City of Guelph

Stormwater Management Master Plan

Appendix K.1 – Hydrologic and Hydraulic Analysis

March 2023

Prepared for:

The City of Guelph

Stormwater Management Master Plan

Appendix K: Major/Minor System Hydrologic and Hydraulic Analysis

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1 Introduction

The objective of the Stormwater Management Master Pan (SWM-MP) is to develop a preferred stormwater management strategy for the City of Guelph. Within the City of Guelph, there are multiple distinct subwatersheds, each of which has unique environmental and infrastructural conditions.

As part of the SWM-MP, a City-wide storm sewer model for the City of Guelph was developed to assess the existing level of service of the City's stormwater infrastructure. The model was constructed as a minor/major system model, including all storm sewers greater than 250mm, stormwater ponds, ditches, and swales, where information was available (**Figure 1.1**).

The model will help City staff anticipate needs regarding infrastructure capacity upgrades or capital improvements as well as to provide direction as to where spare capacity for future development may exist. Along with the existing conditions assessment, the City's existing infrastructure was run against various performance scenarios including:

1. Intensification (urban infill development and increased impervious surfaces);
2. Intensification and climate change;
3. The implementation of grey stormwater infrastructure;
4. The implementation of Low Impact Development (LID) SWM controls as part of volume retention strategy; and
5. 2D modeling of identified flood-prone areas.

The City-wide storm sewer model may serve as a basis upon which the City can further assess the storm sewer system throughout the City of Guelph.

The assessment of the existing stormwater conveyance systems including individual SWM facilities considers the effectiveness of the City's infrastructure at reducing the impacts of urban runoff on infrastructure, property and the environment including the:

- Ability to more closely match pre-development hydrologic conditions by reducing urban peak flows at storm sewer outfalls, maintaining groundwater recharge, and mitigating in-stream and overland erosion;
- Ability to provide conveyance of a 1:5-year precipitation event within the minor system per the City standard level-of-service; and
- Ability to provide conveyance of a 1:100-year precipitation event within the major system per the City standard level-of-service.

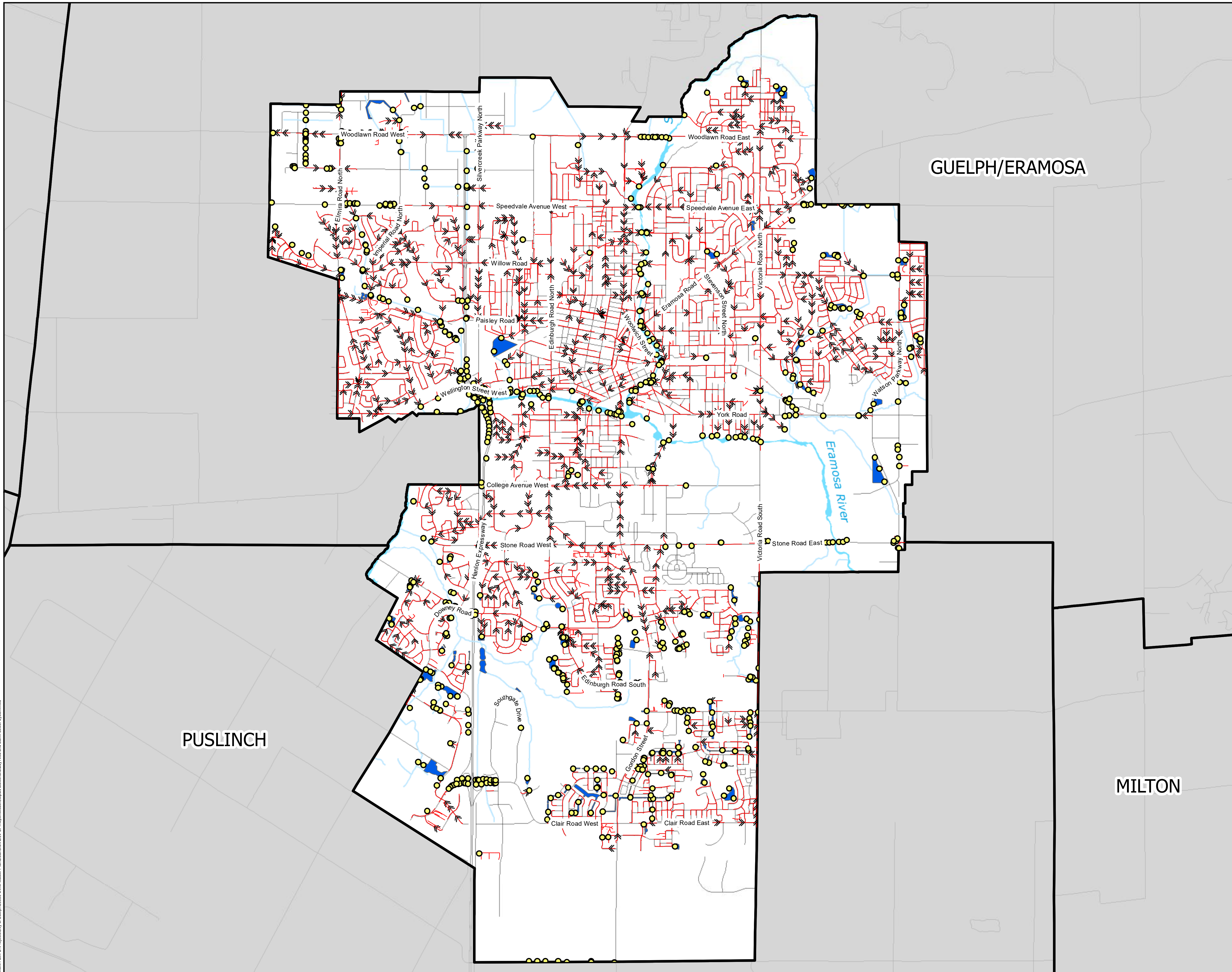
1.1 Study Area

The City of Guelph is located in the center of the Grand River Watershed, and is located at the confluence of the Speed and Eramosa Rivers. **Figure 1.1** illustrates the municipal boundaries of the City of Guelph and represents the SWM-MP study area, including sewers and outfalls within the City limits which were incorporated into the model.

The stormwater conveyance network within the City includes storm sewers that are owned by the City, Province, Township of Guelph-Eramosa, or within private property. The modeled network is comprised of approximately 425 km of storm sewer of varying sizes. **Table 1.1** identifies the ownership, size and installed quantities of all storm sewers within the City. The table shows that pipes of sizes less than 450 mm diameter represent the bulk of the storm sewer within the City.

Table 1.1: Existing Storm Sewer Data for City and Private Pipes

Pipe Sizes (mm)	City of Guelph		Other	
	km	%	km	%
Unknown size	0.00	0.0%	1.31	3.9%
Less than 450	194.20	45.7%	7.21	21.3%
450 - 550	78.02	18.4%	5.57	16.5%
575 - 750	65.50	15.4%	2.74	8.1%
800 - 1000	41.09	9.7%	3.28	9.7%
1050 - 1200	21.64	5.1%	2.07	6.1%
Greater than 1200	24.63	5.8%	11.59	34.3%
Total	425.07	100.0%	33.77	100.0%



Legend

- Stormwater Discharge Location
- Road Centreline
- Stormwater Gravity Main
- Stormwater Management Pond
- Municipal Boundary

LOCATOR MAP

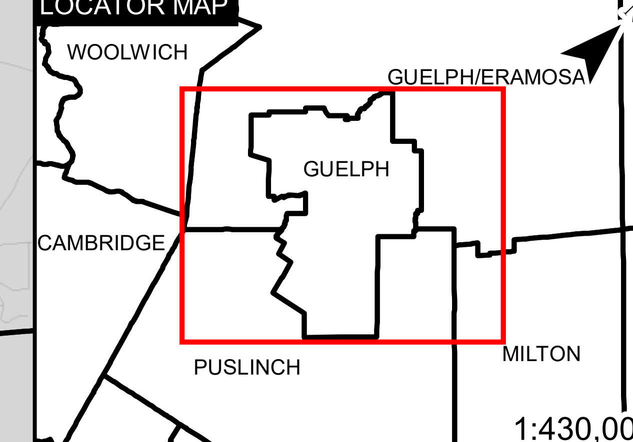


Figure 1.1

Study Area and Storm Sewer System

Date: 2022-09-12
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: J.R.

0 1 2
Kilometres

1.2 Land Use

1.2.1 Existing Land Uses

The City of Guelph is characterized by a mixture of land-uses. Generally, agricultural lands remain only along the periphery of the City at its south end, although these lands will be developed under the Clair Maltby Secondary Plan. Lands that are zoned industrial are clustered primarily in the northwest part of the City between Speedvale Avenue and the northern City boundary, as well as along the Hanlon Expressway in the south end of the City. Approximately, 29% of the City is occupied by private residential property (i.e. residential development areas excluding the municipal right-of-way).

The City is home to a large area of lands zoned as institutional, which are mostly associated with the University of Guelph, but also include Conestoga College, Guelph General Hospital, and St. Joseph's Health Centre.

Guelph's commercial lands are primarily located along Woodlawn Road and Speedvale Avenue, with other commercial hubs at major intersections and along major transitways. Mixed-use corridors and commercial mixed-use centres follow similar trends, especially along Stone Road and Silvercreek Parkway.

Land use designations within the City of Guelph per the City's Official Plan are summarized in **Figure 1.2** and illustrated in **Figure 1.3.**

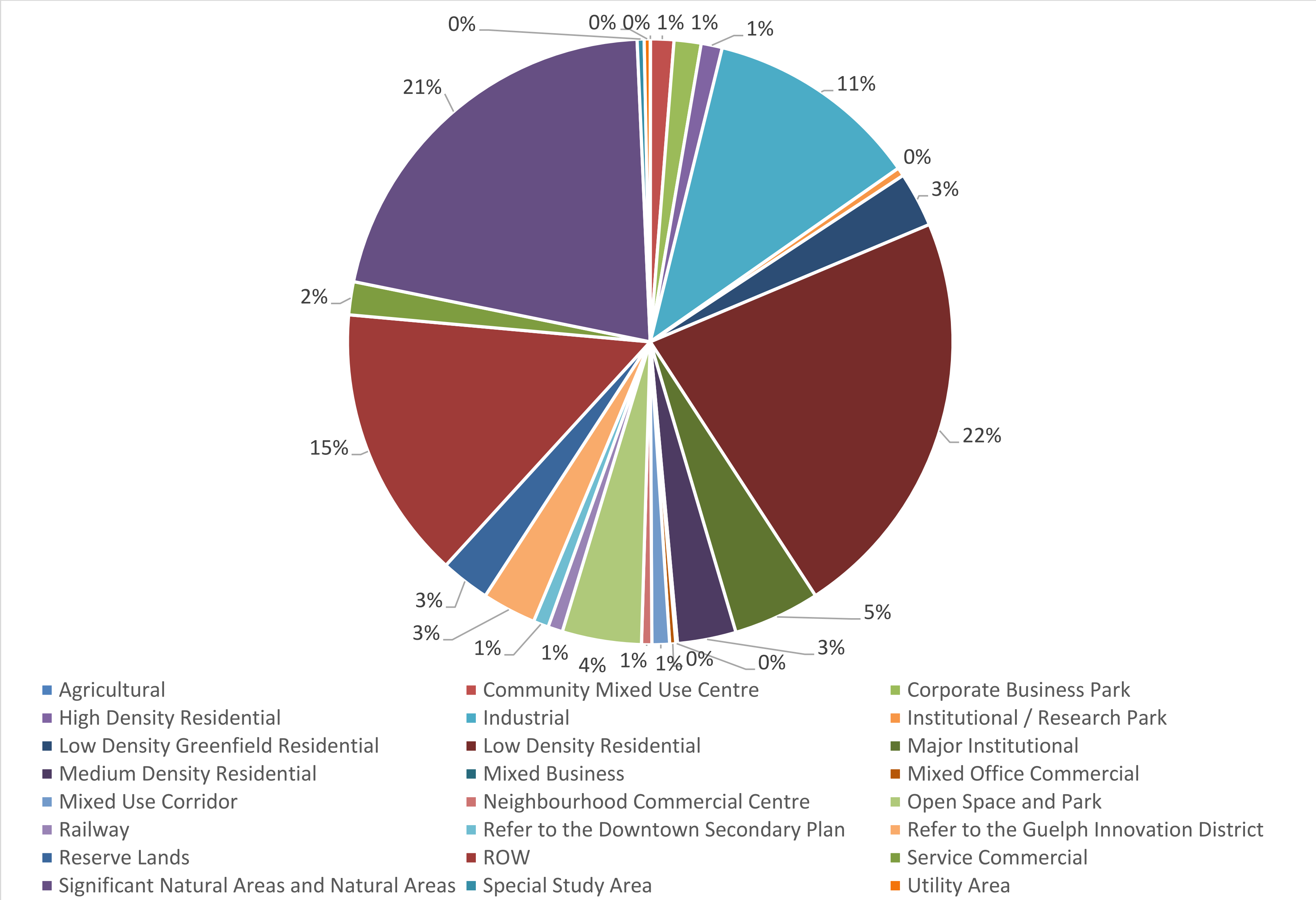
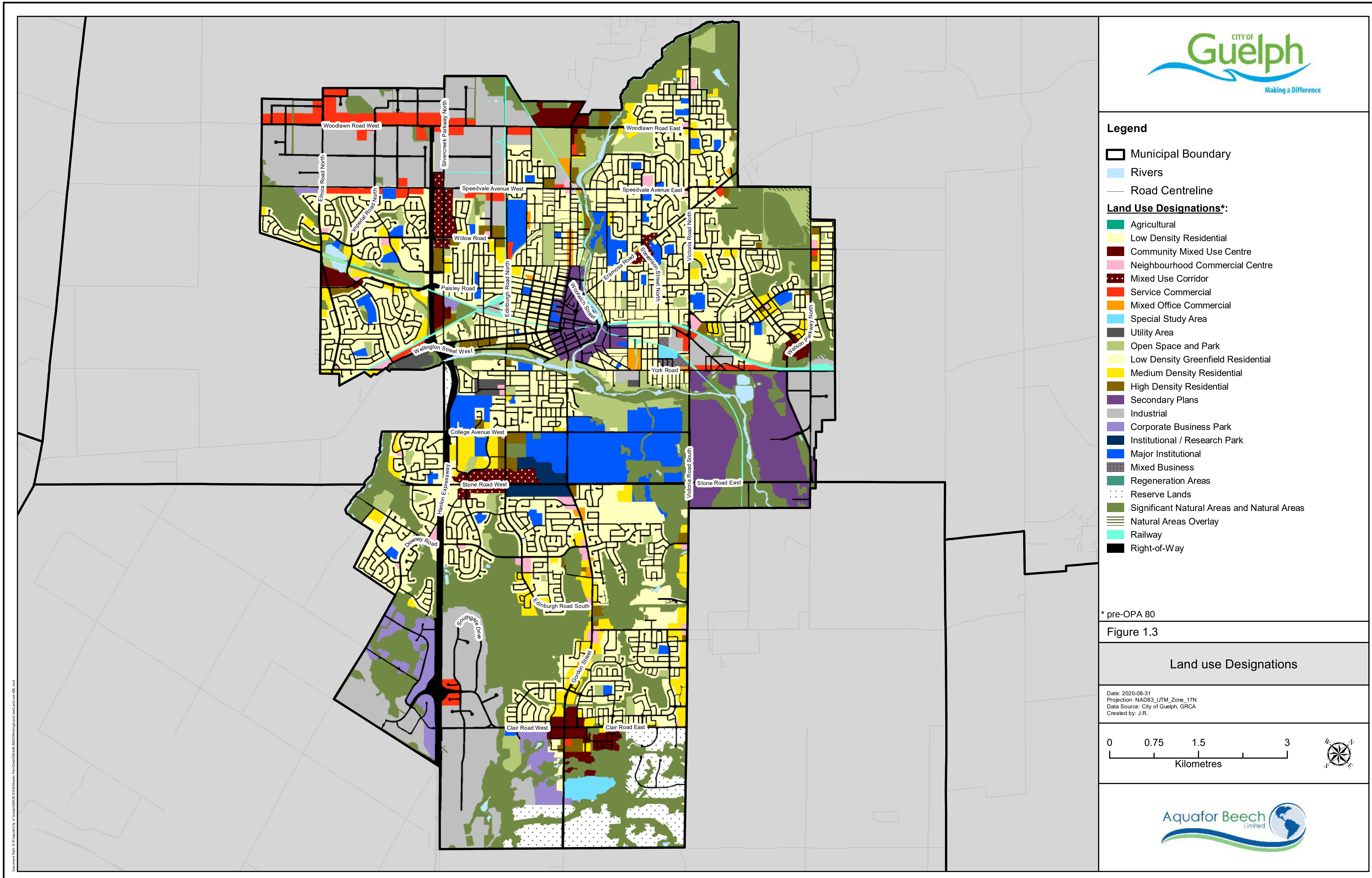


Figure 1.2: Existing City of Guelph Land Use Designations Per Official Plan (pre OPA 80)



Woodlawn Road West
Woodlawn Road East
Silvercreek Parkway North
Speedvale Avenue West
Speedvale Avenue East
Elmira Road North
Imperial Road North
Willow Road
Paisley Road
Edinburgh Road North
Woolwich Street
Eramosa Road
Stevenson Street North
Victoria Road North
Watson Parkway North
Wellington Street West
York Road
College Avenue West
Hanlon Expressway
Stone Road West
Stone Road East
Victoria Road South
Downey Road
Edinburgh Road South
Southgate Drive
Gordon Street
Clair Road West
Clair Road East
CITY OF Guelph
Making a Difference
Legend
Municipal Boundary
Rivers
Road Centreline
Land Use Designations*:
Agricultural
Low Density Residential
Community Mixed Use Centre
Neighbourhood Commercial Centre
Mixed Use Corridor
Service Commercial
Mixed Office Commercial
Special Study Area
Utility Area
Open Space and Park
Low Density Greenfield Residential
Medium Density Residential
High Density Residential
Secondary Plans
Industrial
Corporate Business Park
Institutional / Research Park
Major Institutional
Mixed Business
Regeneration Areas
Reserve Lands
Significant Natural Areas and Natural Areas
Natural Areas Overlay
Railway
Right-of-Way
* pre-OPA 80
Figure 1.3
Land use Designations
Date: 2020-08-31
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: J.R.
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0.75
1.5
3
Kilometres
Aquafor Beech Limited

1.2.2 Proposed Development and Intensification Areas

In accordance with Ontario legislation, the City of Guelph, like all municipalities, is charged with ensuring that they direct proper and orderly development within their urban boundary. The City has many tools to achieve these requirements, including the City's Official Plan and more detailed Secondary Plans.

The City has identified several Significant Growth Areas, which are targeted for more intensive development. These, in addition to the proposed development in the City's greenfield areas, are presented in **Figure 1.4**.

1.3 Previous City-Wide Model

The 2012 SWM-MP also completed a model, covering most of the City, except for the newest neighbourhoods in the south end. This model included trunk sewers (600mm or greater) and the first section of each municipal lateral sewer connecting in to the trunk sewer. The 2012 SWM-MP identified a total storm sewer length of 344.3km, which was used to estimate the percent of the total network that was surcharged or flooded. Note that this percentage should not be compared to the results of the 2022 model, as different lengths of storm sewer were modeled in 2012 versus 2022.

Table 1.2: Summary of 2012 Model Results

		Length (km)	Percent of Total†
5-year	Storm Sewer Surcharged (water level above storm sewer but below surface)	63.13km	18.3%
	Storm Sewer Flooded (water levels above surface)	26.30km	7.6%
100-year	Water Depth on Road 0.15-0.25m	42.11km	N/A‡
	Water Depth on Road >0.25m	20.88km	N/A‡

†Percentage is likely an underestimate as municipal lateral storm sewers were not modeled but are included in the total storm sewer length.
‡Road length in 2012 was not available to calculate the percentage.

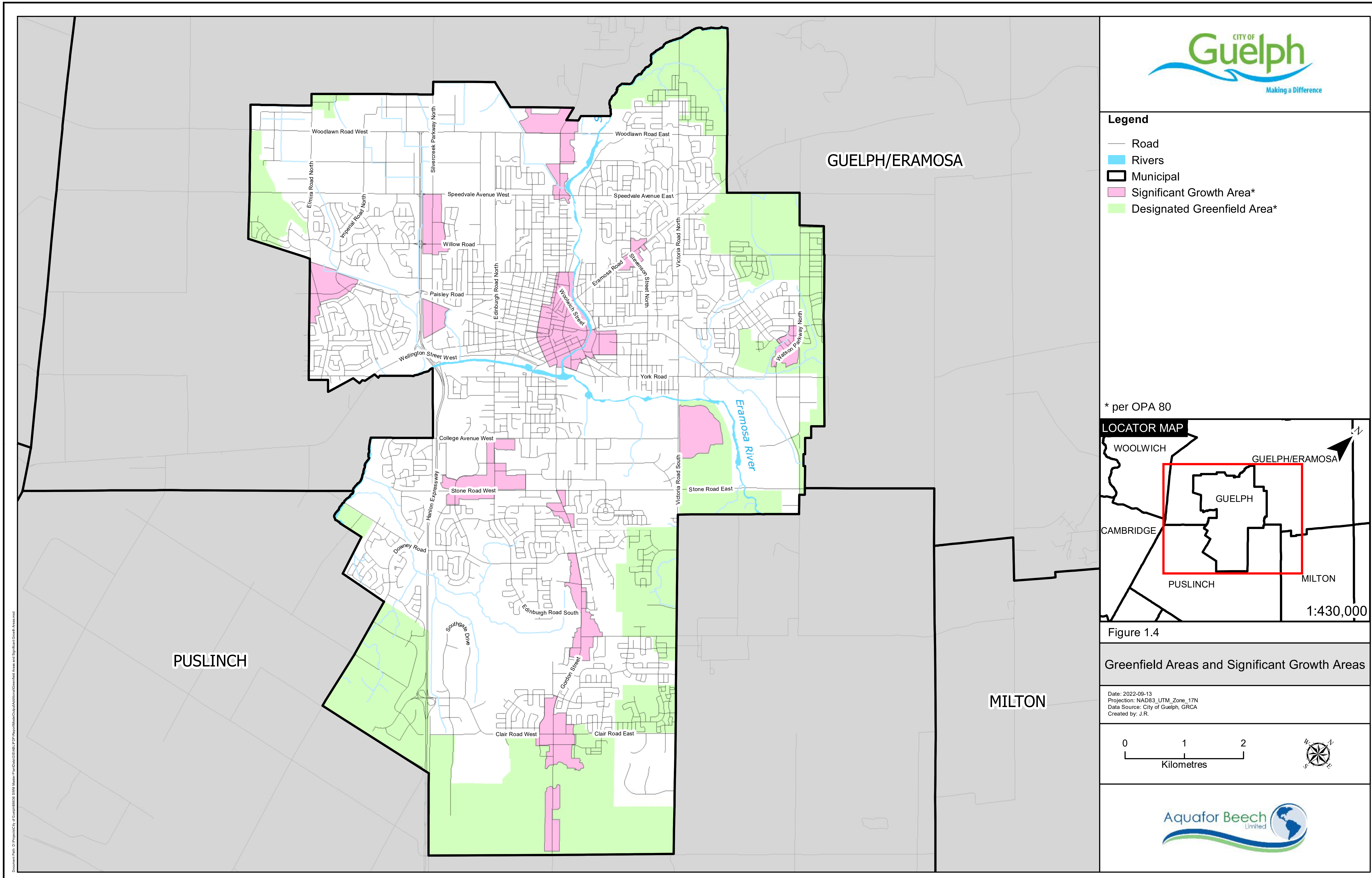


Figure 1.4

Greenfield Areas and Significant Growth Areas

2 Hydrologic Modeling

2.1 Hydrology

Hydrology is the science which deals with the interaction of water and land, and the processes by which precipitation is transformed into runoff, infiltrated into the groundwater system or taken up by vegetation in a process called evapotranspiration. These processes are generally called the hydrologic cycle. Urban hydrology more closely looks at the influence of the urban landscape on the hydrologic cycle. The most dramatic hydrologic changes brought about by urbanization are the inclusion of hard surfaces that reduce infiltration and evapotranspiration and conveyance systems such as storm sewers and ditches designed to rapidly move water away from runoff sources towards watercourses. These changes can result in increases in flooding, channel erosion, sediment transport, and pollutant loadings which can cause deterioration in natural channel morphology, fish and wildlife habitats, recreational opportunity and aesthetics.

It is important that the existing hydrologic characteristics of the study area be established. This information is critical in defining existing flood characteristics and providing key information on the selection and design of stormwater management facilities for future urban redevelopment lands.

2.2 Model Development

The hydrologic model selected for application in this study was PCSWMM 2022. PCSWMM 2022 has the capacity of using a number of versions of EPA SWMM5 for performing the hydrologic and hydraulic calculations. For the existing condition model, SWMM 5.1.015 was selected, as it is the latest official version of SWMM currently available.

2.2.1 Map Coordinate System

The model was setup in PCSWMM 2022 using the NAD83 UTM zone 17N coordinate system. All the GIS files prepared for this model used the same coordinate system.

2.2.2 Junctions

Junctions are drainage system nodes where links join together. The data required for junctions in PCSWMM include the vertical information, invert elevations, junction depth and the upstream and downstream conduit invert elevations. The other hydraulically significant details regarding the junctions (i.e. losses and drops) are not typically necessary for a generalized model such as this model.

The City provided the location, size, ground and invert elevations of the manholes and outlets. Staff at Aquafor Beech Limited input the detailed information for the storm sewer network into the model.

2.2.3 Conduits

There are various types of conduits: closed (pipes) and open (ditches, natural channels). By default, a conduit is assumed to be a straight line connecting two junctions – the upstream and the downstream junctions. The system calculates the length on the basis of a straight connection; however, this length can be overridden by a user-specified pipe length. The order of the node specification does not have any effect on the computations, but only on the sign of the flow. The flow in the downstream direction is assumed as positive flow.

The following types of links are available:

- **Standard conduits**, including circular, rectangular, square, and elliptical pipes, as well as natural channels; and,
- **Miscellaneous conduits**, open or closed, specified through the assigned transacts.

The natural channel systems were placed according to the location and details provided regarding the stream network. The conduits were named according to the subcatchments and the upstream and downstream junctions. The required data for conduits in the City model include upstream and downstream inverts, outlet elevation, length, roughness and cross-sectional geometry. The elevation of the outlet can be defined from the junction's elevation and the DEM.

The conduit lengths were determined using the stream and sewer networks and placing the junctions approximately where indicated and measuring the length of the attached conduit in the map. These lengths were based on the NAD83 UTM zone 17N coordinate system. The City also provided the location, size, length, shape, material type, slope, roughness coefficient, and invert elevation of the links (pipes).

2.2.3.1 Manning's Roughness Coefficient

The velocity of pipe flow is dependent on the surface roughness of the sewer. A lower surface roughness results in a higher velocity. The roughness coefficients for smooth bore pipes was defined per *Development Engineering Manual* by the City of Guelph (2019), as shown in **Table 2.1**, along with other assumed roughness values.

Table 2.1: Manning's Roughness Coefficient Based on Pipe Material

Pipe Material	Manning's Roughness Coefficient (n)
Smooth bore pipes	0.013
Corrugated Metal	0.024
Open Channel	0.035

2.2.3.2 Channel Cross-Sectional Geometry

There are several options in PCSWMM to represent the cross-sectional shape of the surficial conveyance features. All surficial conveyance features within the City's urban stormwater conveyance system were modelled as being irregular. The cross-sectional information was obtained from the Digital Elevation Model (DEM) that was provided by the City.

2.2.4 Data Gap Analysis

Input information for the conduits, junctions, and natural channels for the PCSWMM model was derived from storm sewer network data received from the City of Guelph. An extensive data gap analysis was conducted on the information received, with additional information gathered from as-built drawings and documentation where possible. Key data gaps which were corrected included:

- Missing data;
- Sump depth assumptions;
- Incorrect inverts; and
- Riverine system.

2.2.4.1 Missing Data

When data was still unavailable, City staff conducted field surveys to measure storm sewer inverts, conduit pipe sizes, material, cross sections, etc., of the existing storm sewer and natural channel networks in order to fill in the data gaps. If a new storm sewer network configuration was identified in the field which disagreed with the City's existing data, the new configuration was measured and redrawn according to the field survey.

2.2.4.2 Sump Depth Assumptions

Sump depth is the elevation difference of the invert of the lowest pipe attached to the structure to the inside bottom of the structure. In the PCSWMM model, the invert elevations of junctions were assumed to be the same as the lowest invert elevation of the connected pipe, which means the sump depth was assumed to be 0 m. This assumption was approved by the City and included in the model, as the actual sump pump depth was not available from City records.

2.2.4.3 Incorrect Inverts

Nearly 500 storm sewer inverts were found to be inaccurate in the City's GIS layer, which if modeled, would show constrictions that don't actually exist. Discrepancies of 0.1m or less were assumed to be accurate, and were not modified. Discrepancies between 0.1m and 0.5m were visually inspected and cross-checked with as-built drawings, as necessary. Discrepancies greater than 0.5m were assumed to be a data entry error, and were corrected by visually inspecting the storm sewer profile upstream and downstream of the discrepancy.

2.2.4.4 Riverine System

The river geometry is not part of this project and was not modeled in the PCSWMM model. However, the outfalls were modeled and analyzed along the river system, and their results were shown in the model results.

2.3 Stormwater Management Facilities

According to the City's GIS database, a total of 123 SWM facilities exist within the City of Guelph. Upon review of background information (ECAs, Design Briefs and Design Drawings), another three (3) stormwater management facilities were identified within the City. Other revisions included: combining SWMF 118 and 119 into one facility (SWMF 118/119) and combining SWMF 16 and 113 into one facility (SWMF 113), as most of SWMF 16 was incorporated into SWMF 113. This results in a total of 122 facilities owned and operated by the City (**Figure 2.1**).

While the City's GIS layers, spreadsheets and database identified three types of SWM facilities (wet pond, dry pond, and greenway), the SWM reports identified two additional types, including infiltration facility and wetland. There were also several facilities that combined a wet or dry pond with an infiltration facility. A total of 36 facilities were re-classified based on the information available within the available design reports, design drawings, and as-built drawings.

Of the 122 facilities, 95 provide both quality and quantity control, 20 provide only quantity control, and 7 provide only quality control. These 122 SWM facilities provide some level of control to 2899 ha (46.6 percent) of the City. Of this area, approximately 1746 ha (28.1 percent) are controlled for water quality, and 2335 ha (37.6 percent) are controlled for water quantity.

A review of background information including design briefs and Environmental Compliance Approvals (ECAs), formerly known as Certificates of Authorization (CofA), was able to establish detailed stage-storage-discharge relationships for just over half of the 122 of the SWM facilities. In the case of the 54 stormwater facilities where information was found to be partially or completely missing, a reasonable functional relationship was assumed based by using LiDAR to approximate storage volumes above the pond base or pond permanent pool. Key elevations were extracted from as-built drawings, where available, which are summarized in **Table 2.2**. Where no information was available regarding the outlet structures and discharge rates, engineering best practices were applied.

