Flood Plain Mapping Study

Fenelon South Tributary

Technical Report

November 2023

KAWARTHA CONSERVATION

Kawartha Lakes Jump In

Executive Summary

The primary goals of this study are to create hydrologic and hydraulic models of the watershed and produce floodplain mapping for Fenelon Falls South Creek. The mapping will allow the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use planning and identify flood hazard reduction opportunities.

The Fenelon Falls South Floodplain Mapping Study has been subject to a comprehensive peer review for core components: data collection, data processing, hydrologic modeling, hydraulic modeling, and map generation. The process was supported throughout by a Technical Committee consisting of technical/managerial staff from Ganaraska Conservation, the City of Kawartha Lakes, and Kawartha Conservation.

Topics discussed in this study include:

- Previous work completed
- Collection of LiDAR and Orthophoto data
- Proposed land use
- Delineation of hydrology subcatchments
- Creation of a Visual OTTHYMO hydrology model
- Calculation of hydrology model parameters
- Derivation of flow peaks at key nodes along the watercourse
- Survey of existing road crossing structures
- Creation of a HEC-RAS 2D hydraulic model
- Analysis of the spills
- Creation of floodplain maps

Key findings of this study include:

- The flood flows are higher than what was modelled in the 2010 Valdor Study. This is due to:
  - The overall catchment size is larger than what was derived in 2010. This is due to the greater quality of mapping data available to the study team.
  - This study created 44 subcatchments, as compared to only four in the 2010 study. This allowed the study team to refine subcatchment hydrology values.
  - Due to the greater quality of elevation data provided by the LiDAR data, more realistic overland flow routes and lengths were captured by the study team, resulting in longer times to peak for each subcatchment.
  - Channel routing in this study is based on elevation data derived from LiDAR, and provides more realistic channel slopes, lengths, and channel shapes. Flow attenuation in this model has a greater impact than on the 2010 analysis/model.
- The 100-year 24-hour Chicago Storm and the Timmins Storm were found to produce similar flood extents; the Timmins Storm produced larger floodplains upstream of Canadian Tire, while the 100-year storm produced larger floodplains in the urban areas north of Canadian Tire. The Regulatory Floodplain was produced by overlaying the 100-year and Timmins Storm floodplains and delineating the greater extent at all locations.
- Flood elevations are generally higher than in the 2010 study, particularly in urban areas. This is due to the improved terrain data in the present model. When the HEC-RAS results from the Valdor study were plotted on the new LiDAR-based terrain, the water

surface elevations were lower than the terrain surface, indicating a likely data error in the 2010 study.

- Three spill areas were identified during this study:
  - County Road 121, where flows cross CR 121 south of the Canadian Tire and split between flowing north on Lindsay Street, and flowing east towards another tributary of the Fenelon River which is outside of the Fenelon Falls South Creek watershed.
  - West Spill, where backwatered flows result in a spill outside of the watershed to the west which will flow into Cameron Lake
  - Lindsay Street Spill, where storm sewer surcharging and minor spills from the west and south contribute to significant urban inundation.

Key recommendations of the study include:

- Flow monitoring should be conducted to facilitate future model calibration. Monitoring would ideally be completed upstream of Canadian Tire to avoid complications associated with the spills.
- Future model updates should include climate change considerations in accordance with the Federal Flood Mapping Framework to assess future climate conditions on existing infrastructure.
- The spills out of the watershed at CR 121 should be considered in future studies of the watercourse to the east to ensure that accurate stream flows are modelled.
- Future developments within the Development Control Areas associated with the Regulatory Floodplain be floodproofed to an elevation 0.3 m higher than water surface elevation of the closest portion of the floodplain.

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1 Introduction

1.1 Objective

The objective of this study is to generate updated floodplain mapping for the Fenelon Falls South watercourse to protect the public from flooding hazards. This is the tenth floodplain study in a multi-year flood line mapping update project undertaken by Kawartha Conservation and the City of Kawartha Lakes. The mapping will allow the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use and identify flood hazard reduction opportunities.

1.2 Study Process

At the project beginning, the Technical Committee (consisting of one representative from each of the City of Kawartha Lakes, Kawartha Conservation, and Ganaraska Conservation) created quality assurance (Q/A) and quality control (Q/C) standards to be applied to all projects in the multi-year initiative. The Q/A methodology for each component ensures a two-fold benefit: that the project design meets industry standards, and that the work outline and planned deliverables are valid. The three goals of the Q/C component are: that the product is consistent with standards and generally accepted approaches; that the study results meet Technical Committee's requirements, and that the products and results are scientifically defensible. Each methodology was peer-reviewed for Q/A and Q/C by an external firm or agency. Four separate components of the project were established for Q/A and Q/C:

- Mapping and air photo
- Survey data collection and integration
- Hydrology modeling
- Hydraulic modeling

For the mapping and air photo portion of the project Q/A, the City of Kawartha Lakes and Kawartha Conservation created a request for proposal (RFP) for geographic data acquisition using LiDAR technology. For the survey data collection and integration, Kawartha Conservation purchased new digital survey equipment and established procedures for survey collection. The GIS staff from Ganaraska Conservation peer-reviewed the RFP and survey purchase/procedure and confirmed they met industry standards. For the Q/C portion, Ganaraska Conservation's GIS measured the accuracy of the LiDAR elevation data and orthoimagery, and confirmed the data meets the Province of Ontario's 2009 "*Imagery and Elevation Acquisition Guidelines*" (herein referred to as the *2009 Ontario Guidelines*).

For the Q/A portion of the hydrology and hydraulic modeling components, a hydraulic/hydrologic modeling procedures document was created that: established data input parameters to meet municipal and provincial standards; put in place data collection and extraction procedures; and short-listed computer models. The document was peer-reviewed by Greck and Associates and was found to be satisfactory.

1.3 Watercourse Context and Description

Rural drainage from land west of County Road 121 drains to an un-named watercourse, which in turn flows northeast and forms the upstream channel of what eventually becomes the Fenelon Falls South creek. Once it reaches the commercial area at County Road 121, the creek continues to flow northeast behind the hardware stores, crossing under the Community Centre entrance, passing through culverts under Eva Street before entering an enclosed storm sewer at the west end of the parking lot associated with Fenelon Falls Secondary School. The storm sewer follows the parking lot access road and joins the larger sewer within Helen Street/County Road 8 system, eventually joining the Lindsay Street/County Road 121 sewer and discharging to the Fenelon River/Trent Severn Waterway downstream of the bridge at the existing restaurant. Major flow exceeding the capacity of the Helen Street storm sewer overtops Helen Street and is conveyed through an existing industrial and residential area to the outlet of Cameron Lake above the falls. An overview of the study area is indicated in **Figure 1-1**.

The upper portion of the watershed South of the Fenelon Falls is rural farmland, meadows and forested areas. Within Fenelon Falls, the watershed is mainly residential with a mix of institutional and commercial land uses. The watershed area is approximately 113 hectares (1.13 km^2) in size. The Fenelon Falls South watercourse main channel is approximately 3.3 km long, with an average slope of 0.76 %.

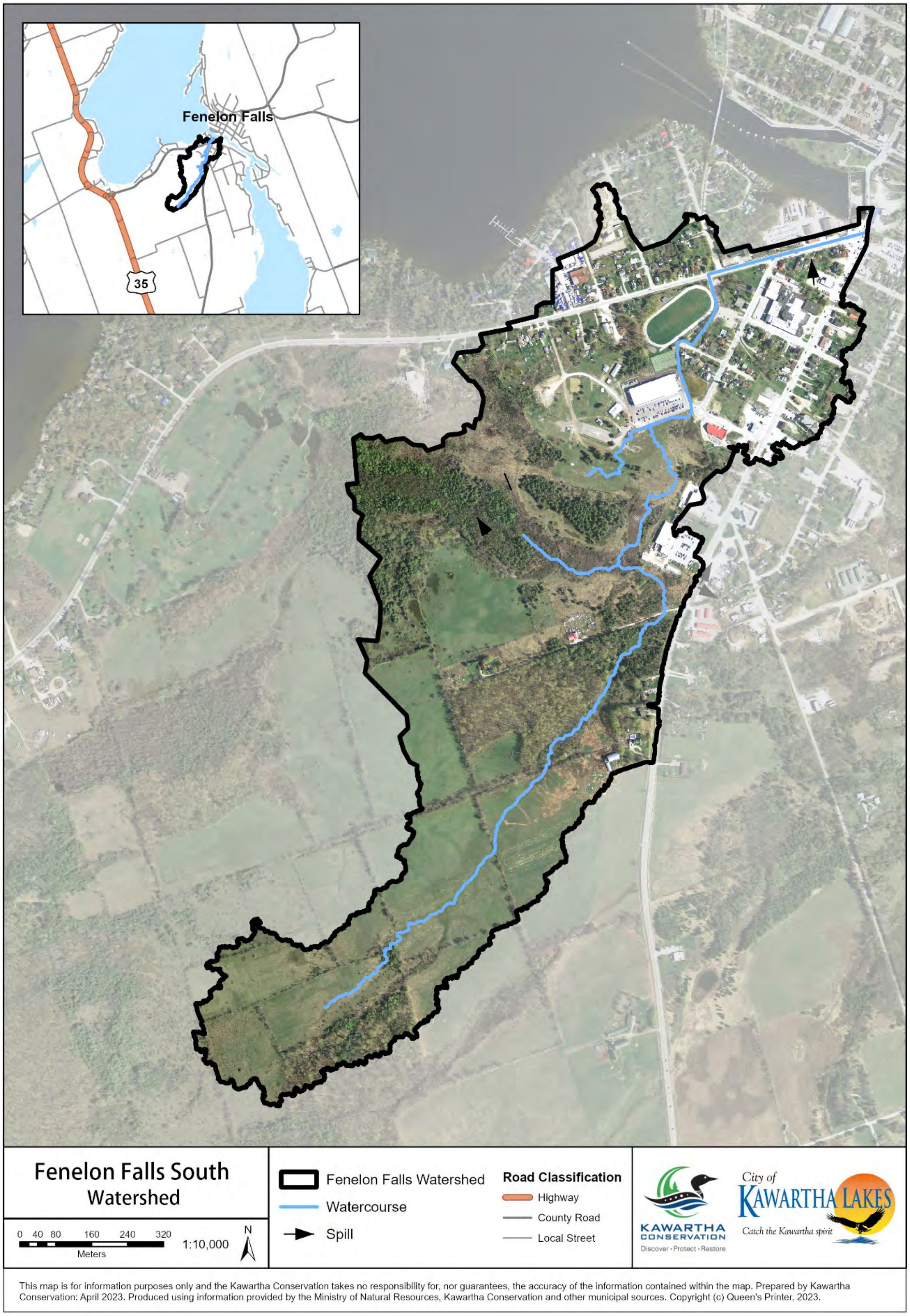


Figure 1-1: Study Area

1.4 Background Information

The Fenelon Falls South watercourse (also referred to in previous studies as Basin DD) has flooded in the past and continues to be prone to flooding. Flooding issues appear to be the result of the limited capacity of the buried downstream reach within the existing Helen Street storm sewer and a poorly defined overland drainage path. In light of the historical flooding problems and to plan for future growth, the City of Kawartha Lakes commissioned the *Fenelon Falls Drainage Study (Basin DD) and Traffic Impact Study,* which was completed by Valdor Engineering Inc. in association with Greck and Associates Limited and Mark Engineering. The study team was tasked with making recommendations for a drainage outlet and traffic improvements for the proposed new arena and community centre as well as other development considerations located in the Village of Fenelon Falls (Basin DD). The purpose of the study was to prepare a conceptual drainage outlet design and traffic study to accommodate the identified future development areas without worsening the existing flooding problems and to minimize traffic impacts within Basin DD. The study was completed as per the Municipal Class EA Planning and Design Process as a Schedule B project. A copy of the report is included in **Appendix A**.

The study completed by Valdor et al included a number of tasks specifically related to assessing the flooding impacts within the study area and included the following:

- Field inspections and survey to confirm general drainage patterns and details associated with the Helen Street storm sewer
- Capacity analysis of the existing storm sewer on Helen Street;
- Hydraulic analysis to determine the existing limits of probable flooding within Basin DD;

A digital base map was prepared using digital elevation mapping (DEM) obtained from First Base Solutions. Contours with 0.25 m intervals were drawn and overlaid with satellite imagery for the study area as well as the legal fabric provided by the City. Using the updated base map, drainage areas were delineated. A drainage area of approximately 27.6 ha in size was estimated for the Fenelon Falls South (Basin DD North and South) tributary with an additional large external drainage area located to the southwest of Basin DD, estimated to be approximately 69 2 ha in size.

1.4.1 Storm Sewer Capacity Analysis

The capacity of the existing Helen Street storm sewer system was calculated by Valdor et al using PCSWMM 2009 which allows for both dual drainage analysis and hydraulic grade line (HGL) calculations. Basin DD was divided into numerous smaller catchments to enable the dual drainage analysis. The diameter, length, inverts and connectivity of the Helen Street storm sewer was coded in PCSWMM based on measurements obtained during the detailed storm sewer survey. The critical storm was determined to be the 24-hr Chicago design storm which was used in the PCSWMM model.

Based on the results of the hydrology/hydraulic modeling using PCSWMM, the pipe capacity of the existing storm sewer along Helen Street was calculated to be less than the 2-yr storm assuming no surcharging. It was noted that flow that exceeds the capacity of the Helen Street storm sewer causes ponding and contributes to the existing flooding in low-lying areas and eventually overtops the road.

1.4.2 Hydraulic Analysis to Determine Existing Limits of Probable Flooding

Valdor et al calculated the extent of probable flooding for the 100-yr and Timmins storm within Basin DD.

Peak flows for the HEC-RAS model were calculated using the hydrology program Visual OTTHYMO (VO2). Model runs were completed using the 100-yr Chicago design storm and the Timmins storm. The model parameter values were calculated for the VO2 model for each catchment using standard methods.

