatial data are required. AHYDTECH assessed all types of data crucial to conduct hydrologic and hydraulic assessments and assembled those datasets to create data inventory of the identified priority area as well as other municipalities under the study area.

5.1.1. Soil Data

Soil data is invaluable to perform hydrological assessments in any given area since it plays an important role in estimating permeability, its infiltration capacity, and rates. It is also essential for hydraulic analysis as the bed material of waterbodies affect the hydrodynamics of flow.

AHYDTECH collected soil data from Soil Survey Complex and National Soil Database/ Soil Landscapes of Canada and compiled those data for the City of Pembroke and Muskrat, Indian, Westmeath watershed (02KC). ***Figure 5-2*** and ***Figure 5-3*** illustrate the collected soil data from the sources.

1. Soil Survey Complex

Documentation of the dataset has been provided with the data. ***Figure 5-2*** shows the soil data class for four (4) Hydrologic Soil Group. Soil Survey Complex data include all types of soil information required to perform hydrologic assessment and modeling.

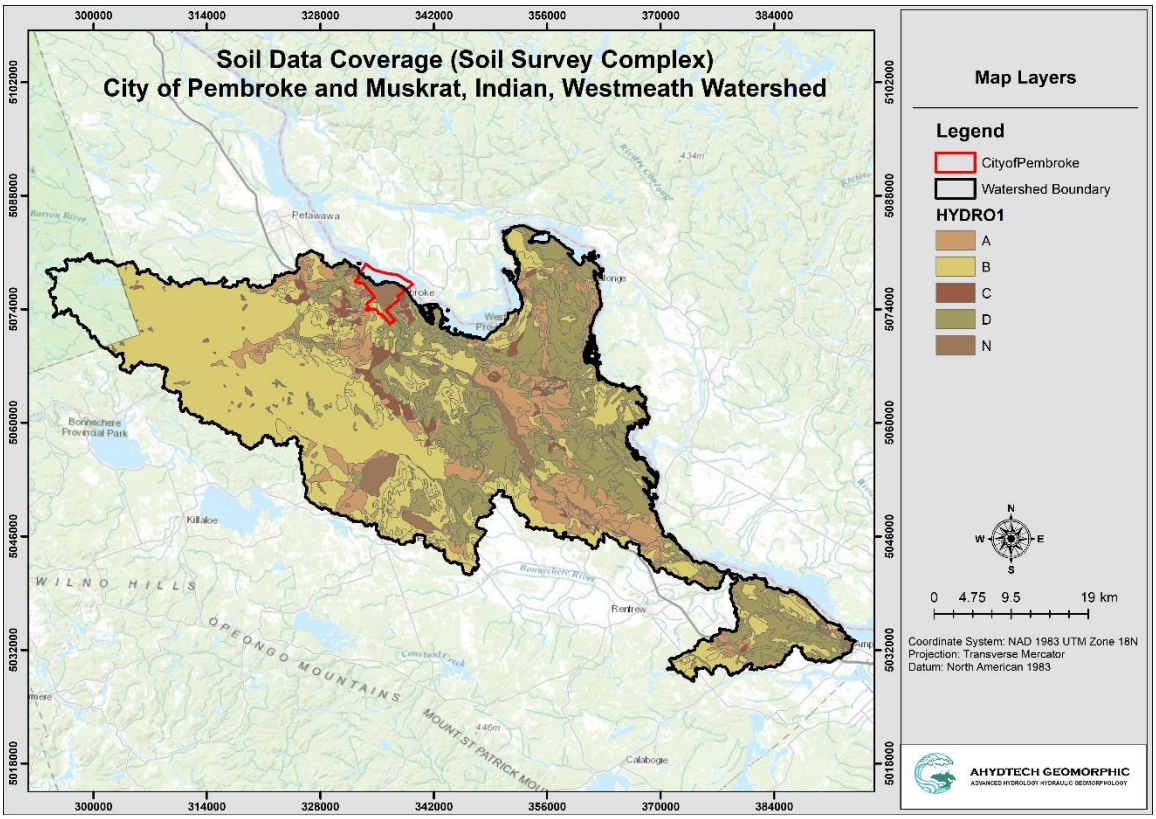

Figure 5-2: Soil Data collected from the Soil Survey Complex

2. Soil Landscapes of Canada (SLC)

The Soil Landscapes of Canada (SLC) provides a comprehensive set of data describing

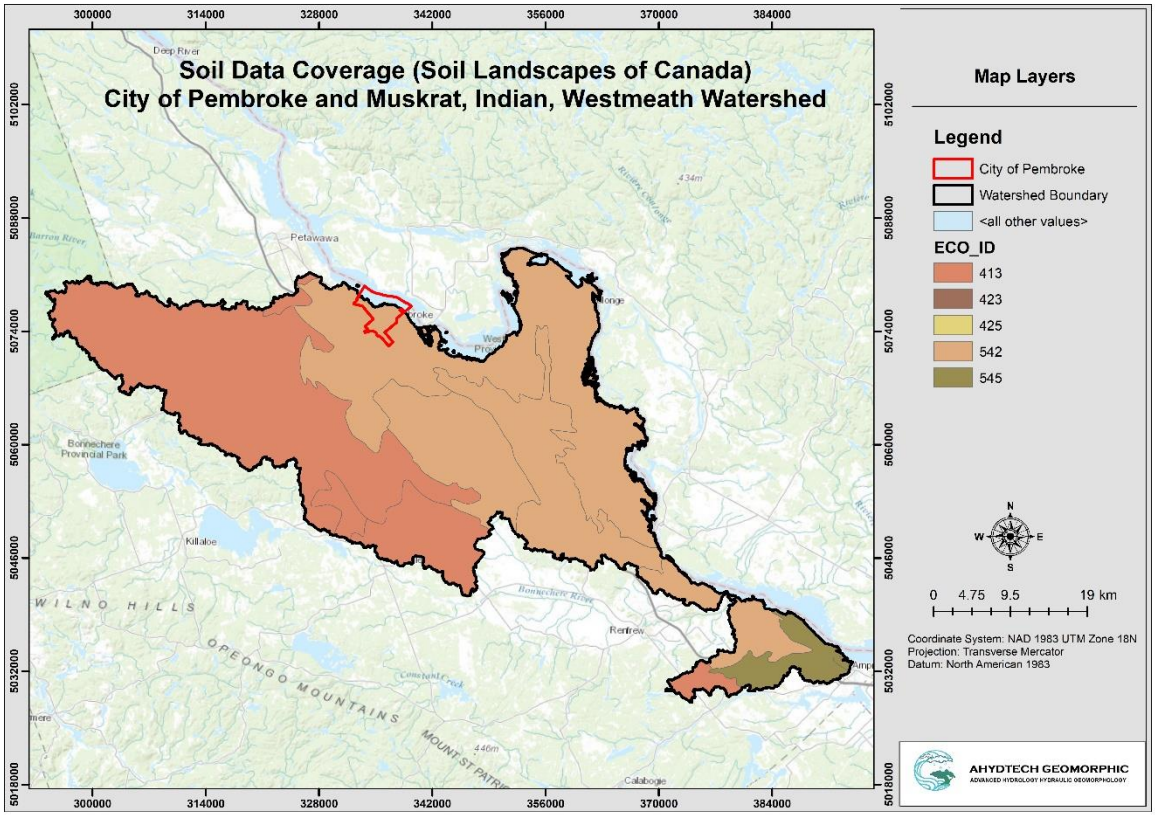

Figure 5-3: Soil Data collected from Soil Landscapes of Canada

the major characteristics of soil and land which includes information on surface form, slope, water table depth, permafrost, and lake etc.

Global Soil Dataset for Earth System Modeling also provides Soil Information for any region. Users can collect data from this database anytime based on their required soil attributes. Thery provide data both in Binary and NetCDF format.

5.1.2. Land Cover Data

Land Cover data has been collected from two different sources.

1. ESRI Global Land Cover Map

The Land Use/Land Cover (LULC) data collected from the Environmental Systems Research Institute (ESRI) was obtained for the year 2022, named *18T_20220101-20230101* and *17T_20220101-20230101*. ESRI provides Sentinel-2 Land Use/Land Cover annually with a 10-meter resolution of Earth's land surface from 2017 to 2022. Data description and documentation have been provided with the dataset.

Class Definition:
ESRI Land Use/ Land Cover provides a 9-class map of the surface, including vegetation types, bare surface, water, cropland, and built areas. Value and definitions of each class have been provided in **Table 5-1**.

Table 5-1: Definition of ESRI Land Cover Classes (Source: Sentinel-2 10m Land Use/Land Cover Time Series)

Value	Name	Description
1	Water	Areas where water was predominantly present throughout the year; may not cover areas with sporadic or ephemeral water; contains little to no sparse vegetation, no rock outcrop nor built up features like docks; examples: rivers, ponds, lakes, oceans, flooded salt plains.
2	Trees	Any significant clustering of tall (~15 feet or higher) dense vegetation, typically with a closed or dense canopy; examples: wooded vegetation, clusters of dense tall vegetation within savannas, plantations, swamp or mangroves (dense/tall vegetation with ephemeral water or canopy too thick to detect water underneath).
4	Flooded vegetation	Areas of any type of vegetation with obvious intermixing of water throughout a majority of the year; seasonally flooded area that is a mix of grass/shrub/trees/bare ground; examples: flooded mangroves, emergent vegetation, rice paddies and other heavily irrigated and inundated agriculture.
5	Crops	Human planted/plotted cereals, grasses, and crops not at tree height; examples: corn, wheat, soy, fallow plots of structured land.
7	Built Area	Human made structures; major road and rail networks; large homogenous impervious surfaces including parking structures, office buildings and residential housing; examples: houses, dense villages / towns / cities, paved roads, asphalt.
8	Bare ground	Areas of rock or soil with very sparse to no vegetation for the entire year; large areas of sand and deserts with no to little vegetation; examples: exposed rock or soil, desert and sand dunes, dry salt flats/pans, dried lake beds, mines.
9	Snow/Ice	Large homogenous areas of permanent snow or ice, typically only in mountain areas or highest latitudes; examples: glaciers, permanent snowpack, snow fields.
10	Clouds	No land cover information due to persistent cloud cover.
11	Rangeland	Open areas covered in homogenous grasses with little to no taller vegetation; wild cereals and grasses with no obvious human plotting (i.e., not a plotted field); examples: natural meadows and fields with sparse to no tree cover, open savanna with few to no trees, parks/golf courses/lawns, pastures. Mix of small clusters of plants or single plants dispersed on a landscape that shows exposed soil or rock; scrub-filled clearings within dense forests that are clearly not taller than trees; examples: moderate to sparse cover of bushes, shrubs and tufts of grass, savannas with very sparse grasses, trees or other plants.

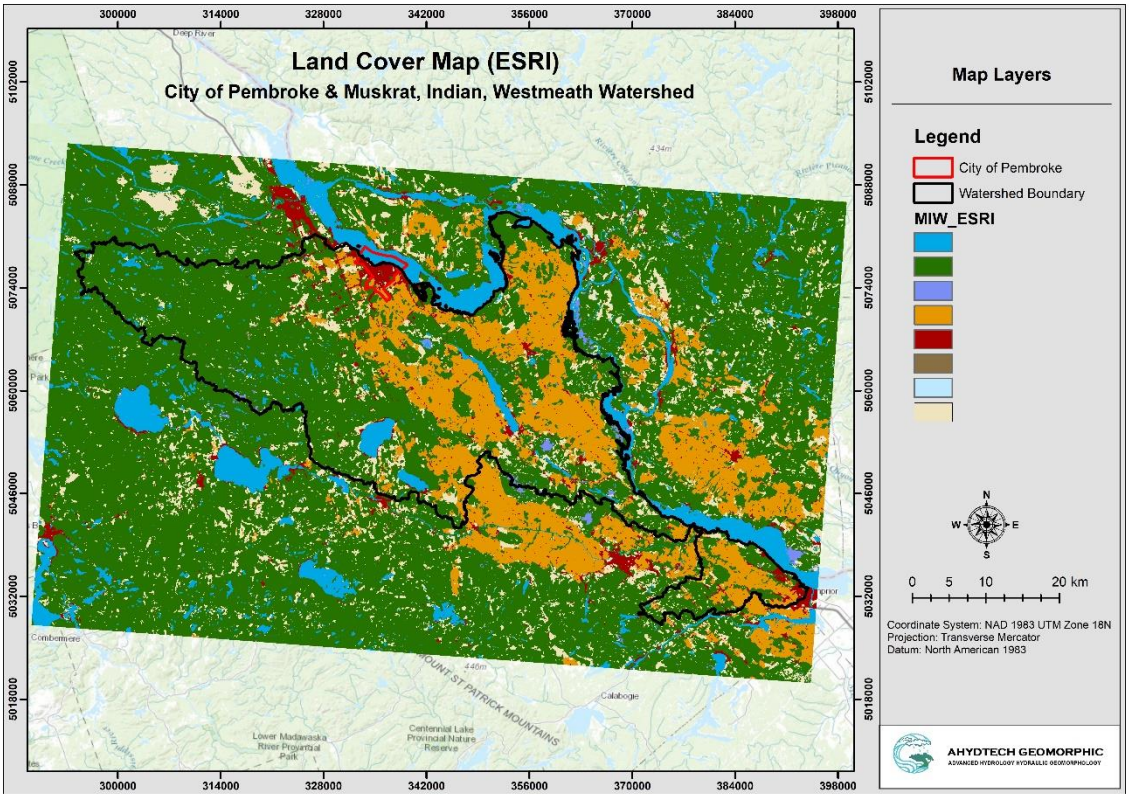

Figure 5-4: ESRI Land Cover Map

2. Ontario Land Cover Compilation Version 2- Ontario GeoHub:

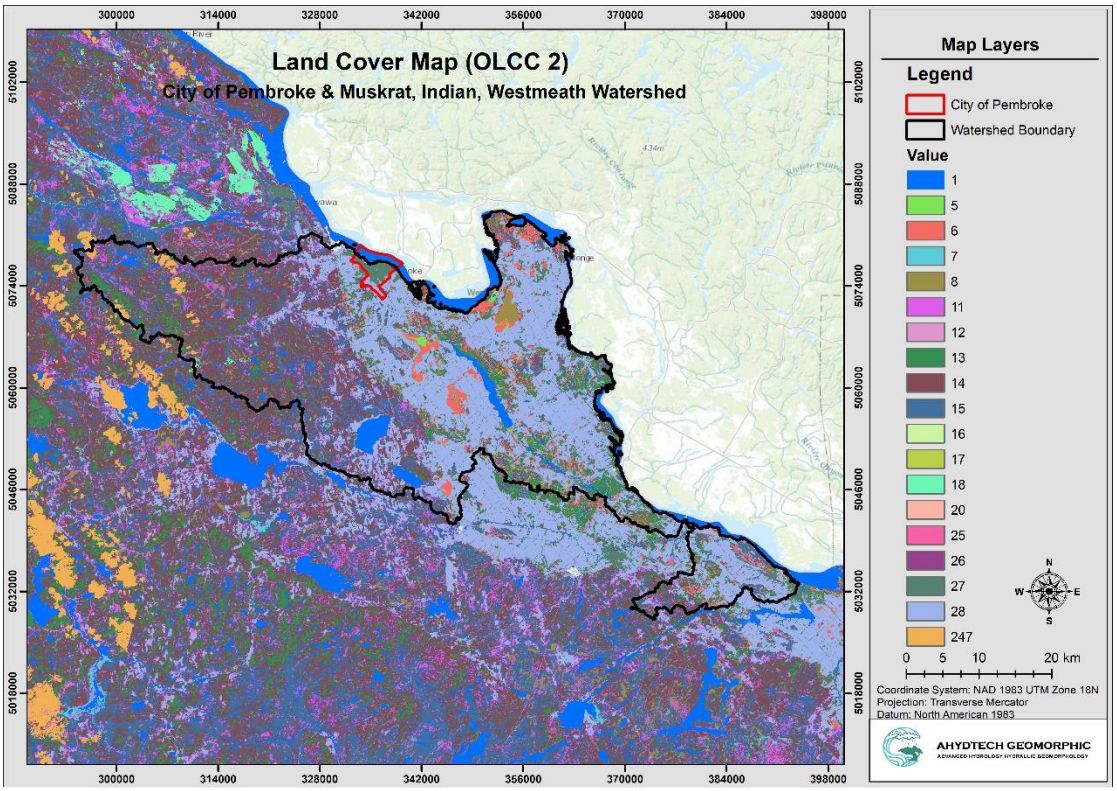

Figure 5-5: Land Cover Map (OLCC Version 2)

Ontario GeoHub provides Ontario Land Cover Compilation (OLCC) with a class structure of 29 land cover classes. The dataset has a pixel resolution of 15 meters. Definition of each class, Data description and documentation have been provided with the dataset.

5.1.3. Topographic Data

Topographic data is required to perform any hydrological and hydraulic assessment. LiDAR Data, Digital Elevation Model (DEM) and Contour Data provide topographic information of any area. AHYDTECH have collected these data from different open-source databases.

1. Watershed Digital Terrain Model (DTM)- LiDAR Derived

LiDAR Data was collected from Ontario GeoHub and compiled for the study area. The LiDAR coverage entirely covers the City of Pembroke. However, it does not cover the entire Muskrat, Indian, Westmeath Watershed. ***Figure 5-6*** shows the LiDAR coverage of the priority areas, both watershed and municipality. The LiDAR has been verified with the NRCan HRDEM Project footprint database.