Table 2.2: Missing Stage Storage Information for SWM Facilities

Pond	Pond Type	Bottom/Permanent Pool Elevation	Emergency Overflow Elevation	Top of Berm Elevation
2	Infiltration		Bottom + 2.44m	Bottom + 3.05m
3	Infiltration	315.77	317.6	318.52
4	Infiltration		Bottom + 1.52m	Bottom + 2.44m
5	On-line Infiltration	318.25	318.25	319.25
6	On-line Infiltration	320.5	320.5	322.25
7	Infiltration	320.65	322.02	322.47
8	Wet	323.85		326.1
9	Dry	326.6		328.1
10	Infiltration	325.25	325.25	325.85
11	Infiltration	322.8	322.8	323.4
12	On-line Pond	327.09	328.72	see GRCA floodplain extents
13	Infiltration	322.8	322.8	323.4
14	Infiltration	316.3	316.95	317.5
17	Dry with Infiltration	322.7	323.3	323.4
19	Wet	327.45		329.15
20	Infiltration			
22	Infiltration			
24	Wet	316.3		316.9
28	Wet	326.99		328.5
32	Dry	334.05	334.61	
35	Wet	320	321	
40	Greenway	333.5	334.95	334.4
41	Greenway	333.2		334.4
42	Greenway	333.2		333.4
43	Greenway	332		333.8
49	Greenway	329.85		332.43
50	Greenway	327.25		
54	Wet	346.8	348.2	348.8
56	Greenway	334.9		336.3
57	Greenway	336.1		337
58	Greenway	335.8		337
59	Greenway	333.8		334.7
60	Greenway	333.8		334.3

Pond	Pond Type	Bottom/Permanent Pool Elevation	Emergency Overflow Elevation	Top of Berm Elevation
61	Greenway	335.3		336.1
62	Greenway	332		333.75
63	Greenway	332		333.75
64	Greenway	332		333.75
65	Greenway	332		333.75
66	Greenway	332		333.75
67	Greenway	332		333.75
68	Greenway	332.5		334.25
69	Greenway	330.25		
78	Greenway	327.75		328.95
80	Dry	322.98	323.7	323.8
84	Greenway	330		
85	Greenway	334.5		
94	Greenway	336.65	337	
98	Infiltration	333.5	334.4	334.5
99	Wet	341.2	341.4	342
105	Wet	330.7	330.85	
106	Wet	341.4	342	342.6
115	Wet	346		347.3
121	Infiltration	330.8	331.8	332.1
129	On-line Pond	321.62	323.7	324

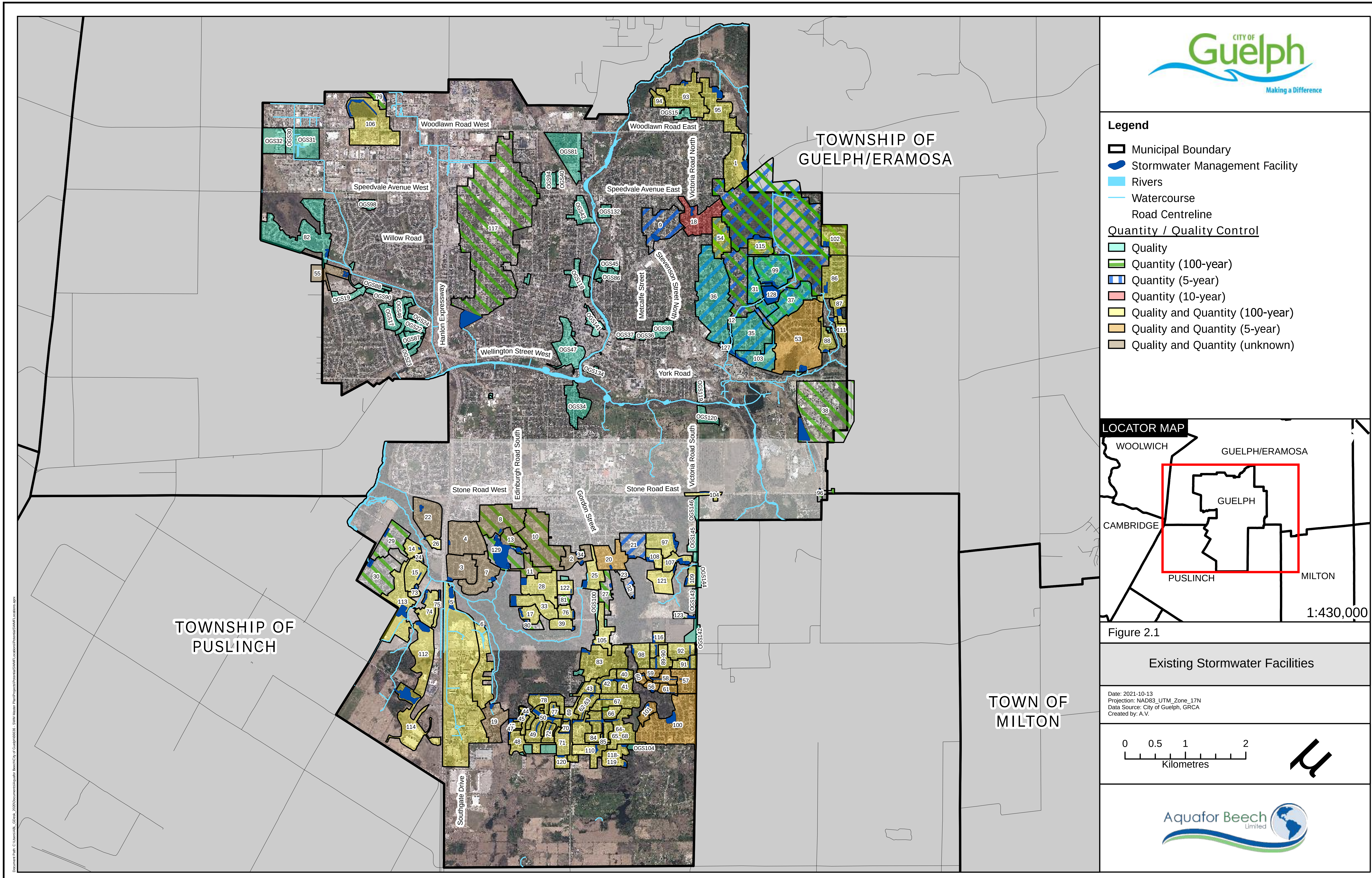


Figure 2.1

Existing Stormwater Facilities

2.4 Surface Hydrology

2.4.1 Subcatchment Delineation

A subcatchment is an area that drains to a particular point. For the model, the discretized subcatchments were assigned based on the land uses and the topographic map provided by the City of Guelph. Required parameters for each subcatchment include area, flow length, width, infiltration parameters, depression storage, percent of directly connected impervious areas, manning's roughness for pervious and impervious areas, and slope. The subcatchments delineation is illustrated in Error! Reference source not found.**.**

2.4.2 Subcatchment Width and Length

The width is a calibration parameter and is not easily measurable in the field. One method for initial estimation of subcatchment width is to calculate it by dividing the area to an assigned flow path length. This parameter may be adjusted significantly during the model calibration during subsequent model refinement by the City. It is often suggested that the subcatchment width be treated as a calibration parameter and adjusted to best simulate runoff in the receiving system. In cases where calibration data is not available, the subcatchment width parameter must be estimated recognizing the impact of assumptions on model output and considering the potential limitations of these assumptions.

The flow length for a subcatchment is the length of the overland flow. PCSWMM uses the EPA SWMM5 hydrology and hydraulics engine. Flow length is not a parameter used by EPA SWMM5, rather it is used to initially estimate the subcatchments width. Measuring the length of the overland flow requires some judgment and approximation as well as use of a DEM to define the major overland flow path.

In development of the PCSWMM model of the City of Guelph, the flow length was estimated recognizing the factors affecting the time of concentration in urban and rural subcatchments. One of the most significant effects of urban development on flow velocity is less retardance to flow. In small non-urban watersheds, much of the travel time results from overland flow in upstream areas. Typically, urbanization reduces overland flow lengths by conveying storm runoff into a pipe or channel rapidly. Since channel designs have efficient hydraulic characteristics, runoff flow velocity increases and travel time decreases.

Subcatchment delineation maps are provided in **Appendix A.**

2.4.3 Infiltration Parameters

Subcatchment infiltration is the process of rainfall infiltration before runoff is generated. Infiltrated water soaks into the unsaturated soil zone of pervious subcatchment areas. There are three methods available in SWMM5 for modelling infiltration. These are Horton's Equation, Green-Ampt Method and SCS Curve Number (CN) Method. The method selected for the City of Guelph model was the Modified Green-Ampt Method.

The Modified Green-Ampt Method requires input parameters including soil type. Soil types include sand, loam, clay etc. The parameters corresponding to each soil type was determined based on **Table 2.3.**

Table 2.3: Soil types for the Green-Ampt Infiltration Method

Soil Type	Suction (mm)	Hydraulic Conductivity (mm/hr)	Initial Deficit (Fraction)
Clay	316.3	0.3	0.385
Silty Clay	292.2	0.5	0.423
Sandy Clay	239	0.6	0.321
Clay Loam	208.8	1	0.309
Silty Clay Loam	273	1	0.432
Sandy Clay Loam	218.5	1.5	0.33
Silt Loam	166.8	3.4	0.486
Loam	88.9	7.6	0.434
Sandy Loam	110.1	10.9	0.412
Loamy Sand	61.3	29.9	0.401
Sand	49.5	117.8	0.417

Source: Rawls, W, J, Brakesiek & Miller, N, 1983, 'Green-Ampt infiltration parameters from soils data', Journal of Hydraulic Engineering, vol 109, 62-71.

2.4.4 Depression Storage

Depression storage is the ability of a particular area of land to retain water in its pits and depressions, thus preventing flow. Depression storage is defined in units of length. The depression storage falls into two categories: impervious and pervious. The impervious storage is the depth of depression storage in the impervious portion of the subcatchment while the pervious depression storage is the depth of depression storage in the pervious portion of the subcatchment. The typical values, in mm, for depression storage based on impervious lands can be found in **Table 2.4.** In this PCSWMM model, all the subcatchments were assumed to have 1 mm impervious depression storage and 5 mm pervious depression storage, while the zero imperious percentage was set to 25%.

Table 2.4: Typical depression storage values for a defined land use

Land Use	Depression Storage (mm)
Impervious surfaces	1.27-2.54
Lawns	2.54-5.08
Pasture	5.08
Foster litter	7.62

Source: ASCE, (1992). Design & construction of Urban Stormwater Management Systems, New York, NY.

2.4.5 Percent Directly Connected Impervious Area (DCIA)

The percent of imperviousness land in each subcatchment was calculated using the land cover map layer. Each land use was assigned with one of the two categories: pervious or impervious. Once the subcatchments were discretized, the percent of impervious land in each subcatchment was calculated using aerial photographs. For the existing conditions model, a complete description of each land use type and its imperviousness is provided in **Table 2.5.** A further breakdown of the subcatchment parameters is found in **Appendix A.**

Table 2.5: Typical Imperviousness for a defined land use

Land Use	Imperviousness
Commercial	0.95
Government and Institutional	0.60
Open Area	0.02
Parks and Recreational	0.02
Residential	0.40-0.50
Resource and Industrial	0.95

To determine the most accurate % impervious area, the Area Weighting tool, located within PCSWMM, was used. This tool calculates a given attribute, in this case the Percent Impervious are based on the area weighting within the subcatchment.

2.4.6 Manning's Roughness for Pervious and Impervious Areas

Manning's roughness coefficient (n) is the resistance from the channel bed to the flow of water in it. Manning's n values were entered into the SWMM5 model for both pervious and impervious areas, as per **Table 2.6.** These values were assigned so that to allow for the Manning's n values to be adjusted depending on the land use. This also allows for the Manning's n values to be easily updated in the subcatchment layer by using the Area Weighting tool. For the impervious and pervious areas initial values of 0.025 and 0.2 were used (James et al., 2005). These values can be changed depending on the land use and the need for verification.

Table 2.6: Manning's Roughness for Pervious and Impervious Subcatchment Surfaces

Areas	Manning's Range
Impervious (Concrete)	0.025
Pervious (Grass)	0.2

2.4.7 Evaporation/Evapotranspiration (ET)

In SWMM5, evaporation forms part of the climatology inputs, and can be entered as a constant value, as 12 monthly values, or as part of a daily time series. For the City of Guelph, the evaporation rate in mm/day was calculated based on the temperatures time series.

2.5 Calibration

The model was quasi-calibrated by adjusting model parameters to produce results matching the measurements from the outfall/ watercourse flow monitoring program within reasonable accuracy in terms of peak flows and runoff volumes (Note: full model calibration will require in-sewer flow monitoring). Calibration relied on observed outfall/ watercourse flow and precipitation monitoring data for input. Observed rainfall data were used to simulate the response of the model. The observed flow at the monitoring locations was then used to verify the flow predicted by the model for a range of rainfall events.

Details on the monitoring program can be found in the Flow Monitoring Program Memo (February 2022). Rain gauge and flow logger locations are shown in **Figure 2.2**, with pertinent details summarized in **Table 2.7**, including the dates of monitoring, catchment land use, and the nearest rain gauge.

Table 2.7: Flow Monitoring Locations

Logger	Location	Launch Date	Stop Date	Land Use	Rain Gauge
Northwest (NW04)	392 Silvercreek Parkway	July 23, 2020	February 8, 2021	Industrial/ Commercial with Ditching	West End Community Centre
Railway (LS02)	175 Inkerman St.	July 6, 2020	February 5, 2021	Mostly Residential	Wastewater Treatment Plant
Schroder (HD02)	61 Schroder Cres.	July 23, 2020	February 8, 2021	Mostly Residential	FM Woods Water Treatment Plant
Stone Road (LS05)	Crane Dog Park	July 6, 2020	February 7, 2021	Residential & Commercial/ Institutional	Wastewater Treatment Plant

Logger	Location	Launch Date	Stop Date	Land Use	Rain Gauge
Waverley (US03)	72 Waverley Dr.	July 6, 2020	June 30, 2021	Mostly Residential	FM Woods Water Treatment Plant
Willow West (WW06)	87 Thornhill Dr.	July 6, 2020	February 8, 2021	Industrial with Ditching	West End Community Centre
Woodlawn (US10)	21 Woodlawn Rd. E.	July 23, 2020	June 30, 2021	Industrial & Commercial	City Hall

The flow and precipitation monitoring data were used as a basis for quasi-calibrating the PCSWMM model. Wet weather flow analysis was completed for the model based on the precipitation data that could cause significant flow within monitored watercourse. The model is only considered to be quasi-calibrated, not fully calibrated, as the monitoring locations were not within the storm sewers.

The calibration procedure was developed in order to enhance the ability of the model to represent existing hydrologic and hydraulic conditions. Subsequent iterations of the model altered key parameters, such as percent imperviousness, drainage area, subarea routing method and percentage routed, catch basin inlet capacity, infiltration parameters, etc. Each iteration compared the flow volumes and peak flows of the model outputs to the monitored values. The calibration was considered complete once a reasonable agreement between the two was achieved.

Key steps of the model calibration methodology are described below:

1. Subcatchment impervious values and other parameters such as infiltration or surface depression were adjusted to a realistic degree for the storm system based on the land use and soil types to achieve a reasonable match between measured and modelled values; and
2. Emphasis was placed on minimizing the differences between the observed and simulated runoff volumes. Following calibration of runoff volumes, the focus shifted to minimizing the differences between observed and simulated peak flow rates, and matching the general hydrograph timing. If the modelled runoff volume was within 20% of the actual volume, the calibration was deemed good; if it was 20% - 50%, it was deemed average; and if it was greater than 50%, it was deemed poor.

A summary of the model calibration results is presented in **Table 2.8**.

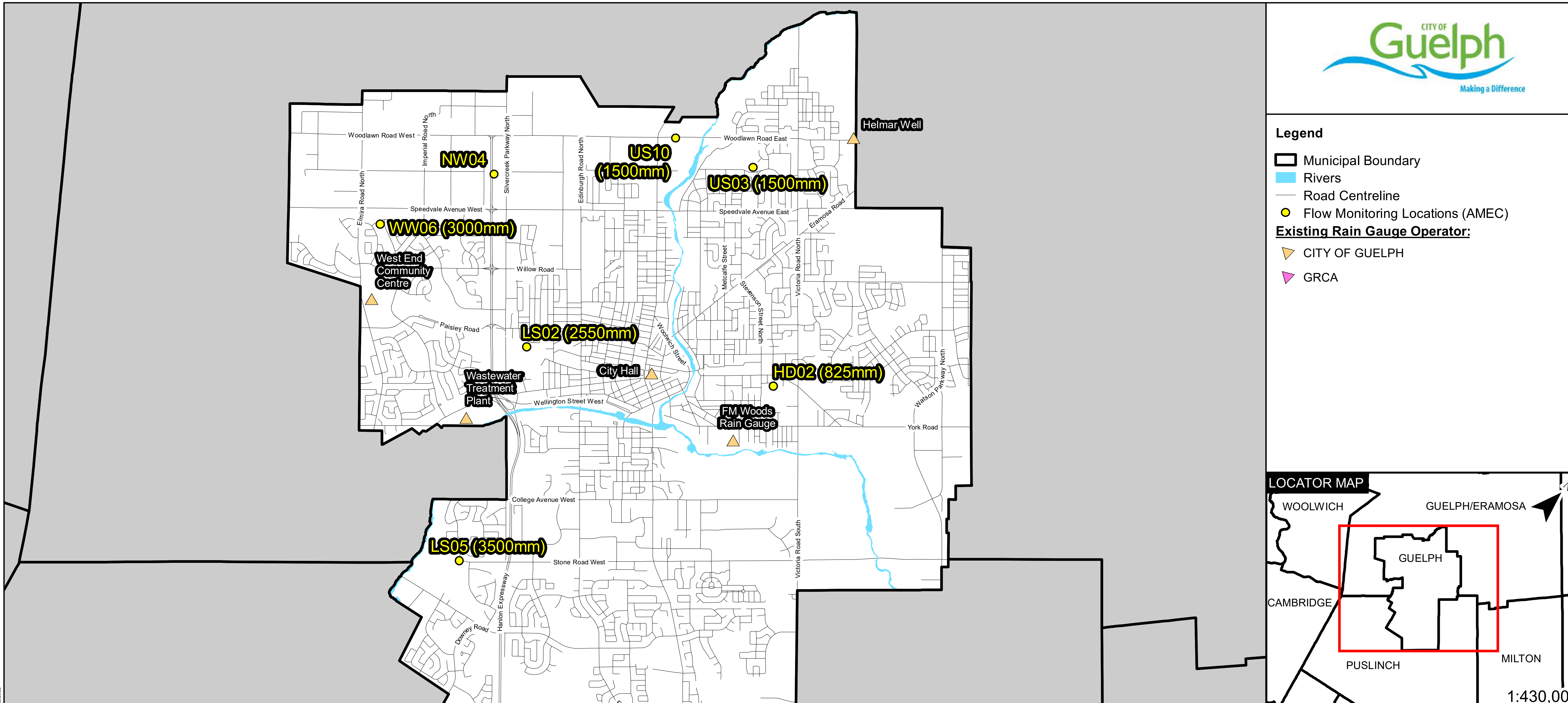


Figure 2.2

Existing Rain Gauge Locations & Flow Monitoring Locations

Date: 2022-09-16
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: J.R.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

Table 2.8: Model Calibration Summary Table

Flow Monitor Location	Event Date	Peak flow (m^3/s)				Total Volume (m^3)			
		Observed	Model	% Difference	Average %	Observed	Model	% Difference	Average %
HD02 (Schroder)	Aug 1st,2020 9pm	2.4	2.6	7%	**-3%**	14650	11000	-25%	**-25%**
	Sep 2nd,2020 12am	2.0	1.7	-12%		4226	2141	-49%	
	Oct 21st,2020 2:30am	0.3	0.3	-3%		2082	2073	0%	
US03 (Waverly)	July 10,2020 6pm	3.9	4.9	26%	**27%**	10950	10200	-7%	**-29%**
	July 19,2020 11am	2.5	4.0	62%		7205	5390	-25%	
	Sep 2nd,2020 12am	3.0	2.8	-6%		8695	4013	-54%	
US10 (Woodlawn)	Aug 1st,2020 8pm	1.5	1.5	5%	**25%**	14500	13540	-7%	**-4%**
	Aug 3rd,2020 12pm	0.6	1.2	93%		2690	3882	44%	
	Sep 1st,2020 11pm	1.5	1.1	-24%		4686	2323	-50%	
LS05 (Stone Road)	July 19,2020 12pm	4.0	4.4	10%	**9%**	11670	11940	2%	**3%**
	July 22,2020 2:30pm	3.9	3.7	-4%		11960	11570	-3%	
	Aug 1st,2020 9pm	3.7	4.4	18%		35720	33840	-5%	
	Sep 2nd,2020 12am	1.8	2.0	14%		5699	6754	19%	
LS02 (NW01 Railway)	Aug 1st,2020 9pm	5.1	6.6	30%	**12%**	46230	55530	20%	**11%**
	Aug 3rd,2020 1pm	6.4	7.8	22%		14430	19060	32%	
	Sep 1st,2020 11pm	6.4	5.3	-17%		15150	12440	-18%	
NW04 (Northwest Channel)	Aug 1st,2020 9pm	1.8	2.4	31%	**60%**	41600	30250	-27%	**-19%**
	Sep 1st,2020 11pm	1.6	3.0	88%		11850	10660	-10%	
WW06 (Willow West)	July 10,2020 6pm	8.4	7.1	-15%	**-8%**	20310	18750	-8%	**-3%**
	July 19,2020 11am	7.5	8.0	6%		21480	24880	16%	
	Sep 1st,2020 11pm	4.3	3.7	-14%		14990	12470	-17%	

2.6 Design Storm

The design storm is a critical precipitation event which is used for assessing the flood hydrograph for a certain return period. Design storms are created based on statistical analysis of historical storm data and are usually region specific. As per the City of Guelph Development Engineering Manual, 2019, design criteria indicate that storm sewers in the City should be designed and sized to accommodate a 1:5-year return storm event without surcharging. Similarly, the manual specifies that the major system overland flow route to SWM facilities shall safely convey the 100-year storm and Hurricane Hazel. The City of Guelph's Development Engineering Manual was used to calculate the 1:5-year and 1:100-year intensities for a 3-hour storm.

2.7 Continuous Model

To estimate the City-wide water balance, a continuous model was run for a typical year from April to November. As 2015 had fairly typical rainfall during this period (636mm), it was selected for the continuous model using data from the F.M. Woods rain gauge.

2.8 Volume Control

Non-traditional source and conveyance control such as Low Impact Development (LID) measures can provide stormwater treatment for individual properties and the collected drainage concentrated within the ROW of a municipal road.

LID source controls measures are small-scale stormwater management techniques located at the beginning of a drainage system where stormwater is captured and treated on-site or close to where the rainfall lands. Due to the relatively small area treated by an individual measure, source controls must be well distributed to treat stormwater runoff effectively. These measures are generally installed on private property within residential, commercial, industrial and institutional land uses, but can also be installed within municipal lands such as parks, trails, municipal buildings and facilities. Source control measures provide treatment for the stormwater generated by roof, driveway, landscape and parking areas.

LID conveyance controls are linear stormwater transport systems that are generally located within the road right-of-way (ROW) of private and public roads where they encourage infiltration of water into the ground, improve water quality and reduce runoff. The suitability of LID conveyance controls depends on many environmental and planning considerations, including soil conditions, ROW size and characteristics, and implementation considerations. Examples of LID conveyance controls may include bioretention, bioswales, perforated pipes, permeable pavement, vegetated and enhanced swales, and proprietary stormwater quality treatment devices.

The Ministry of Environment, Conservation, and Parks (MECP) is currently in the process of formally publishing the Provincial Climate Change Low Impact Development Stormwater Management Guidance Manual, which will include minimum volume targets for LIDs in the province, and will serve as a companion document to the 2003 MOE Stormwater Management Planning and Design Manual.

Three scenarios were modelled as part of the SWM-MP and assume some level of volume control (i.e., 5mm, 14mm, or 28mm). These scenarios correspond to a future in which all catchments are provided with some form of source and/or conveyance control reducing runoff volume significantly. The scenarios assume the application of the specified volume control across all of the City's subcatchments over an extended time period.

Volume control was modeled through a synthetic storm that removes the appropriate volume from the storm that corresponds to the volume control provided by 28mm, 14mm, or 5mm. This has the effect of removing this volume from peak flow. While initial abstraction could be used to simulate the removal of a comparable volume, no reduction in peak flow would be modeled, so the synthetic storm approach was preferred. The assumptions used to generate the synthetic storm events for the 5-year and 100-year events are summarized in **Table 2.9**. Rainfall intensity for each synthetic storm, as compared to the baseline intensity, for each volume control scenario are presented in **Figure 2.3** to **Figure 2.8**.

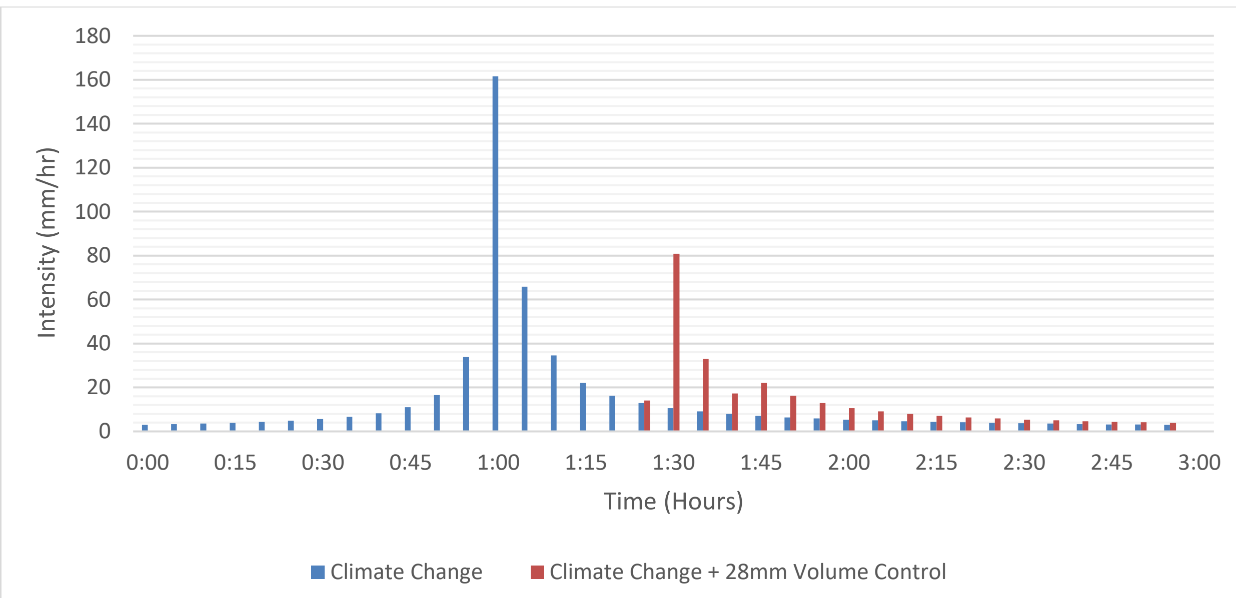


Figure 2.3: Synthetic Storm for 5-Year Event with 28mm Volume Control

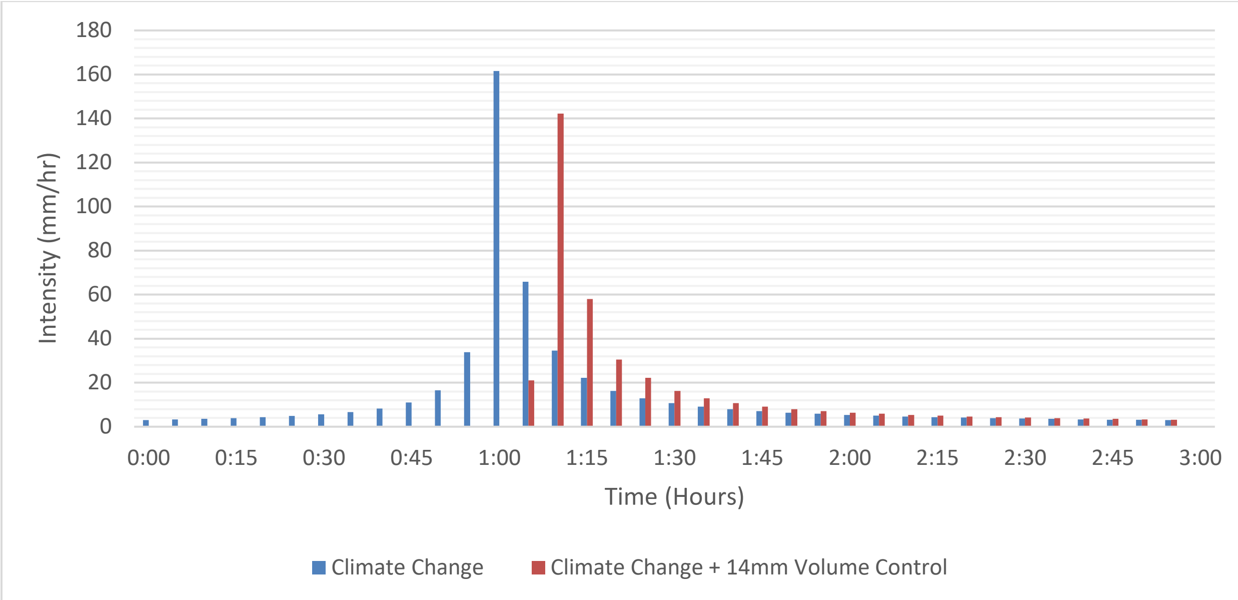


Figure 2.4: Synthetic Storm for 5-Year Event with 14mm Volume Control

Table 2.9: Synthetic Storm Assumptions

Storm Event	Volume Control	Peak Flow Reduction	Lag Time to Peak Flow	Volume Reduction
5-Year	5mm	• No literature value available. • Assume 4% peak flow reduction based on results from the literature for 25-28mm volume control.	• No literature value available. • Assume no lag time.	• 3.5mm
	14mm	• No literature value available. • Assume 12% peak flow reduction based on results from the literature for 25-28mm volume control.	• No literature value available. • Assume 10 min lag time.	• 10mm
	28mm	• Range in literature is 50% to 100% reduction in peak flow from Ontario studies.[1][2][3] • Conservatively, a 50% reduction in peak flow will be assumed.	• Lag time was found to be highly variable depending on when peak intensity occurs in the storm[3] and ranges from 35 minutes[4] to 65 minutes[5] for events slightly smaller than the 5-year event. • Assume a 30-minute lag time.	• 20mm
100-Year	5mm	• No literature value available. • Assume no change in peak flow.	• No literature value available. • Assume no lag time.	• 3.5mm
	14mm	• No literature value available. • Assume 5% peak flow reduction based on results from the literature for 25-28mm volume control.	• No literature value available. • Assume no lag time.	• 10mm

[1] Aquafor Beech modeling study in central-eastern Ontario, not yet released
[2] Elm Drive case study: https://cvc.ca/wp-content/uploads/2021/07/CaseStudy_Elm_Drive_Final.pdf
[3] Lakeview case study: https://cvc.ca/wp-content/uploads/2021/07/TechReport_Lakeview_Final.pdf
[4] Central Parkway case study: https://cvc.ca/wp-content/uploads/2021/07/TechReport_CPW_Final.pdf
[5] Wychwood Subdivision case study: https://sustainabletechnologies.ca/app/uploads/2020/06/Wychwood-Report.pdf

Storm Event	Volume Control	Peak Flow Reduction	Lag Time to Peak Flow	Volume Reduction
	28mm	• Range in literature is 7%-67% reduction in peak flow from Ontario studies (25mm to 28mm of volume control).[236] • Assume 25% reduction in peak flow, based on conservative estimates from representative case studies.	• Little information available in the literature. • Assume 20-minute lag time.[2]	• 20mm

[6] Dingman Creek Subwatershed Study model: https://getinvolved.london.ca/dingmancreek