A hydraulic model using HEC-RAS was prepared to simulate the probable flooding limits along the drainage course in Basin DD. The peak flows applied in the HEC-RAS model were derived based on the VO2 model simulations for Catchment 99, Catchment 26 and Catchment 18. As a conservative measure, the flows from the downstream flow node within a given catchment were used for the HEC-RAS model and applied to the top of the same catchment. Flows were adjusted to account for the flow conveyed under the Lindsay Street culvert and away from Basin DD. Flows applied to the HEC-RAS model in the vicinity of Helen Street were adjusted to account for the flow captured by the Helen Street storm sewer based on the PCSWMM hydraulic model completed for the Helen Street storm sewer capacity analysis. The 100-year water surface elevation of Cameron Lake (255.75m) obtained from Kawartha Conservation was applied as the downstream boundary condition.

Based on the Valdor VO2 and HEC-RAS modeling results, the water surface elevation (WSEL) for 100-year and the Timmins storms were delineated and included the extent of probable flooding associated with the 100-yr lake level in Cameron Lake obtained from Kawartha Conservation. Based on results from the HEC-RAS model it was estimated that Helen Street overtops at approximately the 5-yr storm.

1.5 Updated Modeling Approach

Flooding was assessed using standard steady flow methods derived using Visual OTTHYMO 6.2 (VO6) and HEC-RAS version 6.3.1.

Geographic data (such as subcatchment area, land use, topography, and soil types) was extracted from GIS for each subcatchment to obtain the parameters described in the Hydrology Model Input Parameters section including imperviousness, SCS Curve Numbers (CN), time to peak (T_p), and time of concentration (T_c).

Urban subcatchments have been delineated reviewing engineering reports and field inspection for the Fenelon Falls South watercourse, where applicable.

Runoff hydrographs have been generated for the 2-, 5-, 10-, 25-, 50-, and 100-year events as well as the Regional (Timmins) storm. The source rainfall data utilized for this analysis is from Environment Canada’s rain gauge that was historically located at the Lindsay Filtration Plant from 1965 to 1989. This date range represents historical rainfall conditions since most climate change impacts have been observed since 1990. The 24-year period of record is not sufficient to accurately determine the 50 or 100-year storm, so additional uncertainty is present for large return period events.

Sensitivity analyses have been carried out to determine the impact of changing model parameters on the calculated flows. No flow monitoring data is available to calibrate the hydrologic model. This approach was peer-reviewed by Greck and Associates Limited and was found to be acceptable, as documented in the separate report titled *Peer Review Services for Terms of Reference of Hydrologic and Hydraulic Assessments, Final Report.*

Where not specified, default parameters/values were used within VO6 and HEC-RAS.

Using this approach results in accurate peak flows and associated flood lines along the Fenelon Falls South watercourse. Comparisons of results to the previous study undertaken by Valdor et al was undertaken to evaluate the change in floodplain extents.

2 Rainfall

2.1 Rainfall Data

Rainfall Intensity–Duration–Frequency (IDF) curves define the rainfall input for modeling and provide estimates of the extreme rainfall intensity for different return periods. Rainfall volumes are taken from Lindsay's Atmospheric Environment Services (AES) gauge which was removed from service in 1989. In the initial floodplain study for Ops #1/Jennings Creek, an investigation was carried out to determine the relevancy of using data from this inactive rain gauge. The Peterborough AES rain gauge has a longer time span and has captured higher rainfall volumes than what was captured by the Lindsay rain gauge. It is unknown whether this increase is attributable to Peterborough's longer period of data capture (36 years, from 1971 to 2006 vs. Lindsay's 24 years, from 1965-1989) or to the effects of climate change.

As outlined in the June 2014 *Floodplain Mapping Study, Ops #1 Drain/Jennings Creek* report, the Lindsay Filtration Plant precipitation data and the Peterborough Airport data were compared to evaluate the validity of each data set for use in Fenelon Falls. The analysis found that the Lindsay data was valid for use in Fenelon Falls.

The Ontario Ministry of Natural Resources and Forestry (MNRF) technical manuals provide a rainfall reduction table for the Timmins storm. Given the size of the Fenelon South subcatchment no areal reduction factors are used.

Detailed rainfall information is provided in **Appendix C**. Rainfall intensity is calculated by the formula:

$I = a/(t+b)^c$, where

I in mm/hr

T in minutes

The City of Kawartha Lakes state the relevant IDF parameters for the gauge are shown in **Table 2-1**.

Table 2-1: IDF Parameters in the City of Kawartha Lakes' Storm and Stormwater Infrastructure Guidelines

Return Period (yr)	A	B	C
2	858	6.8	0.822
5	1214	9	0.847
10	1487	10.2	0.858
25	1898	11.7	0.871
50	2110	12	0.87
100	2518	13.2	0.882

2.2 Design Storms

Design storms are characterized by storm duration and rainfall distribution. A variety of rainfall durations (6, 12 and 24 hours) and distributions for 2-100 year return periods were tested to determine which event produced the highest peak discharge at key node locations within the study area.

Rainfall distribution is the specific apportionment of rain over time, or the shape of the storm. The relative importance of these factors varies with the characteristics of a subcatchment. It is standard practice to test different design storms to determine the most conservative flows. The various storm distributions considered in the study are described below.

For more than a century, the American Natural Resources Conservation Service has continually refined empirical formulas for the Soil Conservation Service (SCS) method of predicting storms. Their SCS Type II distribution represents a high-intensity storm based on a 24-hour rainfall and can be used in hydrology studies in Southern Ontario. The bulk of the rainfall occurs in the second half of the storm.

Environment Canada's AES has developed a design storm for Southern Ontario. When compared to the SCS distribution, the majority of the rainfall in the AES storm occurs at the beginning of the storm.

The Chicago storm distribution is one of the commonly used distributions for designing and analyzing storm sewer systems in urban areas.

The worst-case storm (the duration and distribution producing the highest discharges at key nodes) is selected as the critical event for the watershed. The worst-case storm was determined to be the 100-year 24-hour Chicago Storm, additional discussion is included in **Section 5.3**. Detailed rainfall information is shown in **Appendix C**.

2.3 Regional Storm

The Timmins storm was a historical storm event that occurred in September 1961 and is designated as the provincial regional storm event within the subject area. The Timmins storm event resulted in a total rainfall of 193 mm. The storm is defined in Table D-4 of the “MNR River and Stream Systems: Flooding Hazard Limit” (2002). Antecedent moisture content (AMC) condition II, referred to as AMC (II), was applied. An areal reduction factor was not applied to the Regional model.

2.4 Snowmelt and Snowmelt/Rainfall Events

These types of analyses were not carried out for this report.

2.5 Climate Change

Climate change considerations were not included within the terms of reference for this study.

3 Hydrology Model Input Parameters

3.1 Overview

In 2012, the City of Kawartha Lakes and Kawartha Conservation produced a standardized methodology for undertaking floodplain mapping studies within their jurisdictions. This approach was peer-reviewed by Greck and Associates Limited, and their findings conclude the methodology is valid. For this study Kawartha Conservation extracted hydrologic parameters from LiDAR elevation data, Arc Hydro watershed boundaries, Official Plan, and field surveys.

3.2 Digital Elevation Model (DEM)

A LiDAR and orthoimagery full-suite remote sensing data were acquired by the City of Kawartha Lakes in 2012. The acquisition included orthoimagery, LiDAR-derived point cloud data, elevation raster tiles, and other geospatial/non-geospatial datasets produced by the vendor. At the time of the acquisition, the *2009 Ontario Guidelines* was the technical document that set geospatial data acquisition specifications in Ontario and defined geospatial data accuracy targets based on levels or risk.

For the Fenelon Falls South watercourse watershed, two points per square meter LiDAR data was acquired. ArcGIS version 10.1 computer software programs translated the collected data points as a Triangulated Irregular Network (TIN) to isolate bare earth elevation points from the full dataset. This resulting data was converted to a 0.5m raster digital elevation model (DEM) by the LiDAR vendor.

Using the 2014 American Society of Photogrammetry and Remote Sensing (ASPRS) standards for quantifying, testing, and reporting accuracy of geospatial data ("*ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014)")* a Q/C of the vendor-provided DEM was undertaken to determine the positional accuracy of the digital geospatial data. The DEM was found to be in compliance with *2009 Ontario Guidelines*. Full details of this Q/C are in **Appendix M.** This base DEM is of suitable quality for floodplain mapping.

3.3 Orthoimagery

The *2009 Ontario Guidelines* also states the minimum horizontal geospatial data accuracy to be used for the risk. The 2014 ASPRS standards will be used to carry out full Q/C testing of the horizontal accuracy of the orthoimagery. Full details of this Q/C will be included in **Appendix M** once completed.

3.4 Subcatchment Discretization

Subcatchments are delineated employing the GIS Archydro for Water Resources tool set (Version 10.3). Based on the characteristics of the underlying DEM the geomorphological and topographical features are being processed to generate, subcatchment boundaries, longest flow path and the water courses needed to input into the hydraulic model. Utilizing this tool set ensures the connectivity of the delineated features for further processing.

Critical nodes within the watershed were selected by the engineer as the basis to delineate the initial subcatchments in ArcHydro. ArcHydro is suitable for the delineation of rural subcatchments. Urban subcatchments from the previous 2010 Valdor study were used in areas where the storm sewer network is present. The subcatchments that were generated from ArcHydro were split to align with the boundaries of the urban subcatchments. Where LiDAR data did not extend far enough to the west to delineate the entire watershed boundary, the 2010 Valdor subcatchment boundaries that extended beyond the LiDAR data were merged with the generated ArcHydro subbasins to create a boundary that captures the entire study area. **Table 3-1** shows the data source for the delineation of each subcatchment.

Table 3-1: Subcatchment Delineation Data Source

Subcatchment	Delineation Data Source
1000	Valdor
1001	Combination LiDAR/Valdor
1100	Valdor
1101	Valdor
1200	Valdor
1201	Valdor
1300	Valdor
1400	Valdor
1500	Valdor
1501	Valdor
1600	Valdor
1601	Valdor
1700	Valdor
1701	Valdor
1702	Valdor
1800	Valdor
1801	Valdor
1802	Combination LiDAR/Valdor
1900	Valdor
1901	Valdor
1902	Combination LiDAR/Valdor
2000	Valdor
2001	Valdor

2100	Valdor
2101	Valdor
2200	Valdor
2201	Valdor
2202	Valdor
2203	Valdor
2204	Combination LiDAR/Valdor
2205	Valdor
2206	Valdor
2207	Valdor
2300	Valdor
2400	Combination LiDAR/Valdor
2401	Combination LiDAR/Valdor
2500	Combination LiDAR/Valdor
2501	Combination LiDAR/Valdor
2600	LiDAR
2601	Combination LiDAR/Valdor
2700	LiDAR
2701	LiDAR
2800	LiDAR
2900	LiDAR

While it was not necessary to include the high level of discretization in the urban areas for floodplain mapping, the subcatchments were maintained in the model to facilitate future modelling efforts that may include sewer analyses. **Figure 3-1** illustrates the creek subcatchments, and **Appendix D** includes a separate map.

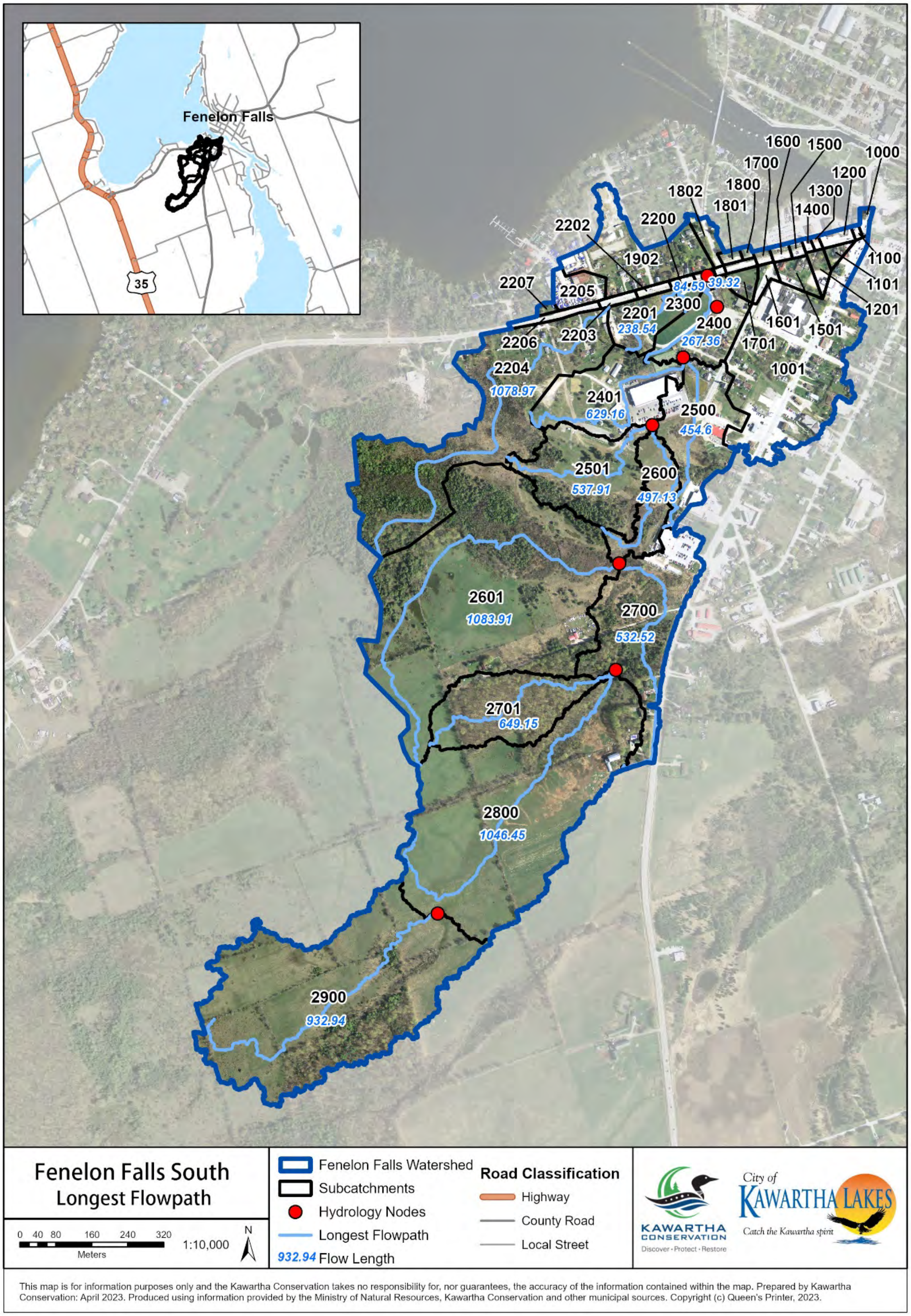


Figure 3-1: Subcatchment Boundaries

3.5 Land Use

The 2022 Schedule 'A' Land Use Plan for the Village of Fenelon Falls within the City of Kawartha Lakes' Official Plan (OP) are the base data referenced for land use patterns.