Ontario Digital Terrain Model (Lidar-Derived) is a raster dataset representing the bare-earth terrain derived from a classified lidar point cloud. Data specifications have been provided below:

Table 5-2: LiDAR Data Specifications

LiDAR Data Specifications	
Name	Ontario Digital Terrain Model (Lidar-Derived)
Producer	Ontario Elevation Mapping Program by Ontario Ministry of Natural Resources and Forestry
Provider	Ontario GeoHub
Metadata type and URL	1-km by 1-km non-overlapping tiles grouped into packages Ontario Elevation Mapping Program
Geographic Reference	GCS_North_American_1983
Access protocol and URL	Ontario GeoHub
Data type	Raster
Resolution	0.5m
Date of data	December 19, 2023
Documentations	Ontario Elevation Mapping Program
Licence type	Open Government Licence – Ontario
Usage Restrictions	Public

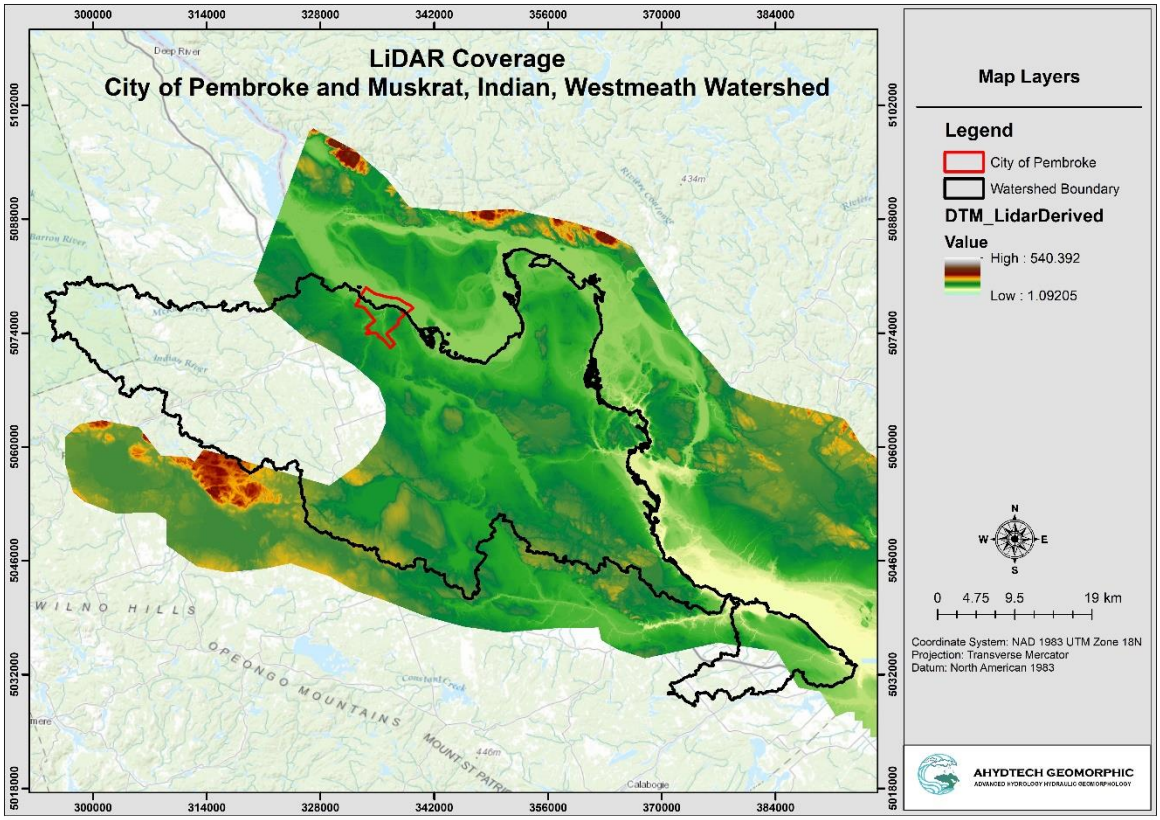

Figure 5-6: LiDAR DTM Coverage

After compiling the dataset, it has been observed that the data does not cover the contributing watersheds of the study area.

2. DEM- Imagery-Derived DEM Package: DRAPE A

Table 5-3: DEM Specifications (DRAPE A)

DEM Specifications (Imagery-Derived DEM Package: DRAPE A)	
Name	Ontario Imagery-Derived DEM Package: DRAPE A
Producer	Ontario Ministry of Natural Resources and Forestry - Provin Mapping Unit
Provider	Ontario GeoHub
Metadata type and URL	1-km by 1-km non-overlapping tiles grouped into packages Algonquin 2015 DEM Package
Geographic Reference	GCS_North_American_1983
Access protocol and URL	Ontario GeoHub
Data type	IMG Raster
Resolution	2 m
Date of data	2014, 2019
Documentations	Provincial Mapping Unit
Licence type	Open Government Licence – Ontario
Usage Restrictions	Public

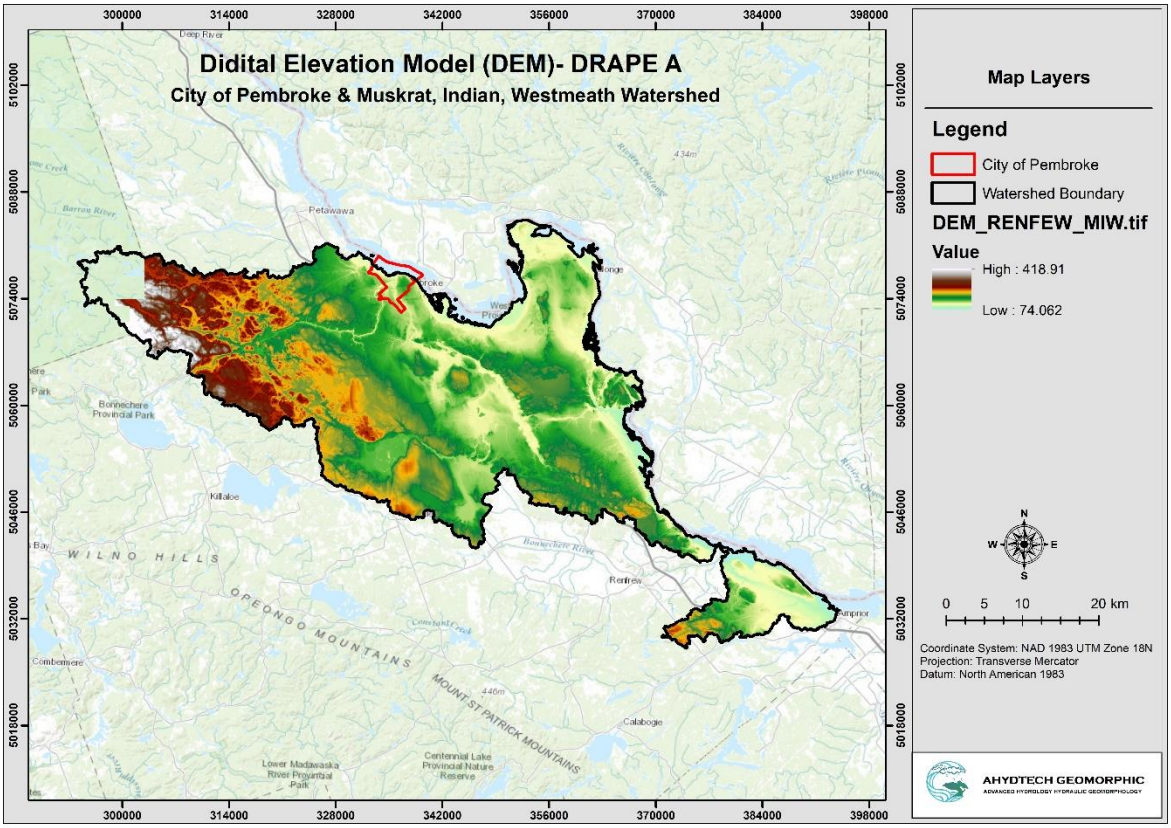

Figure 5-7: DEM (Imagery Derived)- DRAPE A

3. Contour Mapping

Contour Elevation Data was collected from Land Information Ontario using Contour | Ontario GeoHub (gov.on.ca). As a part of Task 7 under this study, a contour elevation map has also been derived from LiDAR. ***Figure 5-8*** shows the contour data extracted from the Land Information Ontario (LIO) for the Muskrat, Indian, Westmeath Watershed and the City of Pembroke.

Table 5-4: Contour Data Specifications

Contour Data Specifications	
Name	Contour
Producer	Ontario Ministry of Natural Resources and Forestry - Provincial Mapping Unit
Provider	Ontario GeoHub
Metadata type and URL	Contour | Ontario GeoHub (gov.on.ca)
Geographic Reference	GCS_North_American_1983
Access protocol and URL	Ontario GeoHub
Data type	Shapefile
Date of data	April 2021
Documentations	Provincial Mapping Unit
Licence type	Open Government Licence – Ontario
Usage Restrictions	Public

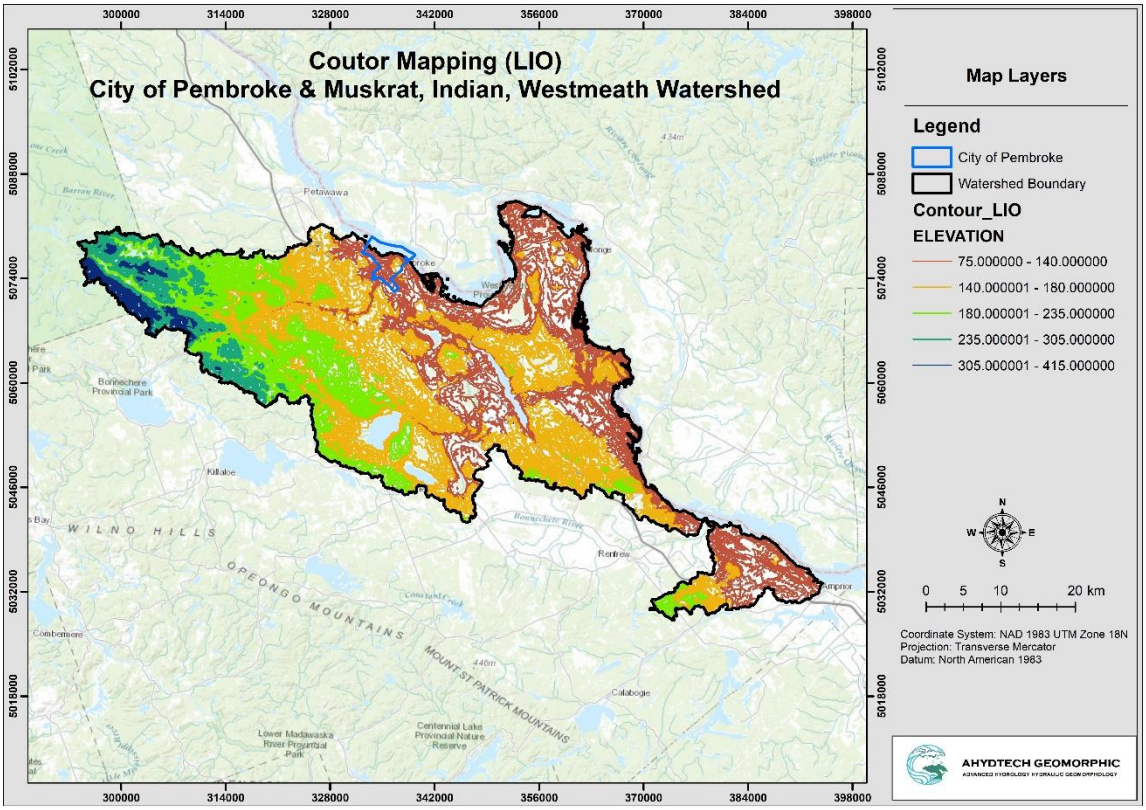

Figure 5-8: Contour Map of Central Ottawa Watershed

5.1.4. Bathymetric Data

Bathymetry data refers to the underwater depths of water bodies including rivers, lakes, ponds, oceans etc. Digital Elevation Model (DEM) typically contains the topographic information of the land surface and does not necessarily provide any detail on the underwater shapes and depths. Hence, for flood hazard assessments and modeling,

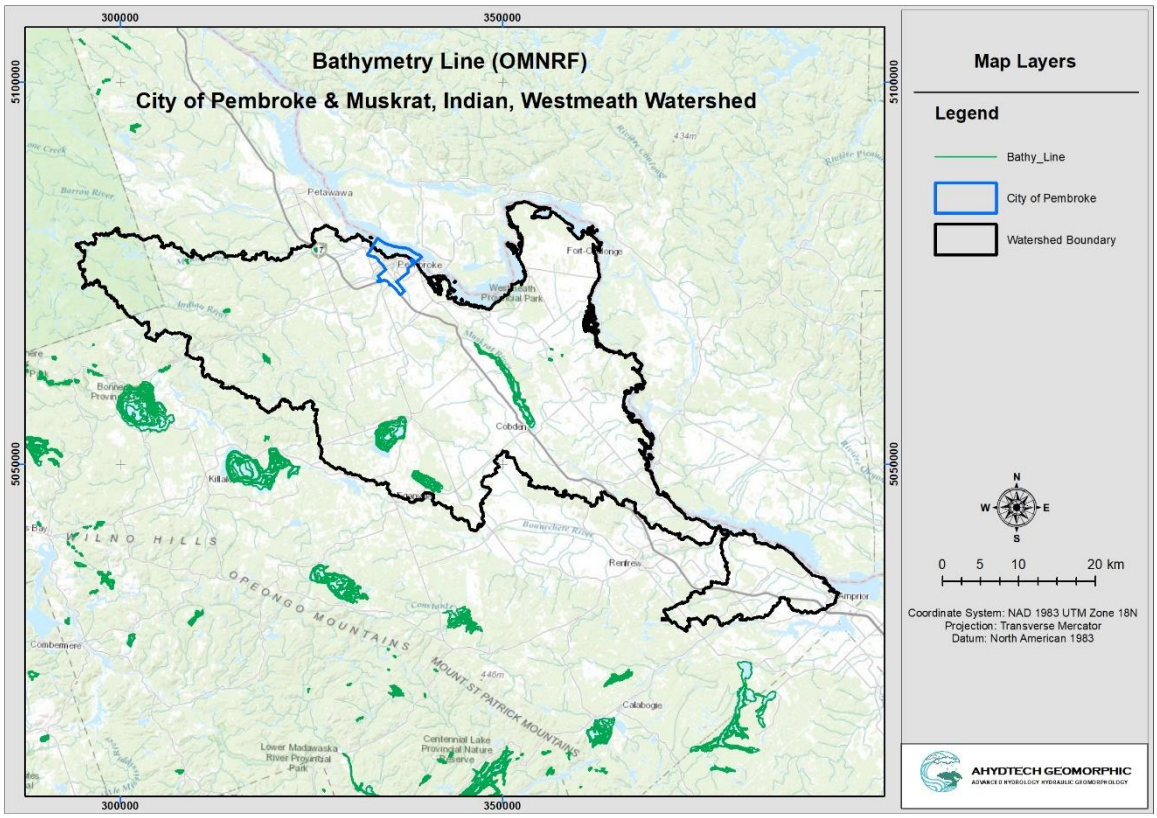

Figure 5-9: Bathymetry Line (Source: Ontario GeoHub)

bathymetry data is very crucial since it is directly associated with the capacity of the waterbodies.