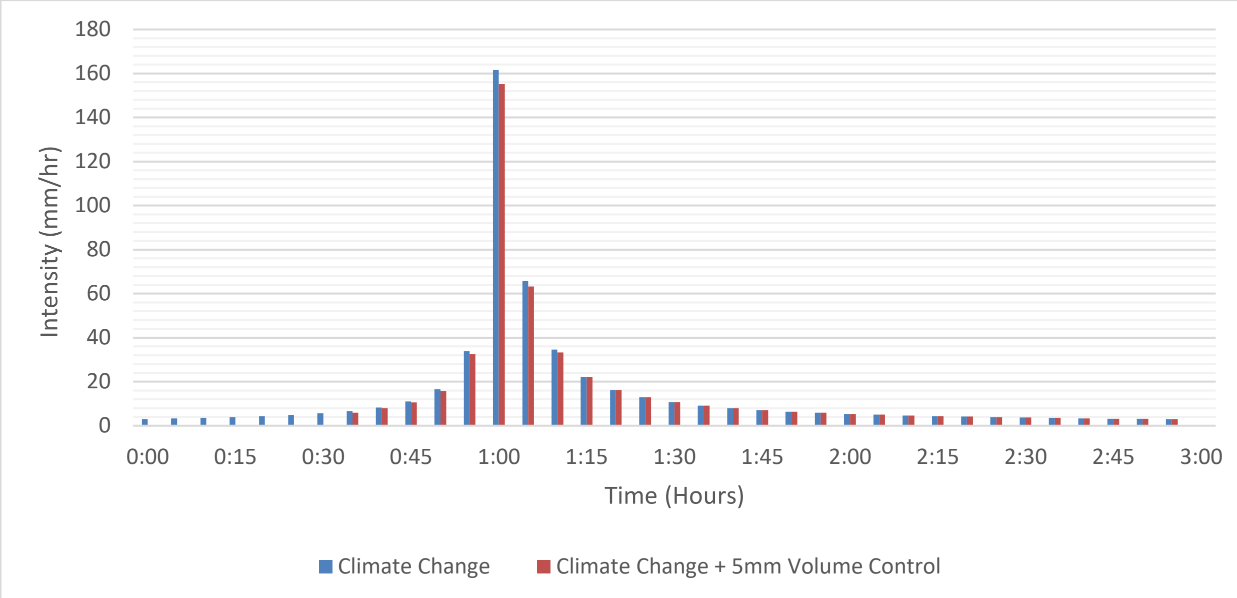


Figure 2.5: Synthetic Storm for 5-Year Event with 5mm Volume Control

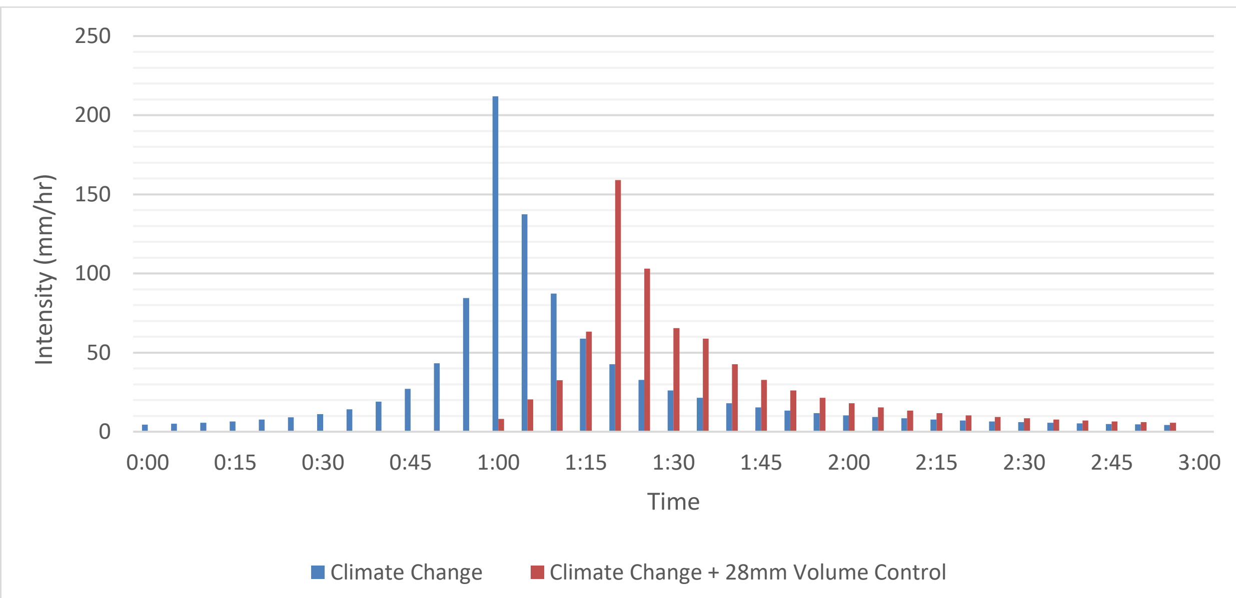


Figure 2.6: Synthetic Storm for 100-Year Event with 28mm Volume Control

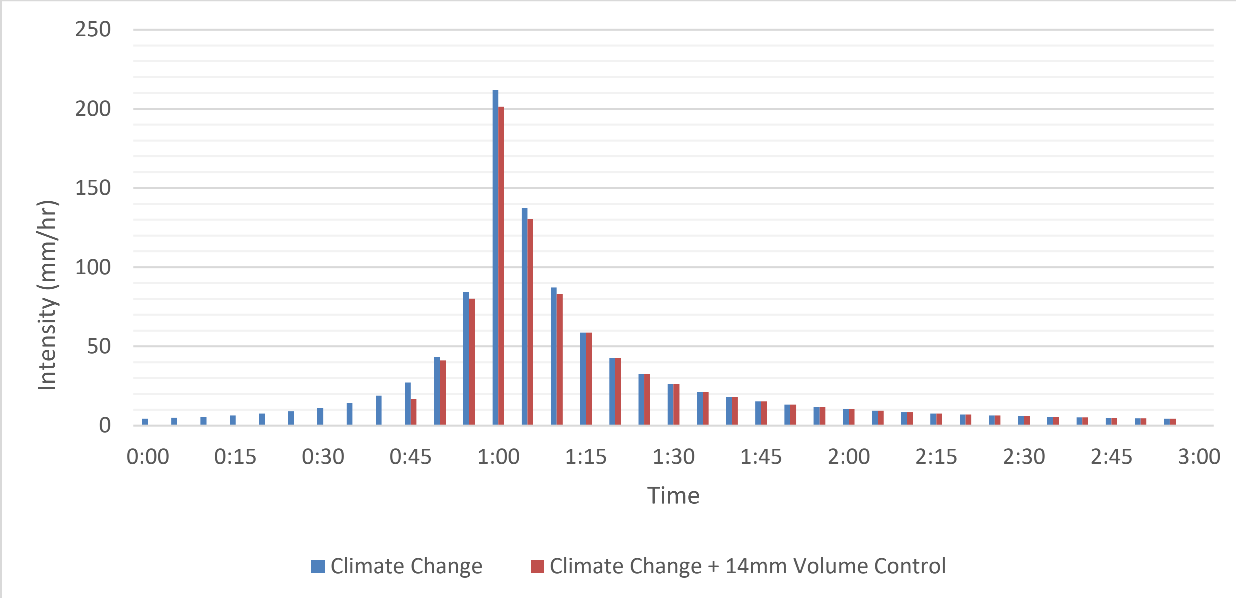


Figure 2.7: Synthetic Storm for 100-Year Event with 14mm Volume Control

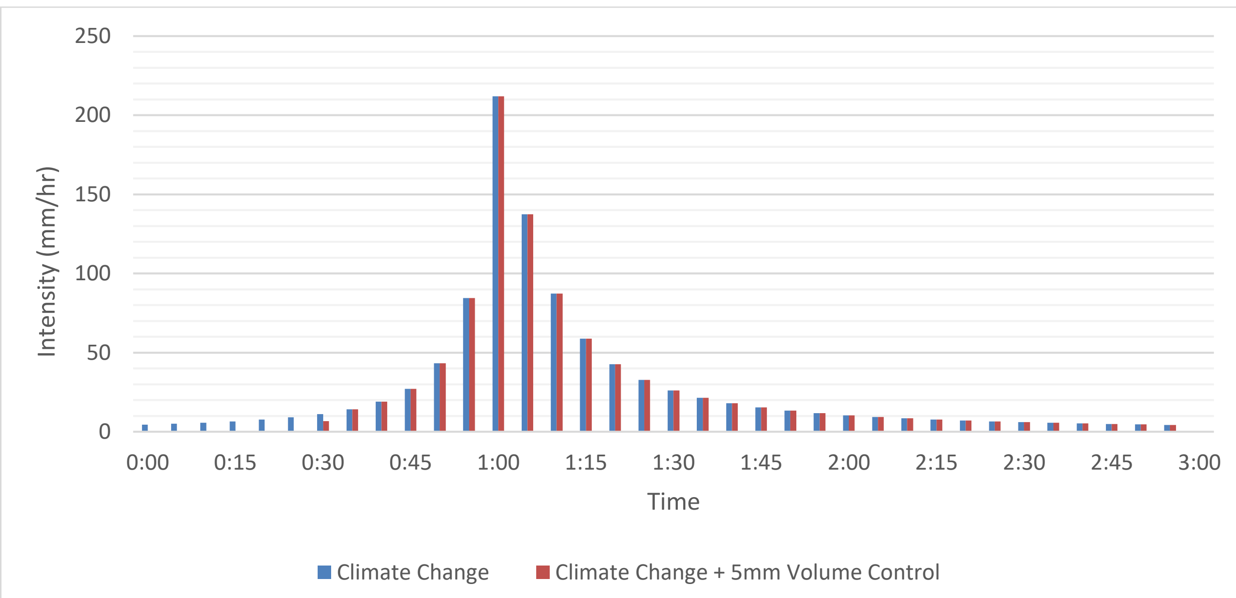


Figure 2.8: Synthetic Storm for 100-Year Event with 5mm Volume Control

3 Assessment of Model Results

A total of eight scenarios were modeled for the City using the PCSWMM model. These scenarios are summarized in **Table 3.1**.

Table 3.1: Model Scenarios

Scenario #	Scenario Name	IDF	TIMP	Storm Parameters
1	Existing Conditions	Existing	Existing	**Minor:** 5-year, 3-hr Chicago **Major:** 100-year, 3-hr Chicago **Continuous:** spring–fall
2	Future Growth	Existing	Future	
3	Future Growth & Climate Change	Climate Change (RCP4.5)	Future	**Minor:** 5-year, 3-hr Chicago **Major:** 100-year, 3-hr Chicago
4	Grey Infrastructure Only	Climate Change (RCP4.5)	Future	
5	Green Infrastructure (28mm Volume Control)	Climate Change (RCP4.5)	Future	
6	Green Infrastructure (5mm Volume Control)	Climate Change (RCP4.5)	Future	
7	Green Infrastructure (14mm Volume Control)	Climate Change (RCP4.5)	Future	
8	2D Model of Top Flood Prone Areas	Climate Change (RCP4.5)	Future	

Scenarios 5–7 represent the application of Low Impact Development (LID). In the LID scenario, a volume retention targets were applied to simulate the City-wide implementation of source and conveyance controls.

The minor system model results were assessed in terms of length of sewers which reached became surcharged. The major system model results were assessed in terms of the length of road right of way (ROW) which exceeded depths of 0.15m and 0.3m. The continuous model results were used to assess water balance.

Results are based on a quasi-calibrated model using stream flow data and not in-sewer monitoring (sewer hydraulics) and therefore results may be conservative. Additional monitoring and calibration is recommended to verify results, which will be a recommendation of the SWM-MP.

3.1 Scenario 1 – Existing Conditions Model

3.1.1 Minor System Results

Based on the parameters discussed in **Section 2**, storm sewers in Guelph are required to accommodate a 1:5-year storm event without surcharging. Therefore, in order to assess whether the City's existing sewers are currently reaching their target level of service, the model was run for a 1:5-year event and assessed for surcharged pipes. The results of the quasi-calibrated existing conditions model are shown in **Figure 3.1**, where surcharged pipes are highlighted in red. Although the storm sewer system was designed to accommodate the 1:5-year storm, 195km of pipes are surcharged under this event, representing 41% of storm sewers. The system performance analysis therefore indicates that these portions of the City's minor storm system network are deficient with respect to the stated level of service criteria.

The surcharged pipes identified in the existing conditions model were compared to the historical flooding records, which are indicated with turquoise triangles in **Figure 3.1**. The modelling results provide a consistent correlation between the location of the reported historical flooding incidents and the proximity of surcharged pipes. It should be noted that detailed records regarding the type of flooding were not available, as such not all flooding locations may be as a result of capacity issues with the minor system. As the model is only quasi-calibrated, additional model accuracy can be obtained through subsequent model calibration by the City of Guelph as part of next steps.

3.1.2 Major System Results

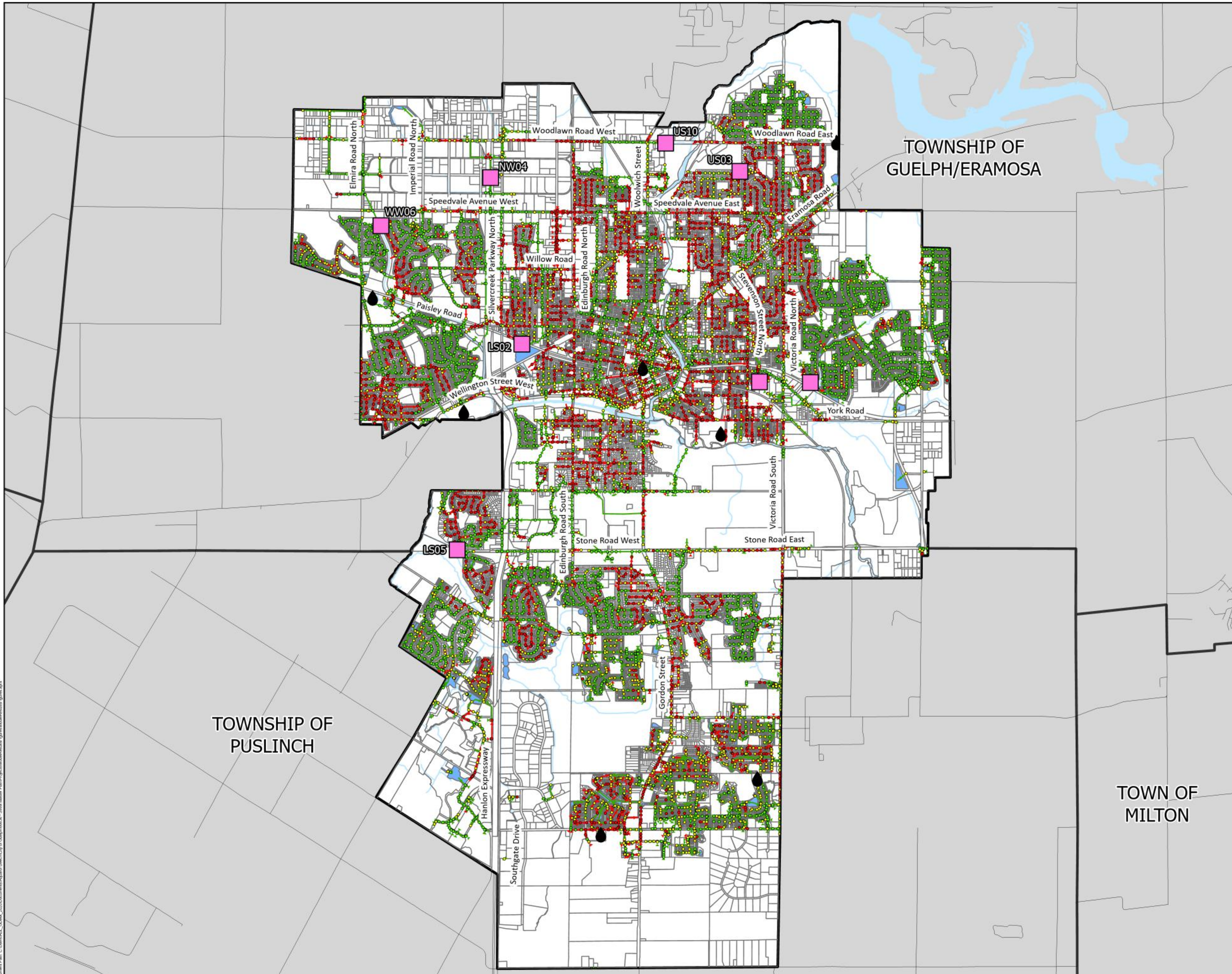
Based on the parameters discussed in **Section 2**, the City's ROW is required to accommodate a 1:100-year storm event. Therefore, in order to assess whether the City's existing ROW are currently reaching their target level of service, the model was run for a 1:100-year storm event and assessed for depth in the ROW. The results of the existing conditions model are shown in **Figure 3.2**, where ROW depths exceeding 0.3m are highlighted in red. Less than 1 percent of the City's ROW have flow depths exceeding 0.3m (1.56km). The system performance analysis therefore indicates that only small portions of the City's major storm system network are deficient with respect to the stated level of service criteria.

3.1.3 Water Balance Results

The results of the existing conditions water balance are summarized in **Table 3.2**. Approximately 71% of precipitation in the City is currently infiltrated, while the remaining 29% is discharged through runoff.

Table 3.2: Existing Conditions Water Balance

	Depth (mm)
Total Precipitation	636.25
Infiltration Loss	453.81
Surface Runoff	185.19
Final Storage	0.8



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

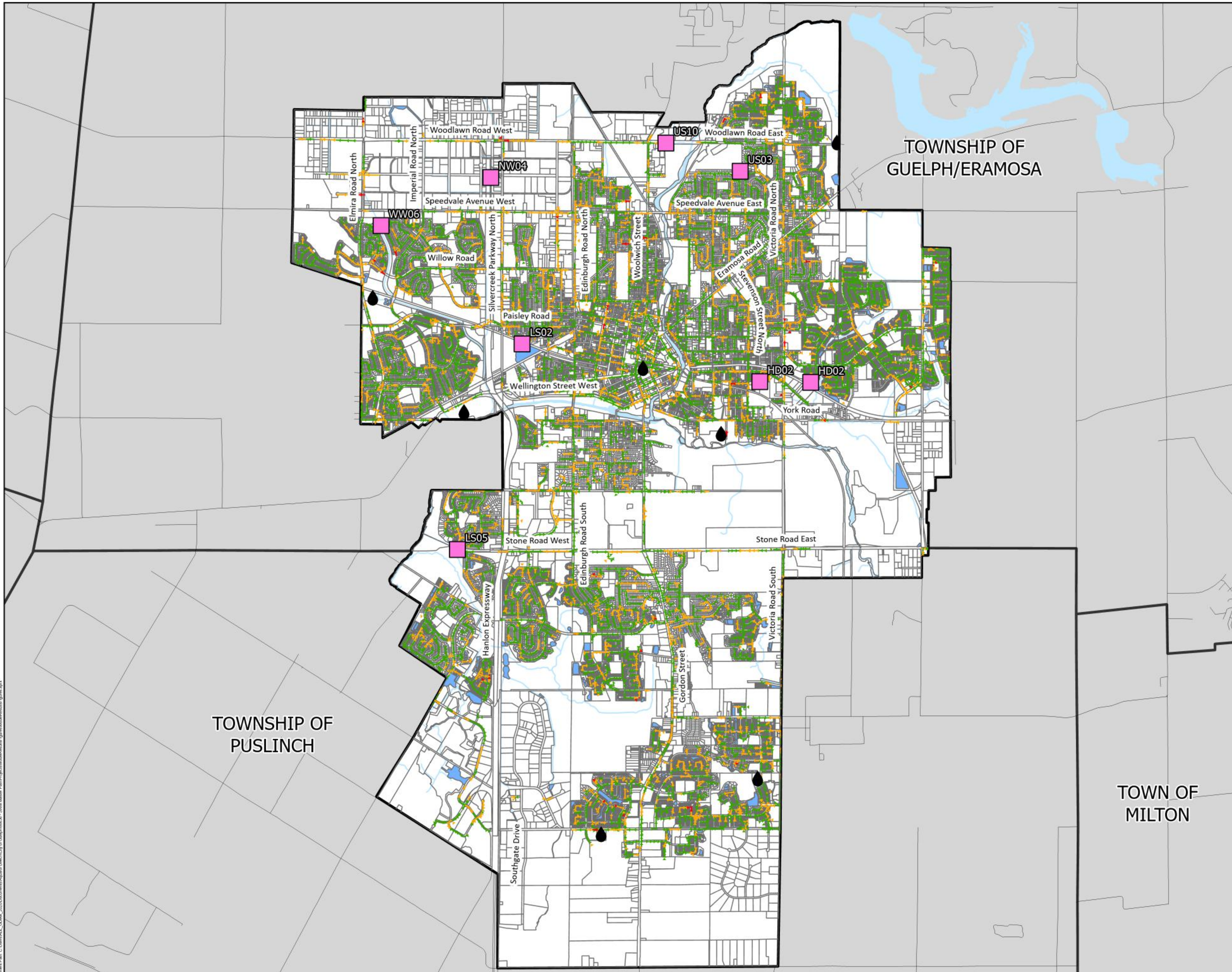
Figure 3.1

Scenario 1 - Existing Conditions Model, Minor System Results

Date: 2023-03-15
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited



City of Guelph — Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.2

Scenario 1 - Existing Conditions Model, Major System Results

Date: 2023-03-15
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.2 Scenario 2 – Future Growth

As noted in **Section 1.2.2,** the City is expected to undergo significant urban intensification and increased density. The intensification scenario is intended to provide an indication of how future development will impact the existing storm sewer network, assuming capacity upgrades do not occur concurrently with intensification. Through discussion with City staff, it was determined that the projected impervious percentage for the intensification scenario would be modelled as described below:

- Strategic Growth Areas (SGA) – Assume 100% TIMP.
- Downtown – Assume 100% TIMP.
- Greenfield Areas – Dolime will not be included in Future Growth scenarios. The Designated Greenfield Areas that are not SGAs or Clair Maltby Secondary Plan or Guelph Innovation District will develop as per their allowable land uses.
- Remaining Traffic Zones – Existing intensification trends to be applied to residential areas by traffic zones.
    - If low density residential undergoes intensification, assume it becomes medium density residential (70% TIMP).
    - If medium density residential undergoes intensification, assume it becomes high density residential (80% TIMP).

3.2.1 Minor System Results

The impacts of the intensification scenario on the existing storm sewer network is displayed in **Figure 3.3. Table 3.3** identifies the change in the level of service provided during the 1:5-year event from the existing conditions model to the future growth scenario. An increase of 85km of sewers become surcharged during the intensification scenario compared to the existing conditions. This suggests that minor system upgrades may be required to accommodate the proposed intensification.

Table 3.3: Comparison of Existing Conditions and Future Growth Scenarios (Minor System)

		Existing Conditions		Future Growth		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	1988 (23%)	-	2857 (32%)	-	869 (44%)	-
	0-1.8m Below Ground Surface	3330 (38%)	-	3647 (41%)	-	317 (10%)	-
	>1.8m Below Ground Surface	3475 (40%)	-	2289 (26%)	-	-1189 (-34%)	-
Minor System Pipes	Surcharged (Bottleneck)	-	195 (41%)	-	281 (60%)	-	85 (44%)
	Unsurcharged	-	276 (59%)	-	191 (41%)	-	-85 (-31%)

3.2.2 Major System Results

The impacts of the intensification scenario on the existing major system is displayed in **Figure 3.4. Table 3.4** identifies the change in the level of service provided during the 1:100-year event from the existing conditions model to the future growth scenario. An increase of 0.53km of roads have a water depth greater than 0.3m during the intensification scenario compared to the existing conditions model. This suggests that major system upgrades may be required to accommodate the proposed intensification.

Table 3.4: Comparison of Existing Conditions and Future Growth Scenarios (Major System)

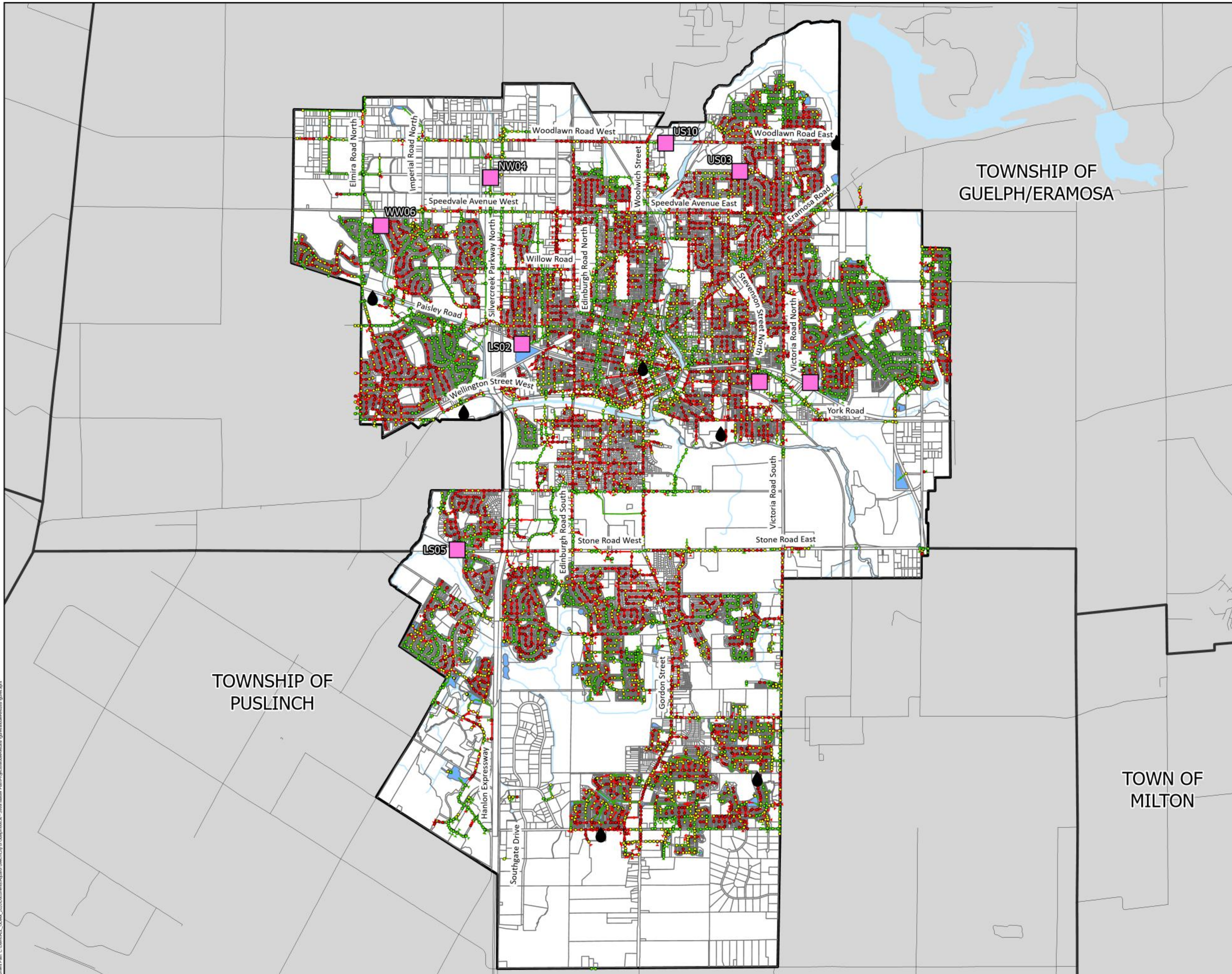
		Existing Conditions	Future Growth	Change in Service
		Length (km)		
Major System	**Depth >0.3m**	1.6 (0.4%)	2.1 (0.6%)	0.5 (31%)
	Depth 0.15m–0.3m	118 (31%)	127 (34%)	9 (8%)
	Depth <0.15m	255 (68%)	245 (65%)	-9 (-4%)

3.2.3 Water Balance Results

The results of the future conditions water balance are summarized in **Table 3.5**. Approximately 59% of precipitation in the City would be infiltrated in this scenario, a decrease of 17% from the existing conditions. The remaining 41% would be discharged through runoff, an increase of 42% over existing conditions.

Table 3.5: Future Conditions Water Balance

	Depth (mm)		Percent Change
	Existing Conditions	Future Conditions	
Total Precipitation	636.25	636.25	-
Infiltration Loss	453.81	376.1	-17.1%
Surface Runoff	185.19	263.2	42.1%
Final Storage	0.8	1.1	37.5%



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

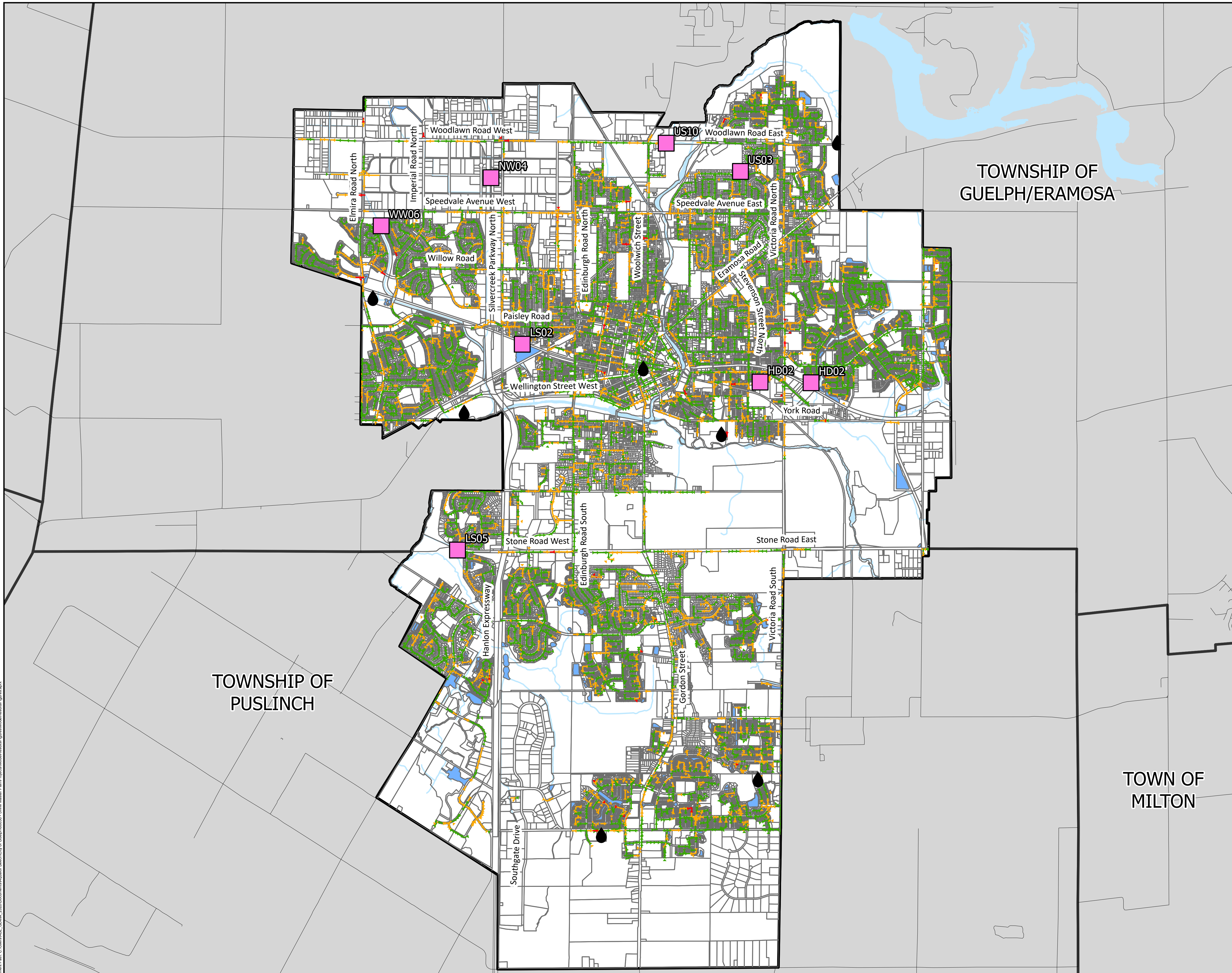
Figure 3.3

Scenario 2 -
Future Growth, Minor System Results

Date: 2023-02-23
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited



CITY OF Guelph

Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.4

Scenario 2 - Future Growth, Major System Results

Date: 2022-09-01
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.3 Scenario 3 – Future Growth and Climate Change Scenario

Climate change resilience, adaptation and mitigation is now considered an integral part of stormwater design and implementation. Alterations to the hydrologic regime caused by climate change could affect the function and vulnerability of existing SWM practices, including the long- and short-term impacts of:

1. More frequent and intense storm events,
2. Rising air and water temperatures,
3. More extended and frequent droughts,
4. More frequent winter thaws,
5. Earlier spring thaws and associated freshets, and
6. Altered plant communities, including die-outs in some vegetation types, reductions in the densities of some species and introduction of new possibly less desirable species.