Land values in the hydrology model do not reflect current land use; instead, the model assumes that all developable areas indicated in the Official Plan are fully built out. The rationale for this decision is that the City of Kawartha Lakes has approved in principle the proposed land use and therefore the flood lines should reflect the most conservative flood scenario. Copies of the OP schedules' maps are found in **Appendix N**.

3.6 Rural Subcatchment Properties

The longest flow paths of each rural subcatchment were derived using ArcHydro. In this process, the downstream node is selected by the user, and ArcHydro calculates the longest overland and channel flow paths. For the subcatchments to the west of the LiDAR boundary, the SCOOP 2013 orthoimagery-derived DEM was used to manually delineate the longest flow path and determine the flow path slope.

3.7 Calculation of Slope

For rural subcatchments, spreadsheets were created to calculate channel and subcatchment slopes, based on overland and channel flow data. Details can be found in **Appendix E**.

3.8 CN Values

The Soil Conservation Service (SCS) curve number (CN) is used to determine runoff. Users must choose which antecedent moisture condition (AMC I, II, or III) is relevant for the model; AMC II represents a dry soil condition, and AMC III represents saturated soil. For this study, the Kawartha Conservation 2010 ELC (Ecological Land Classification), Secondary Plan and Official Plan (OP) data from the City of Kawartha Lakes, and soil type was queried to extract land use, drainage area, and hydrologic soils group data. A weighted CN (AMC II) value was calculated, as shown in **Appendix E**.

The Visual OTTHYMO 6.2 program recommends that the CN value be transformed to CN* (AMC II). The calculated CN values were converted to CN* using the functions within VO6. **Figure 3-2** provides soils information while **Figure 3-3** shows the future land use of the watershed, based on Official Plan (OP) and/or Secondary Plan data. Spreadsheets with the calculations are provided in **Appendix E**.

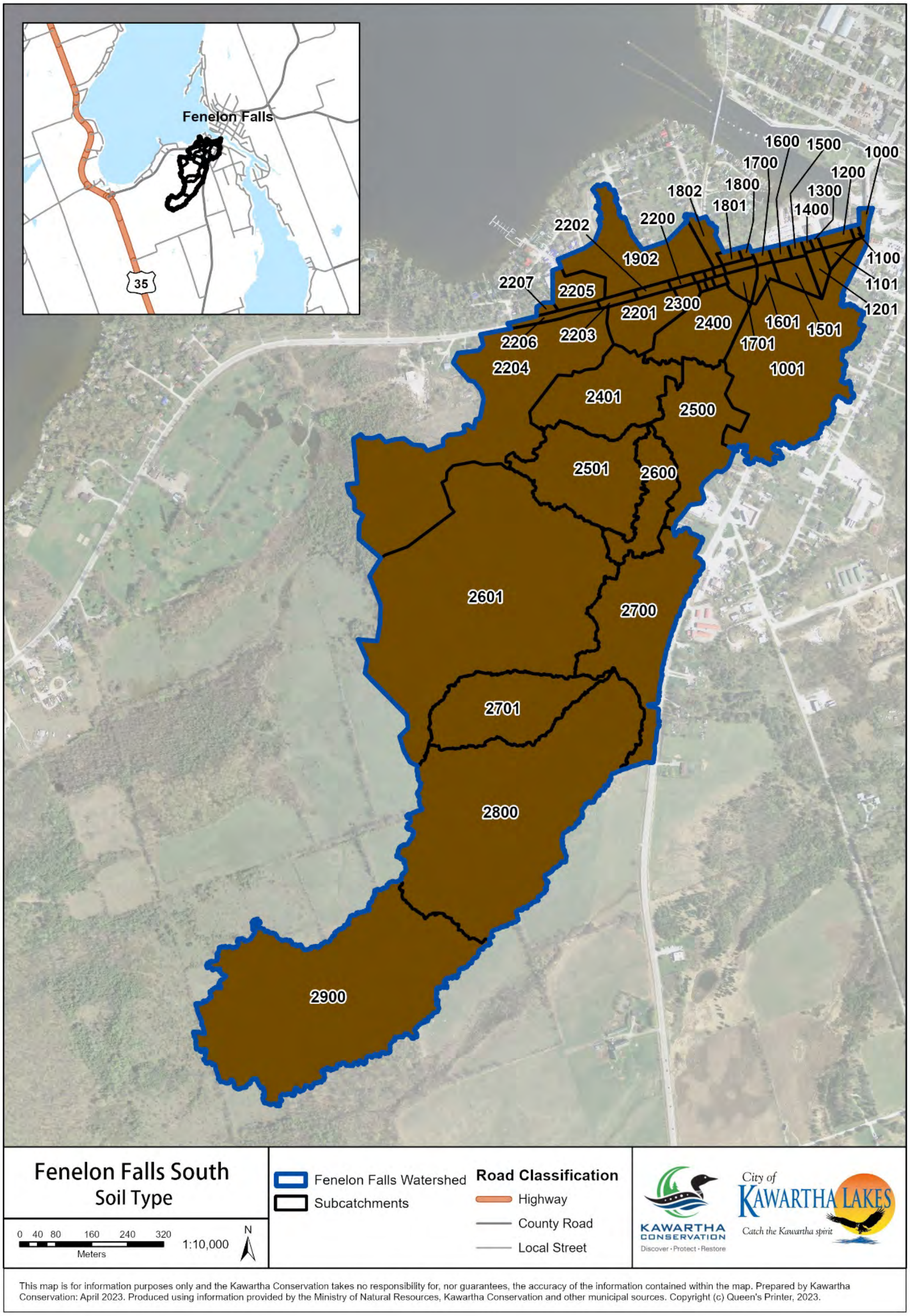


Figure 3-2: Soils

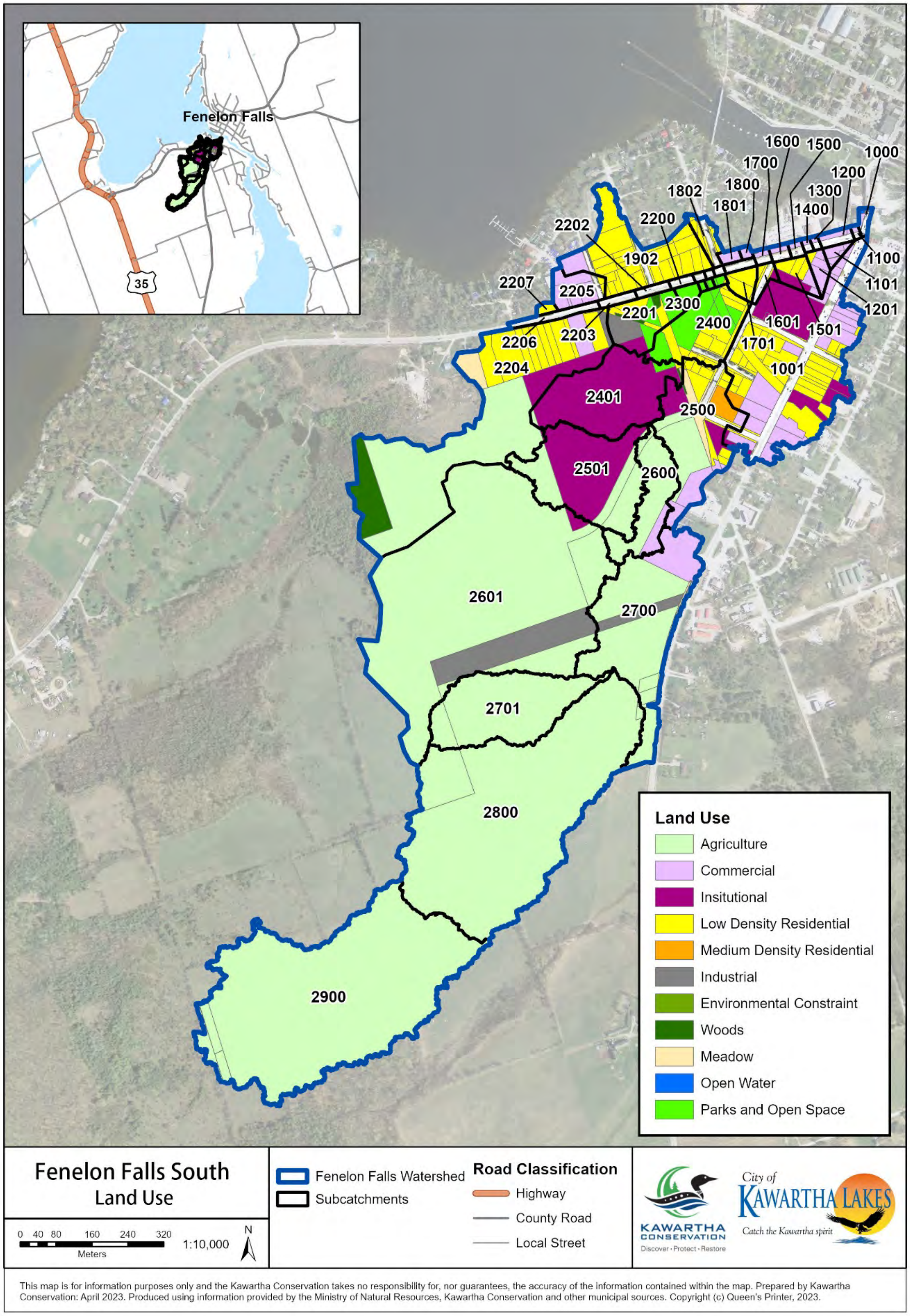


Figure 3-3: Land Use

3.9 Impervious Land Use & Runoff Coefficients

The detailed land use denoted in the OP, Secondary plan, and zoning data determine the weighted total impervious area (T_{imp}), directly connected impervious area (X_{imp}), and runoff coefficient (C) for each subcatchment using the tables from the Hydrologic Parameters List in **Appendix E**.

Subcatchments with a T_{imp} value greater than 20% were modeled with the StandHYD command, otherwise the NashHYD command was used. Spreadsheets with the calculations are provided in **Appendix E**.

3.10 Time of Concentration

Time of concentration (T_c) is a key variable for calculating peak flow. This is the time it takes for the flow wave to travel from the hydraulically farthest point of a subcatchment to the subcatchment's downstream node.

Time of concentration was calculated using the Airport method for subcatchments with a C value less than 0.4; the Bransby-Williams method was chosen if the C value exceeded 0.4.

The Time to Peak (T_p) is defined by VISUAL OTTHYMO 6.2 model via the equation: $T_p = (2/3) * T_c$

Time to peak is used in the NashHYD command only. For urban subcatchments, neither the T_c or T_p are used. Spreadsheets with the T_c and T_p calculations are found in **Appendix E**, using the flow lengths shown in the subcatchment figures found in **Appendix D**.

3.11 Channel Routing

Channel routing in Visual OTTHYMO 6.2 accounts for the time lag of flows being routed in the main channel. HEC-RAS cross sections are input to the Route Channel command within Visual OTTHYMO 6.2. One representative cross-section was selected for each channel reach. The main channel was assigned a Manning's Roughness Coefficient value of 0.035 and the overbanks were assigned 0.08 for most reaches. For Helen Street where the major system is the roadway, a value of 0.011 was used for the entire cross-section to represent asphalt. These values are in accordance with the floodplain mapping guidelines used by conservation authorities in Ontario (Environmental Water Resources Group Ltd., 2017).

3.12 Stormwater Management (SWM) Ponds

No SWM facilities are present within the study area.

4 Hydrologic Model

4.1 Schematic

The information gathered in the preceding sections was used to build a Visual OTTHYMO 6.2 model of the watershed. Each subcatchment contains either a NasHYD or StandHYD node depending on the percent impervious, and all subcatchments except for headwater subcatchments include a channel routing node. AddHYD nodes were included at the outlet of each subcatchment to facilitate extracting flows for the hydraulic model. Due to the close spacing of nodes in the urban area, it is not practical to show all the model nodes in a figure. Please refer to the model files to review the schematic.

4.2 Calibration

Since no rain or flow gauge data is available for this watershed, no calibration can be performed.

4.3 Sensitivity Analysis

A sensitivity analysis was completed to evaluate the impact of hydrologic parameter values on the resulting peak flow rates and water surface elevations. The catchment area, subcatchment slope, subcatchment flow length, impervious depression storage, subcatchment Manning's Roughness coefficient, and initial abstraction were increased and decreased by various factors to determine the impact that each parameter had on the resulting peak flow and water surface elevations. Factors were adjusted by what was considered a reasonable amount for each parameter, where the upper and lower limits could plausibly occur. For the catchment area, slope, and flow length, the values are unlikely to change within the subcatchments where LiDAR is present, but since several subcatchments are based on orthoimagery data, there is increased uncertainty which is evaluated through the sensitivity analysis.

4.3.1 Catchment Area

The catchment area can be impacted by the terrain data used to delineate the catchments. The LiDAR data used in this study has been analyzed and is confirmed to be within specified tolerances defined in the Federal Airborne LiDAR Data Acquisition Guideline from Natural Resources Canada. If the LiDAR covered the entire study area, there would be very uncertainty in the parameters derived LiDAR and analyzing the catchment area would not be necessary. Since several subcatchments are based on orthoimagery-derived terrain data from the Valdor study, there is increased uncertainty in those subcatchment areas. To evaluate the uncertainty, the subcatchment areas were increased and decreased by 25%. The 25% value was selected since it is likely that if LiDAR was used to delineate all subcatchments, the change in subcatchment areas would likely be less than 25%.