Table 5-5: Bathymetry Line Specification

Bathymetry Line Specifications	
Name	Bathymetry Line
Producer	Ontario Ministry of Natural Resources and Forestry - Provin Mapping Unit
Provider	Ontario GeoHub
Metadata type and URL	Bathymetry, Line | Ontario GeoHub (gov.on.ca)
Geographic Reference	GCS_North_American_1983
Access protocol and URL	Ontario GeoHub
Data type	Shapefile
Date of data	2022
Documentations	Provincial Mapping Unit
Licence type	Open Government Licence – Ontario
Usage Restrictions	Public

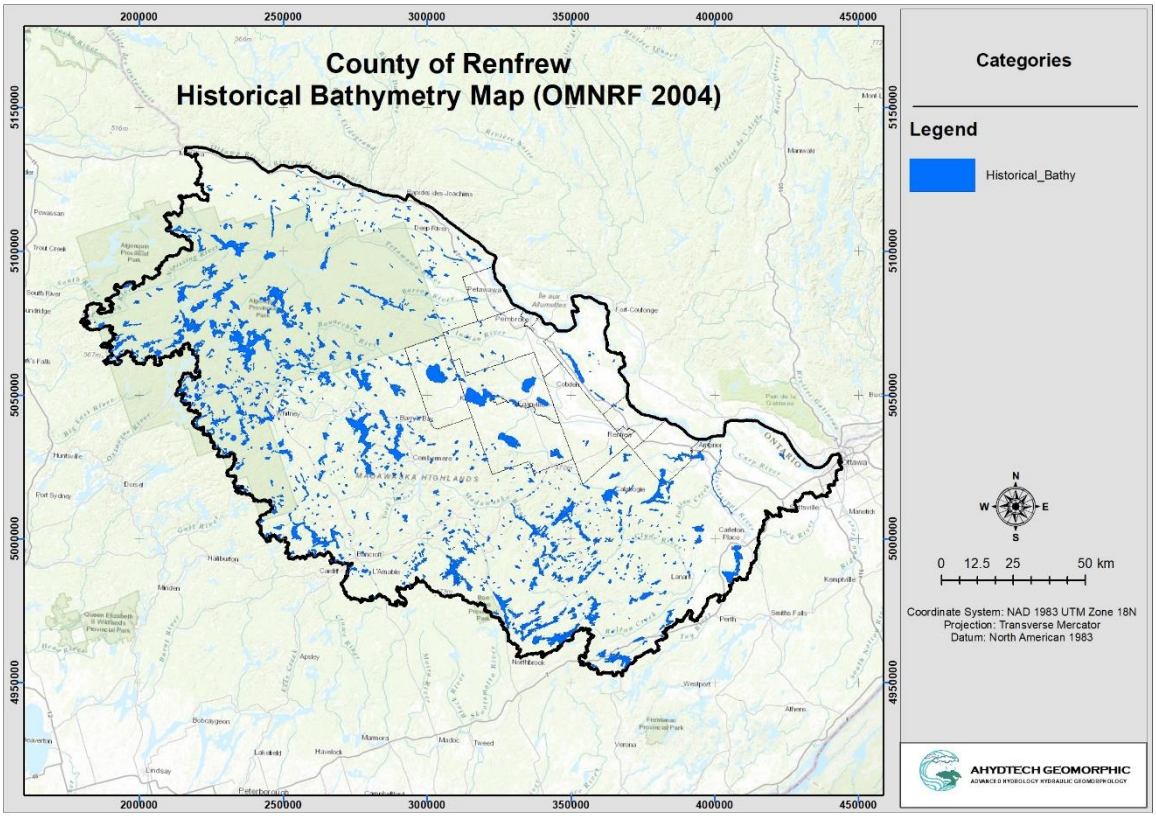

Figure 5-10: Historical Bathymetry Map (2004)

AHYDTECH assessed the available open-source information from different Canadian open data portals. Bathymetry line and historical bathymetry data have been collected from Ontario GeoHub.

5.1.5. Surface Water Networks

Surface water network data is significant in the case of performing hydrologic and hydraulic assessments. AHYDTECH collected this data from two different sources.

1. Ontario Hydro Network (OHN)

Spatial distribution of the drainage network was obtained from Ontario Hydro Network (OHN) - Watercourse | Ontario GeoHub (gov.on.ca).

Table 5-6: Data Specification- OHN Watercourse

OHN Watercourse Data Specifications	
Name	OHN Watercourse
Producer	Ontario Ministry of Natural Resources and Forestry - Provincial Mapping Unit
Provider	Ontario GeoHub
Metadata type and URL	Ontario Hydro Network (OHN) - Watercourse | Ontario GeoHub (gov.on.ca).
Geographic Reference	GCS_North_American_1983
Access protocol and URL	Ontario GeoHub
Data type	Shapefile
Date of data	2010

Documentations	Provincial Mapping Unit
Licence type	Open Government Licence – Ontario
Usage Restrictions	Public

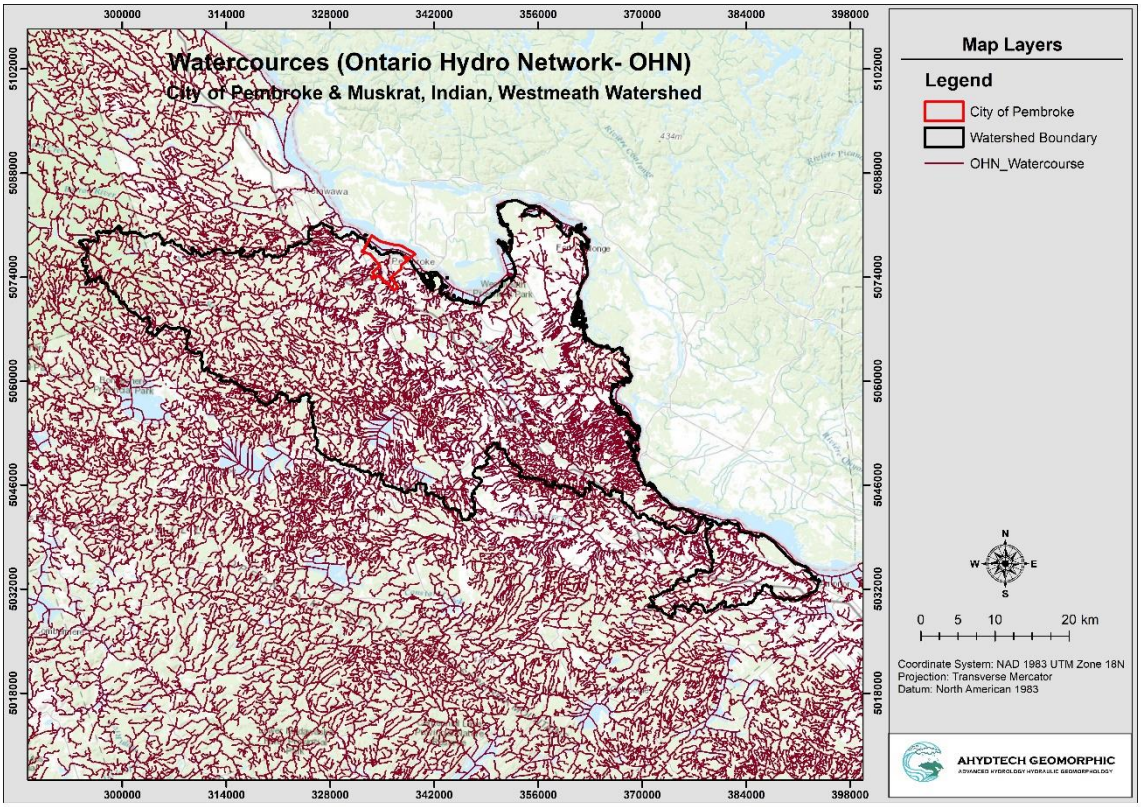

Figure 5-11: Ontario Hydro Network (OHN) Watercourses

2. Ontario Integrated Hydrology

The Ontario Integrated Hydrology (OIH) data is a valuable resource used for generating watersheds and supporting provincial-scale hydrology applications in Ontario. Four key datasets are included in each OIH data package:

- Stream network (Enhanced Watercourse): Represents flowing surface water.
- Hydrology-enforced digital elevation model (Enforced DEM): Provides elevation data.
- Flow direction grid (Enhanced Flow Direction - EFDIR): Indicates water flow directions.
- Raster representation of the stream network (StreamGrid): A visual representation of streams.

AHYDTECH collected these data from [Ontario GeoHub- Ontario Integrated Hydrology (OIH) Data].

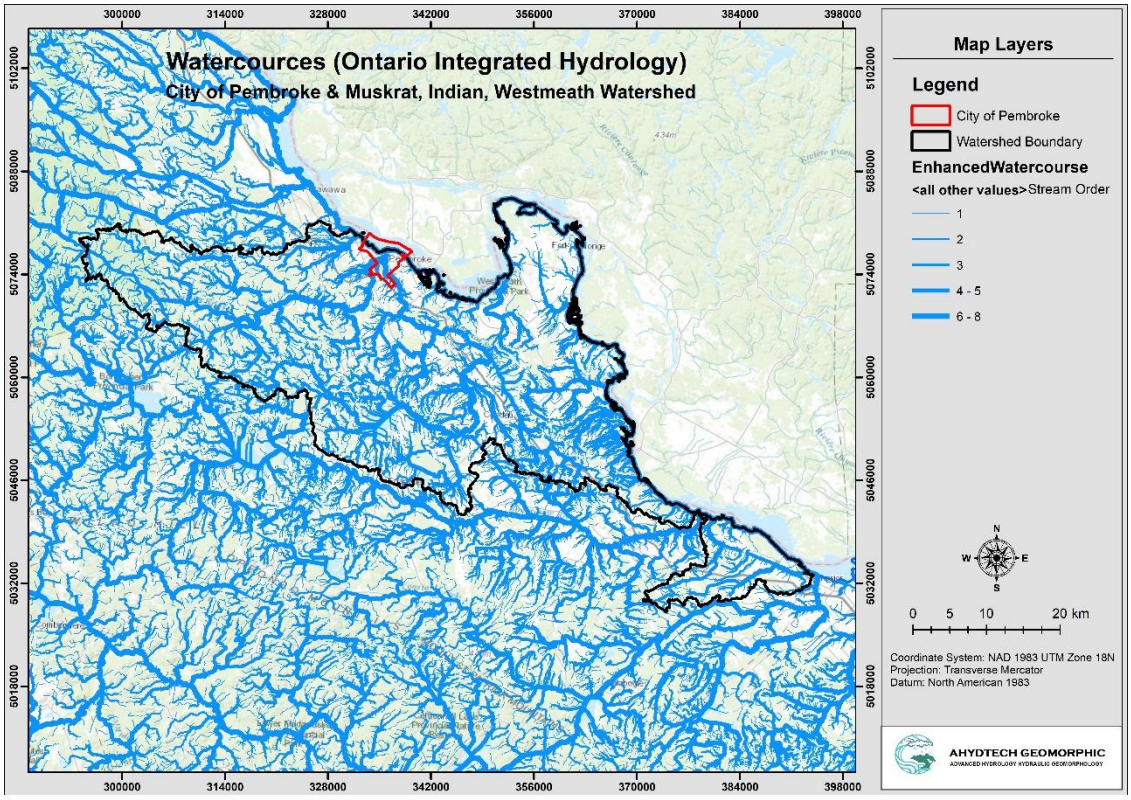

Figure 5-12: Ontario Integrated Hydrology (OIH) Watercourses

5.1.6. Infrastructure Data

Infrastructure data include the locations of bridges and culverts with appropriate dimensions, locations of dams and reservoirs, roads, buildings etc. The County Authority provided the files comprising the locations of bridges and culverts as well as dams and reservoirs. However, no data has been found regarding the detailed measurements of these structures. These data are typically collected as a part of field survey while performing any hydrological and hydraulic assessments for a specific area.

1. **Bridges and Culverts**

   Information on the locations of Bridges and Culverts was provided by the County Authority. Assessing the data, no bridge and culvert was observed within the City of Pembroke. AHYDTECH assessed satellite images and Ontario open data portals and approximately thirteen (13) bridges and culvert locations were found primarily assessing those data. ***Figure 5-13*** shows the locations of approximate locations of bridges and culverts located within the City of Pembroke.

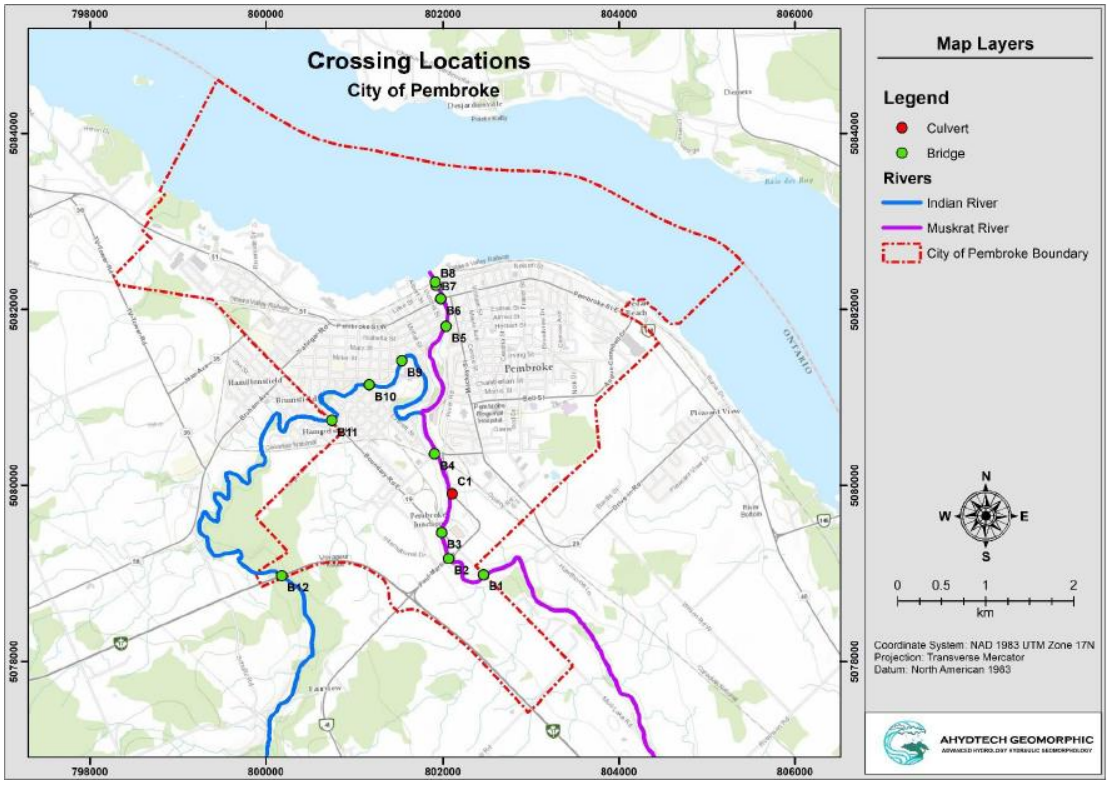

Figure 5-13: Map showing the locations of Bridges and Culverts at the City of Pembroke

2. Dams and Reservoirs

Dams and reservoirs can store large volumes of water, modify flood routing, and significantly reduce peak flows. This helps in managing water resources and mitigating

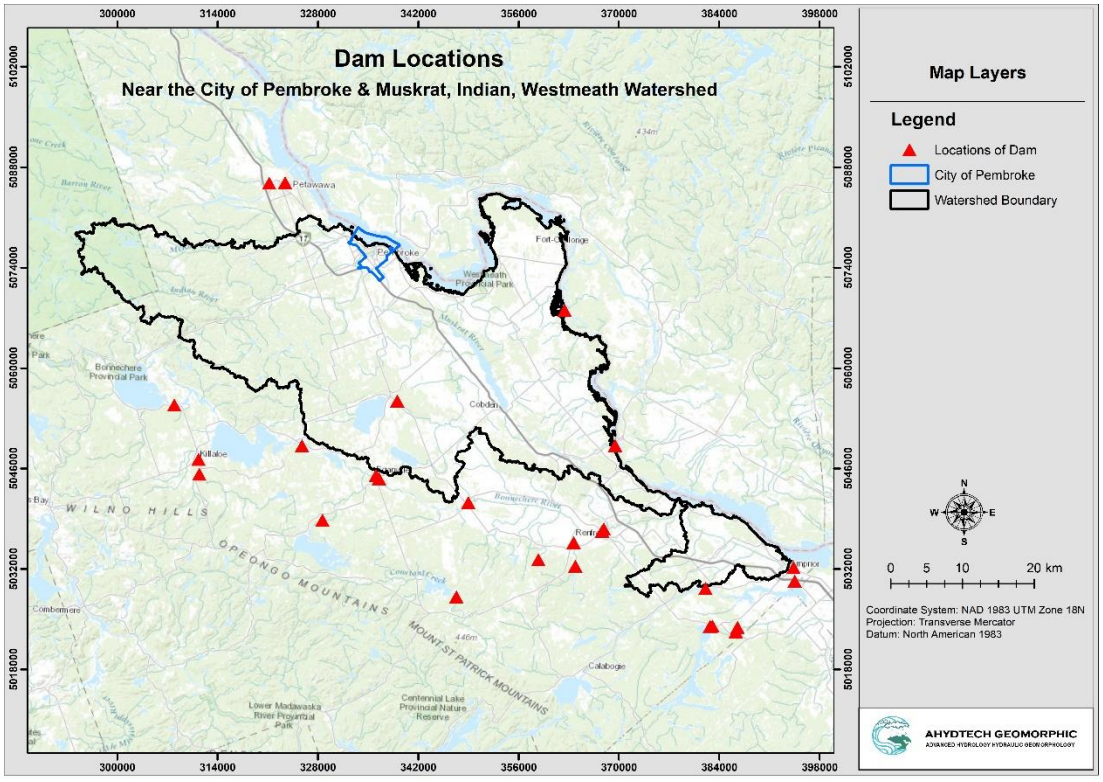

Figure 5-14: Locations of Dams

the risks associated with floods. Properly designed systems can significantly reduce flooding, while undersized structures can increase flooding risks and frequency. While performing any hydrologic and hydraulic assessments, consideration of these structures is a must. The County Authority provided Dam Location Data collected from LIO. Figure showing Dam locations around the Muskrat, Indian, Westmeath watershed and no dams were observed in the City of Pembroke.