Since 2015, several tools have been developed by climate scientists and statisticians to project future IDF relationships for rainfall events in Ontario. The IDF_CC Tool 4.0 was used to generate a local IDF curve that accounts for the possible impacts of climate change. This was documented in the Rainfall and IDF Curve Analysis report, developed for the SWM-MP in October 2021. Based on the results of this analysis, the IDF curve developed for RCP4.5 was selected for use in the model.

3.3.1 Minor System Results

The climate change scenario was developed by rerunning the future growth model with the Climate Change IDF curve for a 1:5-year 3-hour storm event under the RCP4.5 pathway. The impacts of climate change on the existing storm sewer network is displayed in **Figure 3.5,** where surcharged sewers are highlighted in red. **Table 3.6** identifies the change in the level of service provided during the 1:5-year event from the existing conditions model to the future growth and climate change scenario. An increase of 84.3km of sewers become surcharged during the future growth and climate change scenario compared to the existing conditions model. This suggests that minor system upgrades may be required to accommodate the impacts of climate change and development.

Table 3.6: Comparison of Existing Conditions and Future Growth and Climate Change Scenarios (Minor System)

		Existing Conditions		Future Growth and Climate Change		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	1988 (23%)	-	3014 (34%)	-	1026 (52%)	-
	0-1.8m Below Ground Surface	3330 (38%)	-	3505 (40%)	-	175 (5%)	-

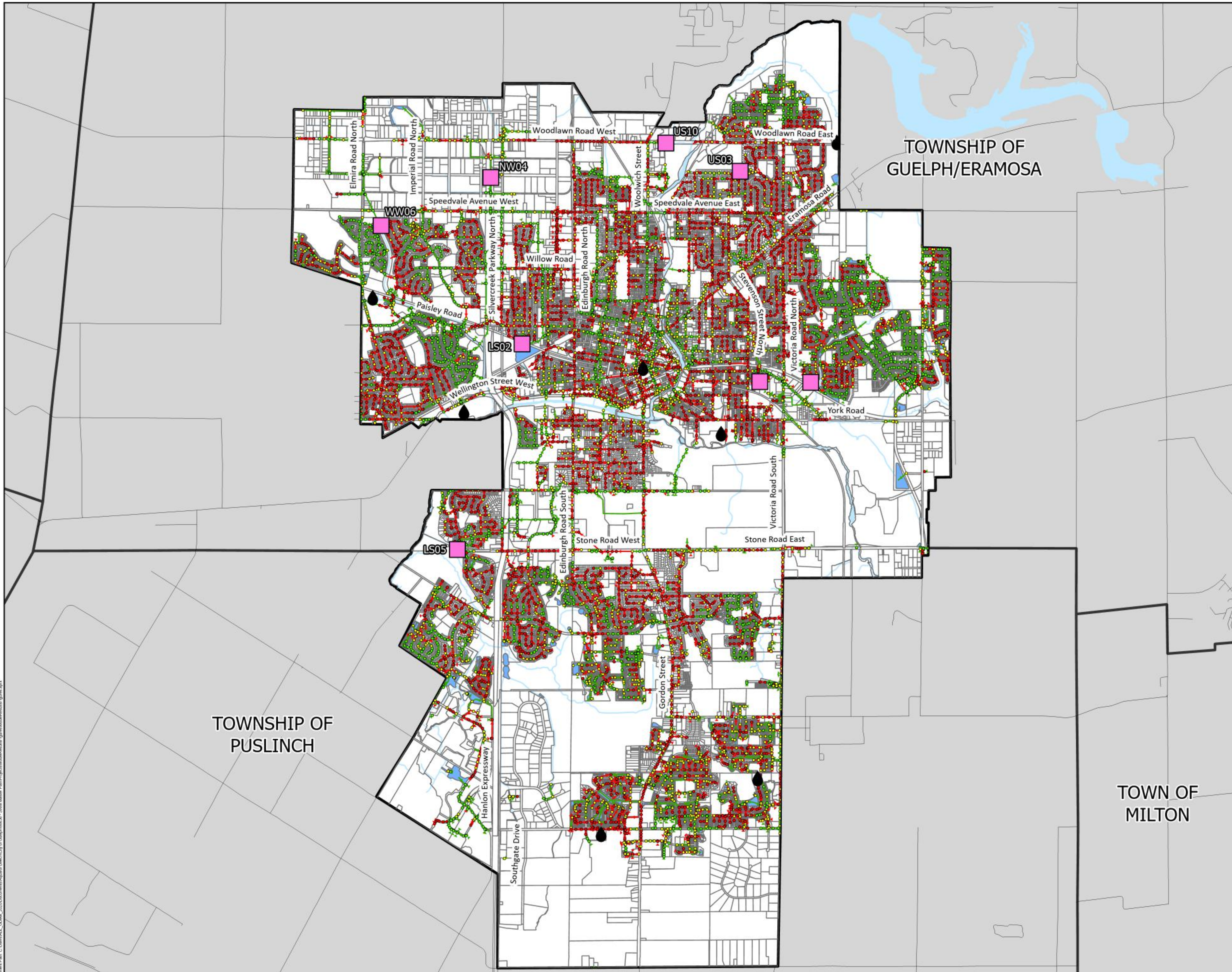
		Existing Conditions		Future Growth and Climate Change		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
	>1.8m Below Ground Surface	3475 (40%)	-	2274 (26%)	-	-1201 (-35%)	-
Minor System Pipes	**Surcharged (Bottleneck)**	-	195 (41%)	-	280 (59%)	-	84 (43%)
	Unsurcharged	-	276 (59%)	-	192 (41%)	-	-84 (-31%)

3.3.2 Major System Results

The climate change scenario was developed by rerunning the future growth model with the Climate Change IDF curve for a 1:100-year 3-hour storm event under the RCP4.5 pathway. The impacts of climate change on the existing major system is displayed in **Figure 3.6,** where water depth greater than 0.3m is highlighted in red. **Table 3.7** identifies the change in the level of service provided during the 1:100-year event from the existing conditions model to the future growth and climate change scenario. An increase of 0.14km of ROW has a flow depth greater than 0.3m during the future growth and climate change scenario compared to the existing conditions model. This suggests that minimal major system upgrades may be required to accommodate the impacts of climate change and development.

Table 3.7: Comparison of Existing Conditions and Future Growth and Climate Change Scenarios (Major System)

		Existing Conditions	Future Growth and Climate Change	Change in Service
		Length (km)		
Major System	**Depth >0.3m**	1.6 (0.4%)	1.7 (0.5%)	0.1 (6%)
	Depth 0.15m–0.3m	118 (31%)	115 (31%)	-4 (-3%)
	Depth <0.15m	255 (68%)	258 (69%)	3 (1%)



City of Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

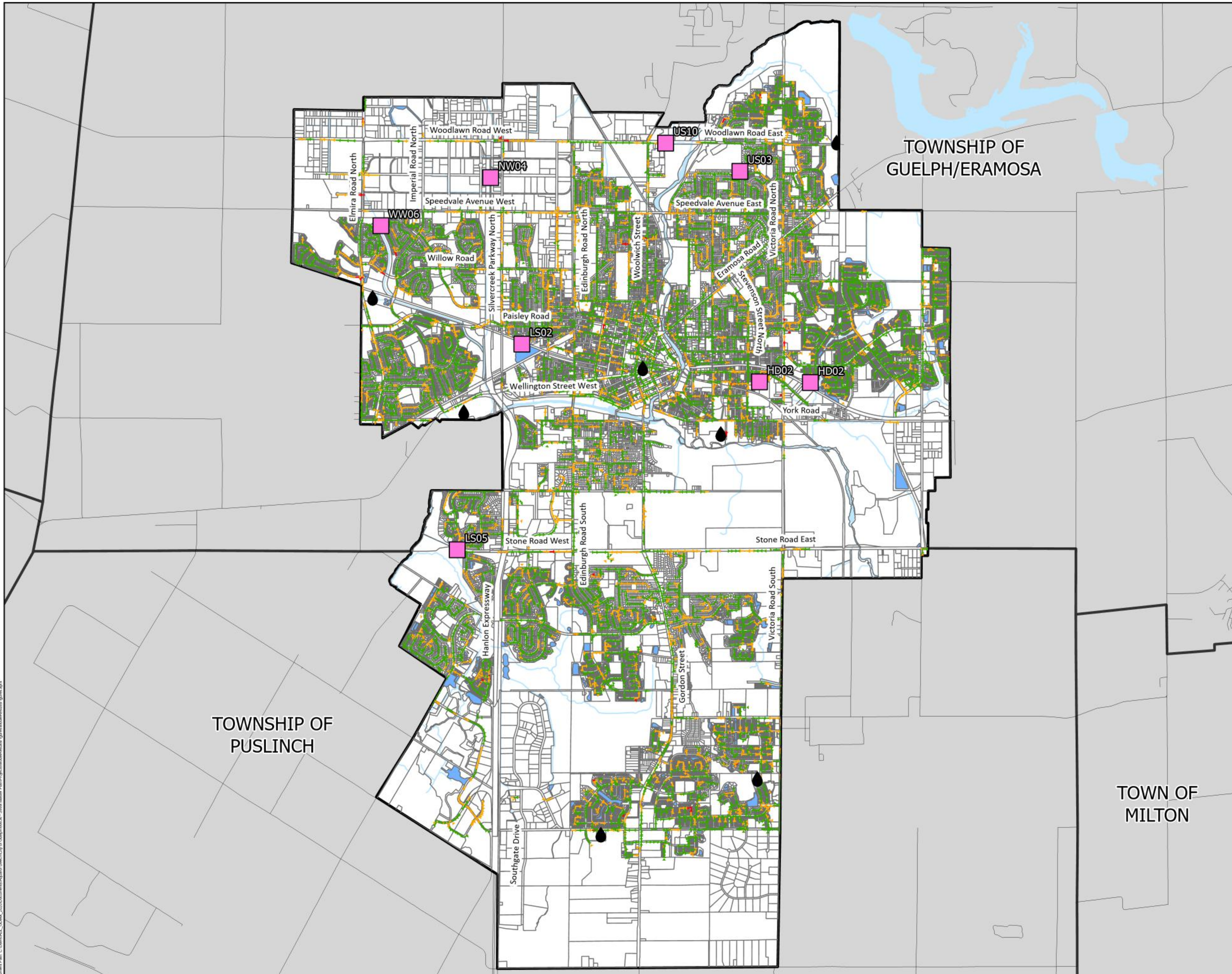
Figure 3.5

Scenario 3 - Future Growth and Climate Change, Minor System Results

Date: 2023-03-15
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited



City of Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.6

Scenario 3 - Future Growth and Climate Change, Major System Results

Date: 2023-03-15
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.4 Scenario 4 – Grey Infrastructure Only

Scenarios 4–7 present alternative solutions for managing the deficiencies noted in Scenarios 1–3. Scenario 4 considers grey infrastructure upgrades only, including new proposed end-of-pipe facilities (identified in the New End-of-Pipe Opportunities report, dated September 2022), as well as upsizing storm sewers in nine bottlenecks.

Stage-storage curves for each proposed end-of-pipe facility were developed based on the conceptual designs, assuming a 200mm orifice at the facility outlet.

Locations for storm sewer upgrades were identified using three criteria (**Figure 3.7**):

1. City-identified areas of concern (frequent impact locations);
2. Density of flooding complaints;
3. Locations of storm sewer surcharge identified in existing conditions scenario; and
4. Capital roads project scheduled for reconstruction.

Streets modeled with storm sewer upgrades are summarized in **Table 3.8**.

Table 3.8: Modeled Storm Sewer Upgrades

Location	Rationale
Paisley (Silvercreek to Rosewood)	• City identified collapsed sewer and has welded maintenance holes shut due to excessive pressure in system • Model results show storm sewer surchared
Waverly	• City identified overcapacity of ditch and storm sewer cuasing flooding at Stevenson and Speedvale, including curb overtopping • Model results show storm sewer surcharged
Empire and Garabaldi	• City identified pressurized catchbasins resulting in water entering at least one building • Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Lane Street	• City identified storm sewer surcharge causing overtopping of curb • Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Fountain / Glasgow	• Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Dever / College	• Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Speedvale / Metcalfe	• Model results show storm sewer surcharged • Hot spot of flooding complaints from residents

Location	Rationale
Eramosa / Cheltonwood / Carter	• Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Dean / Maple	• Model results show storm sewer surcharged • Hot spot of flooding complaints from residents
Edinburgh Road	• Capital roads project • Model results show storm sewer surcharged
Woodlawn Road	• Capital roads project • Model results show storm sewer surcharged
Gordon Street	• Capital roads project • Model results show storm sewer surcharged
Water Street	• Capital roads project • Model results show storm sewer surcharged
Mary Street	• Capital roads project • Model results show storm sewer surcharged
Dean Avenue	• Capital roads project • Model results show storm sewer surcharged
Wellington Street West	• Capital roads project • Model results show storm sewer surcharged
Bristol Street	• Capital roads project • Model results show storm sewer surcharged
Cassino Avenue	• Capital roads project • Model results show storm sewer surcharged
Storm sewer beneath private property from Stevenson Road to Cassino Avenue	• Capital project • Model results show storm sewer surcharged
York Road	• Capital roads project • Model results show storm sewer surcharged
Alma Street	• Capital roads project • Model results show storm sewer surcharged
Lane Street	• Capital roads project • Model results show storm sewer surcharged
Waterloo Avenue	• Capital roads project • No storm sewer surcharging
Wyndham Street	• Downtown Servicing Study recommended upgrade
Cork Street	• Downtown Servicing Study recommended upgrade
Macdonell Street	• Downtown Servicing Study recommended upgrade
Carden Street	• Downtown Servicing Study recommended upgrade
Yarmouth Street	• Downtown Servicing Study recommended upgrade
Ontario Street	• Downtown Servicing Study recommended upgrade
Arthur Street	• Downtown Servicing Study recommended upgrade

Location	Rationale
Manitoba Street	• Downtown Servicing Study recommended upgrade
Oliver Street	• Downtown Servicing Study recommended upgrade
Duke Street	• Downtown Servicing Study recommended upgrade
Huron Street	• Downtown Servicing Study recommended upgrade
Ferguson Street	• Downtown Servicing Study recommended upgrade
Elizabeth Street	• Downtown Servicing Study recommended upgrade
Dublin Street	• Downtown Servicing Study recommended upgrade

Since Scenarios 4–7 were modeled using the climate change IDF curve and future growth TIMP, results were compared to the results from Scenario 3 (Future Growth and Climate Change Scenario).

3.4.1 Minor System Results

The impacts of implementing the proposed end-of-pipe facilites and upgrading storm sewers on the existing storm sewer network is displayed in **Figure 3.8,** where surcharged sewers are highlighted in red. **Table 3.9** identifies the change in the level of service provided during the 1:5-year event from the future growth and climate change scenario to the grey infrastructure scenario. A decrease of nearly 200 km of sewers are surcharged during the grey infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades reduce surcharging.

Table 3.9: Comparison of Future Growth and Climate Change and Grey Infrastructure Scenarios (Minor System)

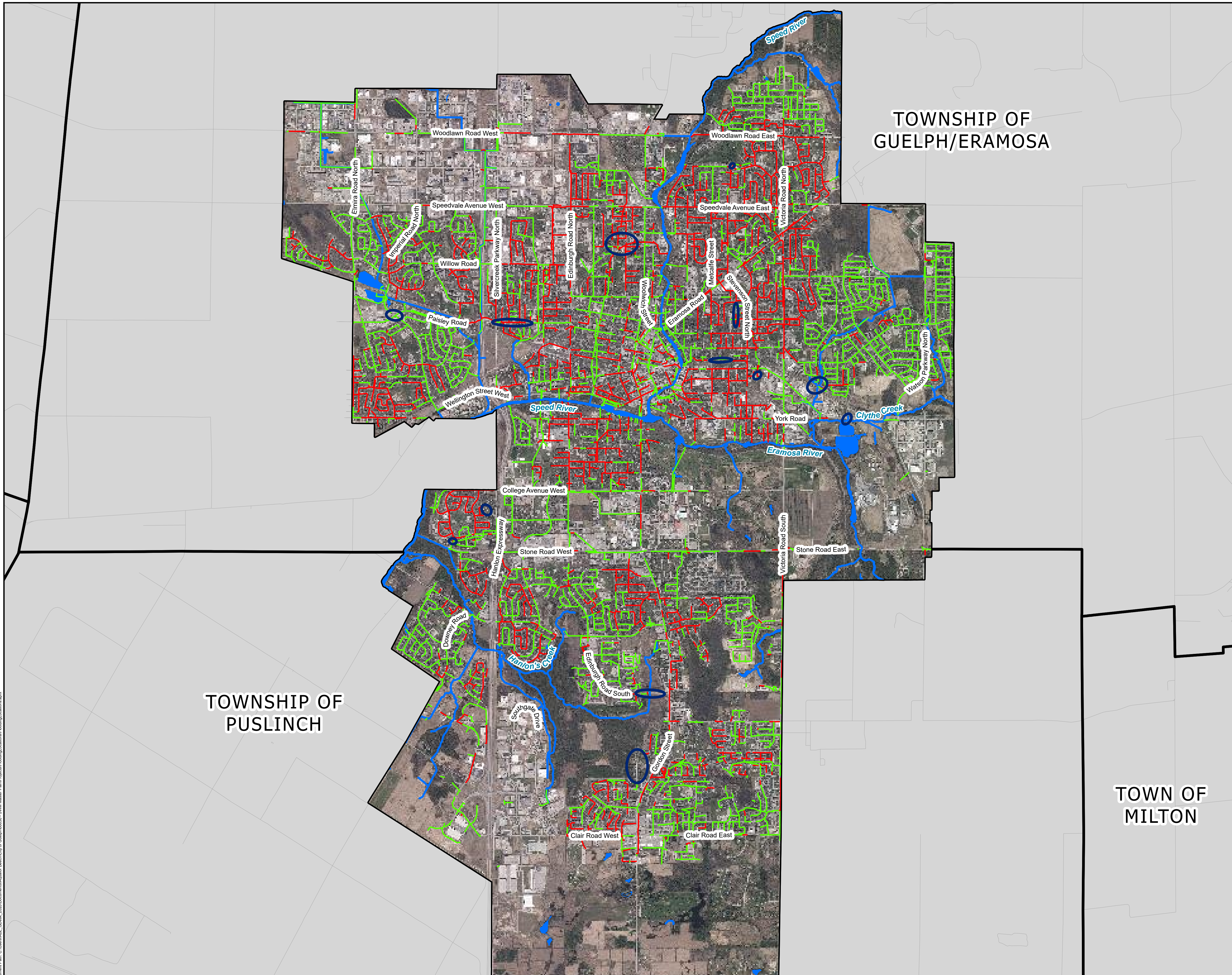
		Future Growth and Climate Change		Grey Infrastructure Only		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	3014 (34%)	-	1034 (12%)	-	-1980 (-66%)	-
	0-1.8m Below Ground Surface	3505 (40%)	-	2976 (34%)	-	-529 (-15%)	-
	>1.8m Below Ground Surface	2274 (26%)	-	4806 (55%)	-	2532 (111%)	-
Minor System Pipes	Surcharged (Bottleneck)	-	280 (59%)	-	81 (17%)	-	-198 (-71%)
	Unsurcharged	-	192 (41%)	-	394 (83%)	-	202 (105%)

3.4.2 Major System Results

The impacts of implementing the proposed end-of-pipe facilites and upgrading storm on the existing major system is displayed in **Figure 3.9,** where water depth greater than 0.3m is highlighted in red. **Figure 3.7** identifies the change in the level of service provided during the 1:100-year event from the future growth and climate change scenario to the grey infrastructure scenario. There is no significant change in ROW flow depths in the grey infrastructure scenario compared to the future growth and climate change scenario, as the proposed upgrades are primarily targeted at the minor system.

Table 3.10: Comparison of Existing Conditions and Future Growth and Climate Change Scenarios (Major System)

		Future Growth and Climate Change	Grey Infrastructure Only	Change in Service
		Length (km)		
Major System	Depth >0.3m	1.7 (0.5%)	1.6 (0.4%)	-0.1 (-4%)
	Depth 0.15m–0.3m	115 (31%)	113 (30%)	-1 (-1%)
	Depth <0.15m	258 (69%)	259 (69%)	1 (0.6%)



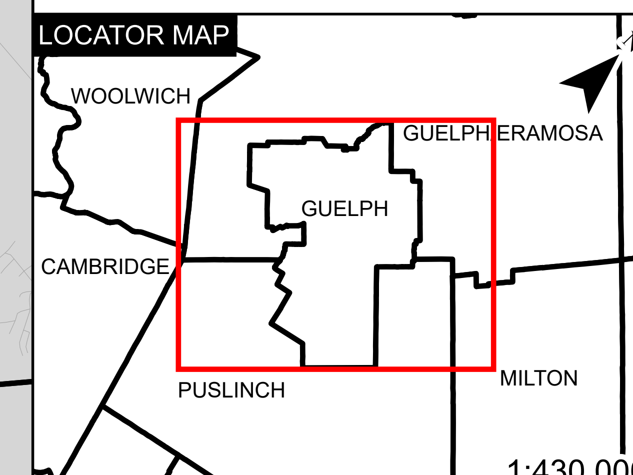


Figure 3.7

Criteria to Identify Storm Sewer Upgrades

Date: 2022-08-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

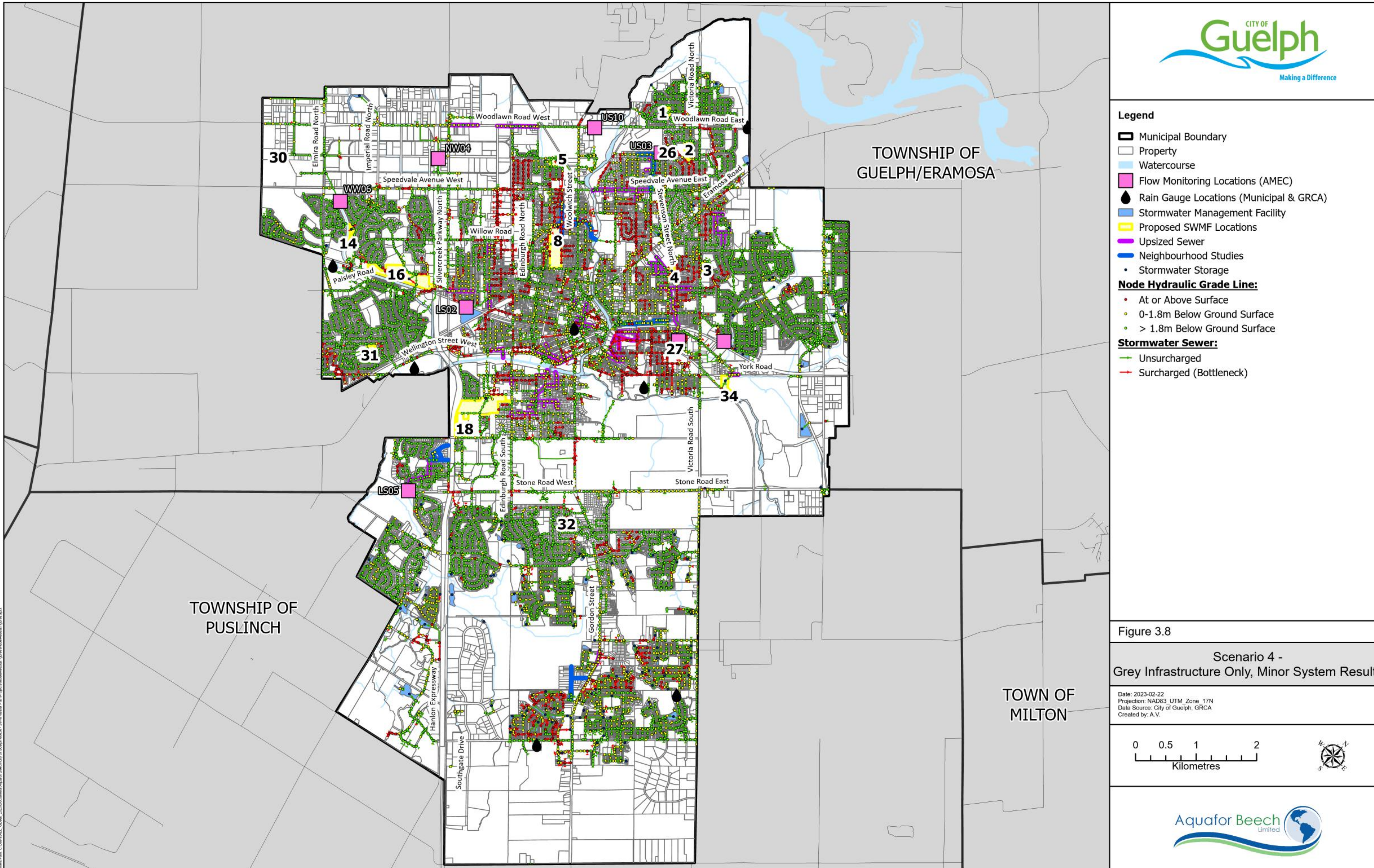
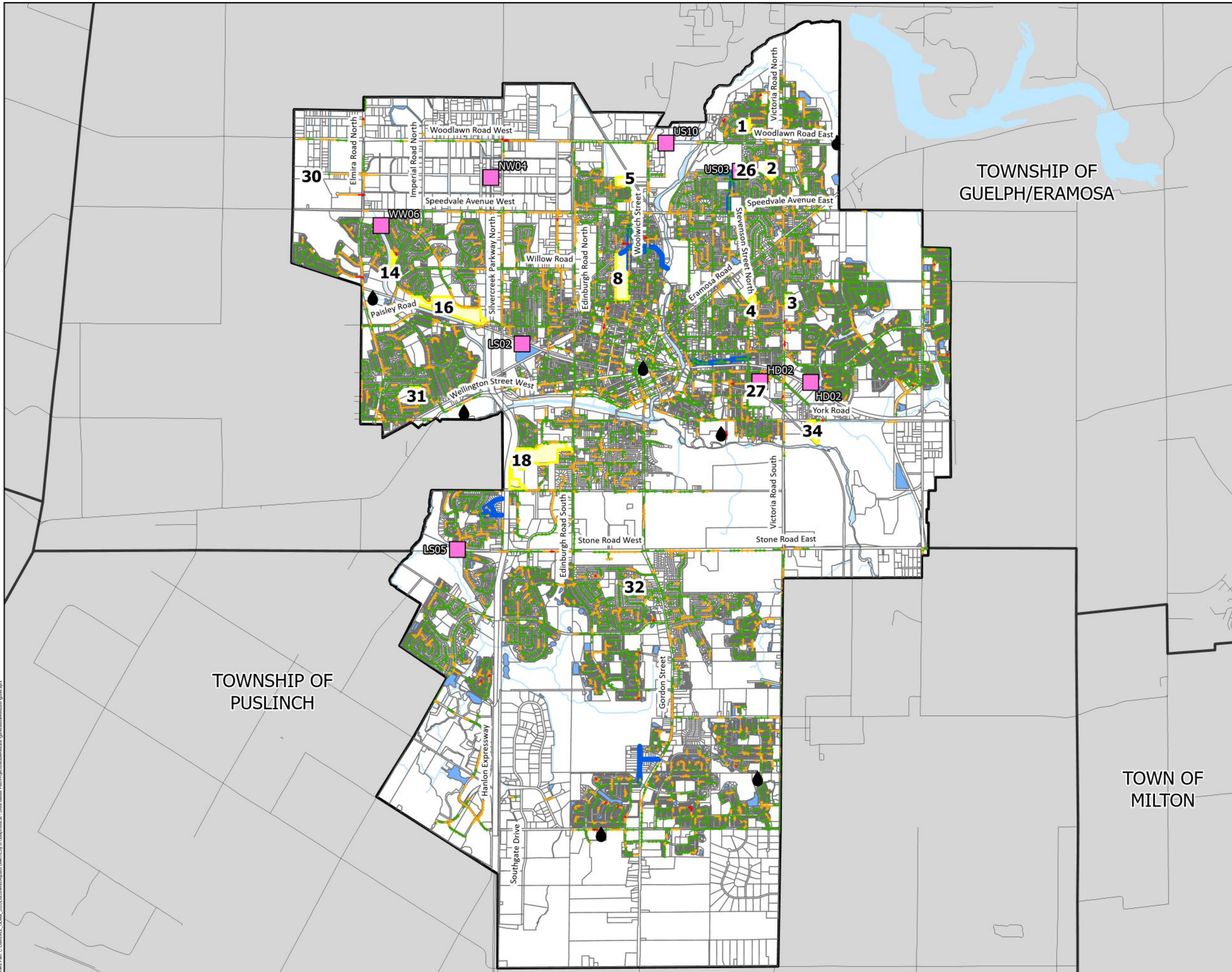


Figure 3.8

Scenario 4 -
Grey Infrastructure Only, Minor System Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.



Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility
- Proposed SWMF Locations
- Neighbourhood Studies

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.9

Scenario 4 -
Grey Infrastructure Only, Major System Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

3.5 Scenario 5 – Green Infrastructure (28mm Volume Control)

For the purposes of this model, a target of 28mm of volume control (the 90th percentile rain event) was proposed for Scenario 5. The 28 mm volume target corresponds to a future scenario in which all catchments are provided with some form of source and/or conveyance control reducing runoff volume significantly. This scenario assumes the application of the 28mm volume retention across all of the City's subcatchments over an extended time period.

3.5.1 Minor System Results

The impacts of implementing the 28mm of volume control throughout the City on the existing storm sewer network is displayed in **Figure 3.10,** where surcharged sewers are highlighted in red. **Table 3.11** identifies the change in the level of service provided during the 1:5-year event from the future growth and climate change scenario to the 28mm green infrastructure scenario. An decrease of 259km of sewers become surcharged during the 28mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce surcharging.

Table 3.11: Comparison of Future Growth and Climate Change and 28mm Green Infrastructure Scenarios (Minor System)

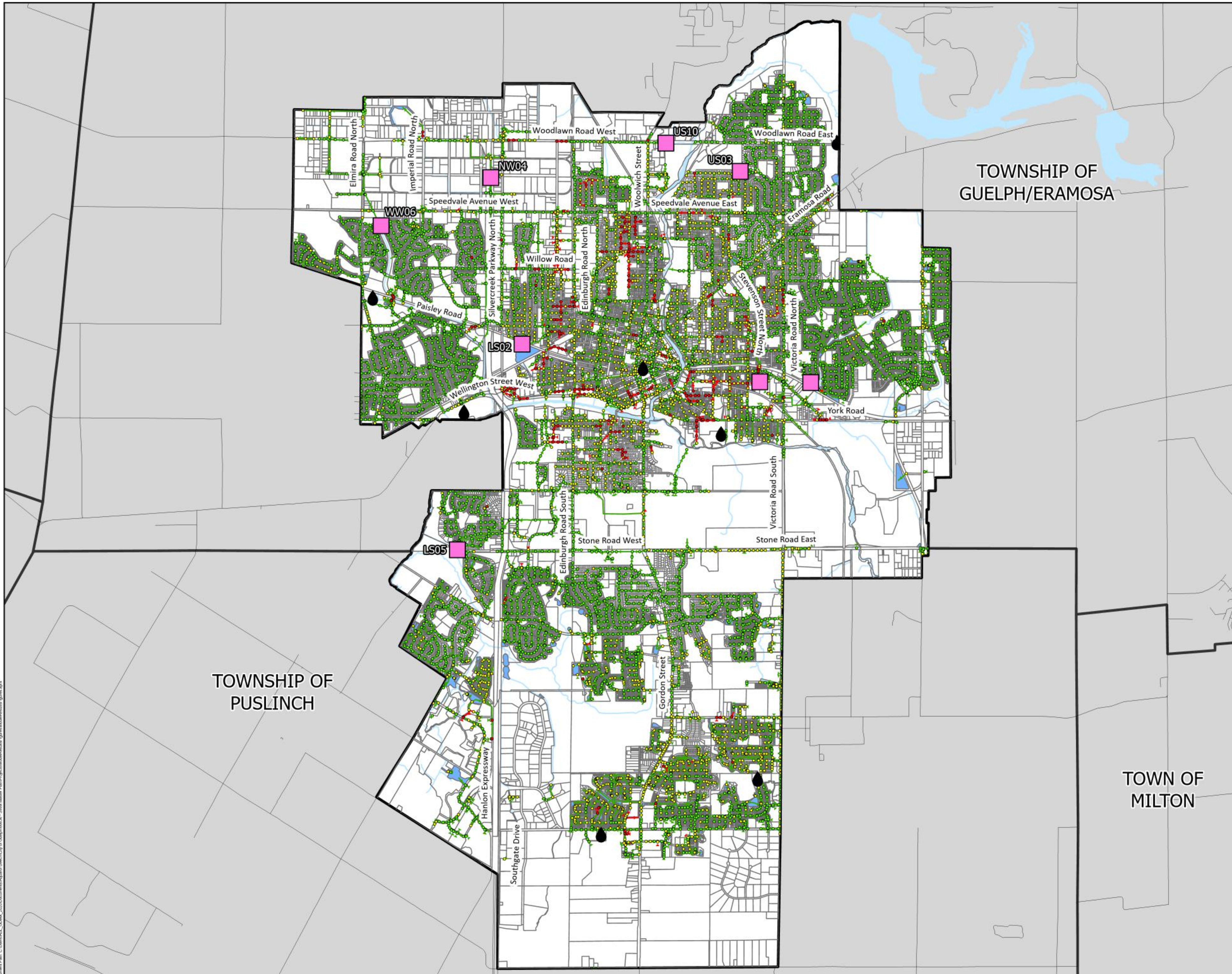
		Future Growth and Climate Change		28mm Green Infrastructure		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	3014 (34%)	-	246 (3%)	-	-2769 (-92%)	-
	0-1.8m Below Ground Surface	3505 (40%)	-	2934 (33%)	-	-571 (-16%)	-
	>1.8m Below Ground Surface	2274 (26%)	-	5,613 (64%)	-	3339 (147%)	-
Minor System Pipes	Surcharged (Bottleneck)	-	280 (59%)	-	20 (4%)	-	-259 (-93%)
	Unsurcharged	-	192 (41%)	-	451 (96%)	-	259 (135%)

3.5.2 Major System Results

The impacts of implementing the 28mm of volume control throughout the City on the existing major system is displayed in **Figure 3.11,** where water depth greater than 0.3m is highlighted in red. **Figure 3.7** identifies the change in the level of service provided during the 1:100-year event from the future growth and climate change scenario to the 28mm green infrastructure scenario. An decrease of 0.8km of ROW has a flow depth greater than 0.3m during the 28mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce ROW flooding.