4.3.2 Slope

The subcatchment slope is used to calculate the subcatchment Time of Concentration and is based on slope of the longest flowpath line. The slope and longest flow path are both determined based on terrain data, so the issue of increased uncertainty due to multiple terrain data sources is also present for the slope and flow length parameters. The subcatchment slopes were increased and decreased by 25% and the Time of Concentration was recalculated based on the adjusted slopes for each run.

4.3.3 Flow Length

The subcatchment flow length is the longest flowpath between the outlet of the subcatchment and the most remote upstream location. The longest flowpath is determined based on the terrain surface and is calculated as part of the subcatchment delineation process. Like the catchment area and slope parameters, there is less uncertainty present where LiDAR data is available and more where orthoimagery-derived terrain was used. Large differences (>2m) between the LiDAR and orthoimagery-derived terrain surfaces were present in forested areas, so it is likely that the tree canopy is being represented as the ground in some areas in the orthoimagery-derived terrain, which would not accurately represent the flow directions present on the ground. The flow length was altered by increasing and decreasing values by 25% and recalculating the Time of Concentration for each run.

4.3.4 Impervious Depression Storage

Impervious depression storage is the depth of rainfall that will be stored in surface depressions before runoff occurs. Depression storage is often lumped into the initial abstraction value, but in Visual OTTHYMO it is a separate parameter. The Visual OTTHYMO User's Manual states that the values of impervious depression storage are typically between 0.8mm and 1.5mm. A value of 1 mm was used in the Fenelon Falls model. To account for the range of possible values, the value was increased to 2mm and decreased to 0mm.

4.3.5 Manning's Roughness Coefficient

The subcatchment Manning's Roughness Coefficient (Manning's n) is a key parameter that represents the roughness of a flow surface using a dimensionless coefficient. The coefficient is determined based on the land cover data. For each land cover type, a range of Manning's can be applied and are typically refined through model calibration. Manning's n can also vary seasonally based on the growth stage of vegetation or presence of snow and can also change with flow depth. In this case, the land cover data is based on the City of Kawartha Lakes Official Plan and the Fenelon Falls Secondary Plan, so the planned land use types are certain, but the precise value of Manning's n is still uncertain due to the ranges of possible values for each land cover type. Manning's n was increased and decreased by 25% to represent the range of values possible for each land cover type.

4.3.6 Initial Abstraction

The initial abstraction is related to the Curve Number and is typically considered to be a combination of canopy interception, surface depression storage, and infiltration that occurs prior to the start of runoff. The initial abstraction value can have a significant impact on runoff and peak flows, particularly for smaller storms where the initial abstraction represents a larger portion of the total rainfall. Due to the wider range of possible Initial Abstraction values compared to the other parameters considered, the Initial Abstraction values were increased and decreased by 50%.

4.3.7 Hydrology Results

The following section summarizes the results of the sensitivity analysis. **Table 4-1** shows the peak flows from the hydrology model for each sensitivity analysis run for each of the nodes used to define flows in the hydraulic model. **Figure 4-1** plots the peak flow rates at VO node 1 for each parameter in order to determine the slope of the line, which represents the relative sensitivity of each parameter. The catchment area was determined to be the most sensitive parameter with a slope of 8.41. The slope parameter had a trendline slope of 0.082, flow length had a slope of -0.596, Manning's n had a slope of 0.034, initial abstraction had a slope of -0.117, and impervious depression storage had a slope of 0. A slope of 0 indicates that the parameter is not sensitive and will not impact the results. The magnitude of the slope is more important than whether the value is positive or negative, since the parameters can be increased or decreased to achieve the desired change in peak flow in a model calibration.

In a model calibration, the catchment size, flow length, and slope are usually not calibrated because there is a low level of uncertainty compared to other parameters. Based on these results, the Manning's n value and the initial abstraction are the most sensitive parameters that also have higher degrees of uncertainty and should be a focus of parameter adjustments if a calibration is completed in the future.

4.3.8 Hydraulics Results

The resulting peak flows from each of the sensitivity analysis runs were then used in the hydraulic model to determine the impact parameter adjustments would have on the water surface elevations. The results show that the slope, impervious depression storage, and initial abstraction do not have an impact on the water surface elevations at the Helen Street Pipe inlet, although the slope and initial abstraction can alter the water surface elevation by up to 2 cm in locations further upstream. Manning's n and flow length were found to have moderate impacts on the water surface elevation, with trendline slope magnitudes of 0.02 and 0.04, respectively. Adjusting the flow length by +/-25% resulted in water surface elevation variations by up to 5 cm. Adjusting the Manning's n values by +/-25% resulted in water surface elevation variations by up to 4 cm. The catchment size was determined to be the most sensitive parameter on the hydraulic model results with a trendline slope of 0.14. Adjusting the catchment area by +/-25% resulted in water surface elevation variations by up to 14 cm.

Since Manning's n was found to be sensitive for both the hydrologic and hydraulic model runs, it will be a critical parameter to be adjusted in a future model calibration. It is also recommended that LiDAR terrain data be captured over the entire watershed to reduce uncertainty in terrain-derived parameters.

Table 4-1: Sensitivity Analysis – Hydrology Results

	Parameter Adjustment Factors						Model Peak Flow Rate (m^3/s) at Specified VO Node														
Run #	**Catchment Area**	**Slope**	**Flow Length**	**Impervious depression storage**	**Manning's Roughness**	**Initial Abstraction**	**1**	**1000**	**1001**	**11000-14**	**22000**	**2400**	**2401**	**2500**	**2501**	**2600**	**2601**	**2700**	**2701**	**2800**	**2900**
1	1	1	1	1	1	1	8.862	0.059	3.081	1.384	2.339	0.416	1.436	0.997	1.282	0.246	1.737	0.717	0.341	0.971	0.848
2	1.25	1	1	1	1	1	10.927	0.074	3.81	1.563	2.834	0.449	1.779	1.237	1.587	0.308	2.171	0.897	0.426	1.214	1.06
3	0.75	1	1	1	1	1	6.722	0.045	2.34	1.055	1.82	0.314	1.088	0.755	0.973	0.185	1.303	0.538	0.256	0.728	0.636
4	1	1.25	1	1	1	1	8.88	0.059	3.081	1.373	2.34	0.416	1.436	0.997	1.282	0.251	1.798	0.734	0.361	1.023	0.901
5	1	0.75	1	1	1	1	8.839	0.059	3.081	1.383	2.338	0.416	1.436	0.997	1.282	0.235	1.67	0.701	0.32	0.908	0.788
6	1	1	1.25	1	1	1	8.768	0.059	3.081	1.357	2.337	0.416	1.436	0.997	1.282	0.207	1.46	0.607	0.301	0.846	0.737
7	1	1	0.75	1	1	1	9.066	0.059	3.081	1.287	2.342	0.416	1.436	0.997	1.282	0.295	2.163	0.881	0.402	1.158	1.01
8	1	1	1	2	1	1	8.862	0.059	3.081	1.384	2.339	0.416	1.436	0.997	1.282	0.246	1.737	0.717	0.341	0.971	0.848
9	1	1	1	0	1	1	8.862	0.059	3.081	1.384	2.339	0.416	1.436	0.997	1.282	0.246	1.737	0.717	0.341	0.971	0.848
10	1	1	1	1	1.25	1	8.865	0.059	3.081	1.383	2.34	0.416	1.436	0.997	1.282	0.274	1.966	0.801	0.387	1.108	0.971
11	1	1	1	1	0.75	1	8.848	0.059	3.081	1.383	2.338	0.416	1.436	0.997	1.282	0.205	1.437	0.6	0.28	0.787	0.684
12	1	1	1	1	1	1.5	8.821	0.059	3.078	1.381	2.28	0.412	1.436	0.993	1.278	0.236	1.664	0.686	0.326	0.928	0.809
13	1	1	1	1	1	0.5	8.938	0.059	3.081	1.371	2.34	0.416	1.436	0.997	1.282	0.256	1.81	0.746	0.356	1.011	0.884

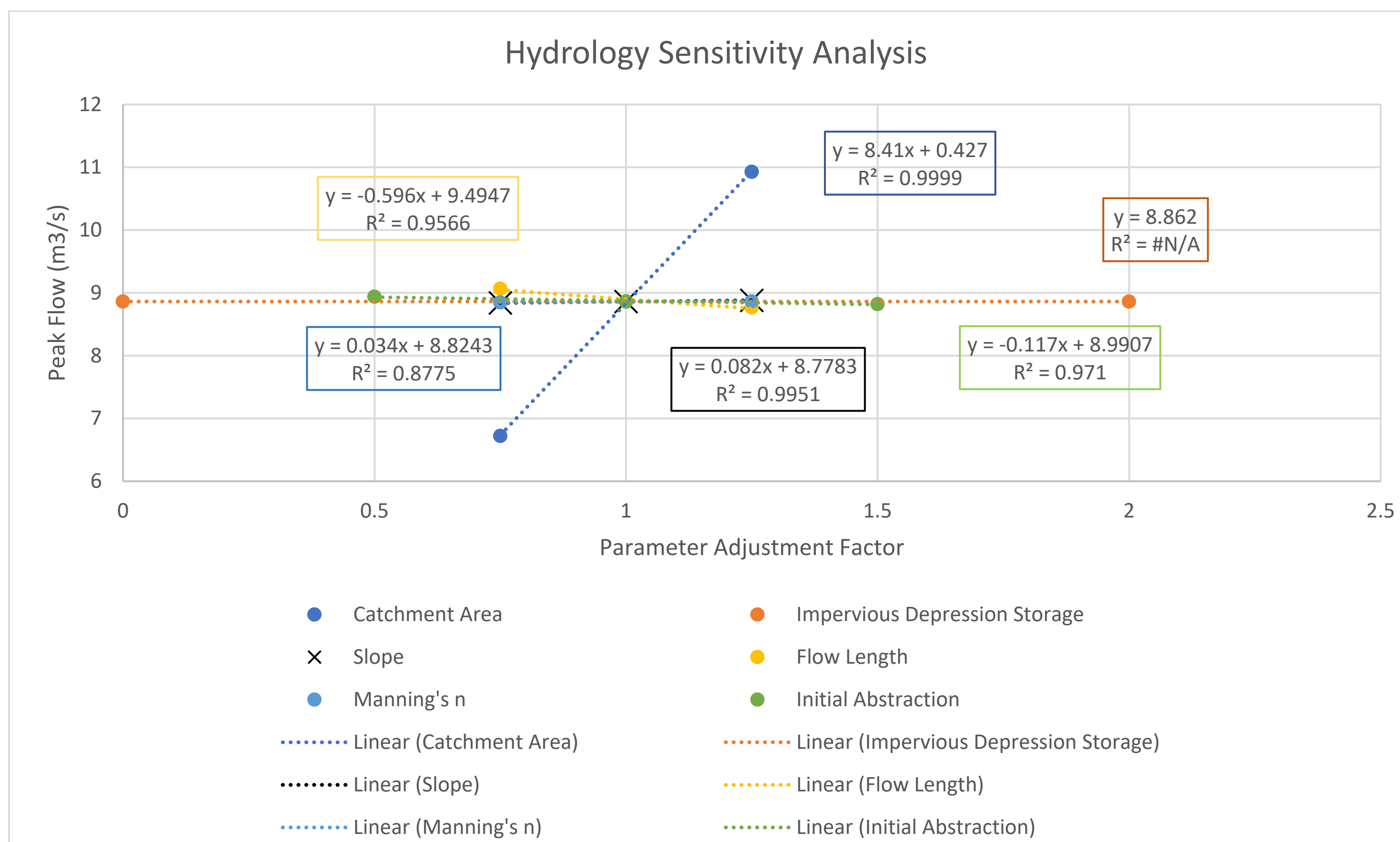


Figure 4-1: Sensitivity Analysis – Hydrology Plot

Table 4-2: Sensitivity Analysis – Hydraulics Results

Run #	Parameter Adjustment Factors for each run						Modelled Water Surface Elevation (m) (Vertical Datum: CGVD28:78)				
							Location				
	Catchment Area	Slope	Flow Length	Impervious depression storage	Manning's Roughness	Initial Abstraction	Helen St Pipe Inlet	Eva St Pipe Inlet	CC Driveway Pipe Inlet	CR121 Pipe Inlet	Private Driveway Pipe Inlet
1	1	1	1	1	1	1	257.08	257.41	257.76	259.59	260.26
2	1.25	1	1	1	1	1	257.11	257.46	257.59	259.61	260.27
3	0.75	1	1	1	1	1	257.04	257.36	257.73	259.54	260.24
4	1	1.25	1	1	1	1	257.08	257.42	257.76	259.59	260.26
5	1	0.75	1	1	1	1	257.08	257.41	257.76	259.57	260.25
6	1	1	1.25	1	1	1	257.07	257.41	257.75	259.56	260.25
7	1	1	0.75	1	1	1	257.09	257.43	257.77	259.61	260.27
8	1	1	1	2	1	1	257.08	257.41	257.76	259.59	260.26
9	1	1	1	0	1	1	257.08	257.41	257.76	259.59	260.26
10	1	1	1	1	1.25	1	257.08	257.42	257.77	259.60	260.27
11	1	1	1	1	0.75	1	257.07	257.40	257.75	259.56	260.25
12	1	1	1	1	1	1.5	257.08	257.41	257.76	259.58	260.26
13	1	1	1	1	1	0.5	257.08	257.41	257.76	259.59	260.26