3. Roads Networks

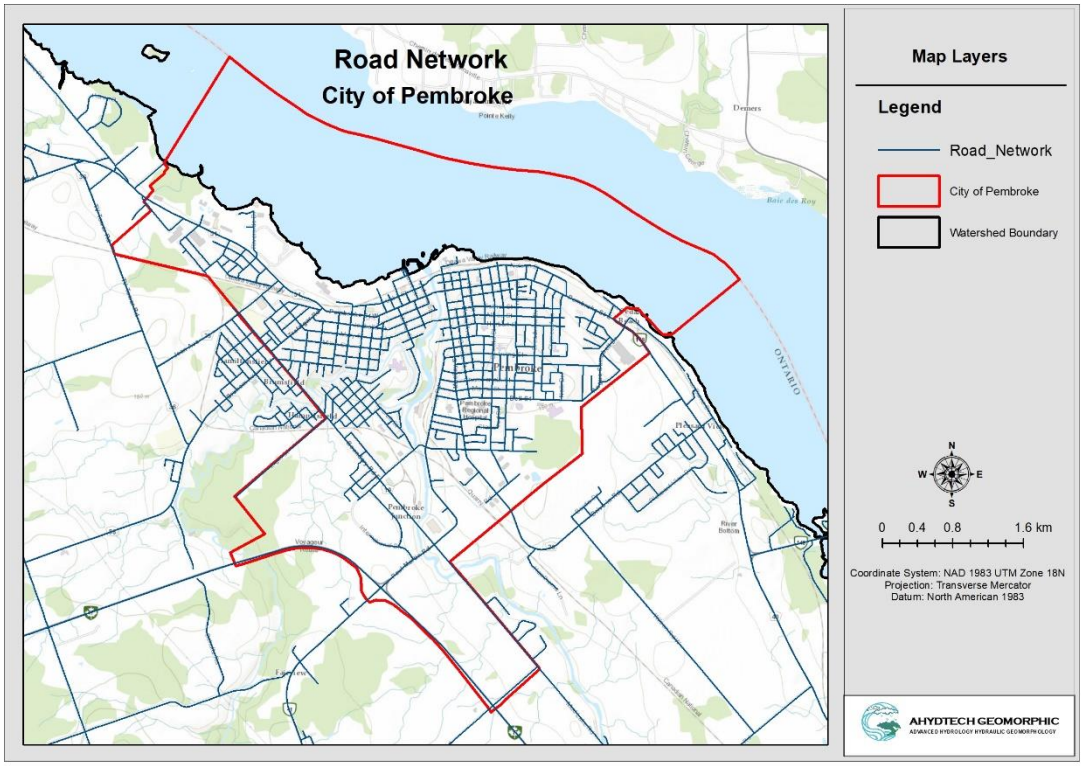

Figure 5-15: Road Network of the Study Area

Road networks and their related structures can alter hydrological connectivity within fluvial systems and shorten a watershed's time of concentration, especially during extreme events when surface flow processes dominate the hydrological response. The location and alignment of the highway can either magnify or eliminate hydraulic problems at the crossings. Road network data was provided by the county authority for the County of Renfrew. ***Figure 5-15*** shows the road network of the City of Pembroke.

4. Building Footprints

Canadian Building Footprints data was collected following the link- https://github.com/microsoft/CanadianBuildingFootprints. This data is essential since it accurately represent the urban terrain in the model. They help in distinguishing between permeable and impermeable surfaces, which is critical for estimating runoff. Besides, building footprints can be used to estimate the potential impact of flooding on built-up areas. This can help in identifying buildings that are at risk during a flood event.

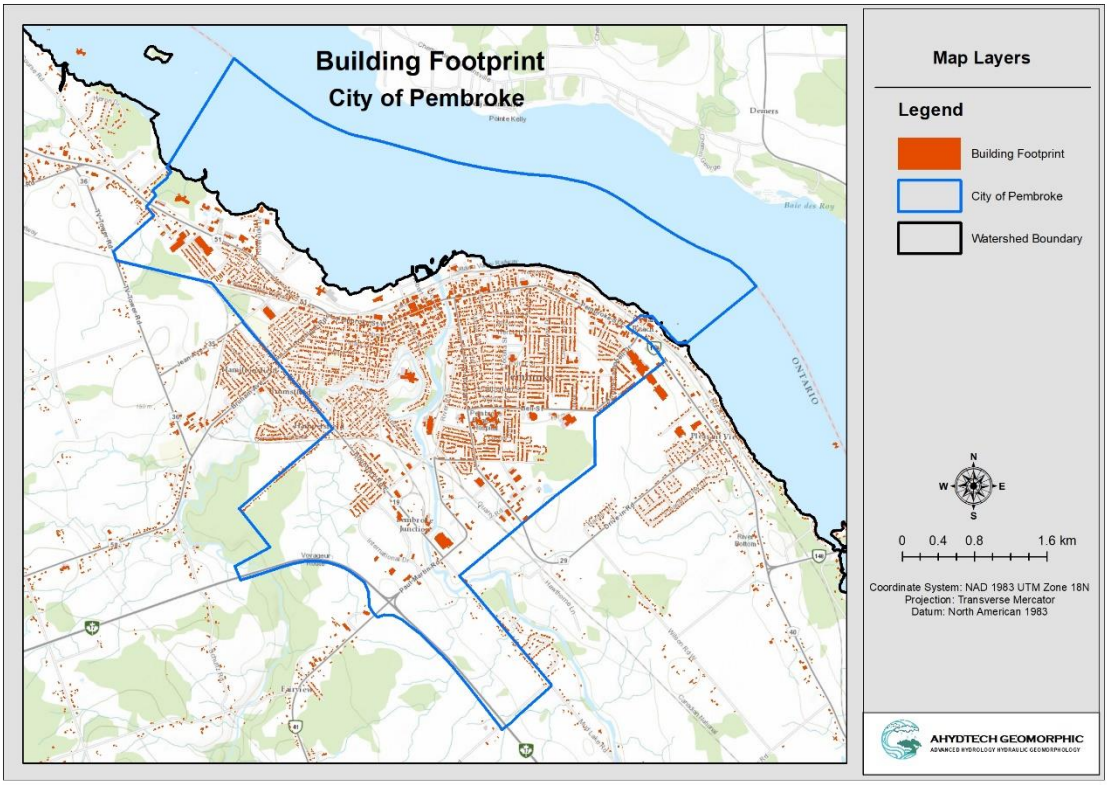

Figure 5-16: Building Footprints (Source: Canadian Building Footprints)

5.2 Hydrometric Data

Hydrometric data, which is essential for the measurement of water-related information, primarily includes data on river flow and water levels (including tides, lochs, and rivers). This data plays a vital role in managing water resources, forecasting and controlling floods, planning irrigation etc. Hydrometric data provides the necessary inputs for hydraulic models and helps in calibration and validation of the models eventually making accurate predictions about water behavior, which is crucial for water resource management, flood prediction, and infrastructure planning.

5.2.1. Discharge Data

Discharge Data is one of the crucial data required for the development, calibration, and validation of hydrologic and hydraulic models. AHYDTECH collected historical discharge data from Environment and Climate Change Canada (ECCC) for all the available stations located within the contributing watershed boundary. Locations of these stations have been illustrated in ***Figure 5-17.***

Two hydrometric gage stations are located within the City of Pembroke, 02KC015- Muskrat River at Pembroke and 02KC018- Indian River at Pembroke. General information regarding the stations have been tabulated below:

Table 5-7: Flow Gauging Stations near Pembroke

Station ID	Station Name	Drainage Area	Period of Record (Flow)	Types of Data	Status
02KC015	Muskrat River at Pembroke	674 km^2	1969-1978, 2008-2024	Flow, Water Level	Active
02KC018	Indian River at Pembroke	465 km^2	2007-2024	Flow, Water Level	Active

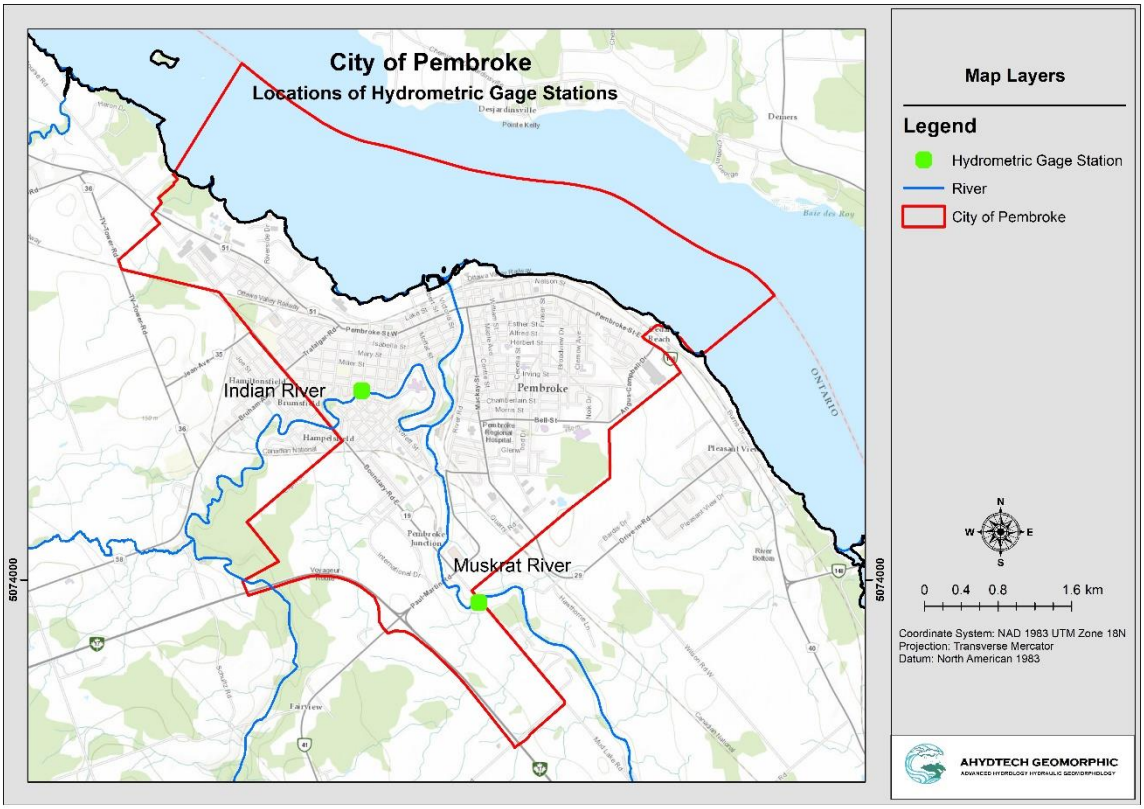

Figure 5-17: Locations of Hydrometric Gage Stations (Discharge) at the City of Pembroke

- **Flood Frequency Analysis**

In 2014, the Spatial Data Infrastructure Unit of the Ontario Ministry of Natural Resources and Forestry (MNRF) generated single station flood frequency estimates for the Water Survey of Canada's (WSC) HYDAT gauges in the Great Lakes watershed systems that lie within the Province of Ontario. The resultant statistics include the flood magnitude with recurrence intervals of 1:2, 1:2.33, 1:5, 1:10, 1:20, 1:25, 1:50, 1:100, 1:200 and 1:500 years for different applications such as floodplain delineation and design of hydraulic structures. Under this program, frequency analysis was conducted for the Station 02KC015- Muskrat River at Pembroke. Findings of the analysis have been tabulated below.

Table 5-8: Flood Frequency Analysis (Station 02KC015- OMNRF 2014)

FREQUENCY ANALYSIS					
02KC015- MUSKRAT RIVER NEAR PEMBROKE					
RETURN PERIOD	EXCEEDANCE PROBABILITY	Flood (m^3/s)			
		Generalized Extreme Value Distribution	Three Parameter Lognormal Distribution	Log Pearson Type III Distribution	Weibull Distribution
1.003	0.997	0.21	-	8.89	1.97
1.05	0.952	14.1	15	17	14.7
1.25	0.8	25.4	26.5	25.7	26.2
2	0.5	37.5	37.8	36.7	37.9
5	0.2	49.8	48.8	49.2	49
10	0.1	55.9	54.3	56.2	54.4
20	0.05	60.7	58.9	62	58.7
50	0.02	65.6	63.9	68.4	63.4
100	0.01	68.4	67.2	72.6	66.4
200	0.005	70.8	70.2	76.4	69
500	0.002	73.2	73.8	80.8	72.2

5.2.2. Water Level Data

Observed Water level data has been collected from Environment and Climate Change Canada (ECCC) for the stations located within the City of Pembroke and contributing watershed boundary. ***Figure 5-17*** shows the hydrometric gage stations locations where discharge and water level data are measured. Both stations provide water level and discharge data on an hourly, daily, monthly, and annual basis.

Table 5-9: Water Level measuring Stations near Pembroke

Station ID	Station Name	Drainage Area	Period of Record (Water Level)	Types of Data	Status
02KC013	Ottawa River at Pembroke	-	1905-1906; 1912-1967; 1969-1994	Water Level	Discontinued
02KC015	Muskrat River at Pembroke	674 km^2	2008-2024	Flow, Water Level	Active
02KC018	Indian River at Pembroke	465 km^2	2007-2024	Flow, Water Level	Active

- **Frequency Analysis (Water Level)**

A station located at Ottawa River at Pembroke, ID- 02KC013 had been discontinued since 1993. It measured streamflow records of the Ottawa River at Pembroke. Under the Canada Flood Damage and Reduction Program (FDRP), floodline mapping was performed in September 1991 by Environment Canada. As a part of the study, Frequency Analysis as performed using Consolidated Frequency (CFA)Tool and Regulatory Flood Elevations were determined for the Station 02KC013. The 1-in-100-year return period was used to compute the regulatory flood elevation for this area. According to the ***MNR Technical Guidelines- River & Stream Systems: Flooding Hazard Limit***, the City of Pembroke and Muskrat, Indian, Westmeath watershed lies between Zone 2 and Zone 3. Hence, both the 100-Year and Timmins Storm Flood must be estimated, and whichever is greater will be

considered as the Regulatory flood event. Findings of 1991 FDRP's frequency analysis have been listed below-

Table 5-10: Results of Frequency Analysis performed under the FDRP study, 1991.

FREQUENCY ANALYSIS			
02KC013- OTTAWA RIVER NEAR PEMBROKE			
RETURN PERIOD	EXCEEDANCE PROBABILITY	Water Level (m)	
		Three Parameter Lognormal Distribution	Wakeby Distribution
1.003	0.997	0.75	0.86
1.05	0.952	1.04	0.99
1.25	0.8	1.3	1.3
2	0.5	1.61	1.61
5	0.2	1.96	1.96
10	0.1	2.17	2.18
20	0.05	2.35	2.39
50	0.02	2.58	2.64
100	0.01	2.73	2.82
200	0.005	2.88	2.98
500	0.002	3.07	3.17

Additional information on historical water level of Ottawa River at Pembroke was collected from multiple sources as a part of Task 3- Identification of Hazard, under this project which has been shown in the following table.

Table 5-11: Identified Historical Flood Elevations at the Pembroke Gauge

Year	Type	Reason	Maximum Water Level at Pembroke	Day
2023	Fluvial, Lake Flooding	Heavy Rain and Snowmelt	113.31	May 3
2019	Fluvial, Lake Flooding	Heavy Rain and Rapid Snowmelt	113.69	May 12
2017	Fluvial, Lake Flooding	Unusually heavy rainfall, coinciding with melting snow	113.03	May 4
1997	Lake Flooding	Spring Thaw	112.56	April 28
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
1957	Fluvial	Hurricane Audrey	112.852	July 7
1951	Fluvial	Heavy Rain, Rapid Snowmelt and Ice Jams	113.34	April 16

Year	Type	Reason	Maximum Water Level at Pembroke	Day
1947	Fluvial	Heavy Rain, Rapid Snowmelt and Ice Jams	113.59	June 18
1928	Fluvial	Heavy Rain and Spring Thaw	113.65	May 19
1909	Fluvial	Heavy Rain and Snowmelt	-	-

5.2.3. Roughness Co-efficient

Roughness Co-efficient is one of the key parameters to develop hydrologic and hydraulic models. It is a crucial parameter in hydrological modeling that represents the loss of energy in open channels due to friction. This frictional resistance is influenced by various factors such as vegetation density, riverbed irregularity etc. On the other hand, the accuracy of the simulated water surface levels in hydraulic modeling depends on the parameterization of Manning's roughness coefficient (n). It reflects hydraulic resistance for flow in a river and flood plain. Roughness in the main channel is usually lower than that in the flood plain. It also varies in the flood plain depending on the type of land use/land cover. Manning's roughness coefficients (n) are typically determined based on the land use and land cover of the study area. Co-efficient values have been assembled for hydrologic and hydraulic modeling purposes following the ***Technical Guidelines for Flood Hazard Mapping (EWRG, March 2017)***. ***Table 5-12*** and ***Table 5-13*** show the lists of Manning's roughness coefficients for different channel types.