Table 3.12: Comparison of Future Growth and Climate Change and 28mm Green Infrastructure Scenarios (Major System)

		Future Growth and Climate Change	28mm Green Infrastructure Only	Change in Service
		Length (km)		
Major System	**Depth >0.3m**	1.7 (0.5%)	0.9 (0.2%)	-0.8 (-93%)
	Depth 0.15m–0.3m	115 (31%)	85 (23%)	-30 (-26%)
	Depth <0.15m	258 (69%)	289 (77%)	31 (12%)



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Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

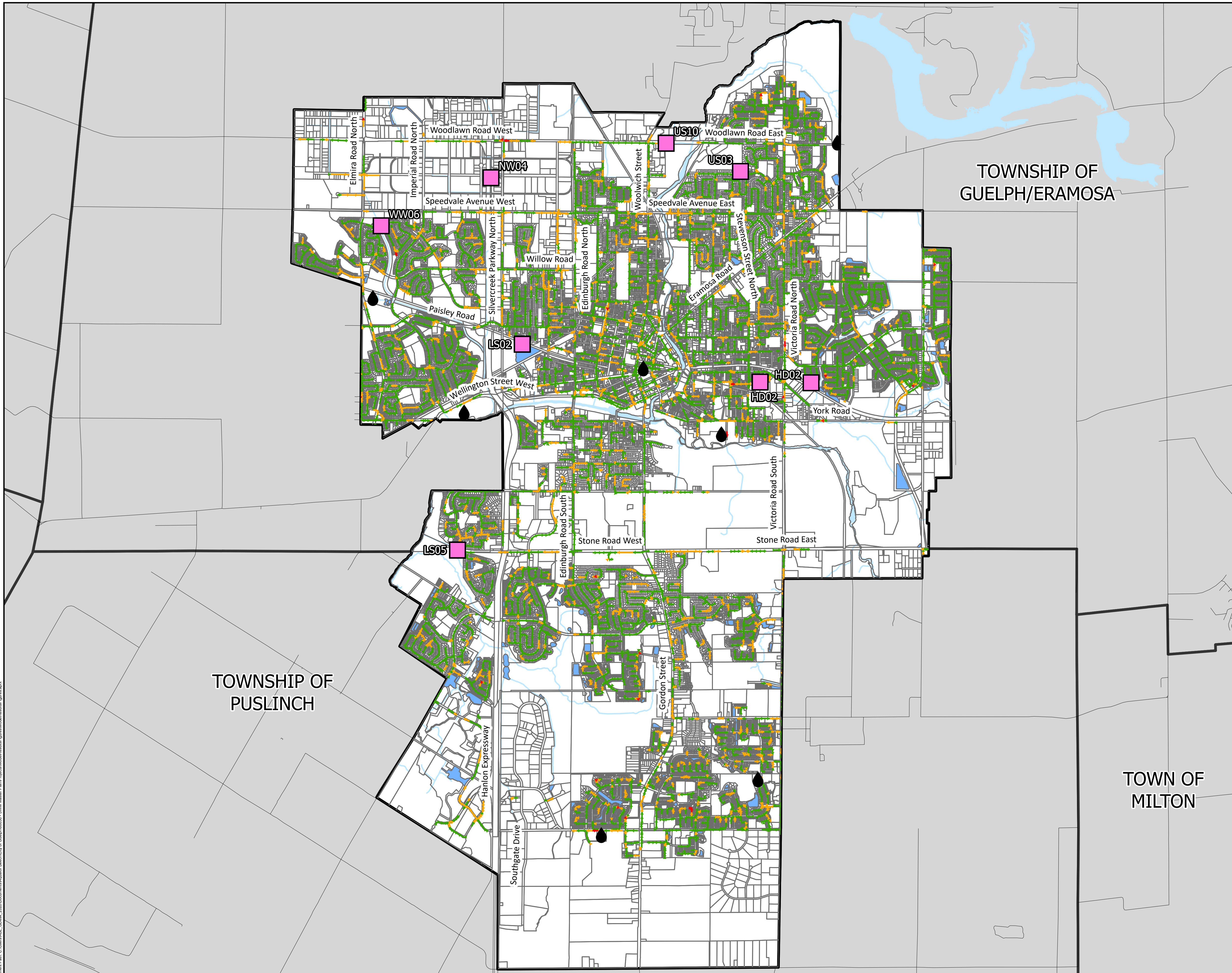
Figure 3.10

Scenario 5 - Green Infrastructure (28mm Volume Control), Minor System Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited



City of Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.11

Scenario 5 - Green Infrastructure (28mm Volume Control), Major System Results

Date: 2022-09-20
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.6 Scenario 6 – Green Infrastructure (5mm Volume Control)

A target of 5mm of volume control is proposed for Scenario 6. The 5mm volume target corresponds to a future scenario in which all catchments are provided with some form of source and/or conveyance control reducing runoff volume significantly. This scenario assumes the application of the 5mm volume retention across all of the City's subcatchments over an extended time period.

3.6.1 Minor System Results

The impacts of implementing the 5mm of volume control throughout the City on the existing storm sewer network is displayed in **Figure 3.10,** where surcharged sewers are highlighted in red. **Table 3.11** identifies the change in the level of service provided during the 1:5-year event from the future growth and climate change scenario to the 5mm green infrastructure scenario. An decrease of 190km of sewers become surcharged during the 5mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce surcharging.

Table 3.13: Comparison of Future Growth and Climate Change and 5mm Green Infrastructure Scenarios (Minor System)

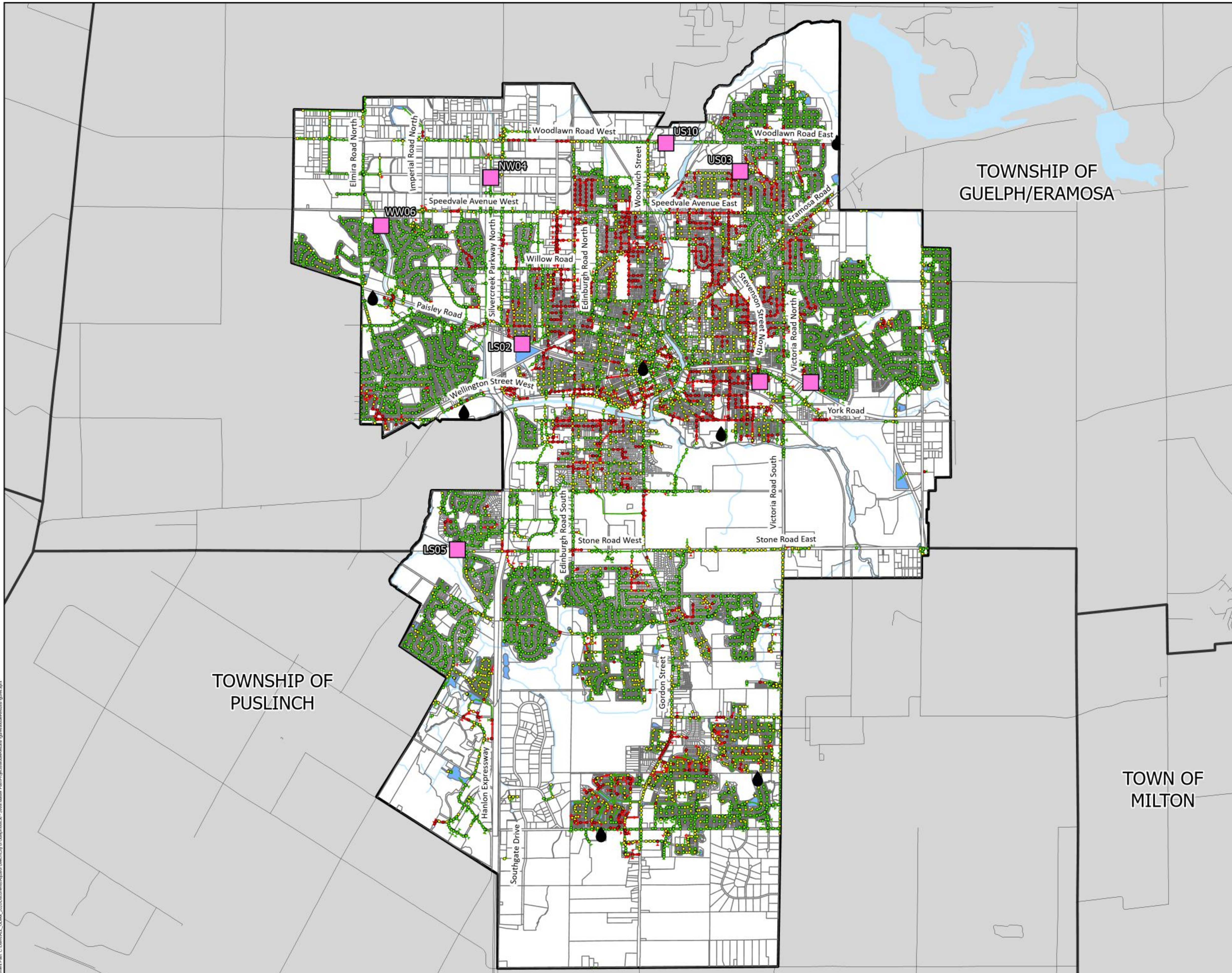
		Future Growth and Climate Change		5mm Green Infrastructure		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	3014 (34%)	-	1141 (13%)	-	-1873 (-62%)	-
	0-1.8m Below Ground Surface	3505 (40%)	-	2858 (33%)	-	-647 (-18%)	-
	>1.8m Below Ground Surface	2274 (26%)	-	4794 (55%)	-	2520 (111%)	-
Minor System Pipes	Surcharged (Bottleneck)	-	280 (59%)	-	89 (19%)	-	-190 (-68%)
	Unsurcharged	-	192 (41%)	-	382 (81%)	-	190 (99%)

3.6.2 Major System Results

The of implementing the 5mm of volume control throughout the City on the existing major system is displayed in **Figure 3.11,** where water depth greater than 0.3m is highlighted in red. **Figure 3.7** identifies the change in the level of service provided during the 1:100-year event from the future growth and climate change scenario to the 5mm green infrastructure scenario. An increase of 0.1km of ROW has a flow depth greater than 0.3m during the 5mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce ROW flooding.

Table 3.14: Comparison of Future Growth and Climate Change and 5mm Green Infrastructure Scenarios (Major System)

		Future Growth and Climate Change	5mm Green Infrastructure	Change in Service
		Length (km)		
Major System	**Depth >0.3m**	1.7 (0.5%)	1.6 (0.4%)	-0.1 (-8%)
	Depth 0.15m–0.3m	115 (31%)	114 (30%)	-1 (-1%)
	Depth <0.15m	258 (69%)	259 (69%)	1 (%)



Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

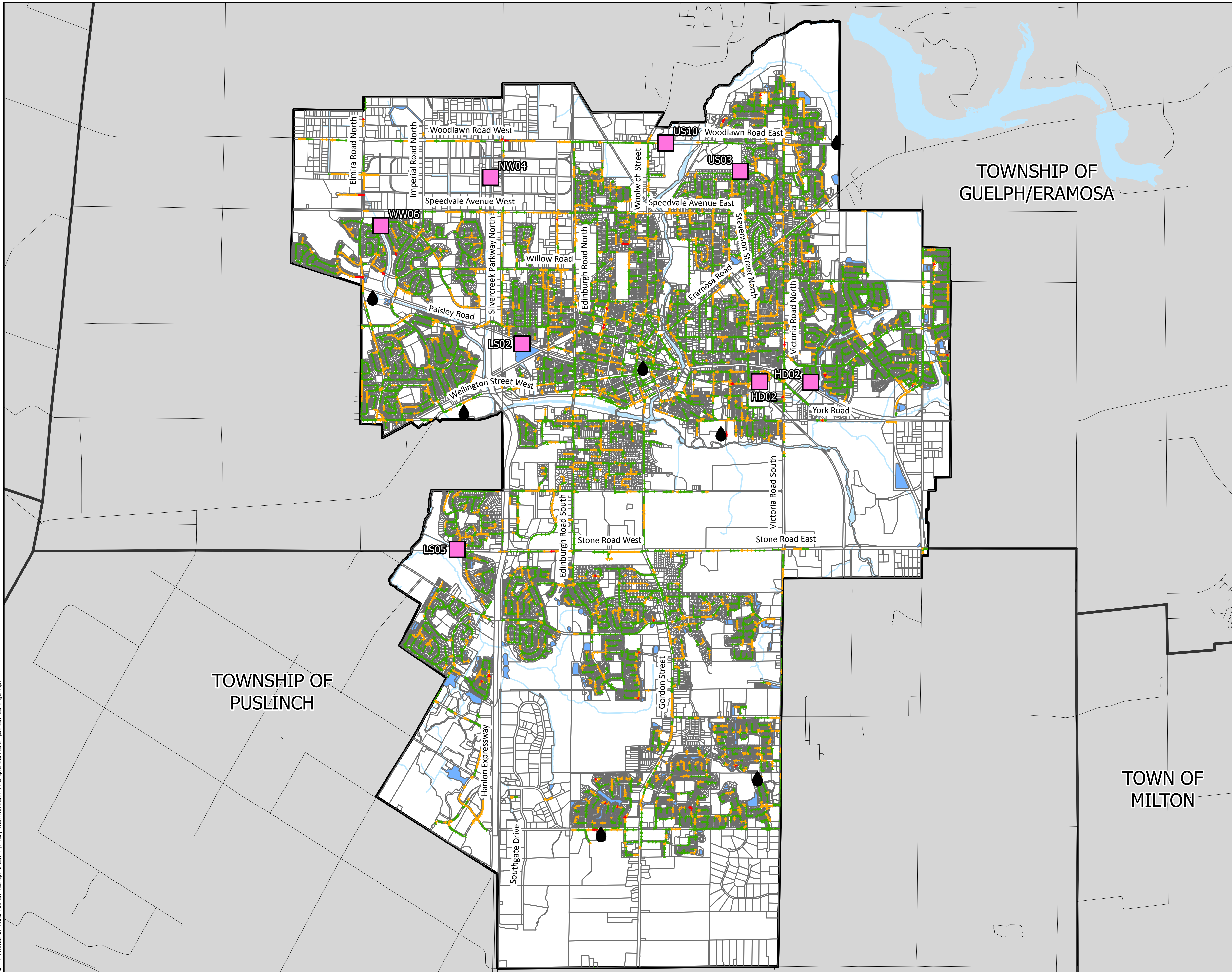
- Unsurcharged
- Surcharged (Bottleneck)

Figure 3.12

Scenario 6 – Green Infrastructure (5mm Volume Control), Minor System Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres



CITY OF Guelph
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Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.13

Scenario 6 - Green Infrastructure (5mm Volume Control), Major System Results

Date: 2022-09-20
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.7 Scenario 7 – Green Infrastructure (14mm Volume Control)

A target of 14mm of volume control is proposed for Scenario 7. The 14mm volume target corresponds to a future scenario in which all catchments are provided with some form of source and/or conveyance control reducing runoff volume significantly. This scenario assumes the application of the 14mm volume retention across all of the City's subcatchments over an extended time period.

3.7.1 Minor System Results

The impacts of implementing the 14mm of volume control throughout the City on the existing storm sewer network is displayed in **Figure 3.10,** where surcharged sewers are highlighted in red. **Table 3.11** identifies the change in the level of service provided during the 1:5-year event from the future growth and climate change scenario to the 5mm green infrastructure scenario. An decrease of 219km of sewers become surcharged during the 14mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce surcharging.

Table 3.15: Comparison of Future Growth and Climate Change and 14mm Green Infrastructure Scenarios Scenarios (Minor System)

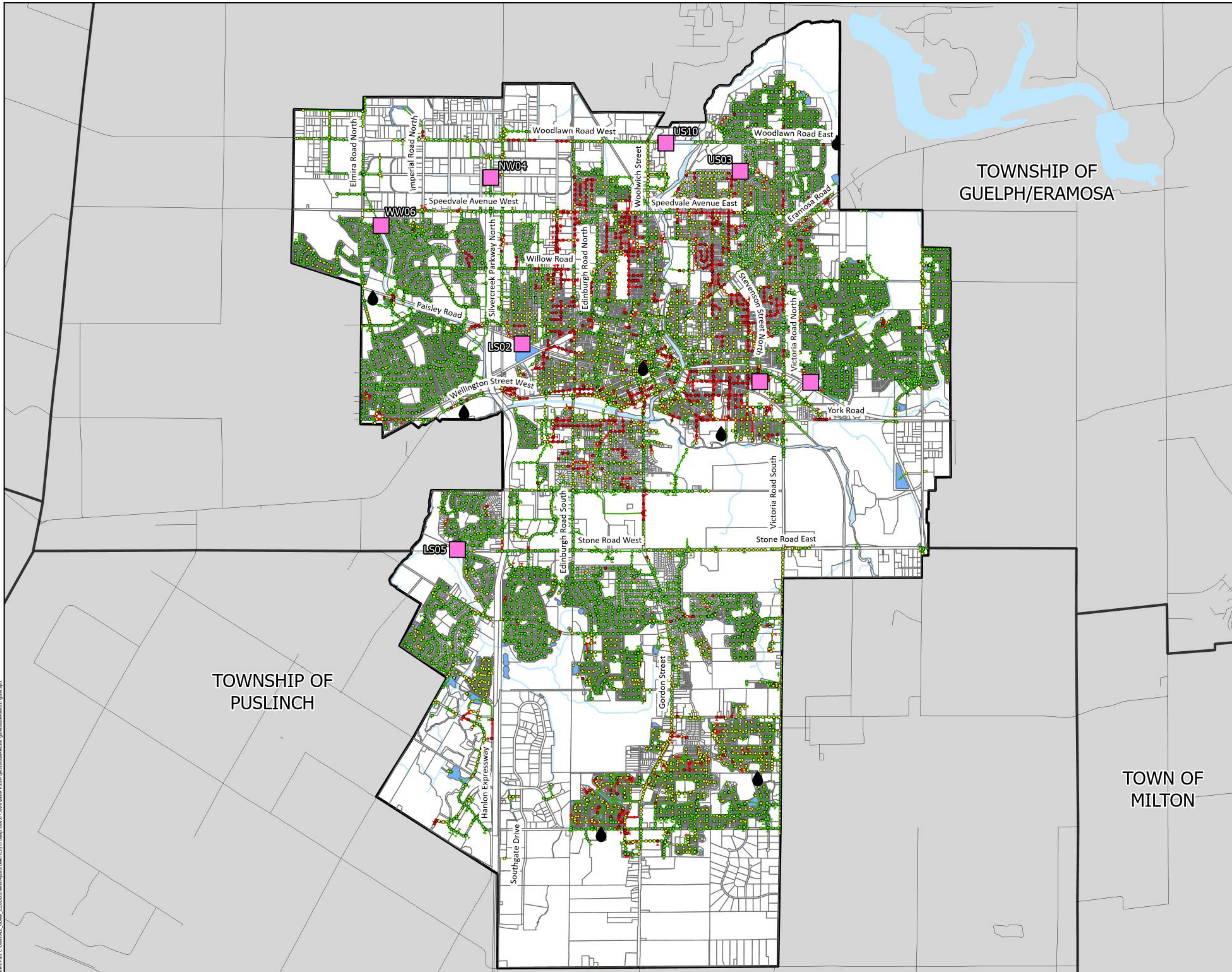
		Future Growth and Climate Change		14mm Green Infrastructure		Change in Service	
		Count	Length (km)	Count	Length (km)	Count	Length (km)
Minor System Nodes	At or Above Surface	3014 (34%)	-	803 (9%)	-	-2211 (-73%)	-
	0-1.8m Below Ground Surface	3505 (40%)	-	2886 (33%)	-	-619 (-18%)	-
	>1.8m Below Ground Surface	2274 (26%)	-	5104 (58%)	-	2830 (-124%)	-
Minor System Pipes	Surcharged (Bottleneck)	-	280 (59%)	-	61 (13%)	-	-219 (-78%)
	Unsurcharged	-	192 (41%)	-	411 (87%)	-	219 (114%)

3.7.2 Major System Results

The of implementing the 14mm of volume control throughout the City on the existing major system is displayed in **Figure 3.11,** where water depth greater than 0.3m is highlighted in red. **Figure 3.7** identifies the change in the level of service provided during the 1:100-year event from the future growth and climate change scenario to the 14mm green infrastructure scenario. An increase of 0.3km of ROW has a flow depth greater than 0.3m during the 14mm green infrastructure scenario compared to the future growth and climate change scenario, suggesting that the proposed upgrades will reduce ROW flooding.

Table 3.16: Comparison of Future Growth and Climate Change and 14mm Green Infrastructure Scenarios (Major System)

		Future Growth and Climate Change	14mm Green Infrastructure	Change in Service
		Length (km)		
Major System	**Depth >0.3m**	1.7 (0.5%)	1.4 (0.4%)	-0.3 (-20%)
	Depth 0.15m–0.3m	115 (31%)	106 (28%)	-9 (-8%)
	Depth <0.15m	258 (69%)	268 (71%)	10 (4%)



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

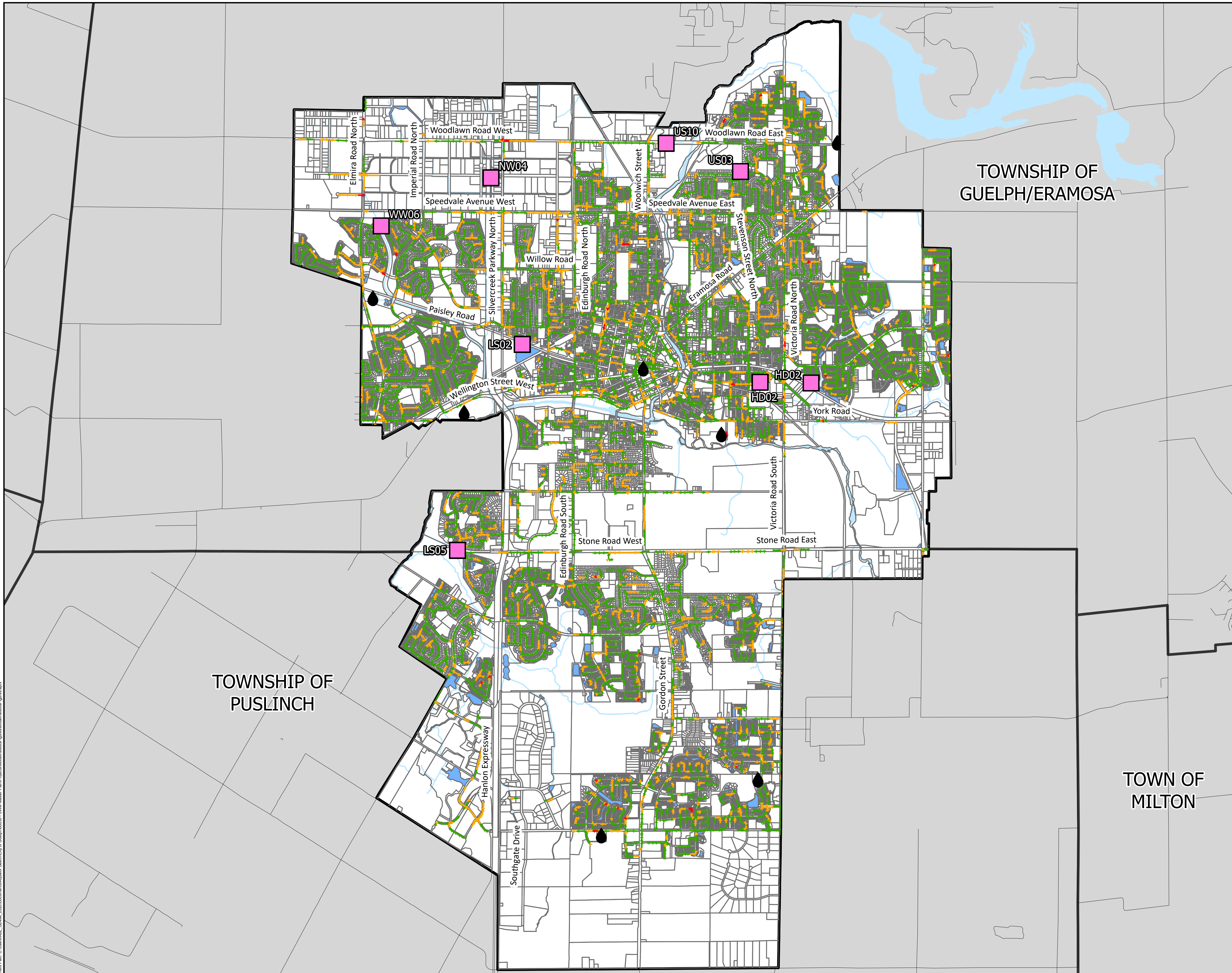
Figure 3.14

Scenario 7 – Green Infrastructure (14mm Volume Control), Minor System Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Flow Monitoring Locations (AMEC)
- Rain Gauge Locations (Municipal & GRCA)
- Stormwater Management Facility

Overland Flooding Depth(m):

- >0.3m
- 0.15m - 0.3m
- 0 - 0.15m

Figure 3.15

Scenario 7 - Green Infrastructure (14mm Volume Control), Major System Results

Date: 2022-09-20
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Aquafor Beech Limited

3.8 Scenario 8 – 2D Model of Top Flood Prone Areas

Based on the results of Scenarios 1–3, in addition to City-identified flooding issues, a total of four locations were identified to complete 2D modeling. Locations for 2D modeling were identified using three criteria (**Figure 3.16**):

1. City-identified areas of concern (frequent impact locations);
2. Density of flooding complaints; and
3. Low points in the road ROW within 20m of a modeled overland flow depth of 0.3m.

Four locations were identified based on these criteria, which are summarized in **Table 3.8**. While the intersections of Exhibition Street and Division Street, as well as Lowes Road West and Dawn Avenue, would have met the above criteria, it was not included in Scenario 8 as it had already been accelerated as a separate study.

Table 3.17: 2D Modeling Locations

Location	Rationale
Paisely at Imperial	• City identified ROW flooding
Carter Street	• Low point near modeled flow depth of 0.3m • Hot spot of flooding complaints from residents
Grove Street	• City identified ROW flooding
College at Stone	• City identified reverse-sloped driveways causing flooding concerns

3.8.1 2D Model Set Up

The 2D hydrologic model was created based on the 1D PCSWMM model. The contributing subcatchments were clipped out of the existing future condition City-wide model being developed by Aquafor Beech for the overland flow. A total of eighty-six (86) subcatchments from 1D model were selected as 2D study area. The Manning's roughness value of overall 2D study areas was assigned to be 0.08, and the roughness value of road areas was assigned to be 0.015. The 2D Nodes were created within the 2D study areas with 10 m resolution for overall 2D areas and 5 m resolution for road areas. The elevations of 2D Nodes were assigned based on the DEM provided by the City. The 2D cells were then generated from the 2D Node layer. A building layer provided by the City was used in the 2D model setting up to ensure that 2D cells were not created on buildings and to allow surface runoff flow surround the buildings. A total of 8557 2D nodes and 8645 2D cells were generated in the 2D study areas.

2D cells in PCSWMM only conduct overland flow and would not simulate precipitation in the 2D study area. Therefore, it is necessary to create subcatchment for every 2D node. The subcatchments were generated in 2D study areas with exact same shape and location of the corresponding 2D cells, and were connected to the 2D nodes. The 2D study area subcatchments were using the same infiltration method and parameters of the 1D model subcatchments, and the slope percentage was recalculated for every subcatchment.

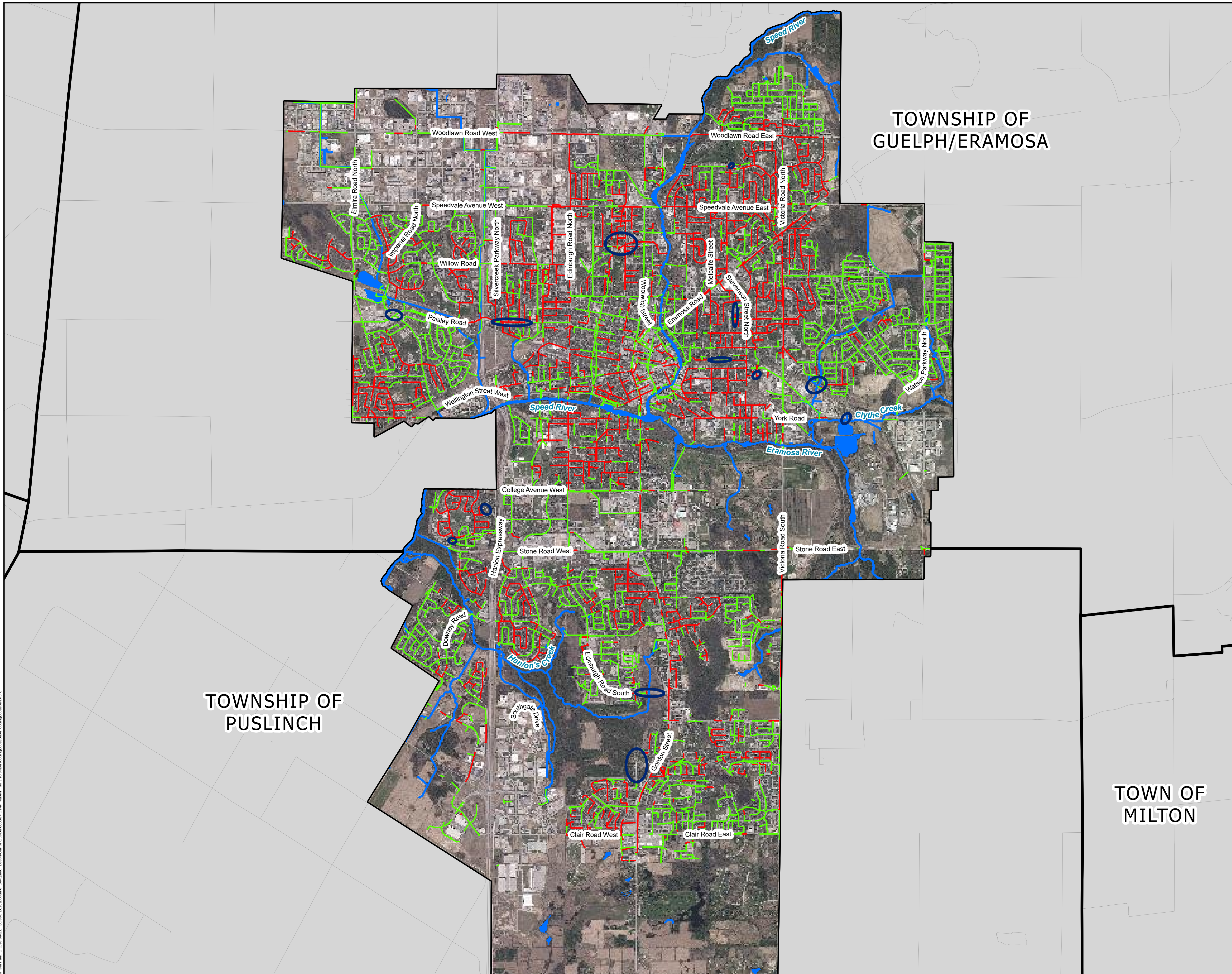
The conduits of the major system within the 2D study areas were deleted, and the 1D major system junctions were connected to 2D overland flow in order to apply the rating curves of catch basins and allow surface flow to transfer from 2D floodplain to minor system. 2D outlets were created where overland flow can exit the 2D study area boundary, such as low elevation ground surface.