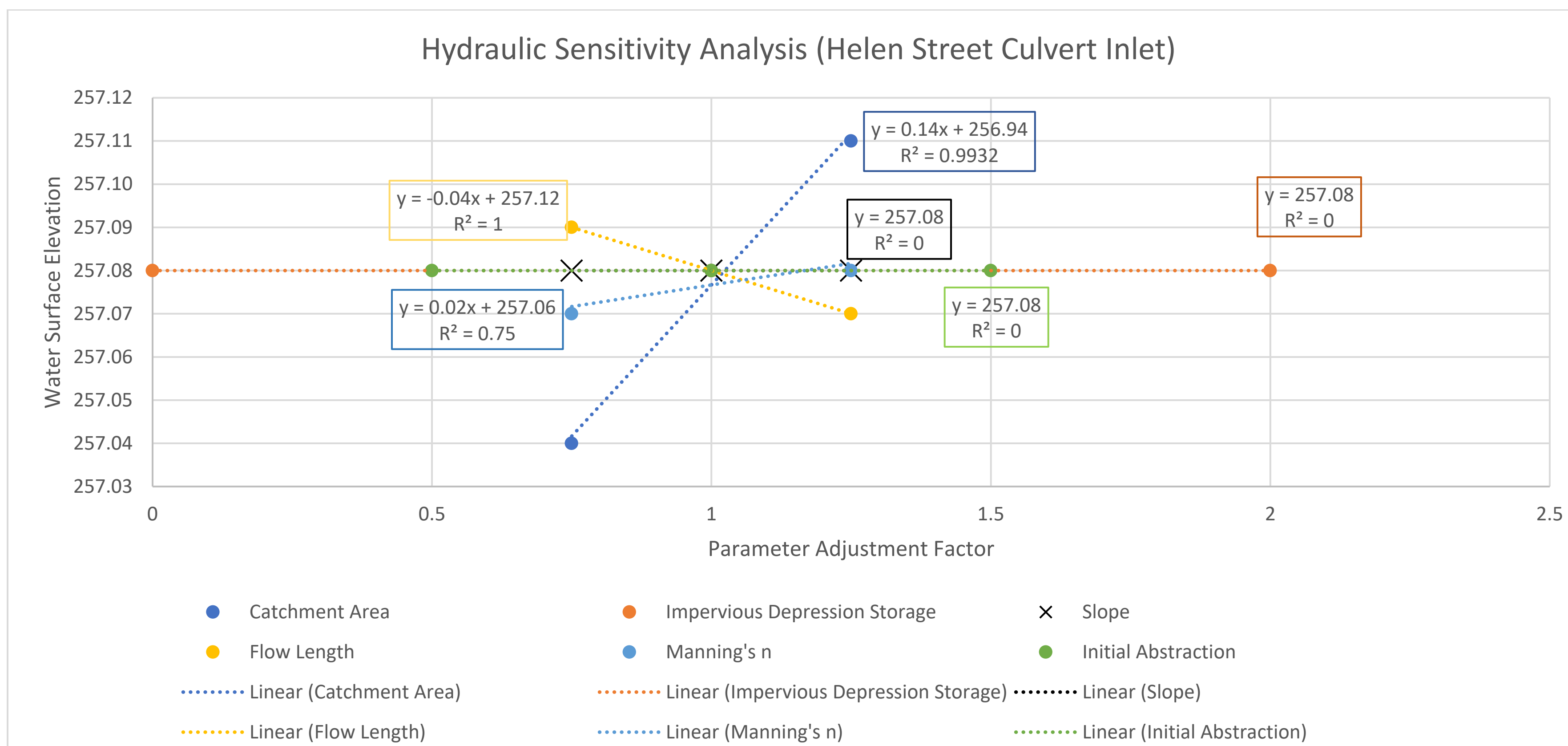


Figure 4-2: Sensitivity Analysis – Hydraulic Plot

4.4 Model Input Data

The model input data are highlighted in **Table 4-1,** below. More details can be found in **Appendix E**. Due to the use of CN* in the hydrologic model, the CN method is not valid for determining initial abstraction. According to the Visual OTTHYMO Reference Manual, the I_A value should be set between 1.5 mm and 5 mm when the Curve Number loss routine is used. To be conservative, an initial abstraction of 5 mm was used for all NasHYD subcatchments, and 1.5 mm was used for all StandHYD subcatchments.

Table 4-3: Visual OTTHYMO Model Input Parameters

Catchment	Area (Ha)	C	T_p (hr)	CN (I)	CN (II)	CN (III)	CN* (AMC II)	X_{imp}	T_{imp}	Hyd
1000	0.14	0.81		81	91	96	90	0.78	0.87	STANDHYD
1001	9.07	0.77		74	87	94	86	0.54	0.75	STANDHYD
1100	0.05	0.90		89	95	98	95	0.88	0.88	STANDHYD
1101	0.19	0.88		83	92	96	92	0.83	0.84	STANDHYD
1200	0.24	0.90		89	95	98	95	0.88	0.88	STANDHYD
1201	0.32	0.84		79	90	95	89	0.78	0.81	STANDHYD
1300	0.06	0.90		89	95	98	95	0.88	0.88	STANDHYD
1400	0.06	0.90		89	95	98	95	0.88	0.88	STANDHYD
1500	0.11	0.86		87	94	97	94	0.82	0.85	STANDHYD
1501	0.56	0.72		69	84	92	82	0.40	0.70	STANDHYD
1600	0.15	0.88		87	94	97	94	0.85	0.86	STANDHYD
1601	0.26	0.74		75	88	94	87	0.56	0.75	STANDHYD
1700	0.12	0.85		87	94	97	94	0.81	0.85	STANDHYD
1701	0.38	0.46		56	75	87	72	0.27	0.51	STANDHYD
1702	0.07	0.87		81	91	96	90	0.80	0.83	STANDHYD
1800	0.14	0.90		93	97	99	98	0.89	0.89	STANDHYD
1801	0.13	0.89		81	91	96	90	0.83	0.84	STANDHYD
1802	0.45	0.59		66	82	91	79	0.46	0.63	STANDHYD
1900	0.05	0.89		93	97	99	98	0.88	0.89	STANDHYD
1901	0.07	0.33	0.17	52	72	86	71	0.10	0.15	NASHYD
1902	3.51	0.51		58	77	89	75	0.34	0.55	STANDHYD
2000	0.04	0.90		95	98	99	99	0.89	0.90	STANDHYD
2001	0.04	0.26	0.19	49	70	84	69	0.02	0.02	NASHYD
2100	0.05	0.89		95	98	99	99	0.89	0.89	STANDHYD
2101	0.04	0.25	0.12	48	69	84	67	0.00	0.00	NASHYD
2200	0.11	0.87		93	97	99	98	0.86	0.86	STANDHYD
2201	1.54	0.54		58	77	89	75	0.28	0.44	STANDHYD
2202	0.16	0.84		89	95	98	95	0.82	0.83	STANDHYD
2203	0.17	0.87		93	97	99	98	0.86	0.88	STANDHYD
2204	11.31	0.43		56	75	87	72	0.12	0.21	STANDHYD
2205	0.83	0.87		81	91	96	90	0.82	0.83	STANDHYD
2206	0.33	0.90		95	98	99	99	0.90	0.90	STANDHYD
2207	0.10	0.47		56	75	87	72	0.28	0.52	STANDHYD
2300	0.23	0.25	0.29	48	69	84	47	0.00	0.00	NASHYD
2400	2.47	0.37		53	73	86	70	0.15	0.26	STANDHYD

2401	4.17	0.97		81	91	96	97	0.29	0.87	STANDHYD
2500	4.12	0.58		63	80	90	77	0.30	0.45	STANDHYD
2501	4.86	0.73		70	85	93	83	0.18	0.53	STANDHYD
2600	2.14	0.43	0.28	58	77	89	77	0.13	0.13	NASHYD
2601	20.70	0.41	0.44	57	76	88	76	0.09	0.11	NASHYD
2700	6.38	0.43	0.28	58	77	89	77	0.13	0.14	NASHYD
2701	4.55	0.35	0.50	56	75	87	75	0.01	0.01	NASHYD
2800	16.90	0.35	0.73	56	75	87	75	0.01	0.01	NASHYD
2900	17.23	0.35	0.90	56	75	87	75	0.01	0.01	NASHYD

5 Hydrology Model Results

5.1 Comparing model inputs: 2010 Valdor vs. 2023 Kawartha Conservation

The Fenelon Falls South watercourse was modeled in 2010 by Valdor Engineering Inc. As discussed in the previous section, Kawartha Conservation re-created the hydrologic breakdown using the most recent LiDAR and GIS data. Differences between the 2010 and 2023 data were discovered with respect to drainage areas, land use, and ground elevation.

Tributary Area

Area differences are highlighted in **Table 5-1** and in **Figure 5-1.** The hydrologic model produced by Valdor contained only 4 subcatchments, while the Kawartha Conservation model includes 44. Using 44 subcatchments in a small watershed was not necessary but provides additional options for future modelling efforts as the storm sewer network could easily be added. The overall watershed delineation is similar between the two models, although the Kawartha Conservation model includes additional areas in the headwaters, and an additional subcatchment along Lindsay Street was added since the Lindsay Street storm sewer connects with the Helen Street storm sewer close to the outlet to the Fenelon River. A portion of the western external area subcatchment in the Valdor model was found to drain to a tributary upstream of the Canadian Tire instead of directly to Helen Street, so the subcatchment boundaries were adjusted to reflect the drainage paths, leading to increased drainage area upstream of Canadian Tire and less drainage area in the Western external area.

Table 5-1: Comparing Tributary Areas at Key Nodes

Key Node Location	Tributary Area (Ha)		% Difference
	Valdor	Kawartha Conservation	
U/S of Canadian Tire	47.4	65.8	39%
Western external area	21.9	11.3	-48%
Helen St. Trunk Sewer Inlet (east of running track)	85.6	83.5	-2%
Helen St. SWM Catchments	11.3	10.7	-5%
Lindsay Street Catchment	N/A	9.1	N/A
Total Area	96.9	114.6	17%

The differences in catchment area can largely be attributed to the use of LiDAR data in this study. In several vegetated areas, the LiDAR contained elevations that were 2-3m lower than the SWOOP orthoimagery-derived DTM, indicating that the tops of vegetation were modelled as the ground in the terrain model, while the LiDAR-based DTM more accurately represents the terrain surface since LiDAR can penetrate canopy coverage.

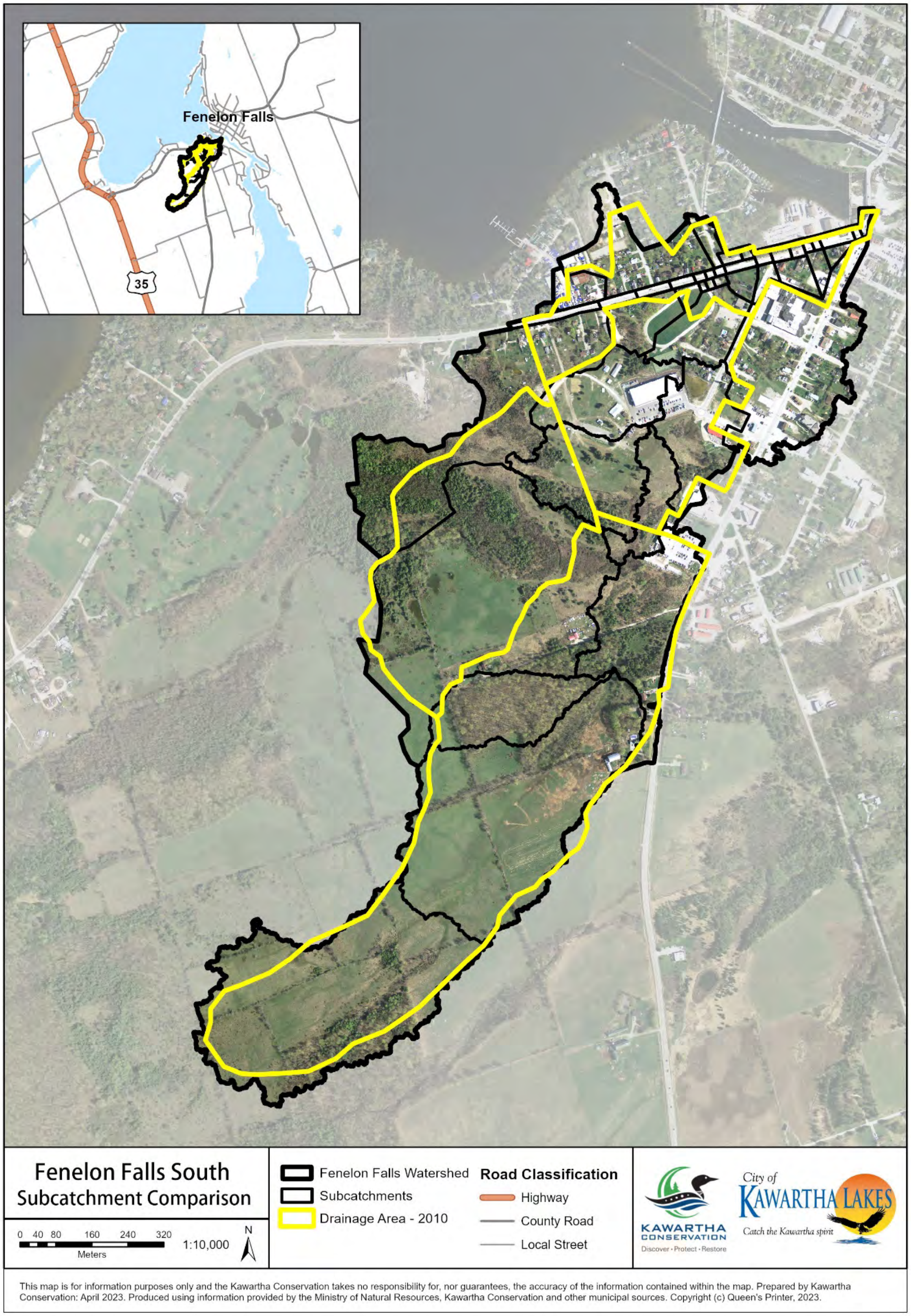


Figure 5-1: Valdor vs. Kawartha Conservation Subcatchments

5.2 Comparing Hydrology model output: 2010 Valdor vs. 2023 Kawartha Conservation

Valdor only modelled the 24-hour Chicago storm and the Timmins Storm. Kawartha Conservation staff modeled the 100-year storm with 6, 12, and 24-hour durations using AES, SCS, and Chicago storm distributions to determine which duration and distribution produces the largest peak flows. In this study, the 24-hour Chicago Storm produced the highest peak flow at most key nodes. The 24-hour Chicago Storm produced the highest peak flows in most of the watershed, but the Timmins Storm produced higher peak flows in rural areas upstream of the Canadian Tire. The Regulatory Floodplain was produced by overlaying both the 100-year and Timmins floodplain extents and delineating the largest floodplain extents in each area. Flow comparisons for the 100-year storm are highlighted in **Table 5-2**, below. **Table 5-3** lists the flows at key nodes for the Timmins storm. Summary output is included in **Appendix G**.