Table 5-12: Manning's Roughness Coefficients (Hydrologic Model)

Manning Roughness Coefficients- Hydrologic Model			
Conduit	'n' Standard	Calibration Range	
		Minimum	Maximum
Concrete	0.013	0.011	0.015
Brick	0.015	0.013	0.017
Plastic	0.013	0.011	0.015
Iron	0.013	0.011	0.015
Corrugated Steel Pipe - 3"x1"	0.024	0.021	0.027
Structural Plate Corrugated Steel Pipe - 6"x2"	0.032	0.026	0.036
Open Channel	'n' Standard	Calibration Range	
		Minimum	Maximum
Overbank			
Woods	0.08	0.04	0.12
Meadows	0.055	0.035	0.07
Lawns	0.045	0.03	0.055
Channel			
Natural	0.035	0.025	0.045
Grass	0.03	0.025	0.035
Natural Rock	0.035	0.025	0.045
Armour Stone	0.025	0.017	0.03

Manning Roughness Coefficients- Hydrologic Model			
Concrete	0.015	0.011	0.017
Articulated Block	0.02	0.019	0.032
Gabions	0.025	0.02	0.03
Wood	0.012	0.011	0.013
Overland	'n' Standard	Calibration Range	
		Minimum	Maximum
Impervious	0.013	0.011	0.015
Lawns	0.25	0.15	0.41
Cultivated	0.3	0.06	0.17
Meadows	0.35	0.025	0.4
Woods	0.6	0.4	0.8

Table 5-13: Manning's Roughness Coefficients (Hydraulic Model)

Manning's Roughness Coefficients- Hydraulic Model			
Conduit	'n' Standard	Calibration Range	
		Minimum	Maximum
Concrete	0.013	0.011	0.015
Brick	0.015	0.013	0.017
Plastic	0.013	0.011	0.015
Iron	0.013	0.011	0.015
Corrugated Steel Pipe - 3"x1"	0.024	0.021	0.027
Structural Plate Corrugated Steel Pipe - 6"x2"	0.032	0.026	0.036
Open Channel	'n' Standard	Calibration Range	
		Minimum	Maximum
Overbank			
Woods	0.08	0.04	0.12
Meadows	0.055	0.035	0.07
Lawns	0.045	0.03	0.055
Channel			
Natural	0.035	0.025	0.045
Grass	0.03	0.025	0.035
Natural Rock	0.035	0.025	0.045
Armour Stone	0.025	0.017	0.03
Concrete	0.015	0.011	0.017
Articulated Block	0.02	0.019	0.032
Gabions	0.025	0.02	0.03
Wood	0.012	0.011	0.013

5.3 Meteorological Data

Meteorological data refers to the various weather-related parameters that are used as inputs for hydrologic models. These parameters include-

- Precipitation Data (Rainfall and Snowmelt)
- Temperature Data
- Evapotranspiration
- Longwave and Shortwave Radiation
- Specific Humidity
- Wind Speed
- Air Pressure

These meteorological variables are often collected from available stations and then used as inputs for hydrologic models. The models use this data to simulate various aspects of the hydrologic cycle, such as runoff, infiltration, evapotranspiration, and groundwater flow. The accuracy of these models heavily depends on the quality and resolution of the meteorological data. Therefore, careful evaluation and processing of this data are crucial for reliable hydrologic modeling. Availability of each dataset at or near the City of Pembroke as well as Muskrat, Indian, Westmeath watershed has been discussed below.

5.3.1. Historical Precipitation Data

Precipitation is the primary and most important data to all hydrologic models. It is the primary source of water entering a watershed. It is highly variable in space and time and accurate data can significantly improve the predictive performance of hydrological models.

After assessing different interactive data portals, hourly precipitation data has been assembled for the available stations near the City of Pembroke and Muskrat, Indian, Westmeath watershed. Although three climate stations are available near the prioritized area, they do not have continuous precipitation data. The availability of precipitation has been assessed thoroughly.

Precipitation Data has been collected using Climate data extraction tool - Hourly climate data (canada.ca) and hourly data has been found available for the Station ID 6106367-Pembroke Climate.

Table 5-14: Climate Stations near the City of Pembroke and Muskrat, Indian, Westmeath Watershed

Station ID	Station Name	Data Range	Number of Years	Latitude	Longitude
6106367	Pembroke Climate	2013-2024	11+	45.8603	-77.2522
6106398	Petawawa A	1969-2023	55	45.9500	-77.3167
6106396	Petawawa AWOS 2	2008-2022	15	45.9500	-77.3167

Daily, Monthly and Annual precipitation data with additional information is also available and can be accessed through Ontario Climate Change Data Portal (yorku.ca), Climate Normals interactive maps - Agriculture and Agri-Food Canada, Canadian Climate Normals etc.

5.3.2. IDF Curves

IDF Curve Lookup is used to derive rainfall intensities for various durations and frequencies. It is also used to design drainage systems and often required to develop hydrologic and hydraulic assessments.

- Ministry of Transportation, Ontario (MTO)

Ontario Ministry of Transportation provides Intensity-Duration-Frequency (IDF) curves for the purpose of precipitation information to be used for drainage management can be accessed through the link- IDF Curve Look-up - Ministry of Transportation (gov.on.ca).

A sample of collected IDF Curve Look-up from MTO has been listed below.

Table 5-15: A sample of collected IDF Curve Look-up from MTO for the City of Pembroke

Rainfall depth (mm)									
Duration	5-min	10-min	15-min	30-min	1-hr	2-hr	6-hr	12-hr	24-hr
2-yr	9.5	11.7	13.2	16.2	20	24.6	34.3	42.3	52.1
5-yr	12.5	15.5	17.5	21.5	26.5	32.6	45.4	56	69
10-yr	14.6	18	20.4	25.1	30.9	38.1	53	65.3	80.4
25-yr	17.2	21.2	23.9	29.5	36.3	44.7	62.2	76.7	94.5
50-yr	19.1	23.5	26.6	32.7	40.3	49.6	69.1	85.1	104.9
100-yr	21	25.8	29.2	36	44.3	54.6	76	93.6	115.3

- Environment and Climate Change Canada (ECCC)

Intensity-Duration-Frequency (IDF) data is crucial for making decisions about the risks associated with severe rainfall. Given the anticipated increase in extreme rainfall due to climate change, particularly in Canada, relying solely on IDF data from historical observations is not suitable for long-term planning. Consequently, Environment and Climate Change Canada recommends the use of a scaling approach. They provide climate change scaled IDF curves that can be accessed through the following link- Climate Data Canada. Climate scaled IDF is available for different Representative Concentration Pathway (RCP) scenarios for the following stations:

Table 5-16: Available ECCC Stations for IDF Curve Data

Station ID	Station Name	Elevation (m)
6106367	Pembroke Climate	161
6106400	PETAWAWA NAT FORESTRY	183

The stations provide both CMIP 5 and CMIP 6 based data for RCP 2.6, RCP 4.5, and RCP 8.5. Data has been made available to any users and practitioners for future climate-based projections. The climate change scaled IDF data is provided for 30-year time periods, from 2011-2040 through 2071-2100. A sample of collected IDF data collected from ECCC for the Station- 6106367, Pembroke Climate has been tabulated below.

Table 5-17: A sample of collected IDF data collected from ECCC for the Station- 6106367

Rainfall Rate (mm/hr)									
Duration	5-min	10-min	15-min	30-min	1-hr	2-hr	6-hr	12-hr	24-hr
2-yr	95	69.8	56.1	35.3	21.9	13.9	6	3.4	1.9
5-yr	123.5	86.5	69.9	44.4	28.1	17.5	7.7	4.4	2.3

Rainfall Rate (mm/hr)									
10-yr	142.3	97.6	79	50.5	32.1	19.9	8.9	5	2.6
25-yr	166.1	111.6	90.5	58.2	37.3	22.9	10.4	5.7	2.9
50-yr	183.8	122	99.1	63.9	41.1	25.1	11.5	6.3	3.2
100-yr	201.3	132.3	107.6	69.5	44.9	27.3	12.6	6.8	3.4
Rainfall Rate (mm/hr) (95%_confidence_limit)									
Duration	5-min	10-min	15-min	30-min	1-hr	2-hr	6-hr	12-hr	24-hr
2-yr	12.9	7.6	6.3	4.2	2.8	1.6	0.9	0.4	0.2
5-yr	21.8	12.8	10.6	7	4.7	2.8	1.4	0.7	0.3
10-yr	29.5	17.3	14.3	9.5	6.4	3.7	1.9	1	0.4
25-yr	39.7	23.4	19.3	12.8	8.6	5	2.6	1.3	0.6
50-yr	47.5	27.9	23.1	15.3	10.3	6	3.1	1.6	0.7
100-yr	55.4	32.6	26.9	17.8	12	7	3.6	1.9	0.8

5.3.3. Historical Temperature Data

Temperature affects various hydrologic processes such as evaporation, condensation, and snowmelt. These processes are integral to the water cycle and influence the amount and distribution of water in a watershed. Hourly temperature data is required to perform continuous hydrologic modeling for any watershed. It is essential to generate runoff from precipitation. AHYDTECH collected temperature data using Climate data extraction tool - Hourly climate data (canada.ca).

Near the City of Pembroke and Muskrat, Indian, Westmeath watershed, three climate stations are available which provide hourly temperature and dew point temperature data.

Table 5-18: Available Climate Stations providing Hourly Temperature data

Station ID	Station Name	Data Range	Number of Years	Latitude	Longitude
6106367	Pembroke Climate	2010-2023	14	45.8603	-77.2522
6106398	Petawawa A	1969-2023	55	45.9500	-77.3167
6106396	Petawawa AWOS 2	2008-2022	15	45.9500	-77.3167

Pembroke climate is the only station located within the City of Pembroke and data from this station should be used extensively for hydrologic modeling. In case of any data gaps, data from other available stations can be used. Daily, Monthly and Annual data with additional information is also available and can be accessed through Ontario Climate Change Data Portal (yorku.ca), Climate Normals interactive maps - Agriculture and Agri-Food Canada, Canadian Climate Normals etc

5.3.4. Evapotranspiration Data

Evapotranspiration is a key component of hydrological cycle that links land surface water balance and land surface energy balance. It is one of the most important hydrological parameters that is required to develop continuous hydrologic modeling. It also plays an important role in simulating the hydrological effect of climate change. Proper assimilation of ET data enhances the accuracy of hydrological model.

Evapotranspiration data can be accessed utilizing Open Government Portal Canada. They provide a 30-year Average Potential Evapotranspiration (PET) dataset across Canada using historical climate station data.

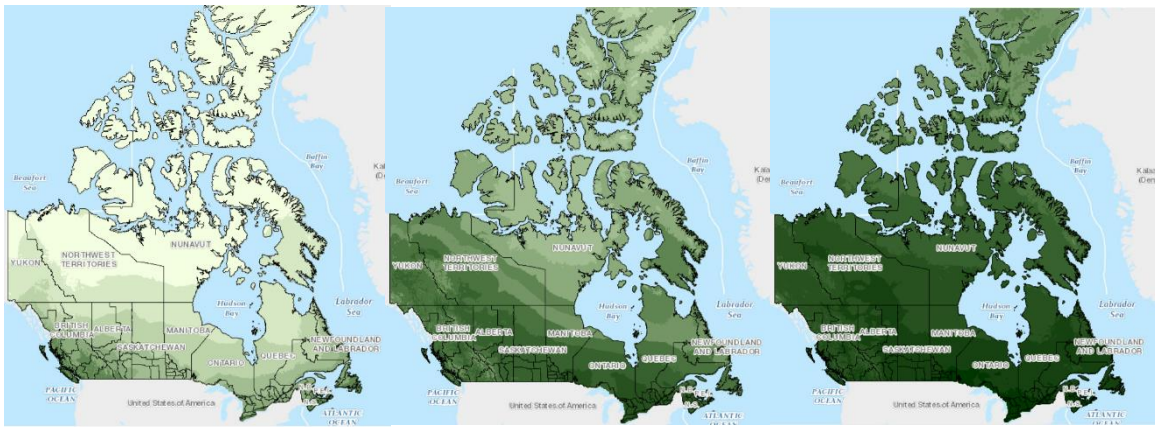

Figure 5-18: Evapotranspiration Data Map Ontario (January, May, August)

AHYDTECH assembled monthly evapotranspiration data for the study area for three different categories.

Table 5-19: 30-year Average Potential Evapotranspiration Data for the Study Area

Potential Evapotranspiration (mm)			
Month	1961-1990	1971-2000	1981-2010
January	50-60	40-50	50-60
February	50-60	50-60	50-60
March	60-80	80-90	80-90
April	80-90	80-90	90-100
May	90-100	90-100	100-110
June	100-110	90-100	100-110
July	110-120	100-110	100-110
August	>120	100-110	>120
September	100-110	100-110	110-120
October	90-100	90-100	90-100
November	70-80	70-80	70-80
December	50-60	40-50	50-60

5.3.5. Snowmelt Data

Snowmelt data plays a crucial role in hydrologic modeling, particularly in regions where snowfall is a significant component of the annual water cycle. It is an essential parameter for simulating snowmelt-runoff mechanisms and streamflow prediction where accurate prediction of streamflow is essential for water resource management, flood forecasting, and infrastructure design.

- Ontario Snow Survey Location Data

This dataset contains location information for Ontario's snow monitoring networks. The Surface Water Monitoring Centre (SWMC) uses this data to assess current snow cover, frozen ground conditions, snowpack, and potential snowmelt contributions to streamflow. The data is collected twice a month from November 15 until May 15 and is located in a

corporate water and climate database. This data helps the Ministry of Natural Resources and Forestry (MNRF) and conservation authorities assess the potential for flooding at the local and provincial scale. AHYDTECH collected the location information from Ontario Geohub- Snow Survey Location and assessed the convenience for the City of Pembroke and Muskrat, Indian, Westmeath watershed.

5.3.6. Solar Radiation Data

Solar radiation is an important hydrological parameter that affects the hydrological cycle. Both direct and diffuse solar radiation are affected by surface characteristics such as slope, aspect, altitude, and shading. Therefore, it is crucial to consider these factors in hydrological modeling.

Historical Solar radiation data for different durations and locations can be extracted from NASA Power that is available for public use and can be accessed anytime.

5.3.7. Relative Humidity

Relative humidity affects the rate of evapotranspiration, which is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Incorporating relative humidity data in hydrologic models can help in achieving more accurate and reliable results. These results can be further used to find out the impact of climate change, change in land use, urbanization, forecast runoff and extreme events like flash floods etc.

AHYDTECH collected Relative Humidity data using Climate data extraction tool - Hourly climate data (canada.ca) for the climate stations listed in ***Table 5-14***. Relative Humidity data for different durations and locations can also be extracted from NASA Power that is available for public use and can be accessed anytime.

5.3.8. Windspeed Data

Wind patterns can influence the distribution and intensity of precipitation, which is a critical input for hydrologic models. In colder climates, wind speed can affect the distribution of snowfall and the formation of snowdrifts, which can impact the timing and volume of snowmelt runoff. Therefore, wind speed data is crucial for hydrologic modeling due to its impact on several key processes.

Windspeed data using Climate data extraction tool - Hourly climate data (canada.ca) for the climate stations listed in ***Table 5-14***. Historical Windspeed data for different durations and locations can also be obtained from NASA Power which is available for public use and can be accessed anytime.

5.3.9. Climate Change Monitoring Network and Model Data

The Environment and Climate Change Canada (ECCC) operates a long-term climate monitoring network and has been involved in joint climate modeling activities. These efforts have facilitated the creation of climate change projections for both Canada and the world. ECCC has recently set up the Canadian Centre for Climate Services (CCCS) to enhance the availability of regional climate data, information, and tools, which could be beneficial for outlining flood risk areas.

5.4 Previous Floodplain Mapping Studies

- **Floodline Mapping Report for the City of Pembroke under Flood Damage Reduction Program (FDRP) (1991)**

The study report presents information regarding the methods used to estimate the flood risk areas along the Ottawa River shoreline within Pembroke Township. Flood Frequency analysis was performed for the Station 02KC013- Ottawa River at Pembroke, results of which has been summarized in ***Table 5-10*** . Some major observations from the report have been listed below:

I. This study provided information on the Regulatory Flood Elevations for the shoreline along the Ottawa River between the shoreline upstream- Township of Petawawa and downstream- Westmeath, which were covered by previous two studies by FDRP.
II. The 1-in-100-Year return Period flood was used to compute the regulatory flood elevation.
III. A freeboard allowance of 0.16m was added to the 1-in-100-year flood level at the Pembroke Gauge for the consistency with the flood mapping study undertaken upstream. A regulatory flood elevation of 113.89m was assumed for the entire shoreline.
IV. The project did not receive FDRP funds to prepare 1:2000 scale topographic mapping and perform the required engineering studies due to the program priorities and funding constraints.
V. Highest recorded flood elevation before 1991 was 113.70m GSC at Pembroke Gauge in May16, 1960 flood.

Table 5-20: Summary of 1991 flood frequency analysis

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

This study is almost 34 years old. Since then, changes in the landscape have occurred along the shoreline and floodplain. As a result, there will be discrepancies between the originally plotted flood elevations and the current state of the land.

- **Ottawa River Floodplain Mapping Report by MacLaren Plansearch Inc. (1984)**

A floodplain mapping study of the Ottawa River within the boundaries of the Regional Municipality of Ottawa-Carleton was completed in 1984. The study was undertaken due to the frequent flooding event caused by high water levels and waves along the City of Ottawa. The study report has been summarized below-

I. The study performed field investigations, data collection, hydrological analysis and hydraulic models and prepared floodplain mapping.
II. This study was based on available flow monitoring data with topographic mapping produced by Northway-Gestalt Survey Corporation Limited.
III. The hydrologic analysis involved a detailed examination of historical streamflow data from three-gauge locations: Chats Falls, Britannia and Grenville/Carillon.