3.8.2 2D Model Results

The results of 2D model on the existing storm sewer network are displayed in **Figure 3.17** to **Figure 3.20**, where surcharged sewers are highlighted in red. Compared with the climate change future growth scenario, these figures show that some of the minor system pipes in 2D model are not surcharged in the 1:5-year event while the 1D model results show surcharged. This is because the 2D model would have surface water ponding without collected in sewer system. **Table 3.18** shows the highest flood depth in the four 2D study areas.

Table 3.18: Future Growth and Climate Change Condition Flood Depth in 2D Study Areas

2D Study Area	Maximum Flood Depth
Paisley at Imperial	0.82 m (1:5-year event) 1.04 m (1:100-year event)
Carter Street	0.37 m (1:5-year event) 0.75 m (1:100-year event)
Grove Street	0.53 m (1:5-year event) 0.82 m (1:100-year event)
College at Stone	0.47 m (1:5-year event) 0.57 m (1:100-year event)



Legend

- Municipal Boundary
- Rivers
- Watercourse
- Frequent Impact Locations

Stormwater Sewer:

- Surcharge State = 1 (Bottleneck)
- Within Capacity (No Surcharge)

Flooded Addresses Per Km²:

- 0 - 6
- 6 - 12
- 12 - 18
- 18 - 24
- 24 - 30
- 30 - 36
- 36 - 43.03

LOCATOR MAP

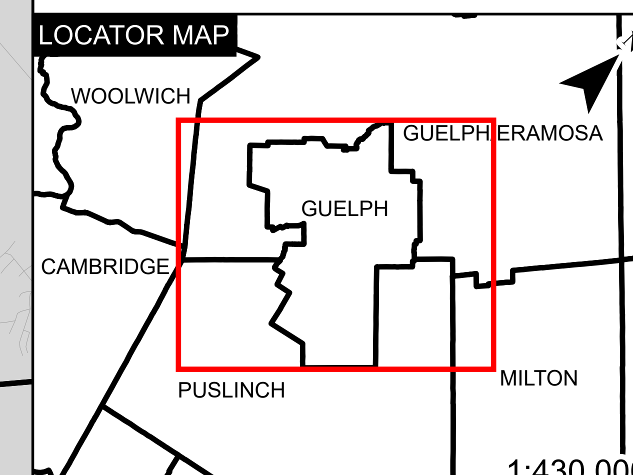
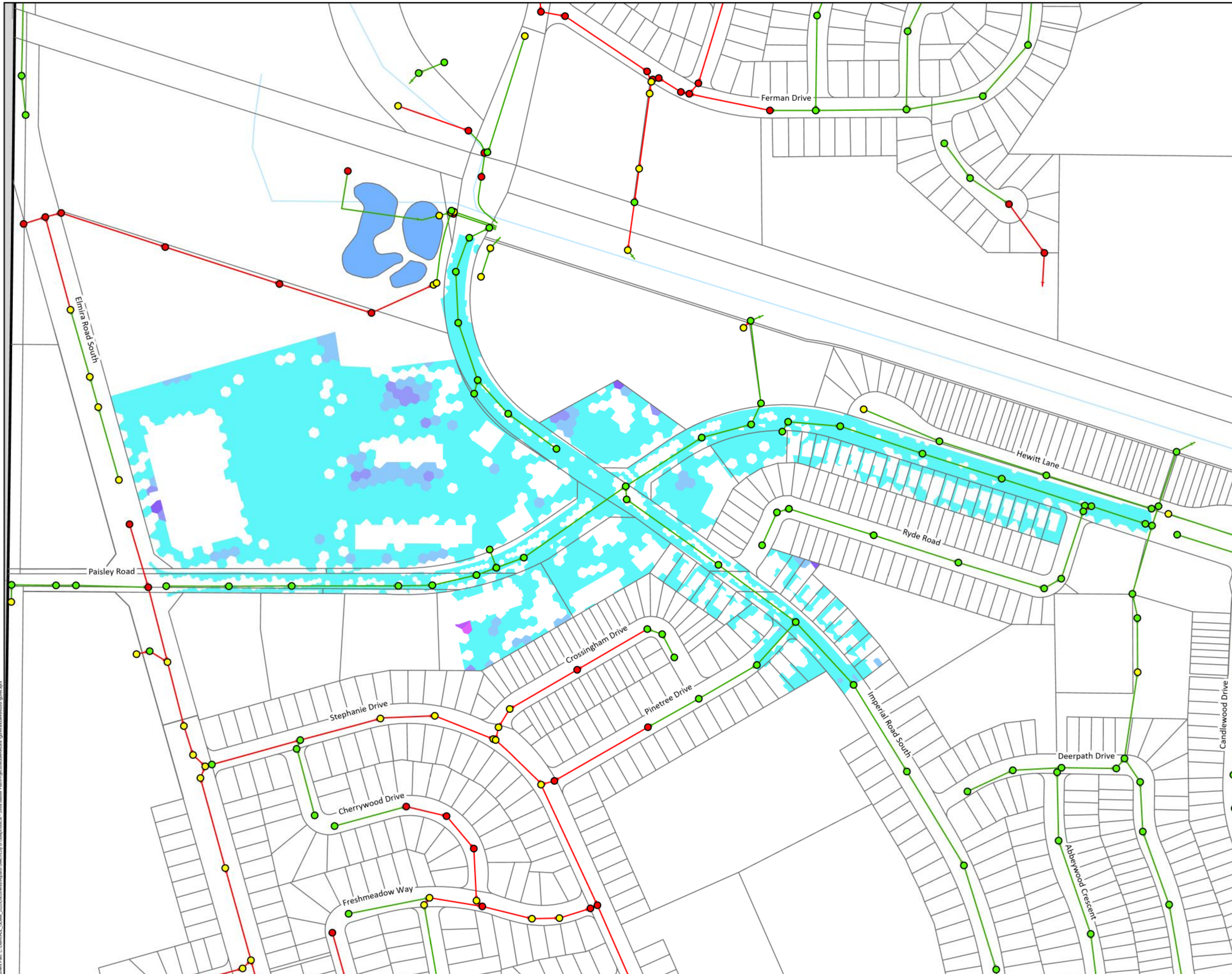


Figure 3.16

Criteria to Identify 2D Modeling Locations

Date: 2022-08-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Maximum Depth (m):

- 0 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.45

LOCATOR MAP

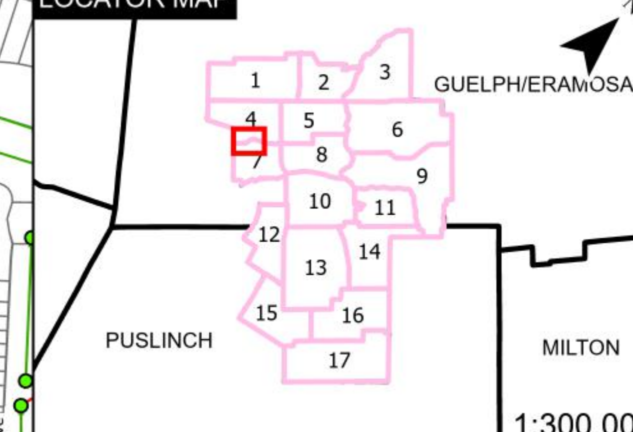


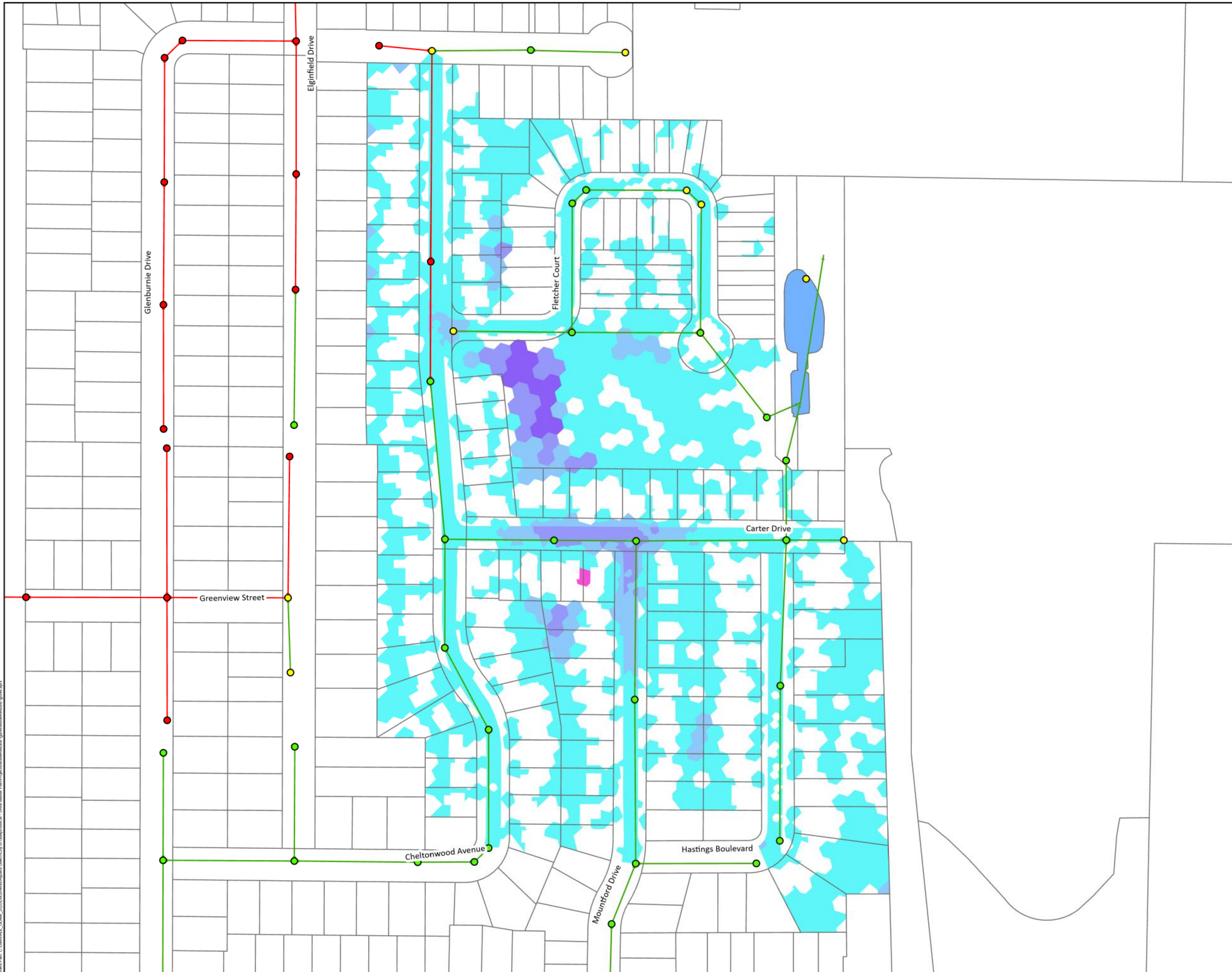
Figure 3.17

Paisley at Imperial 2D Model Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 30 60 120
Meters

Aquafor Beech Limited



Legend

- Municipal Boundary
- Property
- Watercourse
- Stormwater Management Facility

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

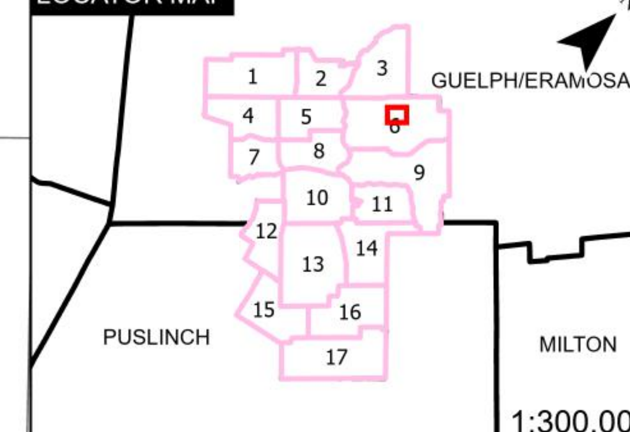
Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Maximum Depth (m):

- 0 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.45

LOCATOR MAP



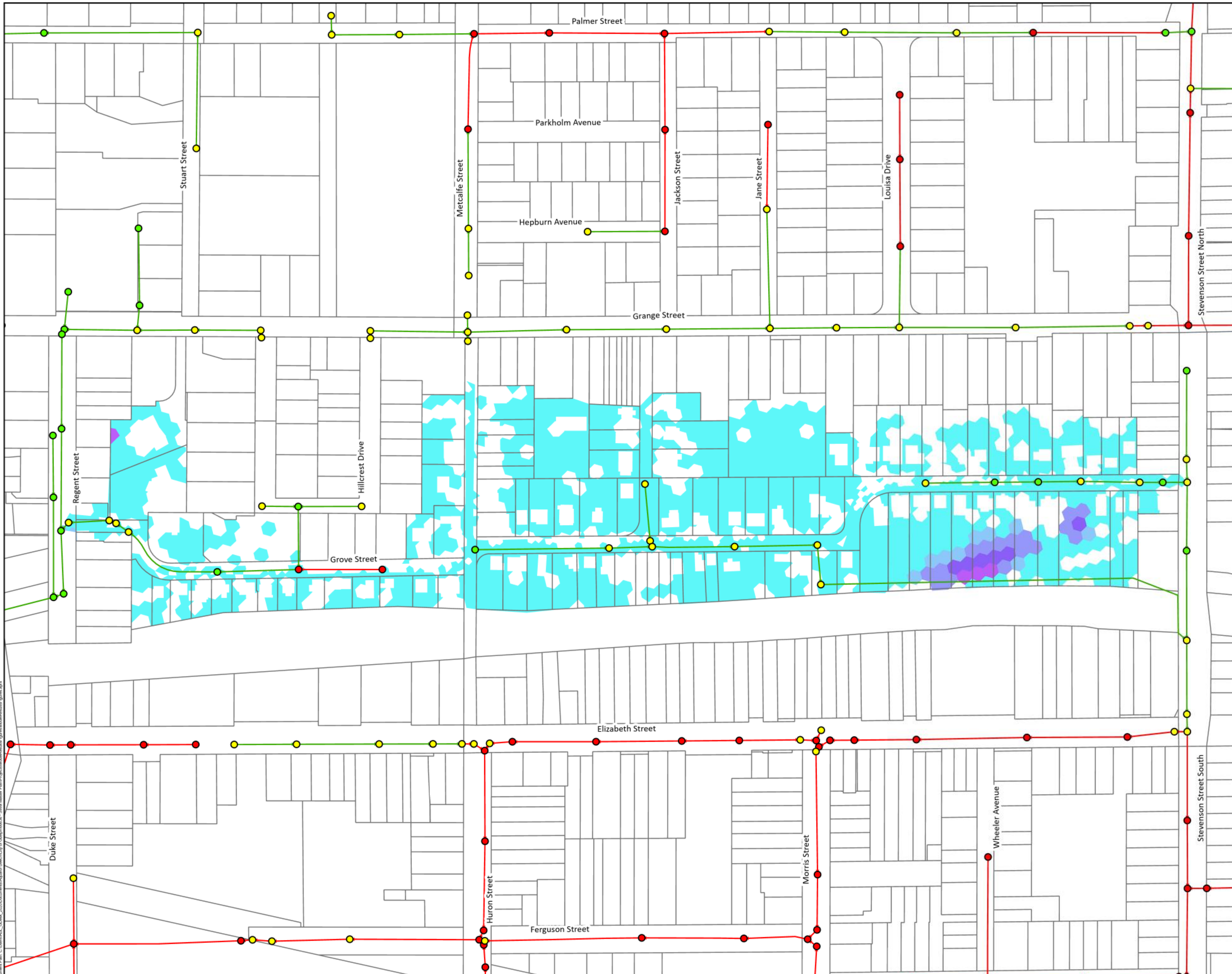
1:300,000

Figure 3.18

Carter Street 2D Model Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 20 40 80
Meters



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Property
- Watercourse

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Maximum Depth (m):

- 0 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.45

LOCATOR MAP

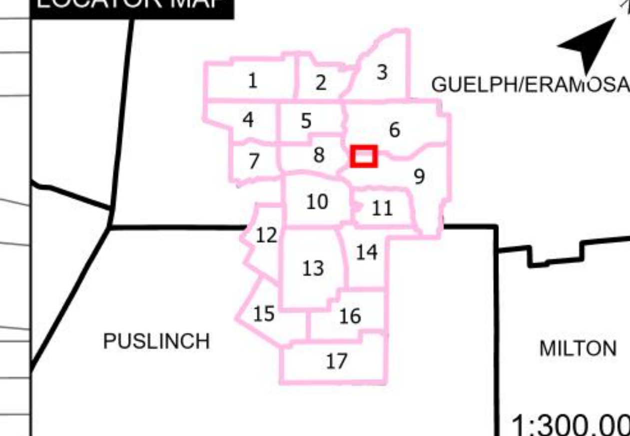


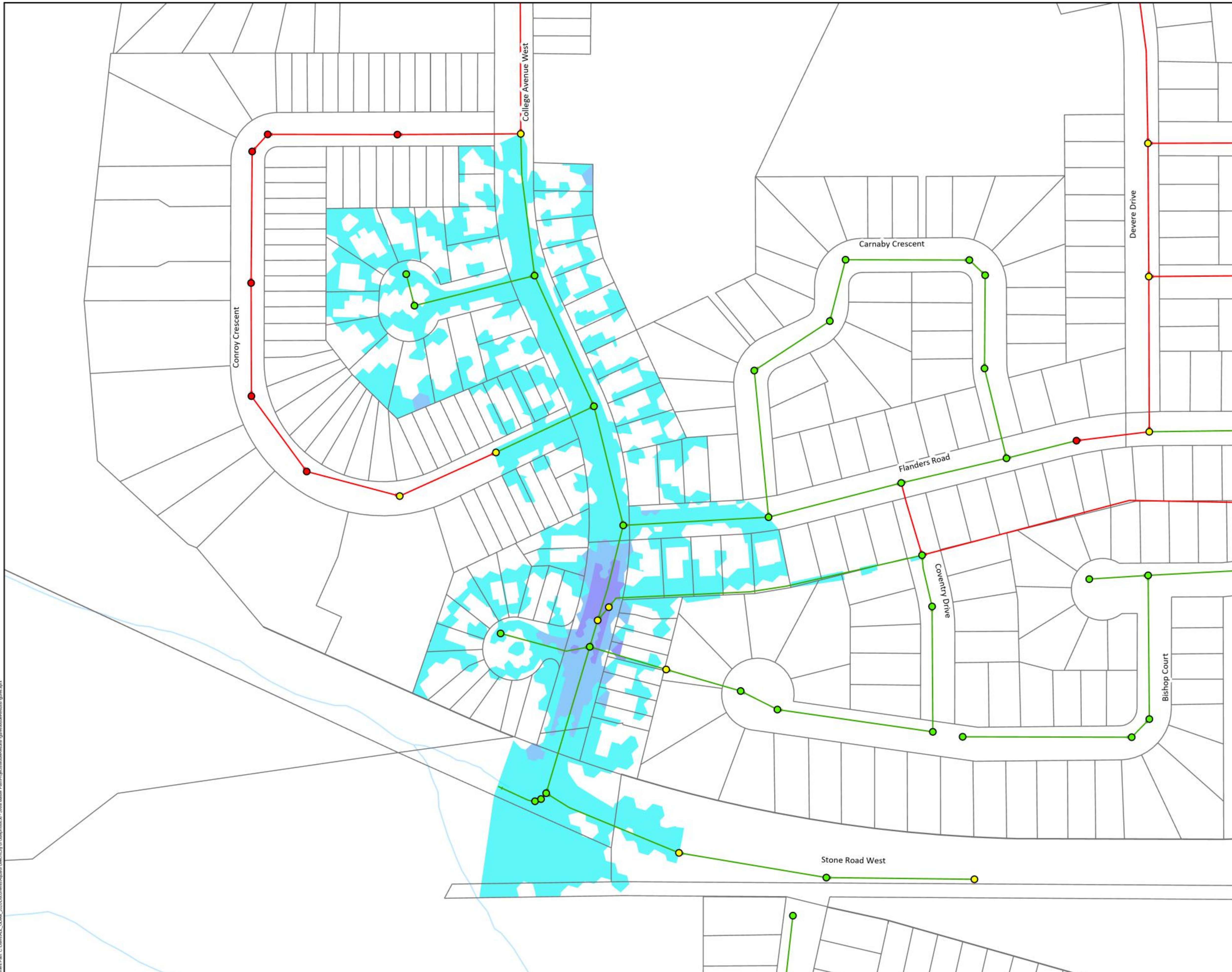
Figure 3.19

Grove Street 2D Model Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 25 50 100
Meters

Aquafor Beech Limited



Legend

- Municipal Boundary
- Property
- Watercourse

Stormwater Sewer:

- Unsurcharged
- Surcharged (Bottleneck)

Node Hydraulic Grade Line:

- At or Above Surface
- 0-1.8m Below Ground Surface
- > 1.8m Below Ground Surface

Maximum Depth (m):

- 0 - 0.20
- 0.20 - 0.40
- 0.40 - 0.60
- 0.60 - 0.80
- 0.80 - 1.00
- 1.00 - 1.20
- 1.20 - 1.45

LOCATOR MAP

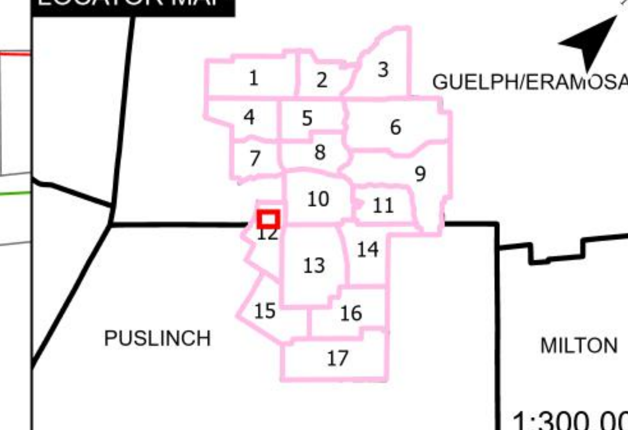


Figure 3.20

College at Stone 2D Model Results

Date: 2023-02-22
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 20 40 80
Meters

3.9 Summary of Results

The results of the eight scenarios were used to establish the preliminary cost implications of the overall SWM-MP strategy. **Table 3.19** represents the preliminary cost implications associated with each of the modelling scenarios, assuming a unit cost of $1,250 per linear metre of surcharged sewer.

It must be noted that the cost implications below are based on the quasi-calibrated model results and as such may not represent the actual cost implications. It is recommended that this preliminary assessment be refined as part of next steps. Furthermore, it is therefore most appropriate at this stage to examine the % of cost change from existing conditions as a means to compare the scenario results. In this manner **Table 3.19** illustrates the effect of future growth (43.7% increase in cost) and climate change (43.2% increase in cost) on existing conditions. The similar results for the Future Growth scenario and Future Growth and Climate Change scenario imply that many of the City's storm sewers are resilient to both development and climate change, but that the remainder are vulnerable to the increase in runoff caused by both scenarios. The remaining scenarios demonstrate the effect of the application of LID via various volume retention target on improving the existing conditions (up to 89.5 per cent reduction in storm sewer replacement costs) and in mitigating the effects of climate change and future development.

Table 3.19: Preliminary Storm Sewer Replacement Cost Estimates

Scenario #	Scenario Name	Total Length of Surcharged Storm Sewers (m)	Preliminary Cost ($ millions)*	Preliminary Cost Implications (% Change from baseline)*
1	Existing Conditions	195.3	$244.1	N/A
2	Future Growth	281	$350.8	43.7%
3	Future Growth & Climate Change	280	$349.5	43.2%
4	Grey Infrastructure Only	81	$101.4	-58.4%
5	Green Infrastructure (28mm Volume Control)	20	$25.6**	-89.5%
6	Green Infrastructure (5mm Volume Control)	89	$111.4**	-54.4%
7	Green Infrastructure (14mm Volume Control)	61	$75.7**	-69.0%

*Assumes a unit replacement cost of $1,250/linear metre

** Does not include costs to implement volume control (See Table 3.20)

3.10 Preferred Model Scenario

Intensification and climate change scenarios demonstrate an increased risk of sewers which are at full capacity or surcharged. It can be determined that the preferred modelling scenario recommended for adoption is Scenario 6, Green Infrastructure (5mm volume control). Scenario 6 takes into account the predicted impacts of climate change as well as the application of a mitigation strategy through the use of a 5mm volume control. **Table 3.19** indicates that between the climate change scenario with and without volume controls, there is a potential cost savings of $238 million with the implementation of LIDs, as represented by the total length of surcharged sewers which would require replacement, not counting the cost of LID implementation.

Based on the cost implications of storm sewer replacement associated with Scenario 1 through 3, it is evident that the implementation of City-wide volume targets is beneficial. The implementation of LIDs in the form of source and conveyance controls on a City-wide scale can mitigate the affects of climate change and intensification. Volume targets associated with LID practices will reduce the length of storm sewers which are at full capacity or surcharging during the 5-year storm event.

3.11 Financial Impacts

The anticipated cost to replace the total length of surcharged pipes under Scenario 6 is estimated to be $111.4 million based on a unit cost of $1,250 per linear metre. This represents the estimated capital cost to replace only the sewers which were assessed as part of the storm sewer trunk system network model.

There are also financial implications to the installation of LID measures throughout the City. The costs to implement LID measures on all 425km of the City's road network are summarized in **Table 3.20**.

Table 3.20: LID Implementation Costs

Treatment Measure	Unit Cost ($/m of LID)	City-Wide Implementation ($ millions)
Perforated Pipe	$1160*	$493.2*
Bioretention (Boulevard or Bump Out)	$287**	$122.1**
Bioswales	$402**	$170.9**

* includes cost of road reconstruction typically attributed to stormwater
** in addition to cost of road reconstruction typically attributed to stormwater

As stated previously, it must be noted that the cost implications are based on the uncalibrated model results and as such may not represent the actual cost implications. It is recommended that this preliminary assessment be refined as part of next steps.

3.12 Recommendations and Next Steps

The following recommendations have been developed in support of next steps relating to the advancement of this model:

1. It is recommended that the City undertake monitoring of select storm sewer outfalls, both uncontrolled and SWM facility outlets where stage discharge relationships are not available, in order to calibrate the storm sewer model developed as part of this study. A sample outline of the flow monitoring program is provided in **Appendix D.** The development and implementation of a flow monitoring program is recommended to consisted of:

    a. Supply and installing flow monitors at a minimum of 15 locations within the storm system selected in consultation with the City for a period no less than 1-year. The selection of the monitoring locations within the storm sewer system should be based on the characteristics of the study drainage areas, the service area for the sewer systems and discussions with City staff. Selection of the sites are recommended to be based on the following:
        - Strategic locations within the study area where bottlenecks or flooding events have been previously identified;
        - Locations with satisfactory hydraulic sewer conditions in order to allow for the highest accuracy and reliability;
        - Strategic locations which are located in readily-accessible locations, preferably away from areas requiring high-traffic control or at locations of deep sewers;
        - At representative homogenous catchment areas, such that the hydrologic component of the hydraulic model can be calibrated.

    b. Completion of monthly field verification and calibration of flow monitors;

    c. Collection and storage of data in a digital based format; and

    d. Decommissioning of the flow monitoring equipment following the monitoring period.

2. It is recommended that the City calibrate the storm sewer model developed as part of this study. Calibration to 20% of peak flows and 20% of event volumes are recommended.

    a. The rainfall data selected to calibrate and validate the drainage sewer system model is recommended to include at least three (3) reasonably-sized recorded events.

    b. The events are to be preferably greater than 10mm at a majority of the rain gauges.

   c. The rain gauges shall have suitable coverage of the City, per the recommendations of the Rainfall and IDF Curve Analysis (October 2021)

3. Once the model is calibrated, it is recommended that the City re-run the key scenarios to confirm high-priority locations for storm sewer upgrades and other maintenance activities.

4. On a five-year cycle, it is recommended that the City review the level of volume control required across the City based on the lessons learned from implementing 5mm of volume control, as well as the results of the calibrated model.

5. Of the four locations selected for 2D modeling, it is recommended that:
   a. Grove Street requires additional studies, and is therefore recommended as a Neighbourhood Study as part of the SWM-MP;
   b. Road reconstruction works at Carter Street and College at Stone should include consideration for the major system components as well as storm sewer upsizing (e.g., upstream storage, increasing inlet capacity, etc.);
   c. The intersection of Paisley at Imperial should be investigated further through the City's existing SW0097 Stormwater Sewer Investigation line item, as the 2D modelling shows the ROW depth does not exceed 0.2m. The City previously identified that issues at this intersection may be due to plugged goss traps in catch basins, and this should be investigated.

4 References

ASCE, (1992). Design & Construction of Urban Stormwater Management Systems, New York, NY.