Table 5-2: 100-year 24-hour Chicago Storm Flows at Key Nodes

Valdor Node	KRCA Node	100-year Flows in m^3/s	
		Valdor	**KRCA**
Catchment #99	28000	1.61	1.66
#101 (VO2)	22	2.45	3.65
#102 (VO2)	24000	3.07	3.82
#103 (VO2)	1	3.39	8.86

Table 5-3: Timmins Flows at Key Nodes

Valdor Node	KRCA Node	Timmins Flows in m^3/s	
		Valdor	**KRCA**
Catchment #99	28000	2.63	2.25
#101 (VO2)	22	3.90	4.63
#102 (VO2)	24000	4.81	5.41
#103 (VO2)	1	5.44	7.84

The peak flows from the Kawartha Conservation model are significantly higher than the peak flows from the Valdor study, particularly in urban areas. The Valdor model did not include channel routing in the model, so flows were effectively transported instantaneously to downstream nodes leading to peak flows occurring more quickly. The Valdor model also used a curve number of 65 for the urban subcatchment, while urban subcatchments in the Kawartha Conservation model range from 75 to 98, leading to significantly more runoff. The Kawartha Conservation model has used more conservative values for initial abstraction; 1.5 mm was used for urban areas and 5 mm was used for rural areas, while the Valdor model used 5 mm in urban areas and 8 mm in rural areas. Finally, the Kawartha Conservation model used percent impervious values based on land use that ranged from 50-90% in urban areas, while the Valdor model used 50% impervious in urban areas. Overall, the parameters used in the Kawartha Conservation model are more representative of the actual watershed conditions and will produce more accurate peak flows than the Valdor model.

5.3 Analyzing Storm Distributions and Durations

Various 100-year storm distributions and durations were modelled to determine which one produced the largest peak flow. The AES, SCS, and Chicago Storms were modelled with 6, 12, and 24-hour durations. Flows were compared at the watershed outlet (Node 1). **Table 5-4** shows the 100-year peak flows at the watershed outlet.

Table 5-4: 100-year Peak Flow Comparison (m^3/s)

	Storm Duration		
Rainfall Distribution	**6-hour**	**12-hour**	**24-hour**
Chicago	8.97	9.3	9.72
SCS	9.25	9.09	8.99
AES	5.53	4.03	2.68

Based on the comparison of flows, the 24-hour Chicago Storm produced the largest peak flow of any distribution and duration. The 24-hour Chicago Storm will therefore be used for all other design storms in the model.

6 Hydraulic Model Input Parameters

6.1 Flow Data

The results of the new VisualOTTHYMO 6.2 hydrological model for the Fenelon Falls South watercourse are reasonable and the best estimate of flow and therefore were used as input to a hydraulic model to establish new Regulatory floodlines for the watershed. For 2D models, flow data must be unsteady, so a 6-hour period was added to ramp up flows from zero to the observed peak flow from the hydrologic model. The peak flow is maintained for an extended period to produce quasi-steady state results that are suitable for Regulatory Floodplain Mapping. **Table 6-1** shows the representative peak flows to be input to the HEC-RAS model. The 2 to 50-year storms were not included in the hydraulic model.

Table 6-1: Input Flows to HEC-RAS

VO Node/HEC-RAS Boundary Condition	100-year Peak Flow	Timmins Peak Flow
1000	0.059	0.017
1001	3.081	1.061
11000-14	1.382	0.595
22000	2.339	1.417
2400	0.416	0.233
2401	1.436	0.497
2500	0.997	0.44
2501	1.282	0.552
2600	0.246	0.202
2601	1.737	1.776
2700	0.734	0.603
2701	0.341	0.371
2800	0.971	1.203
2900	0.848	1.125

6.2 Model Geometry

The geometric data was extracted from the LiDAR DEM using GeoHEC-RAS. This ensures geo-referencing of the geometry. Since LiDAR does not return laser points for any ground below the water surface it is necessary to supplement these areas with surveyed data to create accurate river geometry. Based on surveyed crossing-inverts, the channel bottom corresponded well between the LiDAR and survey data indicating that there was not a significant amount of flow in the channel when the LiDAR was captured and therefore further bathymetric surveys were not needed. All LiDAR and survey data used the CGVD 28:78 vertical datum and the CRCS UTM Zone 17N horizontal projection. Stream crossings have been identified and positioned using the LiDAR data, orthoimagery, field reconnaissance, and information in previous reports. Full photographic records of all hydraulic structures are found in **Appendix I**.

In 2D hydraulic models, the channel and floodplain geometry are represented by an interconnected mesh of cells, as well as hydraulic structures. The 2D mesh was developed based on LiDAR data, and breaklines were added for the channels, crossings and roads. A mesh size of 2 m was used through the developed areas of the model between Cameron Lake and extended upstream past the private driveway south of the Canadian Tire. A mesh size of 5 m was used for the remaining headwater areas.

6.3 Culvert and Road Crossings

Five hydraulic structures are present in the model, and each one was modelled as a culvert. HEC-RAS requires that the elevations of the 2D cells at each end of the culvert must be lower than the culvert invert elevation. To ensure that this was the case in the model, the ‘Adjust Elevations’ tool was used in GeoHEC-RAS to lower the cells at each end of the culverts to 1 cm below the culvert invert. **Table 7-1** provides key details; other relevant data and photographs are found in **Appendix I**.

Breaklines can be enforced for crossings to ensure that the high point of the embankment is represented and that flows cannot “bleed” across the high elevation by having cells straddle the centreline. For the Eva Street and Helen Street crossings, the breaklines were not enforced since a defined embankment is not present and there is no risk of flows “bleeding” across a local high point. For all other crossings, the breaklines were enforced.

Table 6-2: HEC-RAS Structure Data

Street	Material	Bottom	Shape	Invert Elevation (m)		Length (m)	Size (mm)		Manning’s n
				U/S	D/S		Span	Rise	
Private Driveway	CSP	Closed	Circular	259.30	259.10	7.18	500	500	0.024
CR 121	Concrete	Closed	Box	258.60	258.58	20	1200	800	0.013
FFCC Entrance	CSP	Closed	Circular	256.80	256.70	29.27	300	300	0.024
Eva Street	CSP	Closed	Circular	255.70	255.93	54.77	400	400	0.024
Helen Street	Concrete	Closed	Circular	255.56	252.64	504.0	680	680	0.013

6.4 Manning’s n Values

Manning’s n values for the 2D areas were based on the City of Kawartha Lakes Official Plan and the Fenelon Falls Secondary Plan. The land use categories were simplified to developed – low intensity, agricultural, and impervious areas. All forested areas in the study area were classified as agricultural, so no forest cover was modelled. The Manning’s roughness coefficients for each of the land uses were selected from the HEC-RAS 2D Modelling User’s Manual.

For developed – low intensity land use, a Manning’s n of 0.09 was used, for agricultural area, a Manning’s n of 0.05 was used, and for impervious areas a value of 0.03 was used.

6.5 Building Obstructions

Where buildings are in the 2D mesh, flow obstructions were added to the model. The building shapefile was used to define the footprint of each structure, and a height of 4m was assigned to ensure that no flows would cross through building locations. The 2D mesh was also adjusted based on the building footprint so that mesh cell boundaries aligned with the building boundaries to ensure accurate representations of the flow conditions.

6.6 Boundary Conditions

Several boundary conditions were added to the model which represent flow rates from subcatchments and static water surface elevations for Cameron Lake and immediately downstream of the dam on the Fenelon River. The Cameron Lake WSEL is based on the 100-year lake level defined by Kawartha Conservation, obtained from the Valdor study. Level data was not available for the Fenelon River, so the WSEL downstream of the dam was based on the DTM which uses the interpolated elevations based on the surrounding land and generally represents the water surface when the LiDAR was captured. Since the overland flow path discharges entirely to Cameron Lake, the Fenelon River boundary condition only influences the Helen Street storm sewer outfall, which is more than a meter above the water surface and will not exhibit backwater effects based on the Fenelon River WSEL.

Where flows spilled east of Lindsay Street and out of the watershed, a normal depth boundary condition was used. The slope for the boundary condition was the ground slope of the primary flow path measured 10 m upstream of the boundary condition line to 10 m downstream.

The West Spill was also represented as a normal depth boundary condition, but the spill flows will remain within the watershed and flow north towards Victoria Road and rejoin flows on Helen Street. This spill was not mapped since suitable LiDAR-based terrain data was not available for that portion of the watershed.

Internal flow boundary conditions were used to represent subcatchment flows throughout the model. Subcatchments along Helen Street between where the main channel enters the storm sewer and Lindsay Street were lumped together since the level of discretization needed for the previously developed SWMM model was not necessary for the floodplain model. The hydrograph for the lumped subcatchment was determined by subtracting the inflow hydrograph from the outflow hydrograph. All other internal boundary conditions were placed at the upstream end of the subcatchment they were derived from, except for headwater subcatchments, in order to ensure that flows were represented conservatively throughout the model. The flow boundary conditions in headwater subcatchments were placed further downstream in the subcatchments where a clear channel was present.

6.7 Simulation Details

The simulation was run using the diffusion wave computational method with a maximum of 20 iterations per time step. A 0.1% flow calculation tolerance, a 0.003 m water surface calculation tolerance, and a 0.03 m^3/s minimum flow tolerance were used. The variable time step option based on the Courant number was used, with a maximum time step of 160 seconds and a minimum of 0.16 seconds, the maximum Courant number before halving was 3 and the minimum Courant number before doubling was 0.5, the number of time steps exceeding above limits before adjusting the time step was 4, and the Courant computation method was Courant (Velocity-Based). The minimum and maximum time steps were adjusted so that the model ran with minimal iterations per time step, and all other parameters were left at their default values.

6.8 2D Mesh

The information gathered in the preceding section was used to build a HEC-RAS model of the watercourse. The geometry of the model is shown schematically in **Figure 8-1**. Solid red lines are internal boundary condition locations, double red lines are external boundary conditions, orange lines are breaklines, and hydraulic structures are grey with burgundy culverts.

A standard mesh was used, and a mesh spacing of 2 m was applied within the urban area, and a spacing of 5 m was used in rural areas.

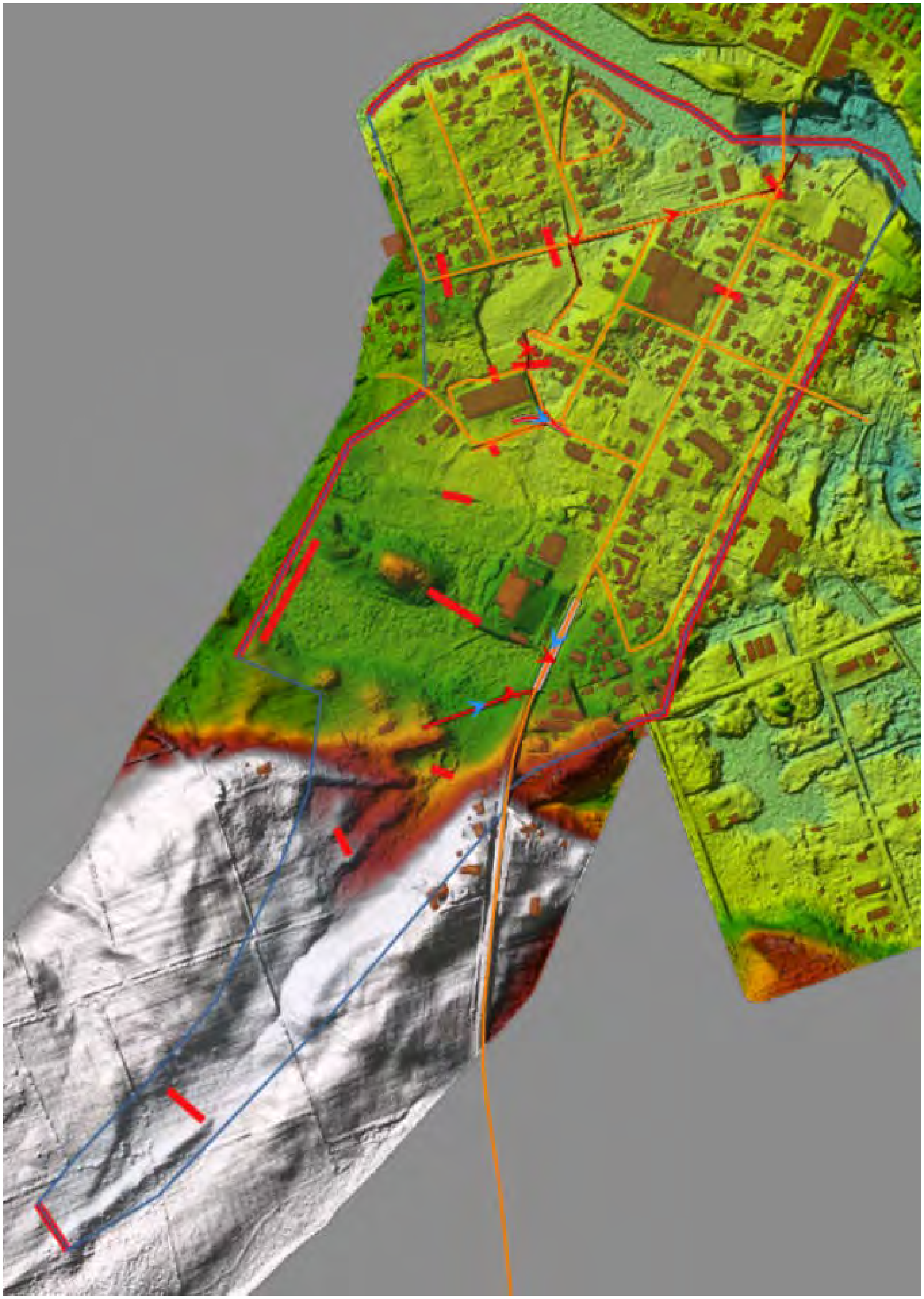


Figure 8-1: HEC-RAS Schematic

7 Hydraulic Model Results

7.1 Comparing Model Data Input (Kawartha vs. Valdor)

The Fenelon Falls South watercourse was previously modeled in 2010 by Valdor using simplified modelling methods to approximate floodplain limits. The methods used are not sufficient for regulatory floodplain mapping. In addition, the current hydraulic model uses a 2D computational method rather than the 1D model from Valdor, which leads to difficulties directly comparing results. HEC-RAS modelling results are included in **Appendix J**.