IV. Hydraulically the study area included four independent reaches- (1) Downstream study limit of Chaudiere Dam; (2) Chaudiere Dam to Britannia Bay; (3) Britannia Bay to Chats Falls Dam; (4) Chat Falls dam to upstream study limit and for each of these reach, design flow rates, downstream water surface elevations were assessed.
V. Flood Frequency analysis was performed to determine discharges for the 2, 5, 10-, 25-, 50- and 100-year return periods at Chats Falls and Grenville/Carillon.
VI. MacLaren (1984) calibrated their HEC-2 model using the May 1974 flood event, for which flows in the tributaries and the water levels at Cumberland and the Rideau Locks were known.
VII. Specific findings include-
    a. Construction of dams along the Ottawa River resulted in a reduction of peak flow rates of more frequent floods.
    b. The flood flow rates at Chat Falls Dam were used for flood profile estimations from Chaudiere Dam to the upstream limit of the study.
    c. Flood depths were calculated for the study area and flood prone areas and structures subject to the 1-in-100-year flooding were identified. Flood mitigations strategies and recommendations were also provided in the report.
VIII. Wind wave analysis was also carried out under this study as due to reports of flood damage caused by waves at locations such as Britannia Bay. Design wave Heights and Wave periods were calculated.
IX. The study considered wave run up separately and adjusted the design 1-in-100-year flood level including an allowance for wave run-up.
X. This mapping has been used by RVCA and the City of Ottawa in the land use planning and development process since 1985.

As this study collected and incorporated several data of the Ottawa River reach downstream of the City of Pembroke and Muskrat, Indian, Westmeath watershed as well as estimated design flood levels considering wave allowance as well as performed several statistical analyses, these data might deem useful for future flood mapping studies to be undertaken by the County of Renfrew.

- **Ottawa River Flood Risk Mapping from Shirley's Bay to Cumberland by Rideau Valley Conservation Authority (RVCA) (2014)**

As 1984 mapping study had become outdated, a new study was required to be performed for municipal planning purposes. The study report has been summarized below-

I. Primary objective of the study was to map the expected extent of inundation during a 1:100-year flood- which is the regulatory flood event.
II. The report provides a summary of the analytical methods used and underlying assumptions applied in the preparation of flood plain mapping for the 60 km reach of the Ottawa River from Cumberland to Shirley's Bay which covers the entire reach of the River within RVCA jurisdiction.
III. The study performed simitar hydrological analysis as 1984 study taken into account additional 28 years of data.
IV. Estimated 1:100-year flood flows based on the longer historical streamflow records were about 3% to 6% lower than those estimated in the previous (1984) study.

These floodplain mapping reports were assessed for relevant information the Ottawa River flooding extents and design flood elevations. A recent study conducted by the Centre d'expertise hydrique du Québec (2008) focused on mapping the Quebec side of the Ottawa River. The study aimed to update water level estimates for the 1:20 and 1:100-year floods along this stretch of the

river, extending from the Carillon Dam up to Waltham, QC. Objective of the study was to update water level estimates for specific flood return periods. The study developed stage-stage relationships for adjacent gauge pairs and used interpolation between gauge locations to estimate flood water level as well as determined non-exceedance probabilities for water levels recorded at hydrometric stations. The study also established relationships between these stations and other locations within the study area. No additional information and report were found on this study.

5.5 Historic Non-Systematic Data

Historic non-systematic data is a term used to describe information that was collected in the past without following a uniform or standardized procedure. This could imply that the data was collected in an ad-hoc manner, without a set methodology or structured plan. Despite the potential value of such data, it's crucial to remember that the absence of systematic collection methods might lead to inconsistencies or biases, which should be considered when analyzing or interpreting this data.

Historical data can enhance the systematic hydrometric record and offer supplementary data for verifying models related to hydrology, hydraulics, ice, and storm surges. In numerous places, historical water levels establish the standard flood hazard line. In certain Canadian jurisdictions, the complete flood hazard zones are delineated, and development is directed, according to flood lines based on historical data. Some of these data are-

5.5.1. High Water Marks

HWMs data are often used to calibrate and validate hydraulic models. These models can then predict future flood events, guide the construction of flood defenses, and inform flood risk management strategies. HWMs data are essential for creating accurate flood maps. These maps can then be used for urban planning, insurance purposes, and emergency response planning.

For the City of Pembroke, Canadian Flood Damage and Reduction Program (FDRP) estimated design water levels for different return periods in 1991, which has been listed in ***Table 5-20***. Local stakeholders and citizens might have additional relevant information or photographs capturing high water marks during historical flood events.

5.5.2. Indigenous Knowledge

Incorporating Indigenous knowledge into hydrologic and hydraulic assessments not only enriches the understanding of water systems but also promotes sustainable and equitable water management practices. In many watersheds, Indigenous people have knowledge of high-water events, ice-jam formation processes, and flow–land use relationships.

For the study area, no open-source indigenous community information has been found regarding flood issues and extents.

5.5.3. Citizen Science

Citizen science can provide valuable information at all levels of flood risk management, particularly for flood hazard assessment. This includes data on rainfall, land-use, and past flood events. Sometimes a single mobile phone-captured photograph and videos can be interpreted by professionals to determine flood extents.

For the study area, no such data has been obtained so far.

5.5.4. Aerial Photographs and Satellite Images

Aerial Photos and satellite images are one of the key sources to identify historical flood locations, severity and extents. According to the information provided by the County authority, High resolution digital air photo coverage of all of Eastern Ontario was obtained through a collaborative project referred to as the DRAPE project (Digital Raster Acquisition Partnership East) in 2008 and 2019. The imagery was captured at a scale of 1:16,667. This high-quality colored photo clearly shows the rivers, creeks, land use, houses, buildings, roads, infrastructure, vegetation and other details.

Historical aerial photographs of Ontario can be obtained from several sources:

Archives of Ontario: The Archives of Ontario holds a collection of black & white positive print air photos from 1946 to 1999.

Ontario Imagery Program: The Land Information Ontario (LIO) acquires, maintains, and distributes high-resolution imagery collected across Ontario.

Satellite images can be downloaded from Ontario Data Catalogue, USGS earth Explorer, Copernicus Open Access Hub etc.

6. Data Gaps Assessment- Muskrat, Indian, Westmeath Watershed and City of Pembroke

While preparing the data inventory, substantial data gaps have been observed in various data categories. To conduct hydrologic and hydraulic assessments for the priority area-City of Pembroke and Muskrat, Indian, Westmeath Watershed as well as to determine future flood hazards, these data gaps must be filled. A list has been prepared identifying the major data gaps found for the study area. These have been discussed below-

City of Pembroke

After preparing the inventory of the required data for conducting hydrologic and hydraulic assessments for floodplain mapping of the City of Pembroke, a summary has been prepared.

Table 6-1: Summary of the Data Inventory- City of Pembroke

Geospatial Data	
Data Type	Data Gap
Soil Data- SSC	Available
Soil Data-SLC	Available
LULC Data- ESRI	Available
LULC Data-OLCC 2	Available
LiDAR DTM	Available
Digital Elevation Model- DRAPE A	Available
Channel Bathymetry	No data has been found.
Flood Hazard Area LiDAR	No data has been found.
Infrastructure	Only Location Information has been found.
Hydrometric	
Discharge Data	Available
Water Level Data	Partially available

Rating Curve	No data has been found.
Meteorological	
Temperature	Available
Precipitation	Available
Winds	Available
Climate Change	Available
Non-Systematic	
Historical observations	Available
High-water Marks	Partially available
Indigenous knowledge	Partially available
Drone	No data has been found.
Citizen Science	No data has been found.
Aerial Photographs	Available
Satellite Imagery	Available

Detail discussion has been provided on the data that are unavailable and partially available from the above list.

1) Channel Bathymetry

Channel bathymetry is a crucial data for hydraulic modeling and floodplain mapping. The city of Pembroke is located at the confluence of Indian and Muskrat River which eventually drains out at the Ottawa River passing through the city. For developing site specific hydrologic and specifically hydraulic modeling, bathymetry survey is essential to acquire details of the channel's geometry, bed elevations and cross sections with small intervals. Before conducting any hydraulic assessments, bathymetry survey will be required for major channels, tributaries, lakes and ponds.

AHYDTECH assessed all the available open data sources, consulted with the local municipalities as well as the County authority for collecting the available information regarding the bathymetry of the rivers located within the study area. No channel cross-section information was found for the tributaries, however, the City of Gatineau performed extensive data acquisition in the area including bathymetric surveys of the Ottawa River in 2019-2020 covering the reach along the County of Renfrew. Therefore, request can be made to acquire these data to the City of Gatineau for flood plain mapping.

Canadian Hydrographic Services Data was also evaluated for the availability along the reach covering the City of Pembroke. ***Figure 6-1*** shows the NONNA Bathymetry data available near the study area.

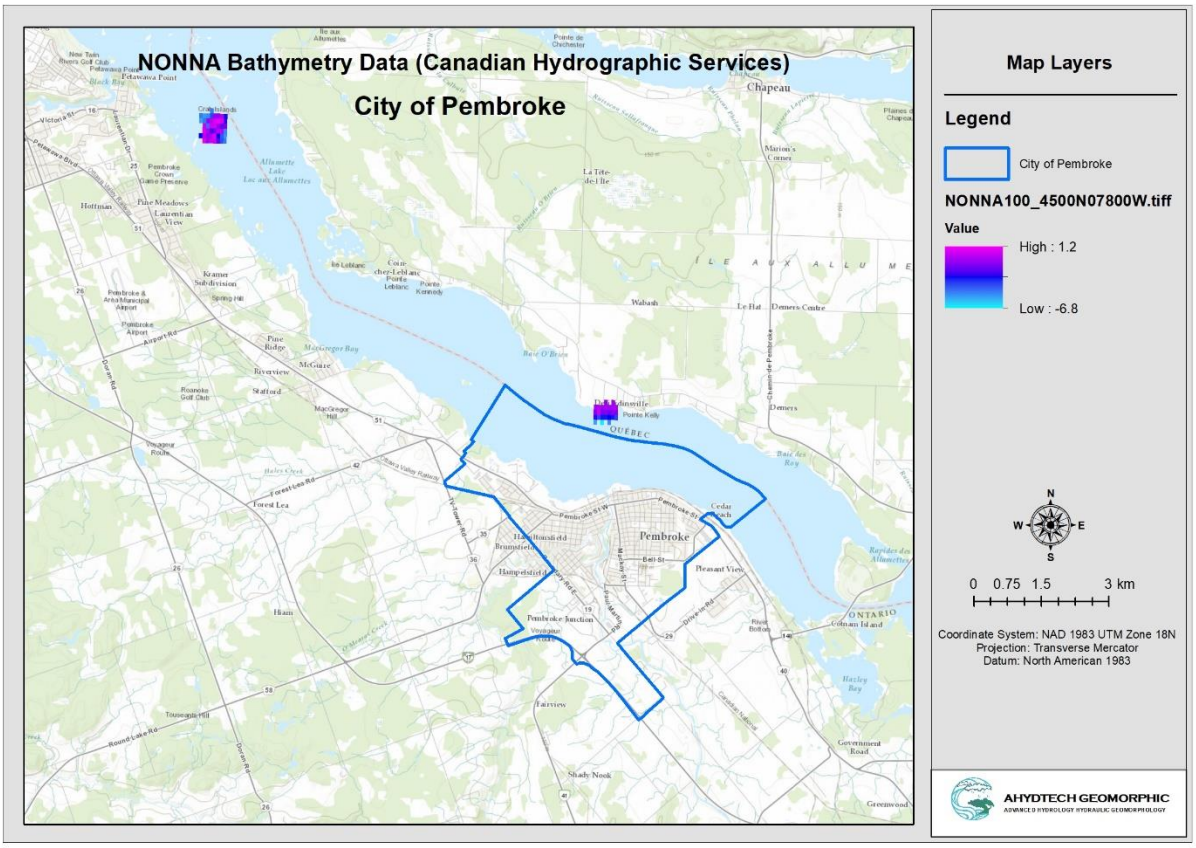

Figure 6-1: NONNA-Canadian Hydrographic Services Data near Pembroke

2) Additional Topographic Data

Topographic Data is one of the primary data that is required to develop any hydrologic and hydraulic analysis. DTM and DEM often contain missing information and have certain inaccuracies. Given that the LiDAR-based DEM data is often insufficient to represent the actual topography and bathymetry of the floodplains and main channels such as Indian River and Muskrat River within the City of Pembroke. Hence, field survey is required to perform for verification of LiDAR and Digital Elevation Model (DEM) for hydrologic and hydraulic assessments.

3) Rating Curve/ Stage Discharge Relationships

The stage-discharge relationship, also known as the rating curve, for rivers and streams in Ontario is typically provided by government agencies and research institutions that monitor water resources. The rating curve is typically developed by making frequent manual discrete discharge measurements at stream gaging stations. Over time, as more data is collected, the rating curve can be refined to more accurately reflect the relationship.

According to a study focused on mapping the Quebec side of the Ottawa River, conducted by the Centre d'expertise hydrique du Québec (2008) developed stage-stage relationships for adjacent gauge pairs and used interpolation between gauge locations to estimate flood water level. These data can be requested from the authority, if required.

4) Hydraulic Structure Information

Different hydraulic structures such as bridges, culverts, dams and reservoirs data must be collected as a part of field investigation and survey. Dimensions, elevations, length, width, diameter, material etc. data must be collected during field reconnaissance.

5) Flood Hazard Area LiDAR

Flood Hazard Area LiDAR is a powerful tool for understanding flood risks, improving preparedness, and enhancing floodplain management. This focuses on collecting elevation data in regions prone to flooding.

No nearby locations and jurisdictions have Flood Hazard Area based on LiDAR and consequently no data has been found for the City of Pembroke. This information is a secondary sourced data derived from LiDAR. To acquire this information, for the City of Pembroke a separate study can be carried out.

6) Water Level Data

As per the discussion provided earlier in **1.5.2.2**, Water Level data is available for the three (3) hydrometric gage stations located within the City of Pembroke. However, the station located at Ottawa River ID-02KC013, Ottawa River had been discontinued since 1994. Hydro Ottawa collects water level information at various location of the Ottawa River, possibly including the Pembroke Gauge. Therefore, UpToDate water level information can be obtained from Hydro Ottawa, if available. The Ottawa River Regulation Planning Board also provides real-time data on water levels and streamflow at various locations along the Ottawa River.

7) Snowmelt Data

High flows usually occur due to the combined effect of precipitation and snowmelt. Station 610600 at Ottawa Macdonald Cartier International Airport provides Rainfall+Snowmelt data for different return periods. Although this station is located way too far from the City of Pembroke and Muskrat, Indian, Westmeath watershed, in case of the absence of these data at nearby stations, this data can be obtained from the respected authority.

8) High-water Marks

Locally collected historical high water mark data has not been found. This data can be collected through extensive field visit and consultation with local people and stakeholders. Water level data is only available at the gauging stations. Additional water level information or high-water mark data will facilitate future floodplain mapping program.

9) Indigenous knowledge

This information can also be collected through extensive field investigation and engagement with local people and stakeholders.

10) Drone

No drone footage or image has been found for the City of Pembroke.

11) Citizen Science

This information can also be collected through extensive field investigation and engagement with local people and stakeholders.

12) Aerial Photographs

High Resolution digital air photos can be obtained from DRAPE A.

13) Satellite Imagery

No satellite imagery has been collected for the City of Pembroke. However, satellite images can be extracted from different interactive sources mentioned in ***section 1.5.5.4.***

Muskrat, Indian, Westmeath Watershed

Data gaps have been explicitly assessed for the Muskrat, Indian, Westmeath Watershed. Summarized information has been provided below-

Table 6-2: Summary of the Inventory- Muskrat, Indian, Westmeath watershed

Geospatial Data	
Data Type	Data Gap
Soil Data- SSC	Partially available
Soil Data-SLC	Available
LULC Data- ESRI	Available
LULC Data-OLCC 2	Available
LiDAR DTM	Partially available
Digital Elevation Model- DRAPE A	Available
Channel Bathymetry	No data has been found.
Flood Hazard Area LiDAR	No data has been found.
Infrastructure	Only Location Information have been found.
Hydrometric	
Discharge Data	Available
Water Level Data	Partially available
Rating Curve	No data has been found.
Meteorological	
Temperature	Available
Precipitation	Available
Winds	Available
Climate Change	Available
Non-Systematic	
Historical observations	Available
High-water Marks	Partially available
Indigenous knowledge	Partially available
Drone	Partially
Citizen Science	No data has been found.
Aerial Photographs	Available
Satellite Imagery	Available

1) Soil Data-SSC

Collected Soil Survey Complex data for the Muskrat, Indian, Westmeath Watershed does not cover the This data is essential to generate Curve Number Grids for the watersheds as well as to determine soil permeability and different hydrologic model parameterization depend on the availability of soil data. ***Figure 5-2*** shows that the western part of the watershed lacks soil information collected from Soil Survey Complex. This missing data can be requested from Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA).

2) LiDAR DTM

Assessing the LiDAR DTM, it has been observed the data does not cover all the watershed areas. From ***Figure 5-6***, it is evident that the LiDAR data do not cover the entire Muskrat, Indian, Westmeath watershed.

This data gap can be eliminated utilizing other elevation data and/or collecting updated LiDAR coverage of the remaining watershed, if available.