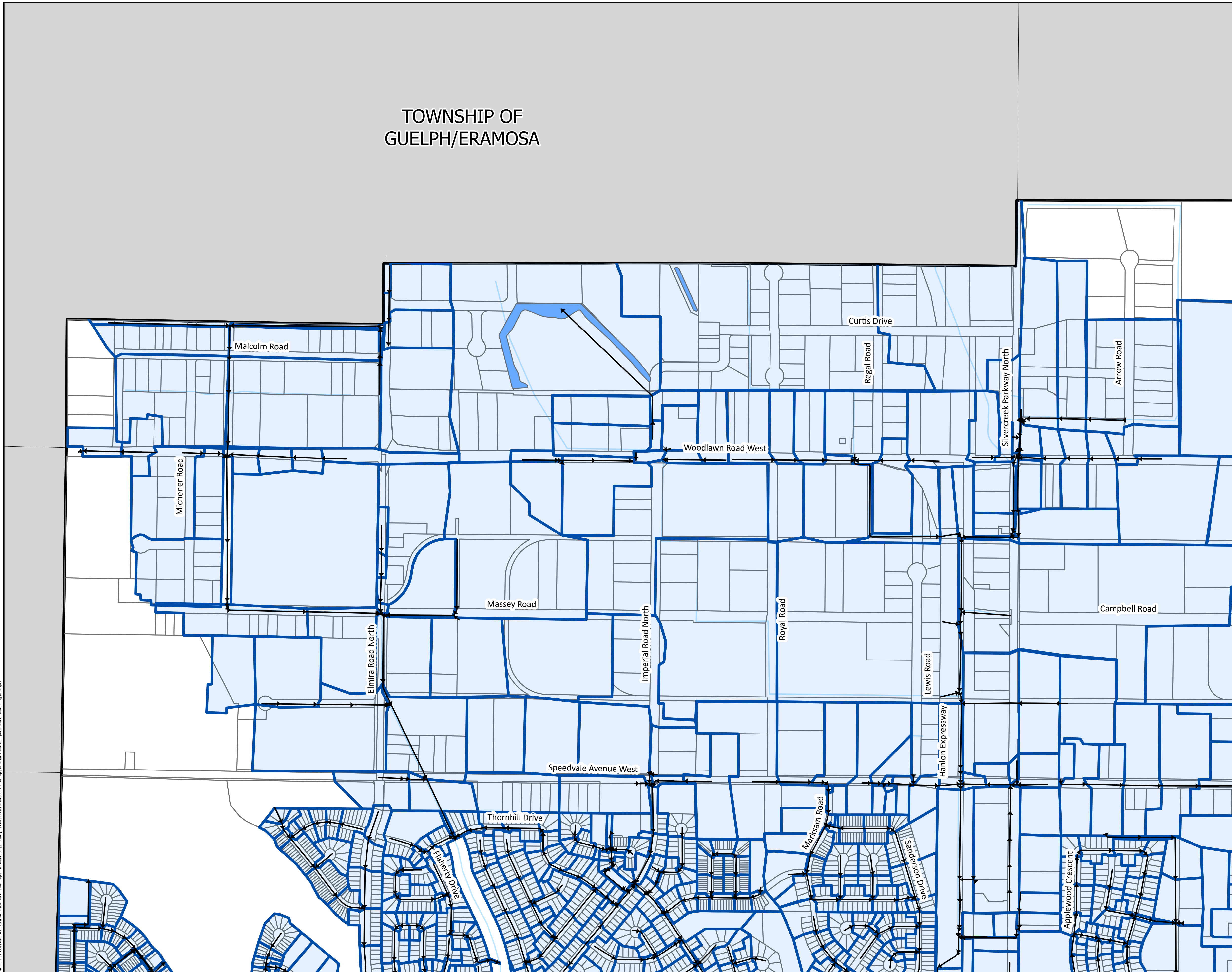
James, W., Rossman, L.E., Huber, W.C., Dickinson, R.E. and James, R.C. (2008) Water Systems Models: User's Guide to SWMM5. Computational Hydraulics International, Guelph, ON.

Urban Drainage and Flood Control District (UDFCD) (2001). Urban Storm Drainage Criteria Manual, 2007 revision. Denver, CO. (http://www.udfcd.org/downloads/down_critmanual.htm).

U.S. Environmental Protection Agency (1983). Results of the Nationwide Urban Runoff Program, Volume I Final Report. NTIS PB84-185552, U.S. Environmental Protection Agency, Washington, DC.

Appendix A: Model Inputs and Calibration Plots

Appendix A1: Subcatchment Delineation



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

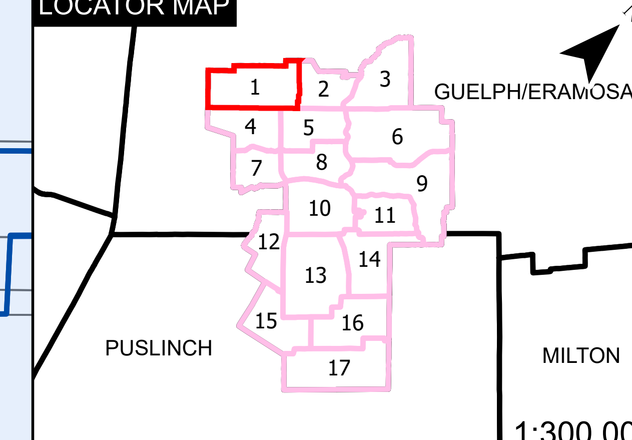
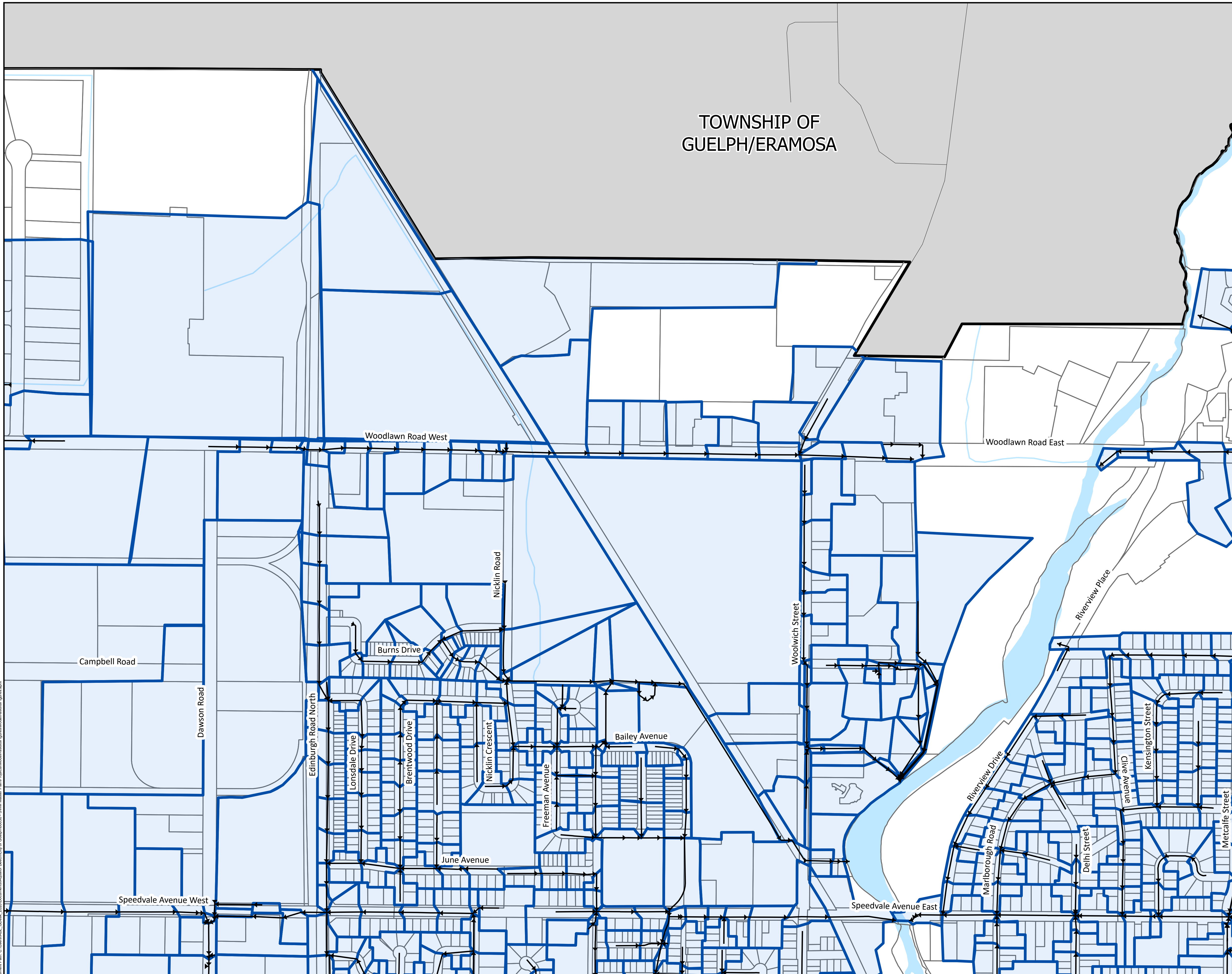


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 112.5 225 450
Meters

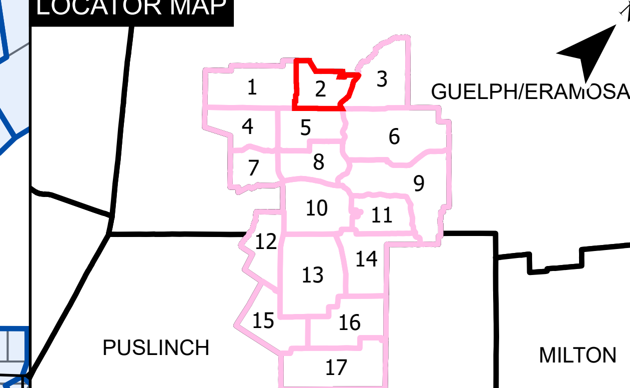


Guelph Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP



1:300,000

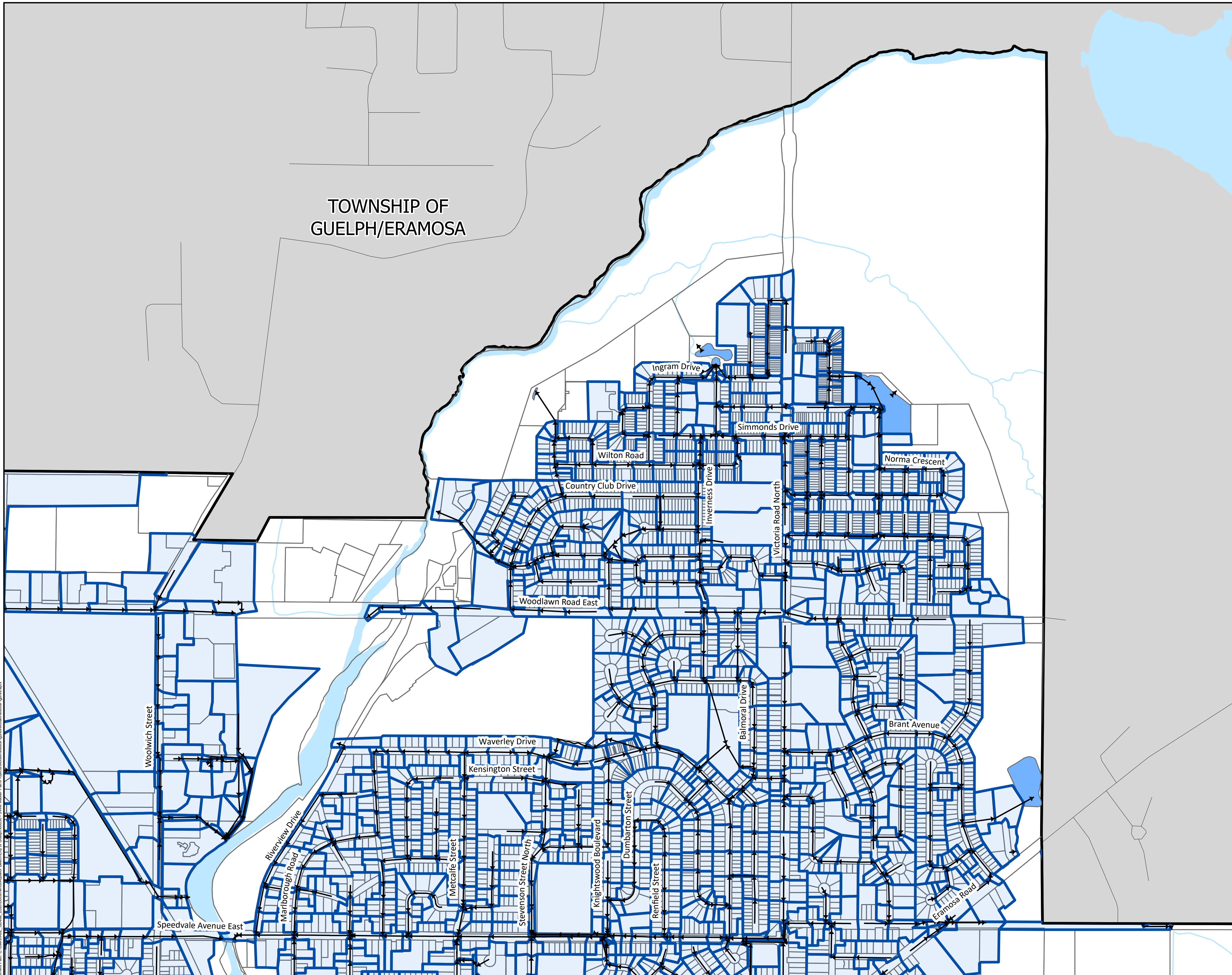
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 75 150 300
Meters

Aquafor Beech Limited

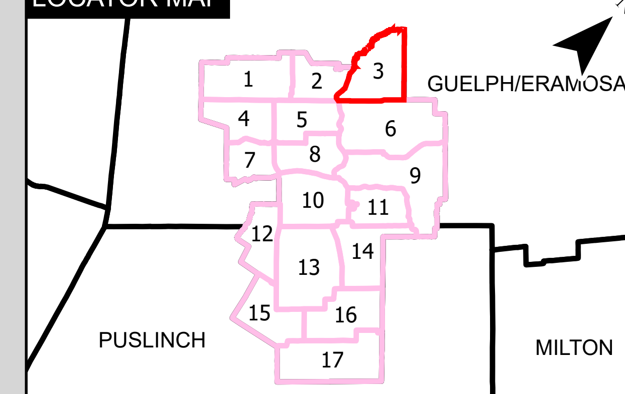


CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP



1:300,000

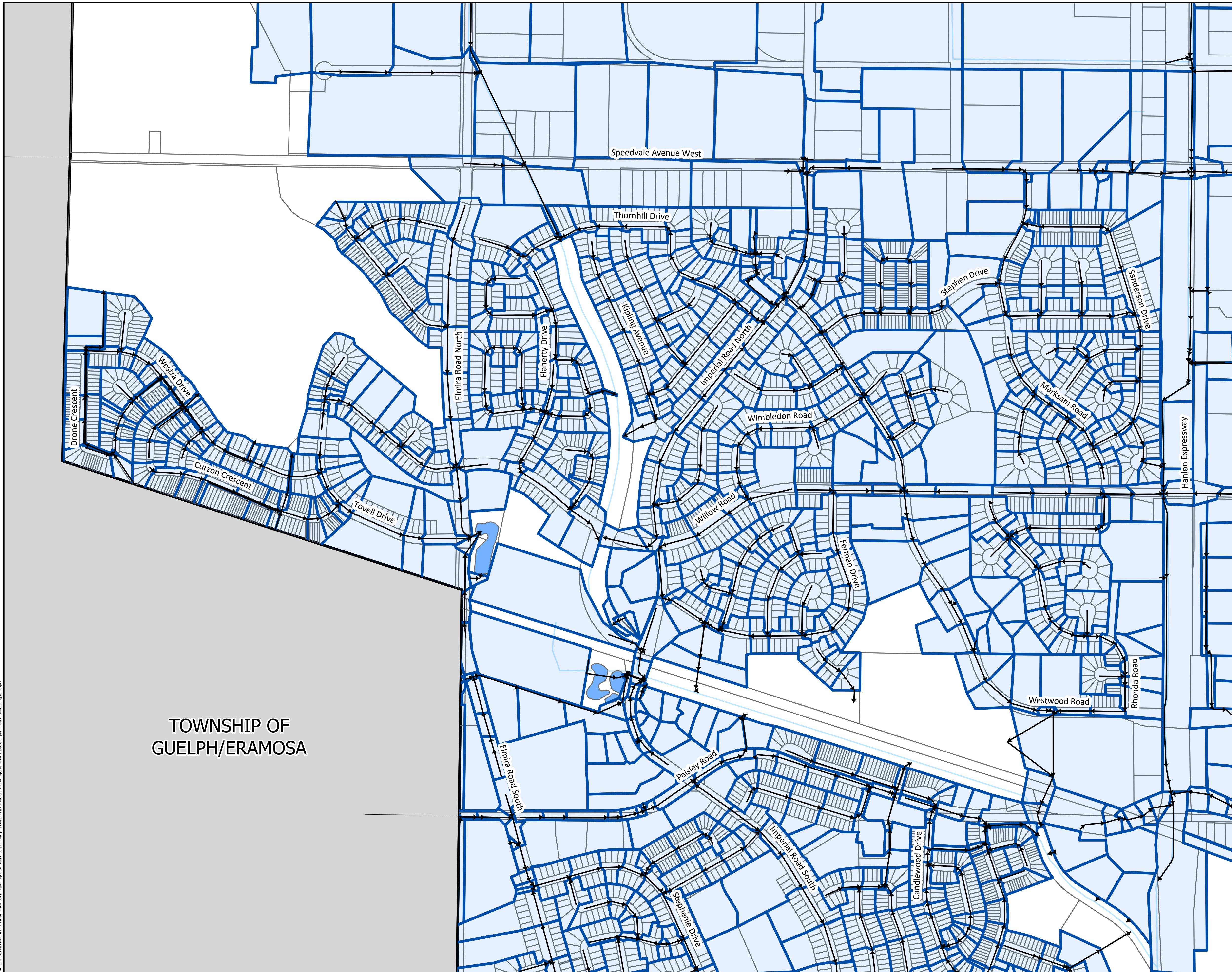
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 110 220 440
Meters

Aquafor Beech Limited



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

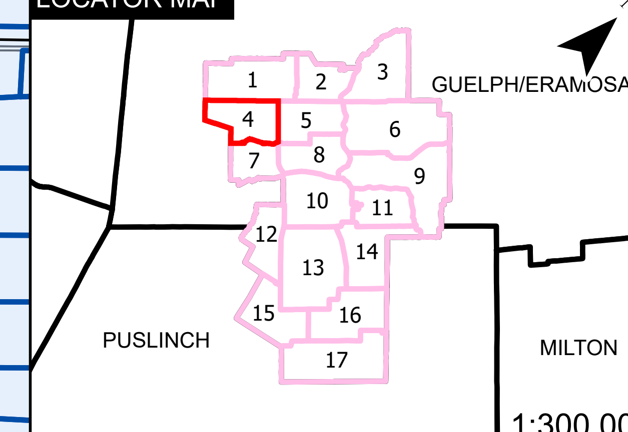


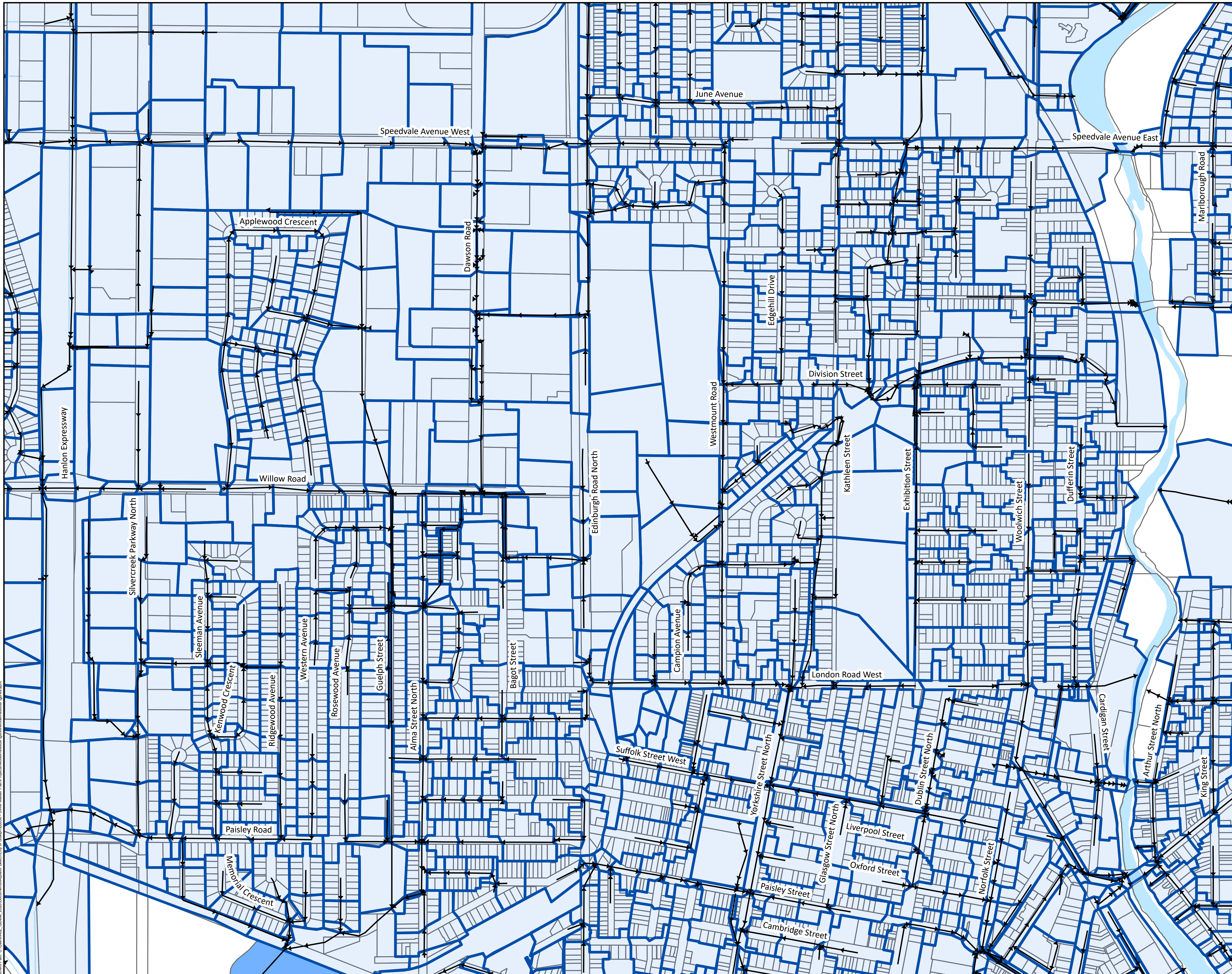
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 90 180 360
Meters

Aquafor Beech Limited



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

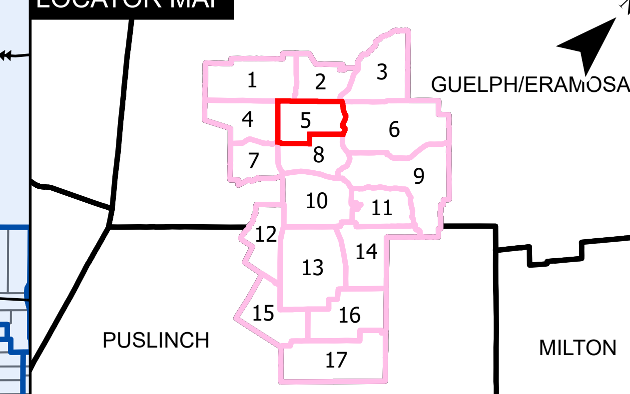


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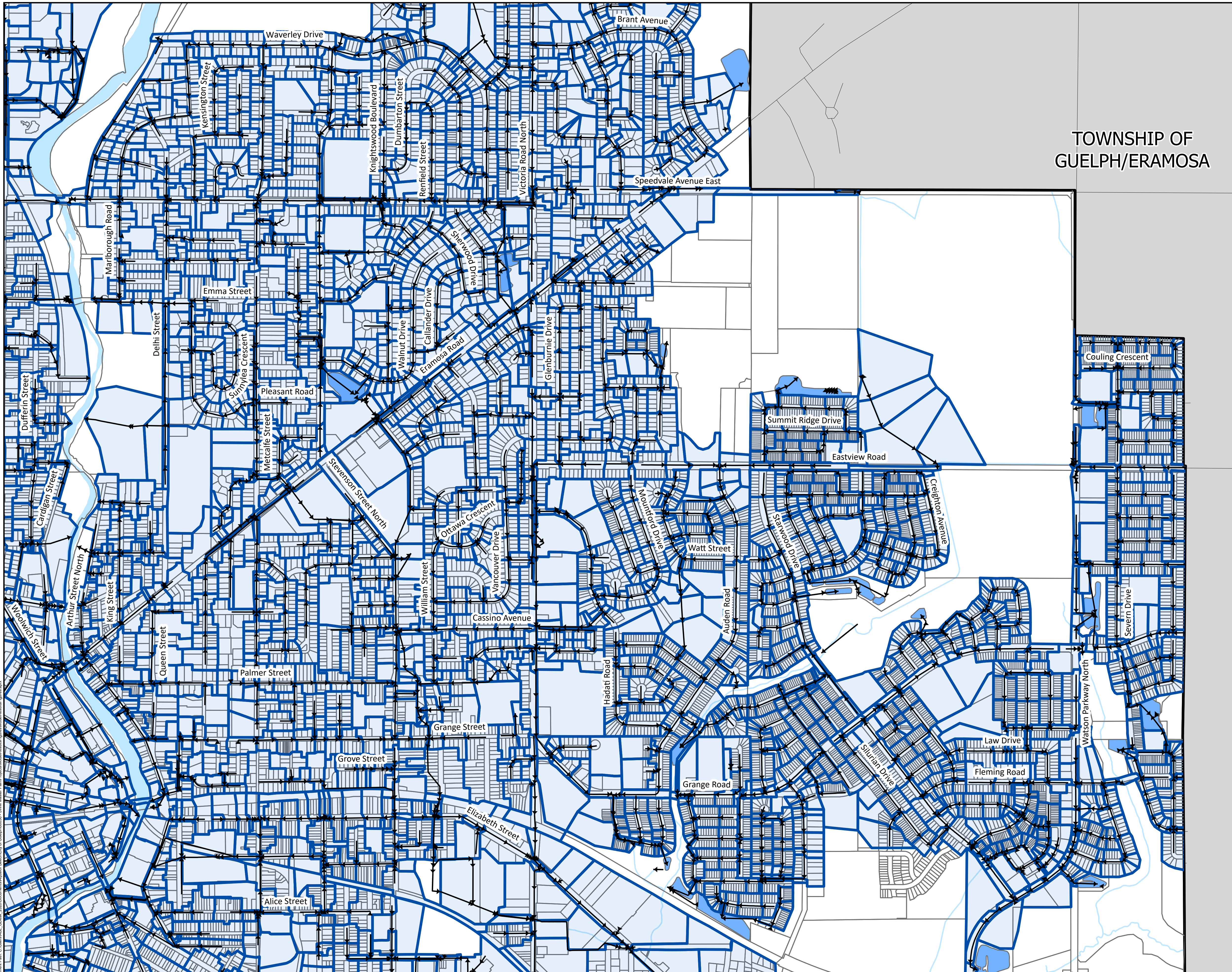
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 80 160 320
Meters

Aquafor Beech Limited



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

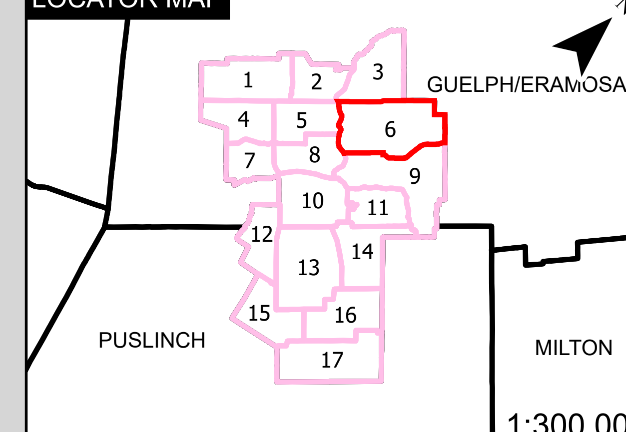
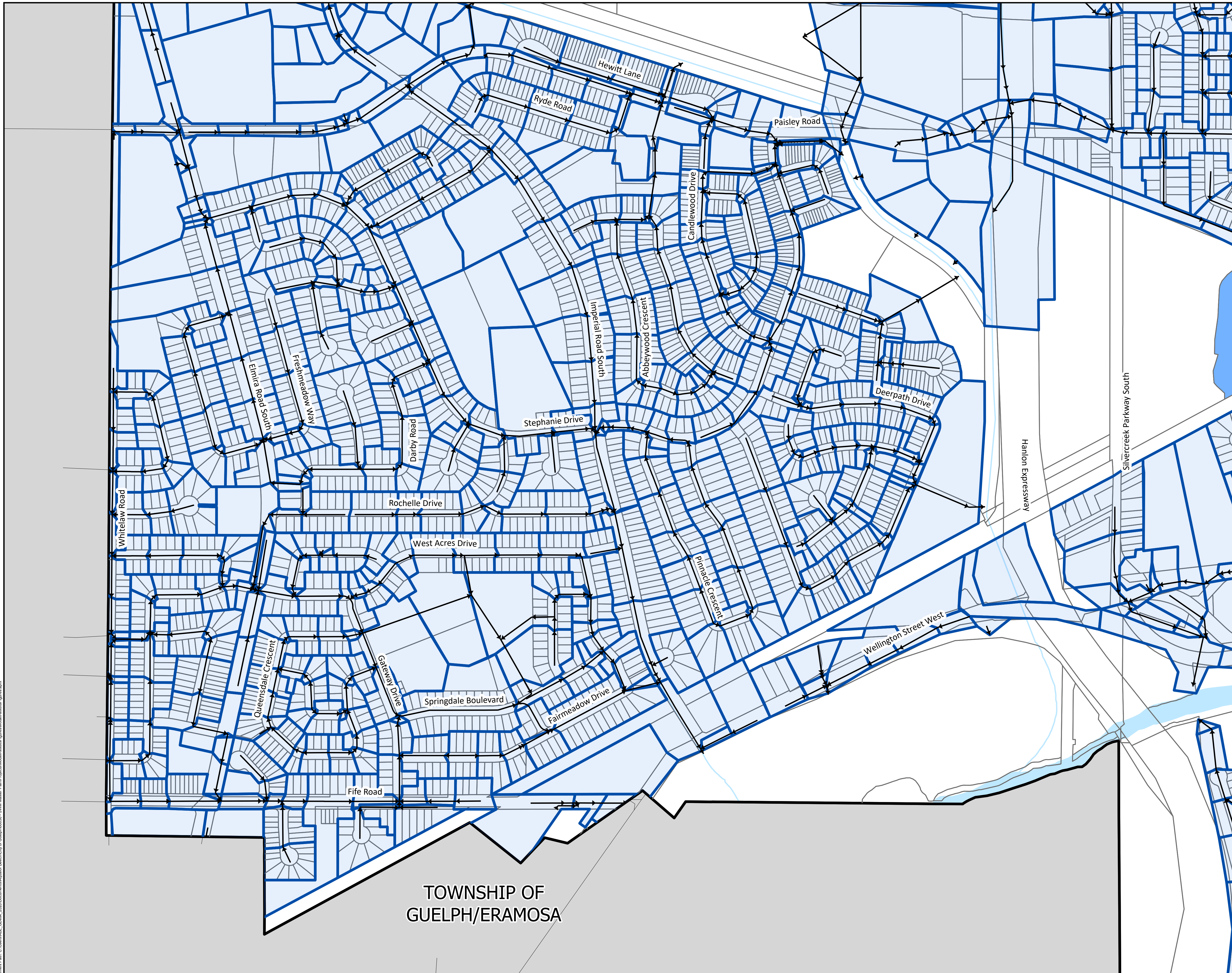