7.1.1 Base DEM

The model established by Kawartha Conservation is geo-referenced from the 2012 LiDAR acquisition, whereas the EWRG model is not georeferenced. As previously mentioned in section 1.4, EWRG used 1”=200’ scale topographical maps with 5’ contours within Town limits, and 1:10,000 scale topographical maps with 5m contours for rural lands outside Town limits. EWRG did not supply digital CAD or GIS files for the flood maps; only paper maps were included in their final report.

7.1.2 Flow Input

The input flows in the Kawartha Conservation HEC-RAS model are different than what was used in the Valdor model. For 1D models, flows are defined by nodes and input directly into the hydraulic model at those flow change locations. For 2D modelling, flows are defined by subcatchment inflows, and channel routing and storage properties are calculated implicitly. Since flows are defined differently between the 1D and 2D hydraulic models, the inflows cannot be compared directly. For details of the peak flows used in the model, please refer to Section 6 “Flow Input to the Hydraulic Model”.

7.2 Comparing Hydraulic Model Output (Kawartha vs. Valdor)

Table 9-1 below showcases the differences between the Valdor and Kawartha Conservation flood elevations as calculated by HEC-RAS for the 100-year and Timmins storms. The flow inputs differ due to the updated hydrology model. Subcatchment inflows, channel routing, and storage properties are modelled differently due to steady-state (1-D) vs unsteady modelling (2-D). More detailed information can be found in **Appendix N**.

In all areas except for upstream of the Private Driveway, the 2023 KRCA model produced higher water surface elevations (WSELs) than the 2010 Valdor model. The Valdor report did not include any references to the vertical datum that was used for the terrain or water surface elevations. When the Valdor WSELs were plotted on the 2012 LiDAR DTM in CGVD 28:78, the WSELs for most cross-sections were below the terrain surface, indicating that the Valdor report used a datum other than CGVD 28:78. Since no datum was provided and the results are not consistent with the data for this study, any elevations from the Valdor report cannot be compared with the present study. The following elevations are presented for reference only and do not represent actual differences in flood elevations between the two studies.

Table 7-1: Comparing Regulatory Flood Elevations

Location	Valdor Flood Elevation (m)		KRCA Flood Elevation (m)	
	100-year	Timmins	100-year	Timmins
U/S Helen Street at Culvert Inlet	256.16	256.3	257.01	256.95
U/S Eva Street Culvert	256.21	256.35	257.36	257.28
U/S FFCC Entrance Culvert	256.6	256.64	257.70	257.67
U/S Canadian Tire/CR 121	259.13	259.16	259.52	259.53
U/S Private Driveway	261.26	261.1	260.29	260.30

The floodplain from the 2010 Valdor study is shown in **Figure 9-1.** The floodplain from the 2023 KRCA study is shown in **Figure 9-2**. Both studies show significant backwatering upstream of the Canadian Tire site. The 2023 floodplains are significantly larger than the 2010 study, with much larger inundated areas at the Community Centre, along Helen Street, and the north end of Lindsay Street. The use of 2D modelling allows multiple flow paths to be represented which improves the precision of floodplain mapping compared to 1D models where significant assumptions are required to model urban streams which can often lead to misleading results.

During the regulatory flood event, safe access (i.e. flood depths less than 0.3 m) will not be possible on Lindsay Street between Green Street and Elliot Street, and on Helen Street between West Street N and North Street.

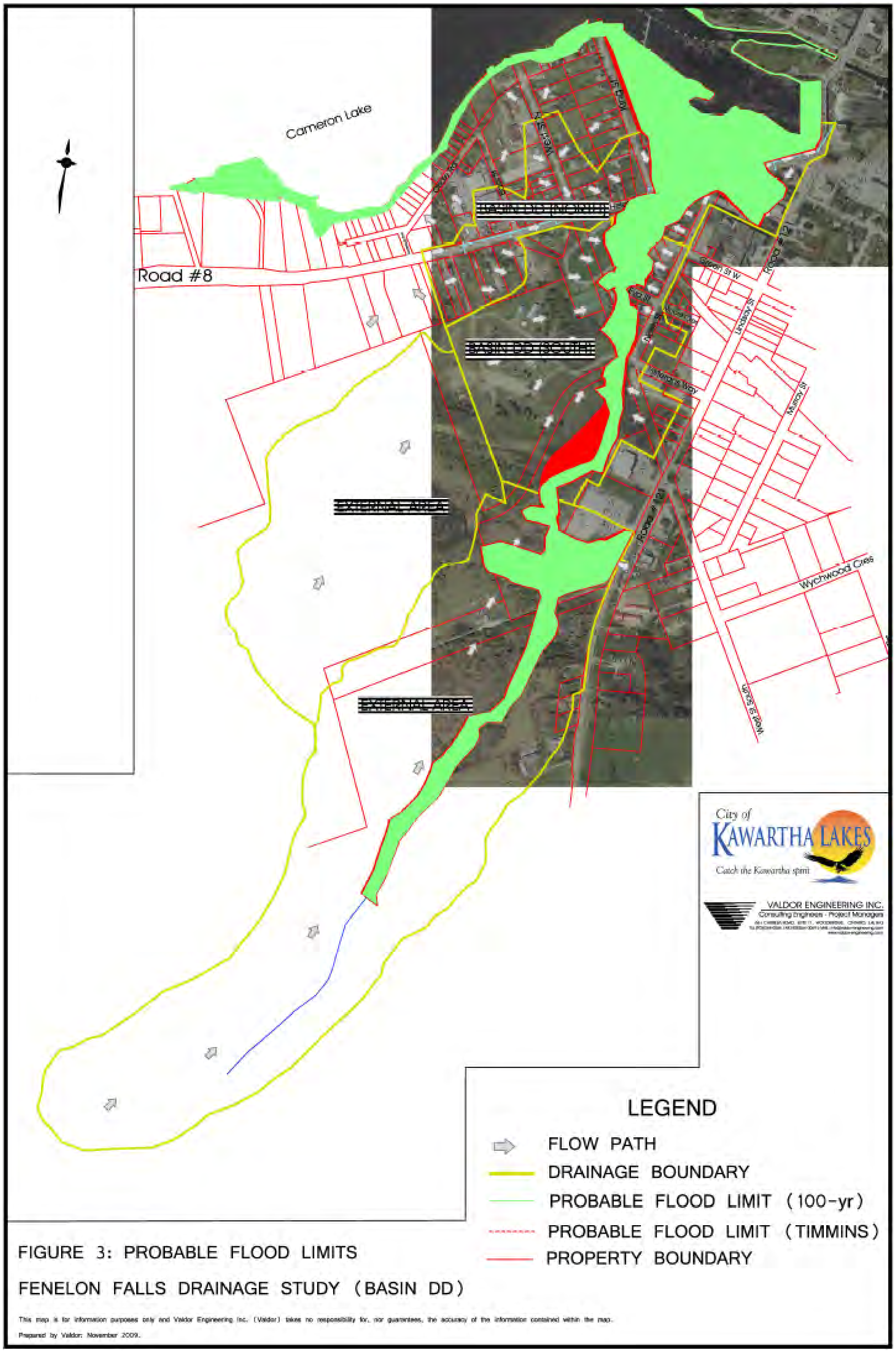
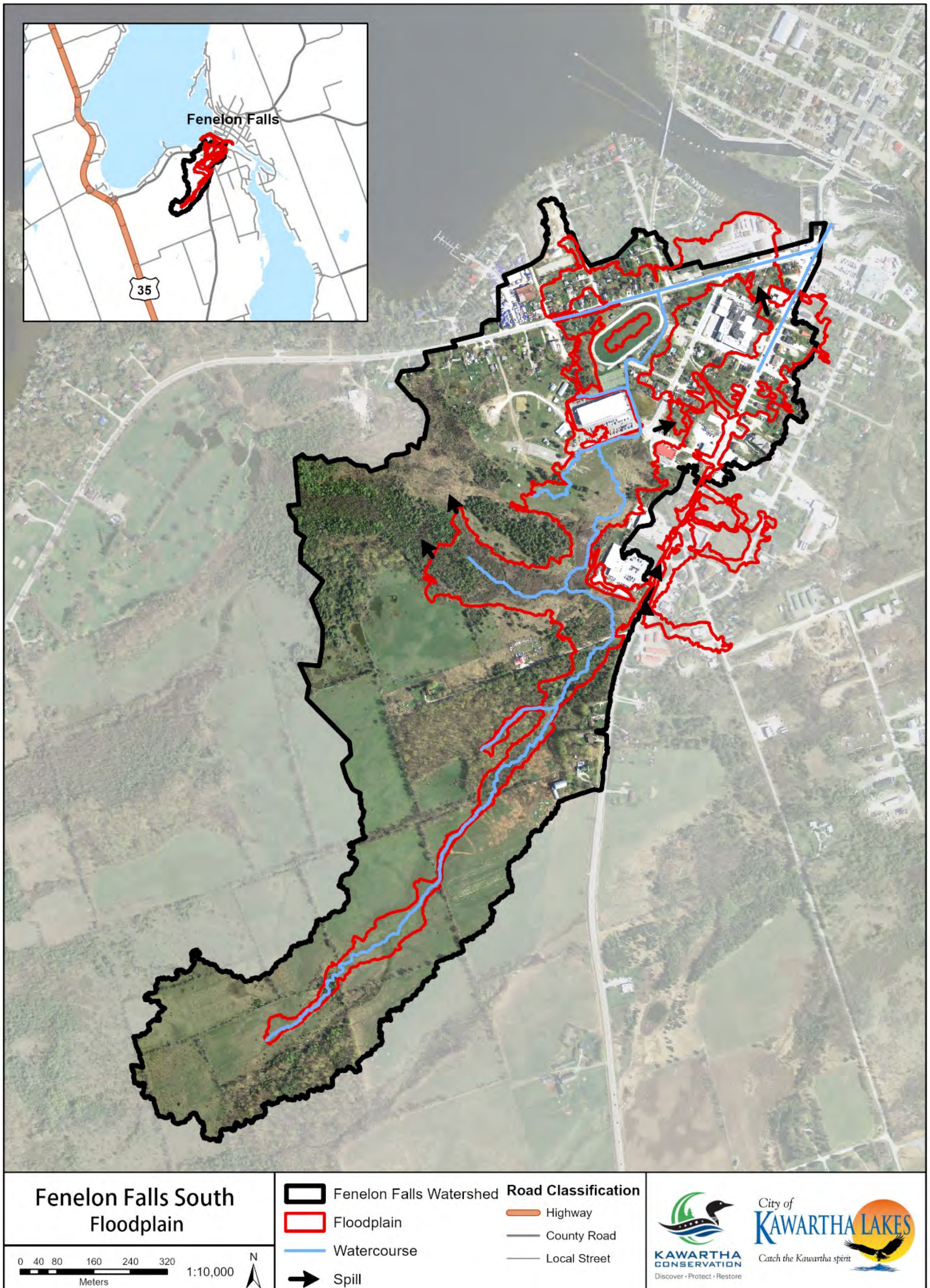


Figure 9-1: 2010 Valdor Floodplain



This map is for information purposes only and the Kawartha Conservation takes no responsibility for, nor guarantees, the accuracy of the information contained within the map. Prepared by Kawartha Conservation: April 2023. Produced using information provided by the Ministry of Natural Resources, Kawartha Conservation and other municipal sources. Copyright (c) Queen's Printer, 2023.

Figure 9-2: 2023 KRCA Floodplain

7.3 Spills

Three significant spills were identified within the model area. Two spills flow out of the modelling area into adjacent watersheds, while the third spill leaves the main channel and flows overland before rejoining the main channel.

7.3.1 County Road 121

County Road 121 was modelled as a 2D Flow Area Connection with a culvert under the road. A channel constriction west of Canadian Tire leads to significant backwatering south of Canadian Tire. This causes flows to cross the road both through the culvert and over land. The total flow leaving the main channel and either crossing County Road 121 (CR 121) or flowing north along the road is 1.03 m^3/s under the 100-year 24-hour Chicago Storm. Of that, 0.69 m^3/s flows east through the culvert and out of the watershed. 0.35 m^3/s spills north along CR 121 and then towards the east, north of West Street S and out of the watershed. Approximately 0.012 m^3/s re-enters the watershed to the north on Lindsay Street. Flow velocities were generally less than 0.5 m/s. **Figure 9-3** shows the flood extents of the spill.

Inundated areas east of CR 121, and between the Canadian Tire and Veterans Way are outside of the Fenelon Falls South Creek watershed. Outside of the watershed, flows have not been modelled, so the resulting delineations are likely an underestimation of flood risk and should be refined when the adjacent watershed to the east is modelled.