3) Channel Bathymetry

No channel bathymetry data has been found for the watershed. As watershed is considered as an ideal unit in hydrologic assessment which does not require extensive bathymetry survey if High-

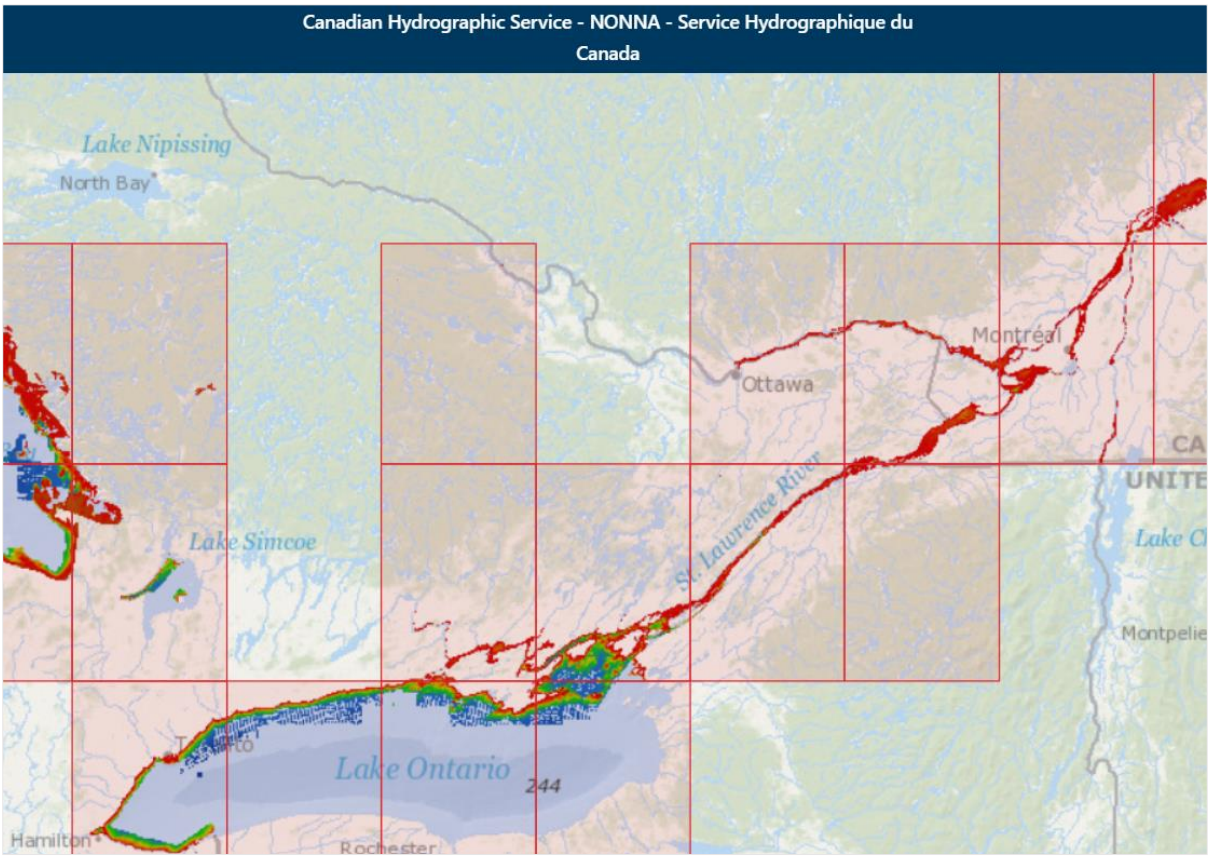

Figure 6-2: CHS NONNA Bathymetry Coverage along the Ottawa River

Resolution DTM is used, it is not required to perform bathymetric survey for the entire watershed for hydrologic assessment. If hydraulic model and floodplain mapping is performed for the entire watershed, detailed bathymetric survey of the watercourses will be required which must cover the full Muskrat, Indian, Westmeath watershed. ***Figure 6-2*** illustrates that CHS NONNA bathymetry does not cover the watershed.

For the Muskrat, Indian, Westmeath watershed, gaps in other data such as water level data, rating curve, Snowmelt, High-water marks, indigenous knowledge, drone footage, citizen science, aerial photographs as well as satellite images can be observed from the previous data gap section specifically discussed for the City of Pembroke.

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Appendix A

Soil Data Coverage for the Entire Central Ottawa Watershed

Table 1: Soil Data Coverage

Watershed	Total Watershed Area (SqKm)	Area Covered (Soil Survey Complex)	Area Covered (%)
Bonnechere River Watershed	2380.27	1928.81	81.0
Central Ottawa- Dumoine Watershed	1692.23	1376.16	81.32
Central Ottawa- Mississippi Watershed	4458.46	3191.02	71.57
Madawaska River Watershed	8506.86	5194.45	61.06
Muskrat, Indian, Westmeath Watershed	1841.22	1759.27	95.55
Petawawa-Barron Watershed and Upper Renfrew County Watershed	4193.87	648.44	15.46

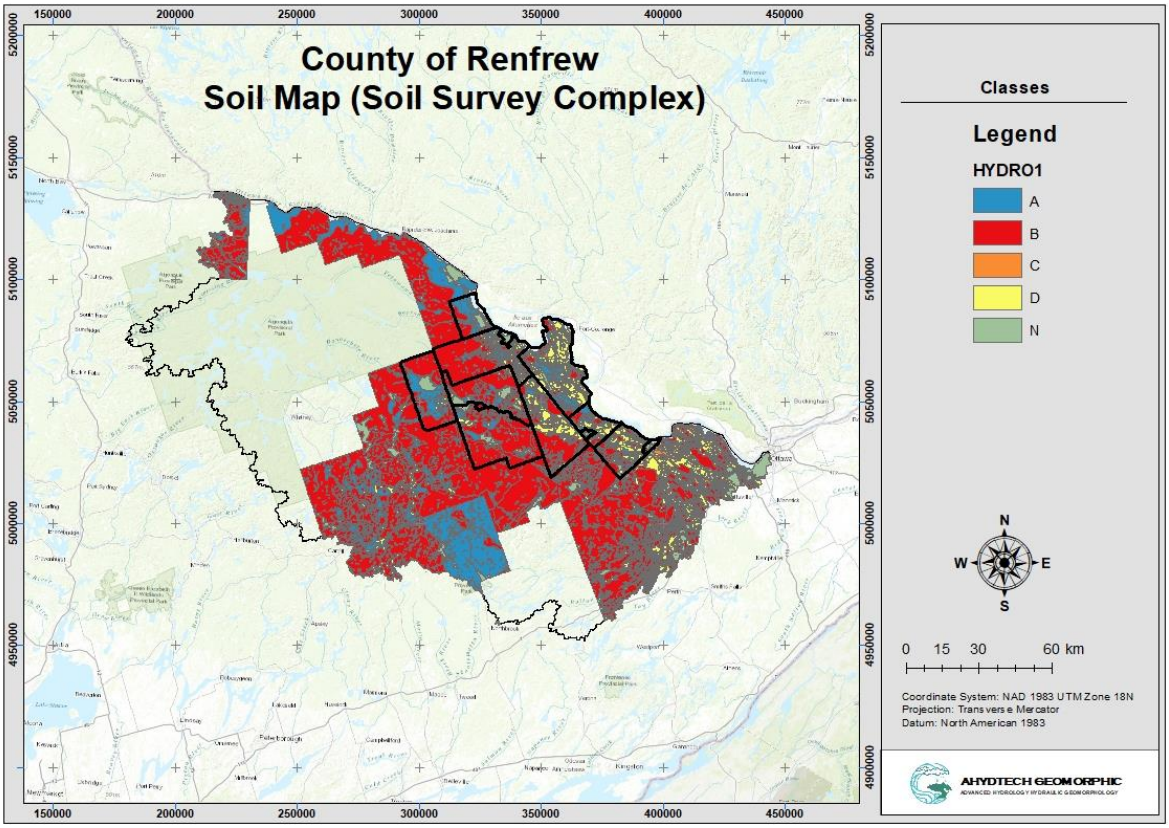

Figure: Soil Data Map of Central Ottawa Watershed

LULC Data Coverage for the Entire Central Ottawa Watershed

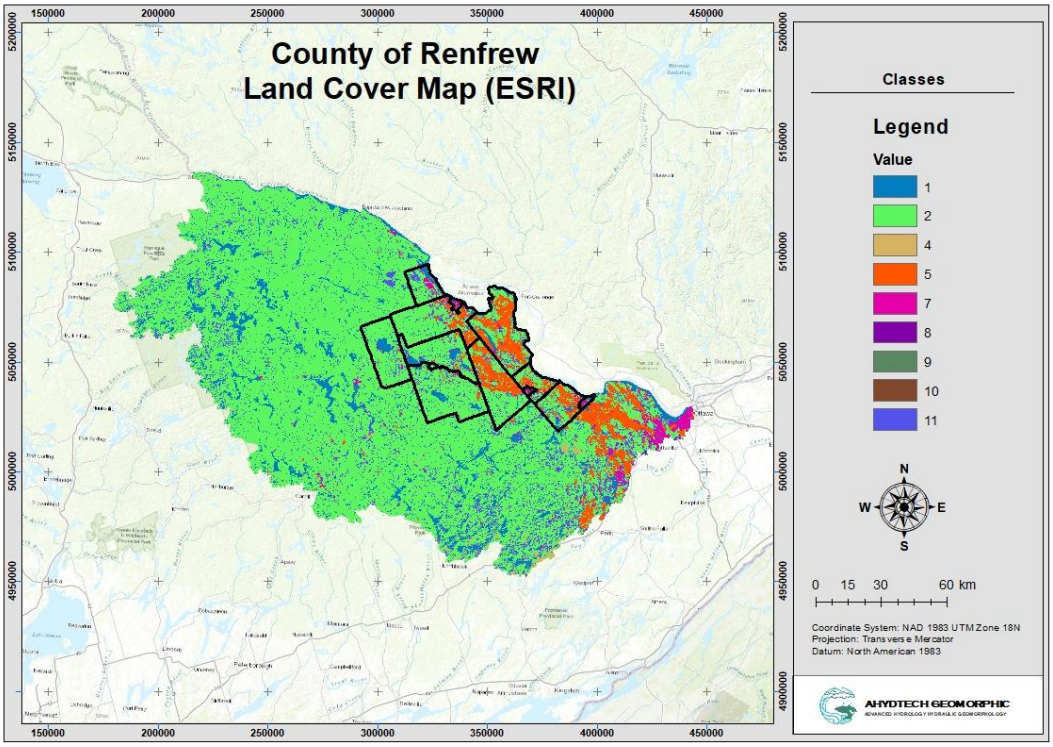

Figure: Land Cover Map (ESRI)

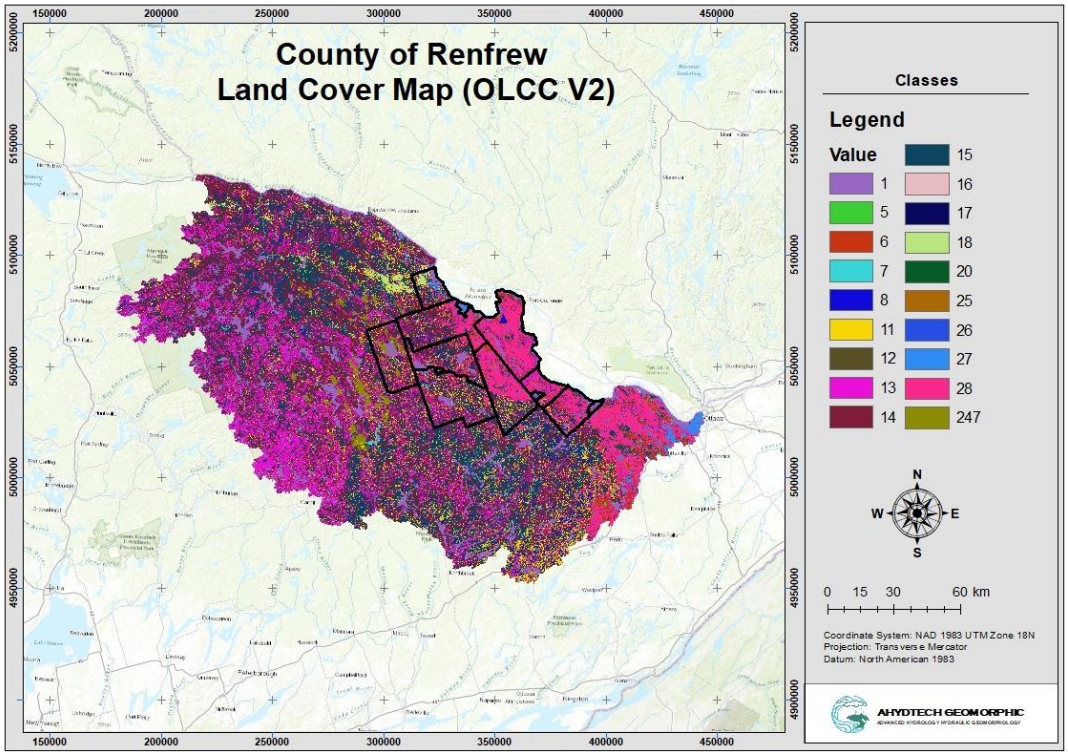

Figure: Land Cover Map (OLCC Version 2)

Surface Water Network

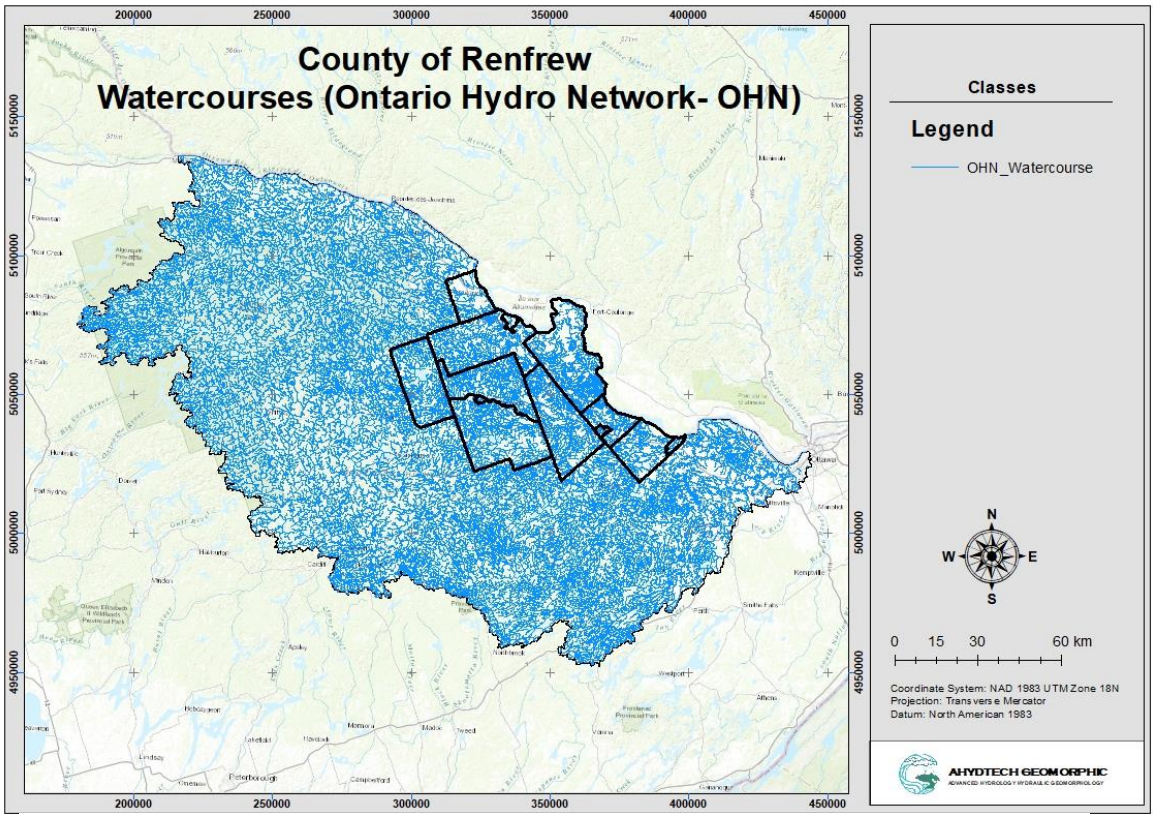

Figure: Surface Water Network (OHN)

Contour Mapping (LIO)

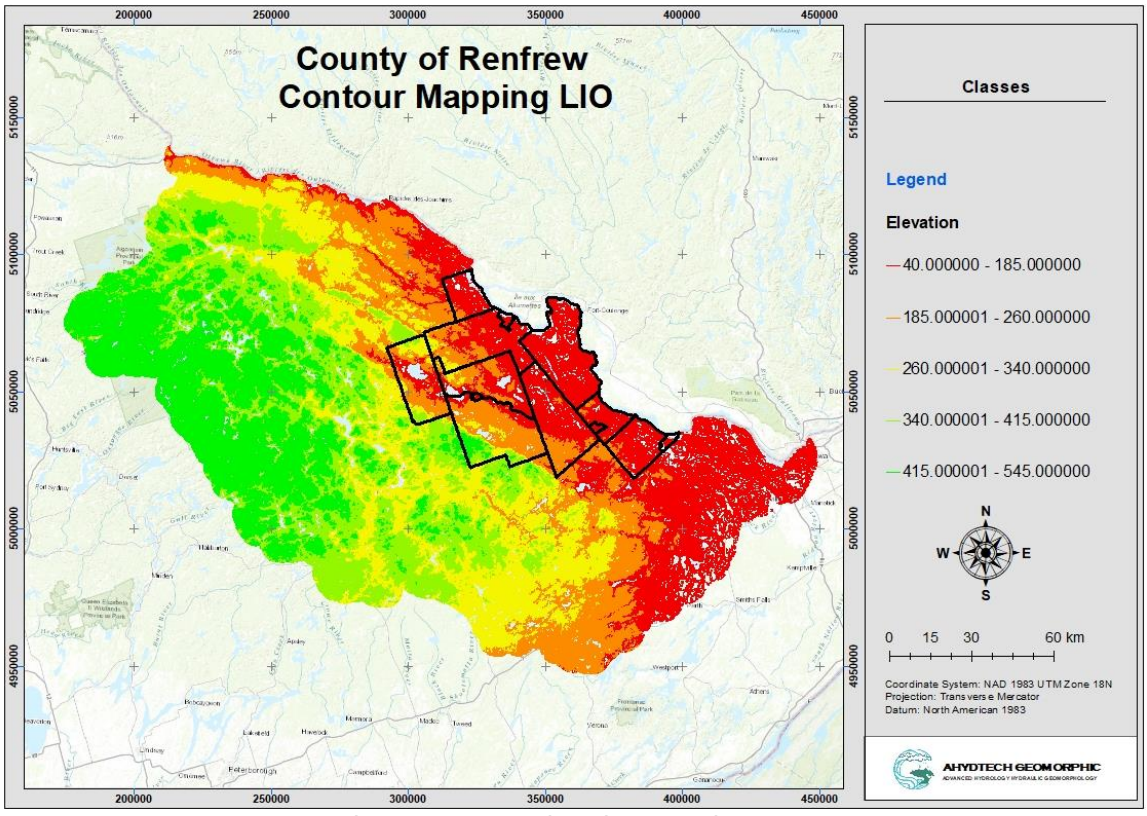

Figure: Contour Elevation Mapping

LiDAR Coverage

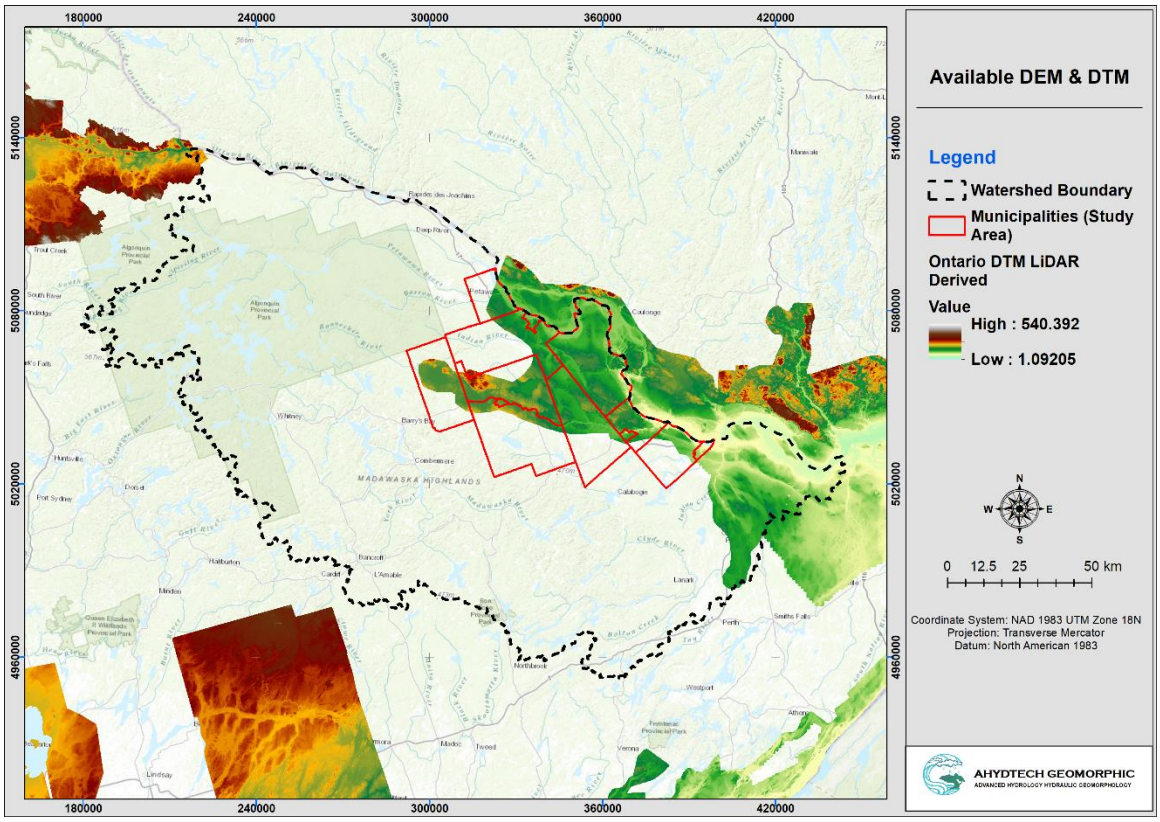

Figure: LiDAR Coverage

Locations of Bridges and Culverts

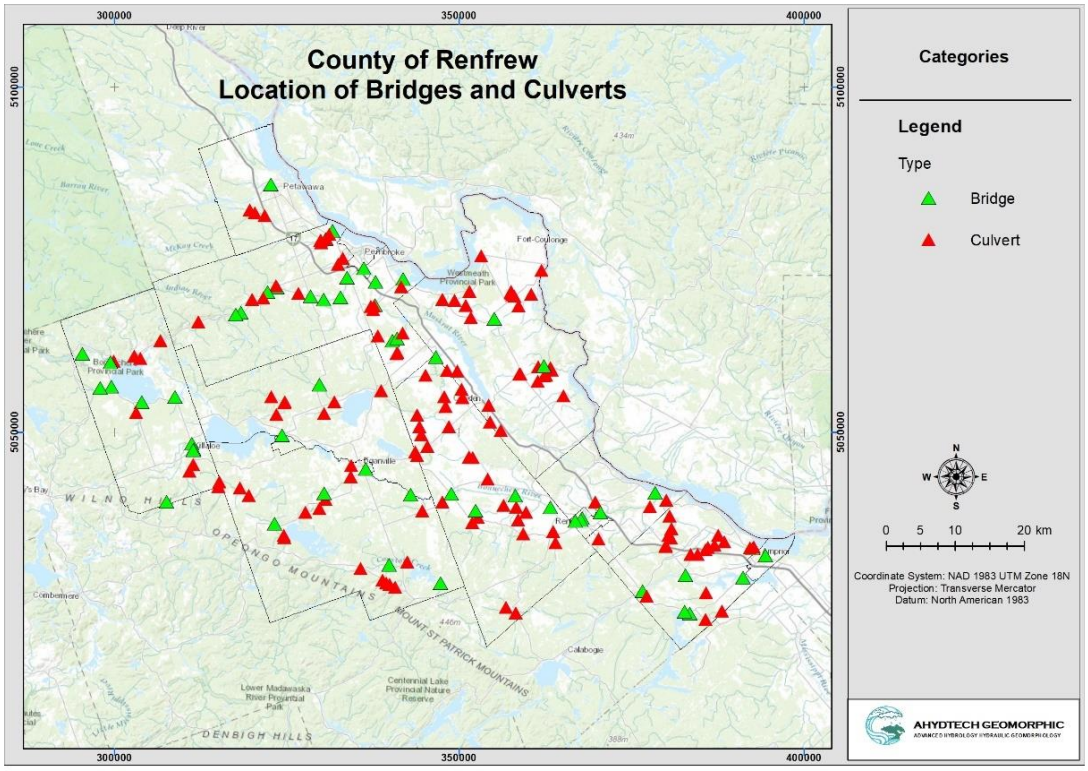

Figure: Locations of Bridge and Culverts

Dams

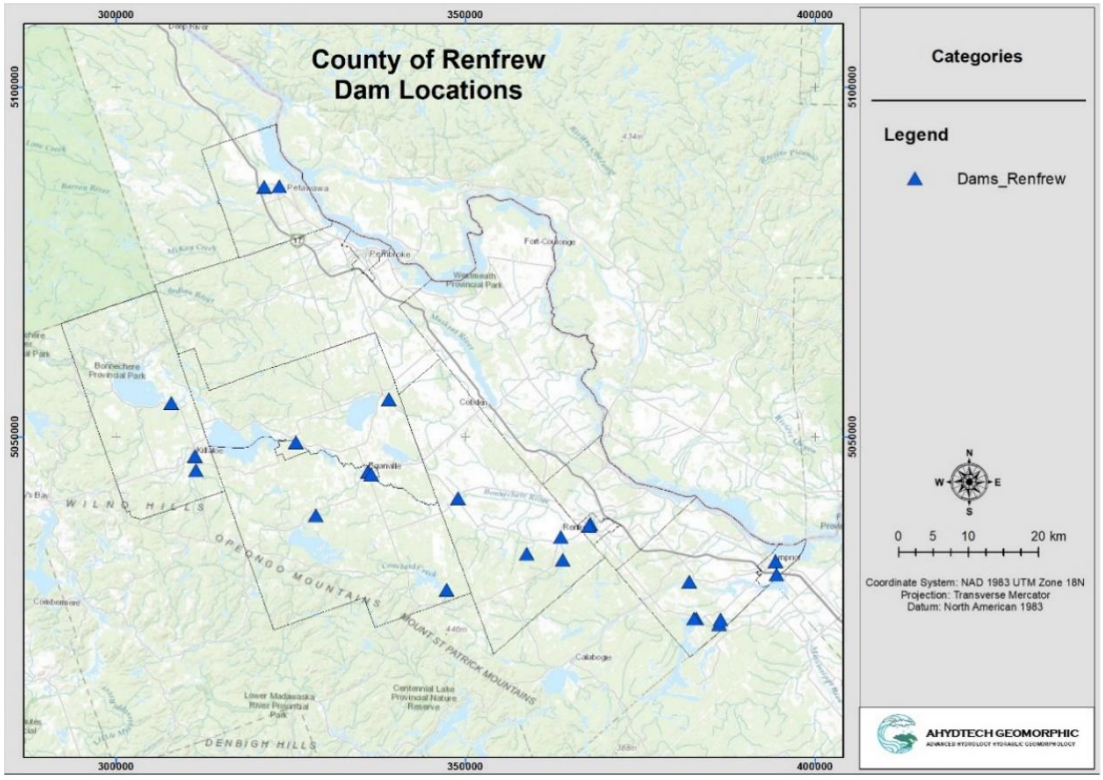

Figure: DAM Locations

Road Network

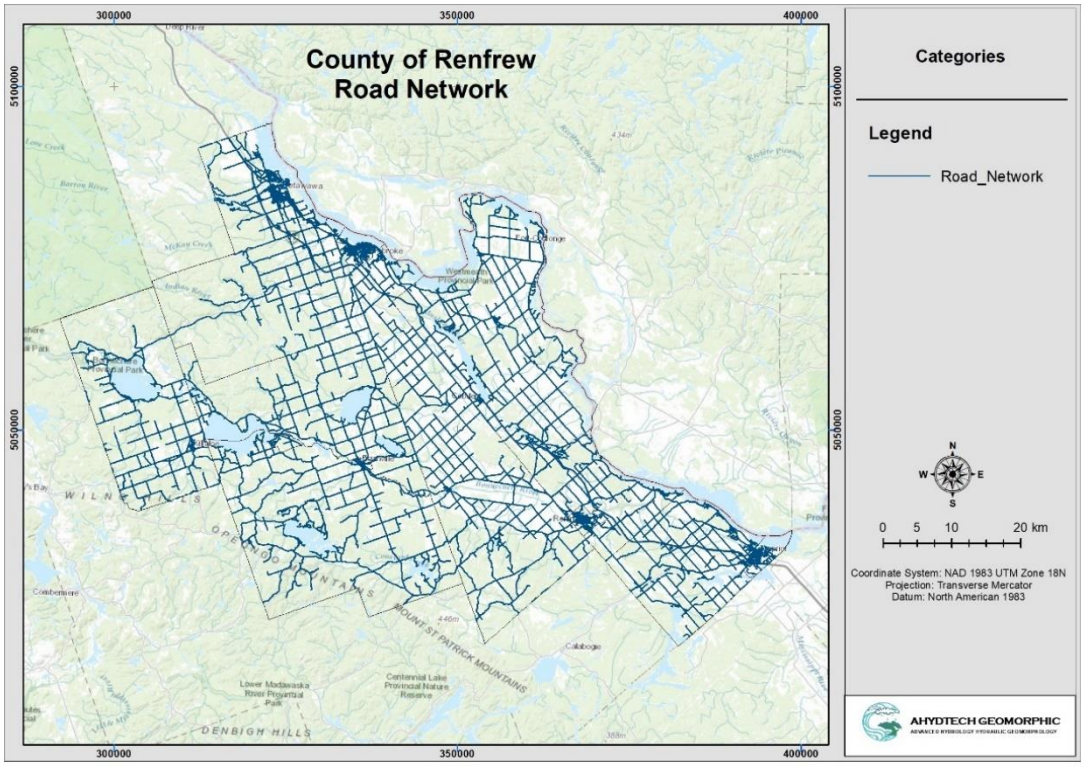

Figure: Road Network

Real-Time Hydrometric Gage Stations

Table: Details of Hydrometric Gage Stations available within the Central Otta Watershed Boundary

Station ID	Station Name	Active Status	Daily/Monthly/Hourly	Flow	Level	Years Available	Drainage Area	Datum
02KA015	AUMOND CREEK NEAR MATTAWA	Active	Daily and Monthly	YES	YES	2009-2021	167.00	-
02KB001	PETAWAWA RIVER NEAR PETAWAWA	Active	Daily and Monthly	YES	YES	1915-2021(Water Level Data Starts from 2002)	4120.00	ASSUMED DATUM
02KC009	BONNECHERE RIVER NEAR CASTLEFORD	Active	Daily and Monthly	YES	YES	1921-2022(Water Level Data Starts from 2002)	2380.00	ASSUMED DATUM
02KC015	MUSKRAT RIVER NEAR PEMBROKE	Active	Daily and Monthly	YES	YES	1969-2022(HAS FLOW DISCONTINUATION, 1979-2007, Level Data Starts from 2008)	674.00	ASSUMED DATUM
02KC018	INDIAN RIVER AT PEMBROKE	Active	Daily and Monthly	YES	YES	2007-2022	465.00	ASSUMED DATUM
02KD002	YORK RIVER NEAR BANCROFT	Active	Daily and Monthly	YES	YES	1915-2022(HAS FLOW DISCONTINUATION, 1994-2005, Level Data Starts from 2006)	844.00	ASSUMED DATUM
02KD004	MADAWASKA RIVER AT PALMER RAPIDS	Active	Daily and Monthly	YES	YES	1930-2022(Water Level Data Starts from 2002)	5800.00	ASSUMED DATUM
02KF001	MISSISSIPPI RIVER AT FERGUSONS FALLS	Active	Daily and Monthly	YES	YES	1915-1919; 1982-2023(HAS FLOW DISCONTINUATION, 1920-1981, Level Data Starts from 2002)	2660.00	ASSUMED DATUM
02KF005	OTTAWA RIVER AT BRITANNIA	Active	Daily and Monthly	YES	YES	1915-2021(Water Level Data Starts from 1915, HAS DISCONTINUATION 1960-2001, Flow Data Starts from 1960)	90900.00	CANADIAN GEODETIC VERTICAL DATUM 1928: EPOCH1997
02KF006	MISSISSIPPI RIVER AT APPLETON	Active	Daily and Monthly	YES	YES	1918-2022(Water Level Data Starts from 2002)	2940.00	ASSUMED DATUM

Station ID	Station Name	Active Status	Daily/Monthly/Hourly	Flow	Level	Years Available	Drainage Area	Datum
02KF010	CLYDE RIVER NEAR LANARK	Active	Daily and Monthly	YES	YES	1970-2022(Water Level Data Starts from 2002)	618.00	ASSUMED DATUM
02KF011	CARP RIVER NEAR KINBURN	Active	Daily and Monthly	YES	YES	1971-2022(Water Level Data Starts from 2002)	258.00	ASSUMED DATUM
02KF012	INDIAN RIVER NEAR BLAKENEY	Active	Daily and Monthly	YES	YES	1971-2022(Water Level Data Starts from 2002, HAS FLOW DISCONTINUATION 1999-2001)	212.00	ASSUMED DATUM
02KF013	CLYDE RIVER AT GORDON RAPIDS	Active	Daily and Monthly	YES	YES	2003-2023(Water Level Data Starts from 2003)	291.00	ASSUMED DATUM
02KF015	GRAHAM CREEK AT NEPEAN	Active	Daily and Monthly	YES	YES	1987-2022(Water Level Data Starts from 2006, HAS FLOW DISCONTINUATION 1996-2005)	26.50	ASSUMED DATUM
02KF016	MISSISSIPPI RIVER BELOW MARBLE LAKE	Active	Daily and Monthly	YES	YES	1988-2022(Water Level Data Starts from 2002)	359.00	ASSUMED DATUM
02KF017	BUCKSHOT CREEK NEAR PLEVNA	Active	Daily and Monthly	YES	YES	1993-2022(Water Level Data Starts from 2002)	152.00	ASSUMED DATUM
02KF018	FALL RIVER AT OUTLET OF BENNETT LAKE	Active	Daily and Monthly	YES	YES	2003-2022	280.00	ASSUMED DATUM
02KF019	MISSISSIPPI RIVER AT OUTLET OF DALHOUSIE LAKE	Active	Daily and Monthly	YES	YES	2003-2022	1310.00	ASSUMED DATUM
02KF020	SHARBOT LAKE AT OUTLET OF SHARBOT LAKE	Active	Daily and Monthly	YES	NO	2003-2022	139.00	ASSUMED DATUM