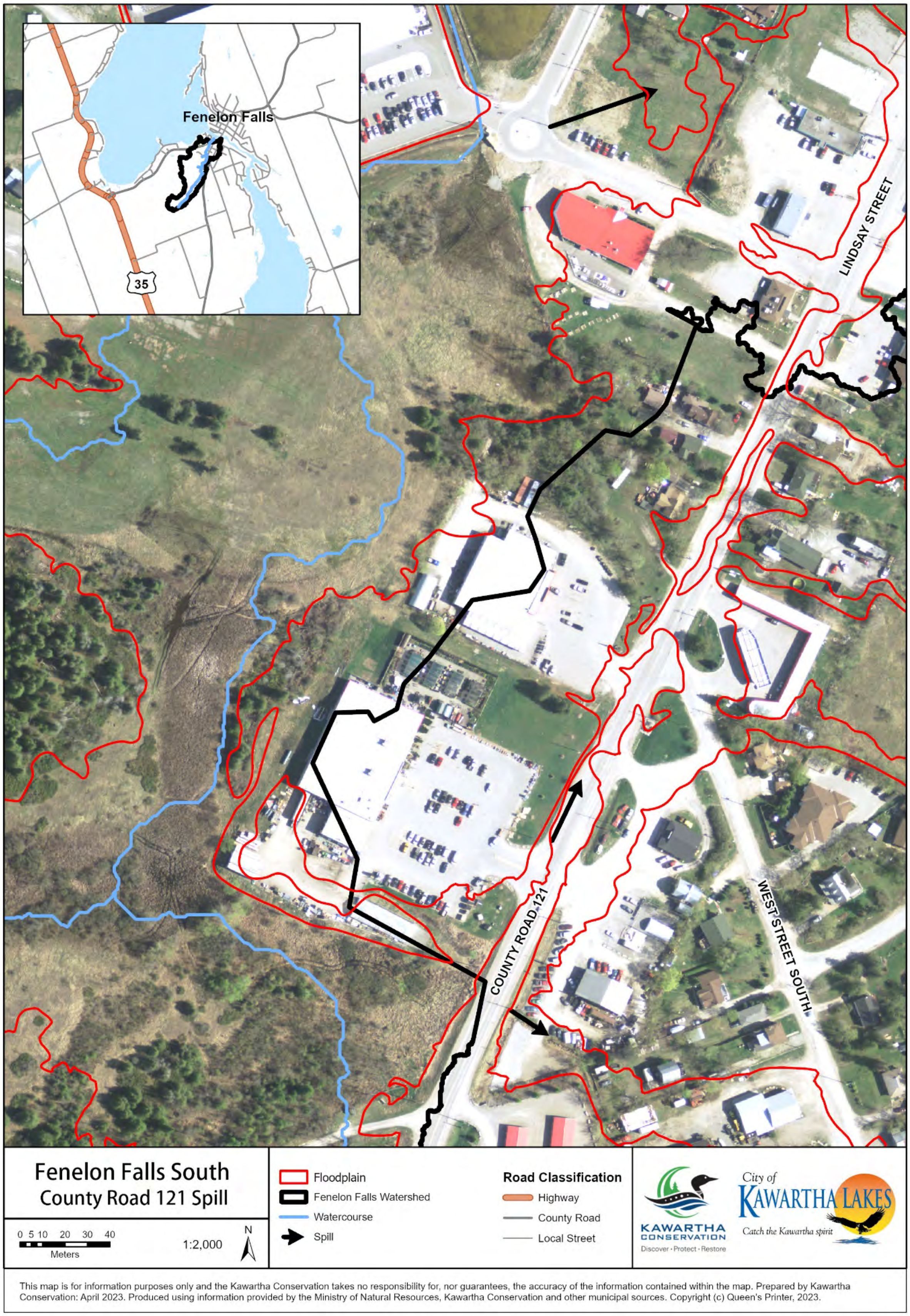


Figure 9-3: CR 121 Spill

7.3.2 West Spill

A spill was present on the western edge of the study area caused by the same backwatering that caused the CR 121 spill. A flow rate of 2.59 m^3/s leaves the hydraulic model study area to the west during the 100-year 24-hour Chicago Storm, but remains within the watershed and likely flows north toward Victoria Road based on the orthoimagery-derived DEM. Velocities along the spill boundary were between 0.1 - 0.3 m/s. The spill is shown in **Figure 9-4**.

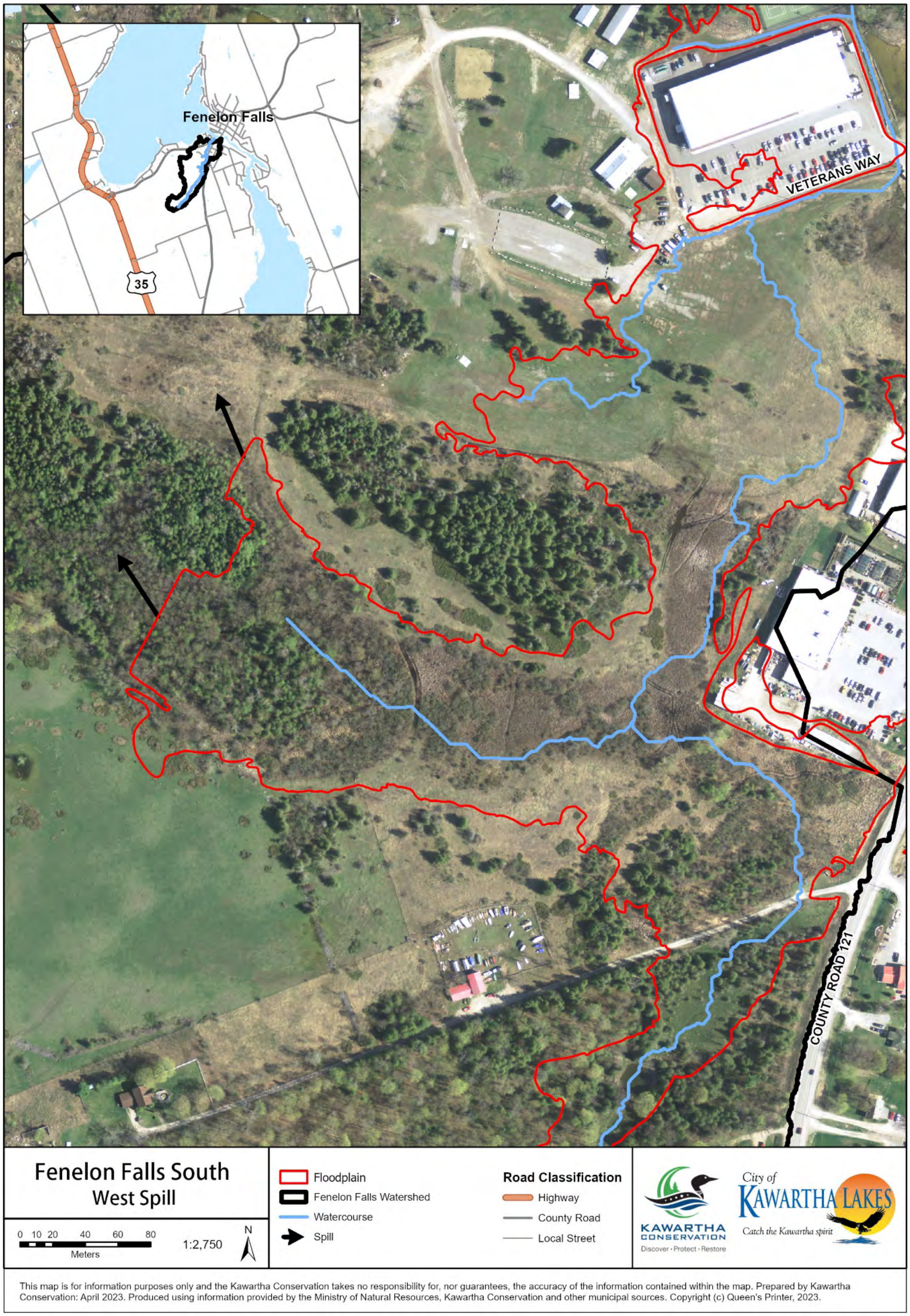


Figure 9-4: West Spill

7.3.3 Lindsay Street

The Lindsay Street spill consists of three flow sources, a portion of the spill flow from CR121, a spill originating east of the Community Centre at North Street and Veterans Way, and subcatchment flows from the Lindsay Street subcatchment. The observed inundation is primarily caused by the subcatchment peak flow of 3.08 m^3/s. This area is considered a spill because it is located in an urban area without a defined channel. The spill flow rejoins the primary flow path on Helen Street at Hadley Lumber. A total of 3.12 m^3/s follows the Lindsay Street flow path and rejoins the primary flow. Flow depths of up to 60 cm were present along Lindsay Street so safe access is not present from south of Elliot Street to Green Street East. Flow velocities were generally less than 0.5 m/s, except for the portion of the spill between Lindsay Street and Helen Street where velocities reached 1.5 m/s. The spill is shown in **Figure 9-5**.

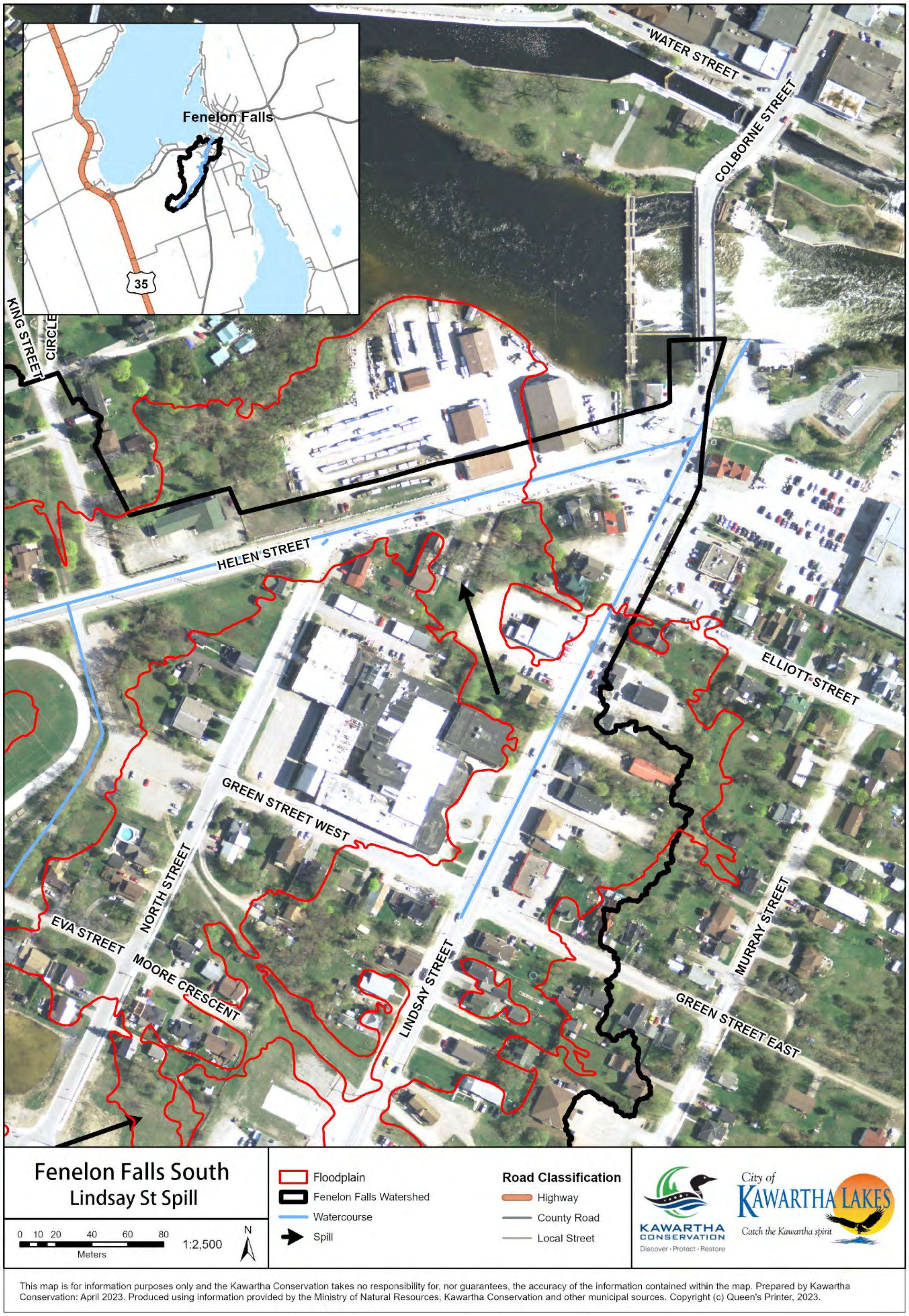


Figure 9-5: Lindsay Street Spill

8 Conclusions and Recommendations

8.1 Conclusions

The Fenelon Falls South hydrology and hydraulic models were developed in accordance with floodplain mapping standards and include conservative parameter estimates to ensure that the floodplain extents are not underestimated. While 2D modelling is not included in provincial flood mapping guidelines, the governing principles of 1D modelling were applied, including running the 2D model at the peak flow rates for an extended period to produce steady-state results and eliminate storage attenuation effects. While the peak flows are larger in the present study compared to the 2010 Valdor study, improved data and methods were applied to the current study to provide increased confidence in the results.

The results of the modelling show that significant urban flooding occurs during the 100-year and Regional Storms. The urban flooding primarily occurs along Lindsay Street and Helen Street. The Lindsay Street flooding primarily results from subcatchment flows that will surcharge the storm sewer system during large storm events. Flooding along Helen Street is due to the stream flows exceeding the capacity of the Helen Street storm sewer and flowing overland northward towards Cameron Lake. Additional spills occur at CR 121 upstream of the Canadian Tire site towards the east, and from the western edge of the watershed to a forested area.

8.2 Recommendations

It is recommended that the results of the HEC-RAS model for the Fenelon Falls South watercourse be used for generating the Regulatory Floodplain maps. Copies of the floodplain maps are appended at the back of this report. We also recommend the following:

- Flow monitoring should be conducted to facilitate future model calibration. Monitoring would ideally be completed upstream of the Canadian Tire site to avoid complications associated with the spills.
- Future model updates should include climate change considerations in accordance with the Federal Flood Mapping Framework to assess future climate conditions on existing infrastructure.
- The spills out of the watershed at CR 121 should be considered in future studies of the adjacent watercourses to ensure that accurate stream flows are modelled.
- Future developments within the Development Control Areas associated with the Regulatory Floodplain be floodproofed to an elevation 0.3 m higher than water surface elevation of the closest portion of the floodplain.
- Consideration should be given to updating the hydraulic model and associated floodplain mapping once new LiDAR data becomes available for the study area.

9 Appendices

(Bound in a separate document)

Appendix A: Previous Report Excerpts

Appendix B: Study Terms of Reference

Appendix C: Rainfall Data

Appendix D: Subcatchment Maps

Appendix E: Hydrology Parameter Calculations

Appendix F: Visual OTTHYMO Output

Appendix G: Hydrology Model Flow Summary

Appendix H: Sensitivity Analysis

Appendix I: Structure Photo Inventory

Appendix J: HEC-RAS Output

Appendix K: Model Files

Appendix L: Peer-Review Correspondence

Appendix M: Digital Elevation and Orthoimagery Quality Check

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