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 130 260 520
Meters



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

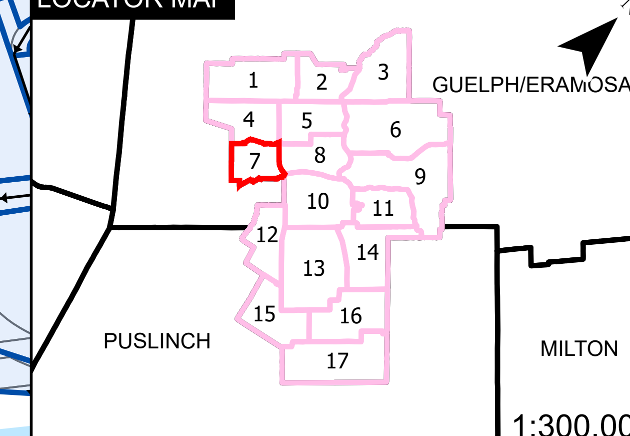


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

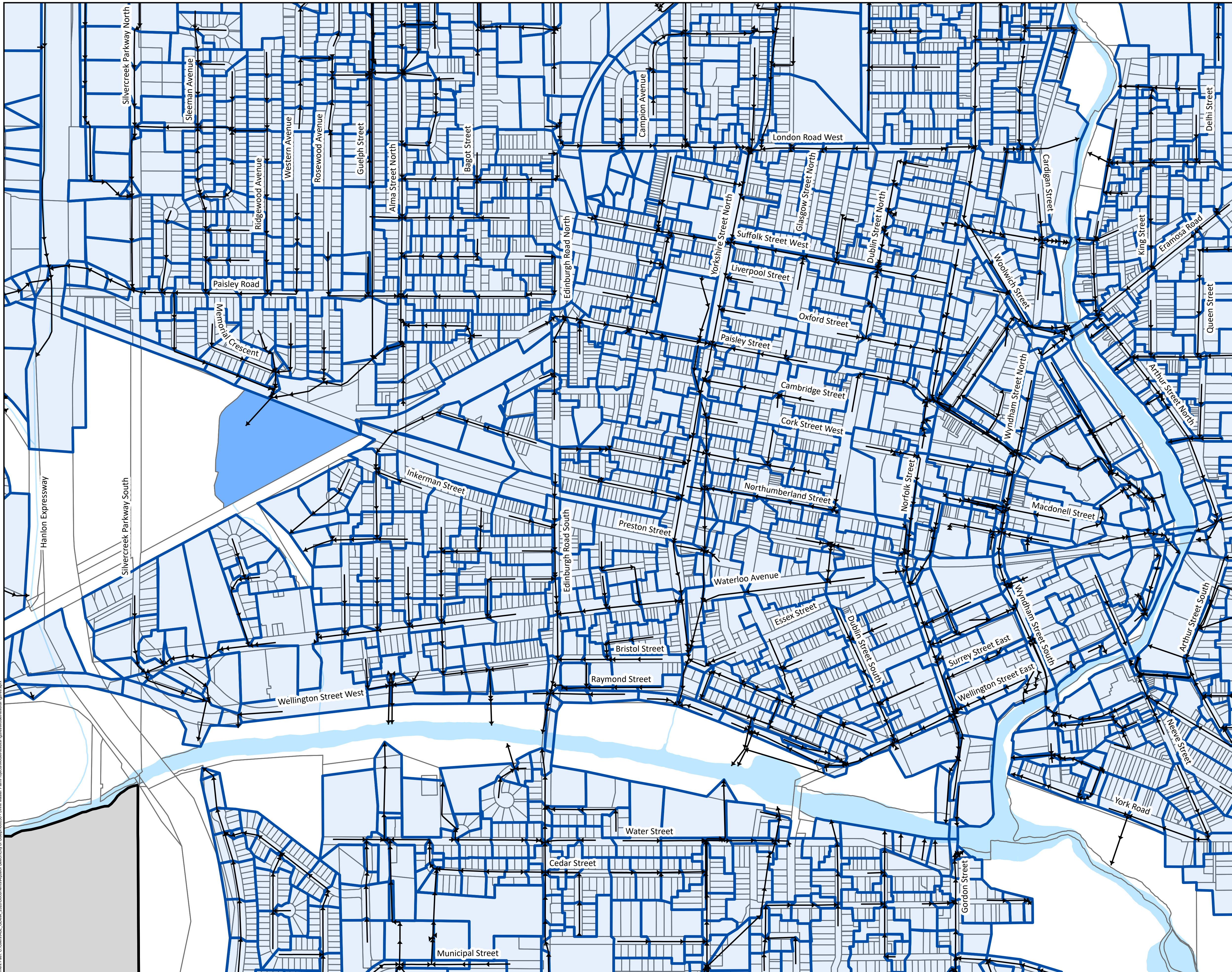
0 70 140 280
Meters

Aquafor Beech Limited

CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment



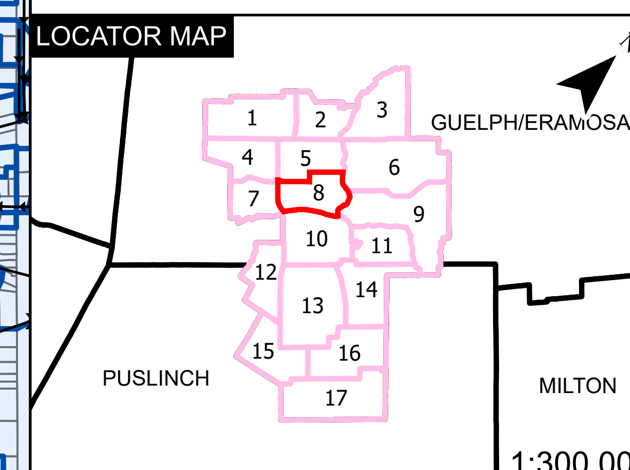


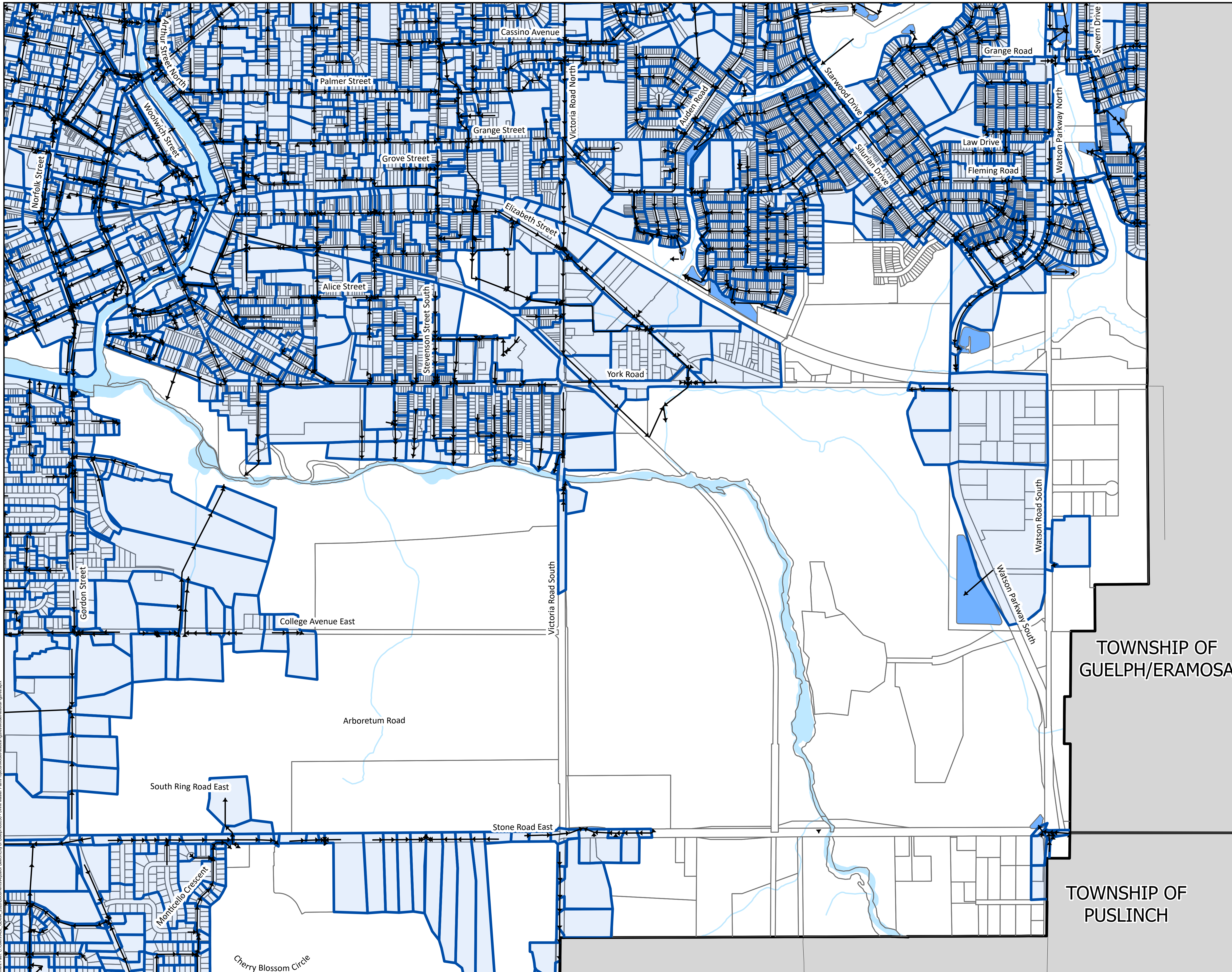
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 87.5 175 350
Meters

Aquafor Beech Limited



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

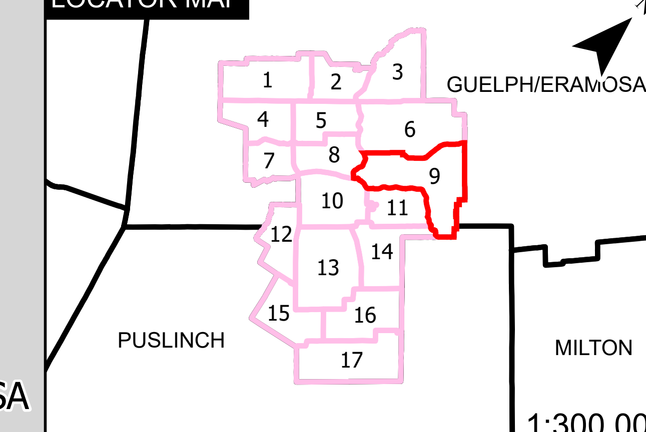


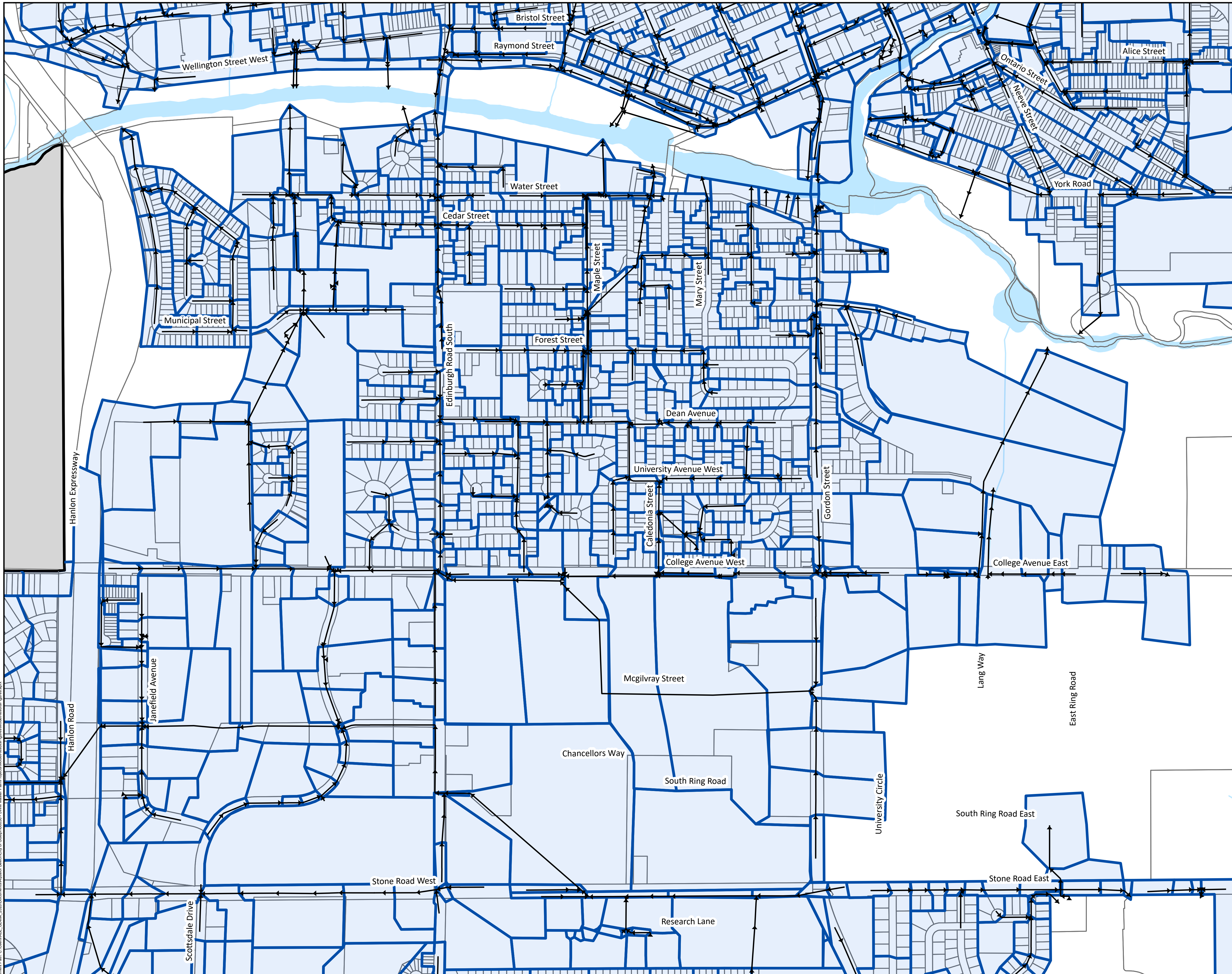
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 145 290 580
Meters

Aquafor Beech Limited



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

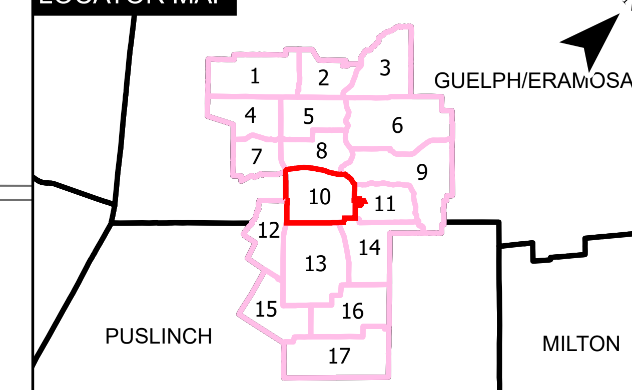


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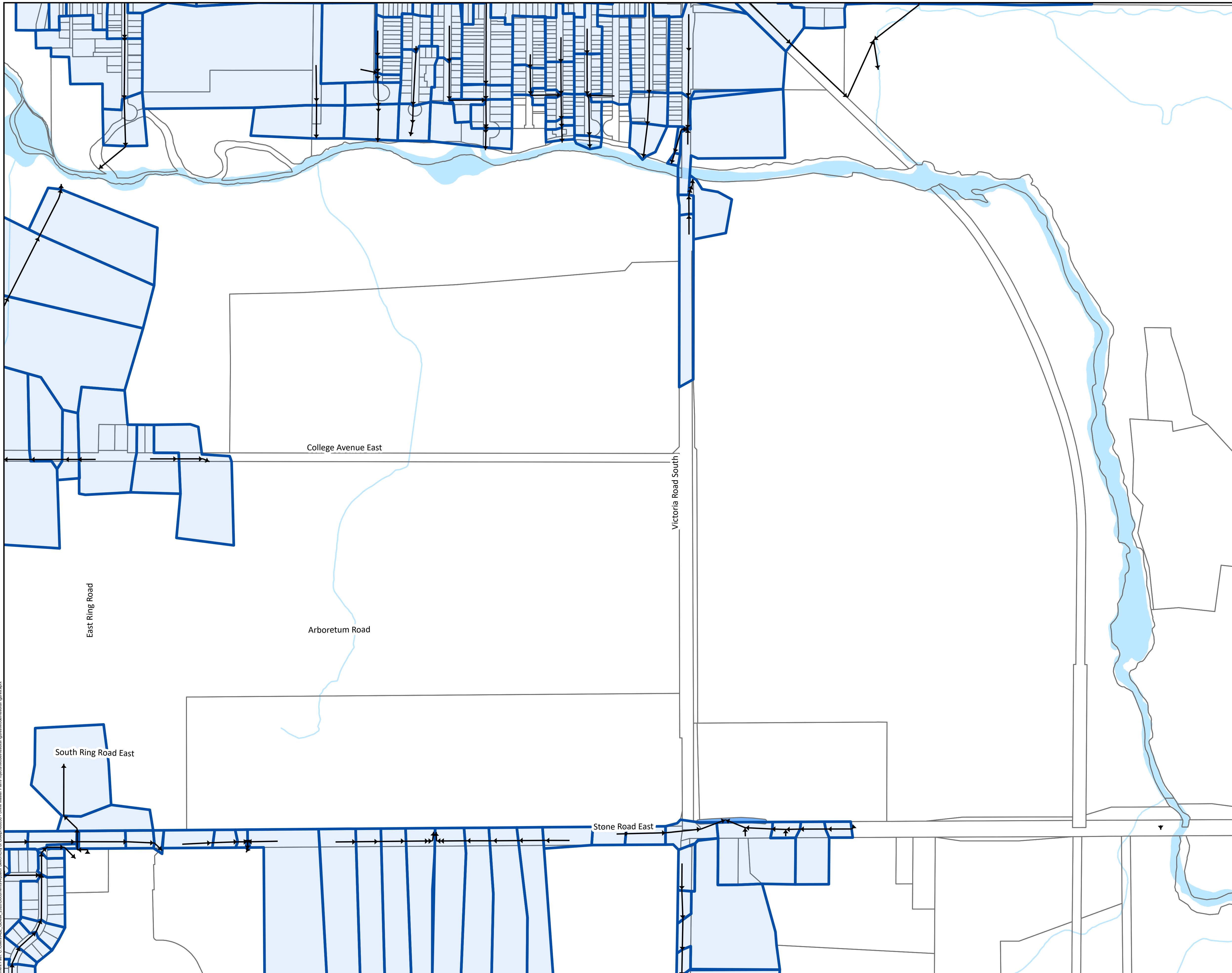
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 95 190 380
Meters



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

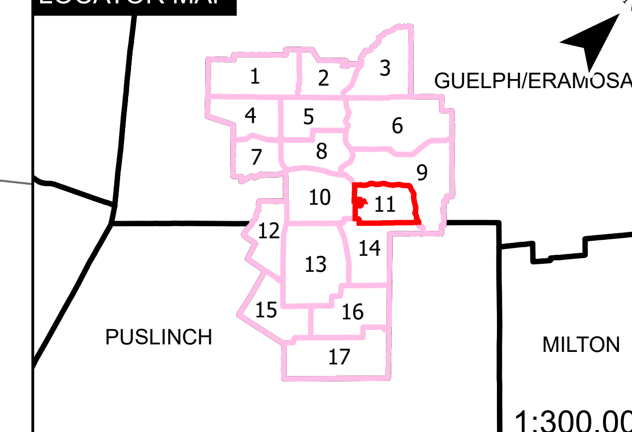
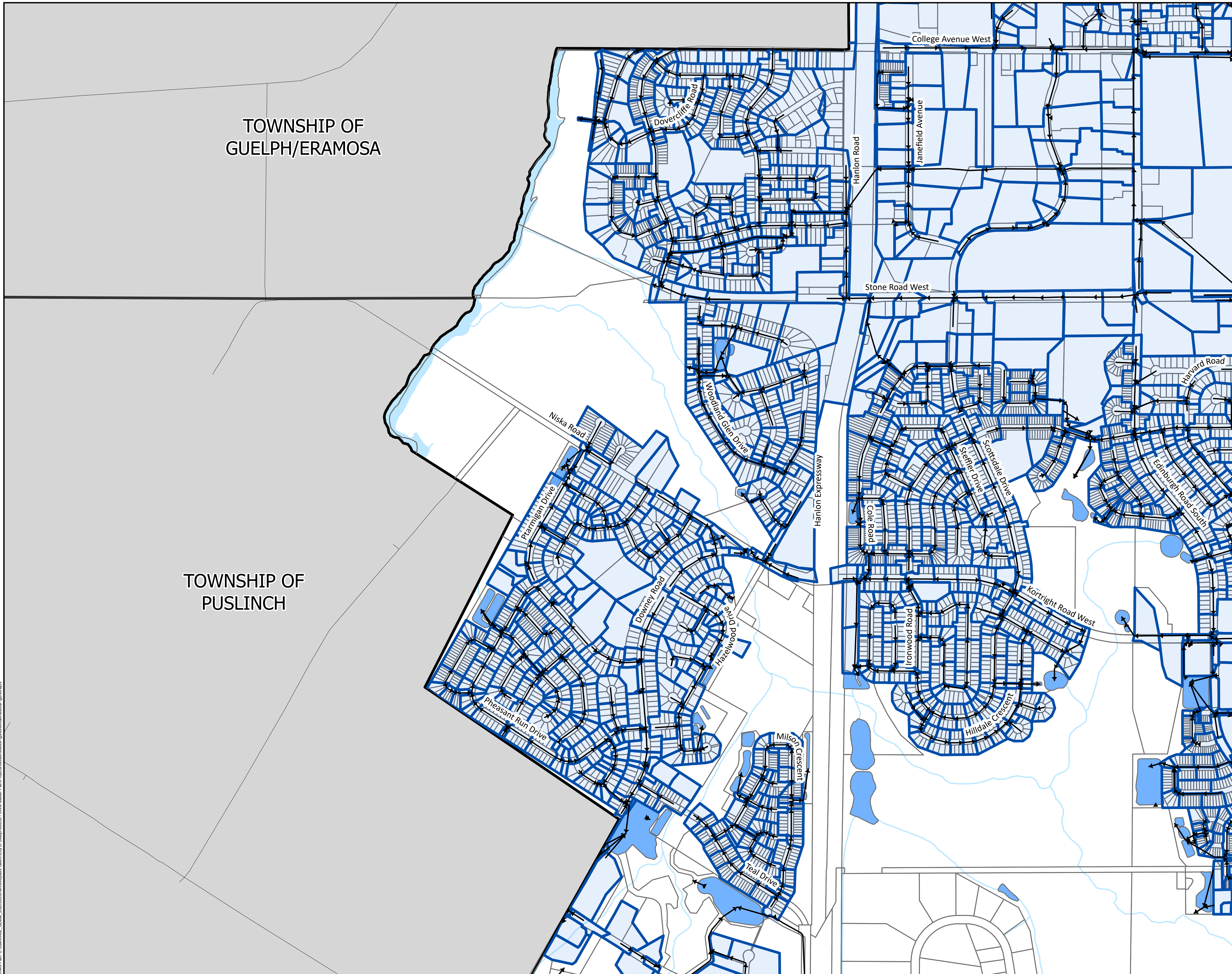


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

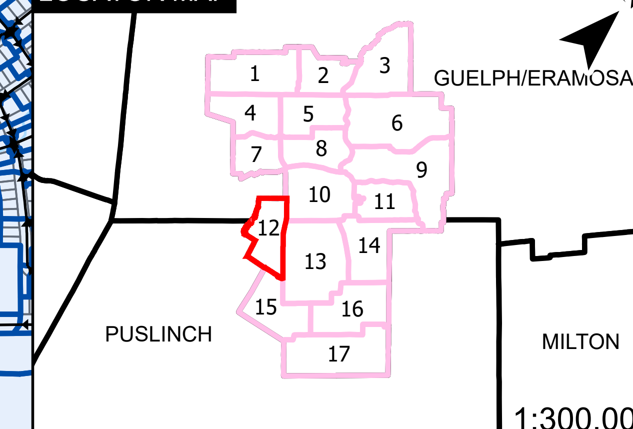
0 75 150 300
Meters



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP



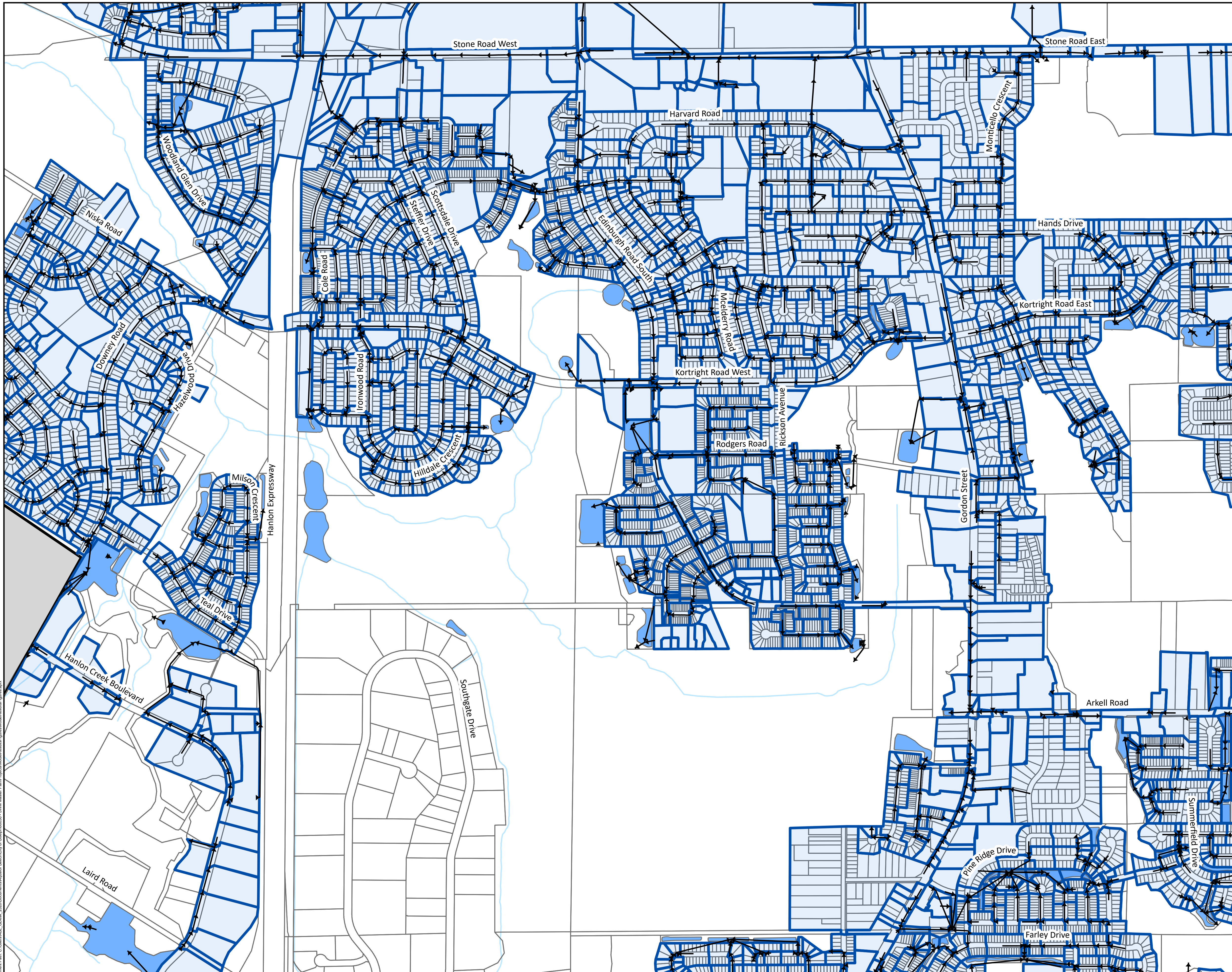
1:300,000

Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 125 250 500
Meters



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

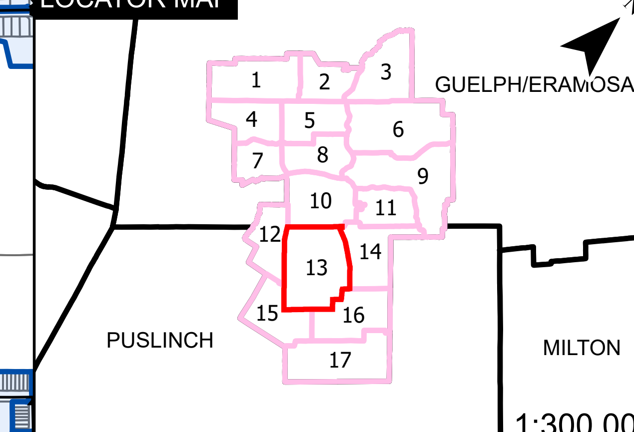
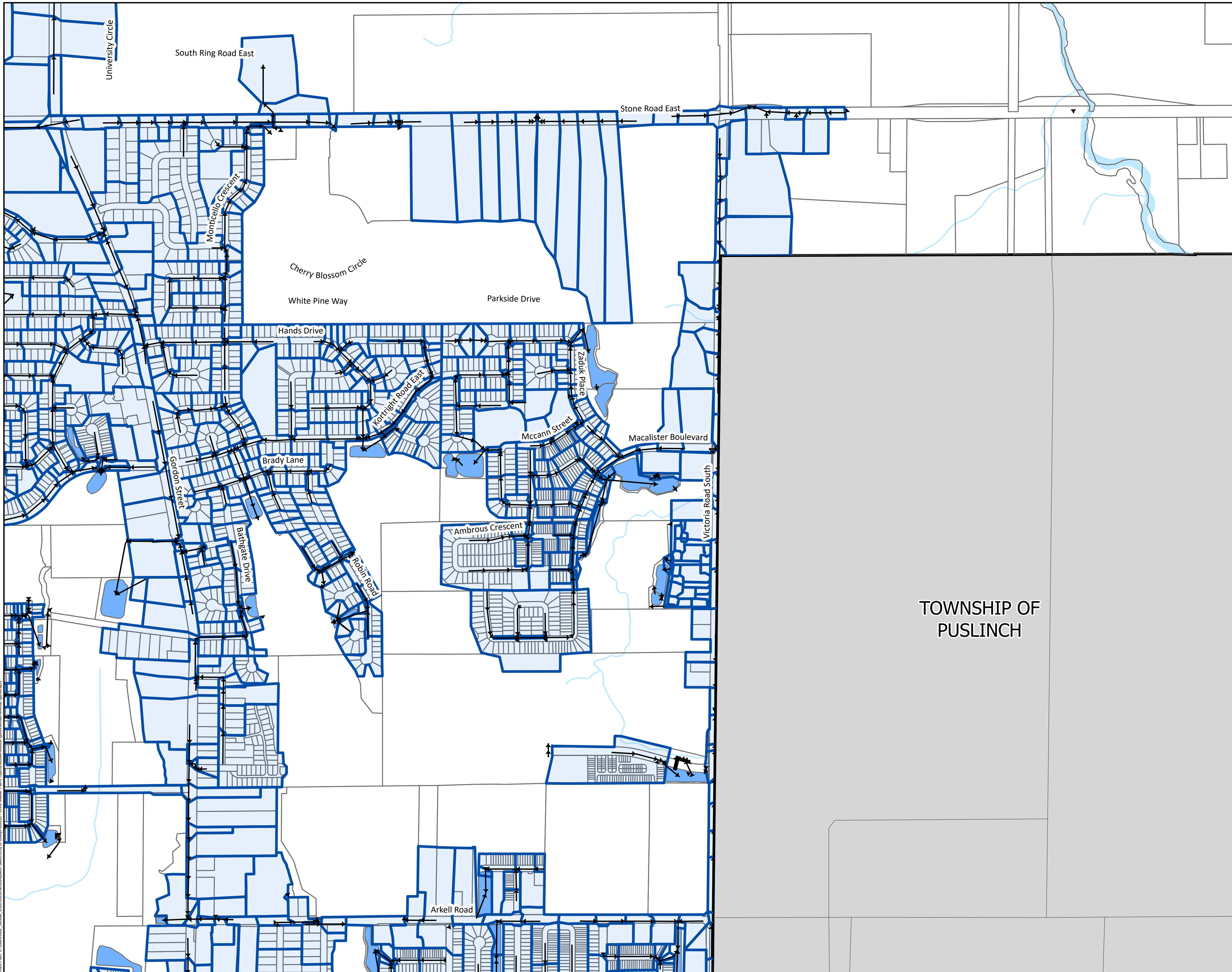


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 130 260 520
Meters



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

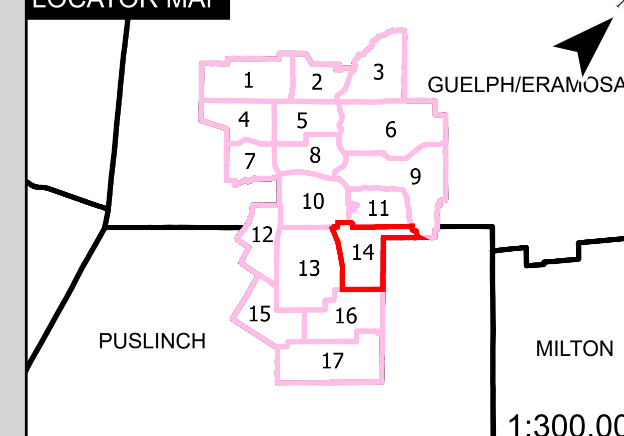
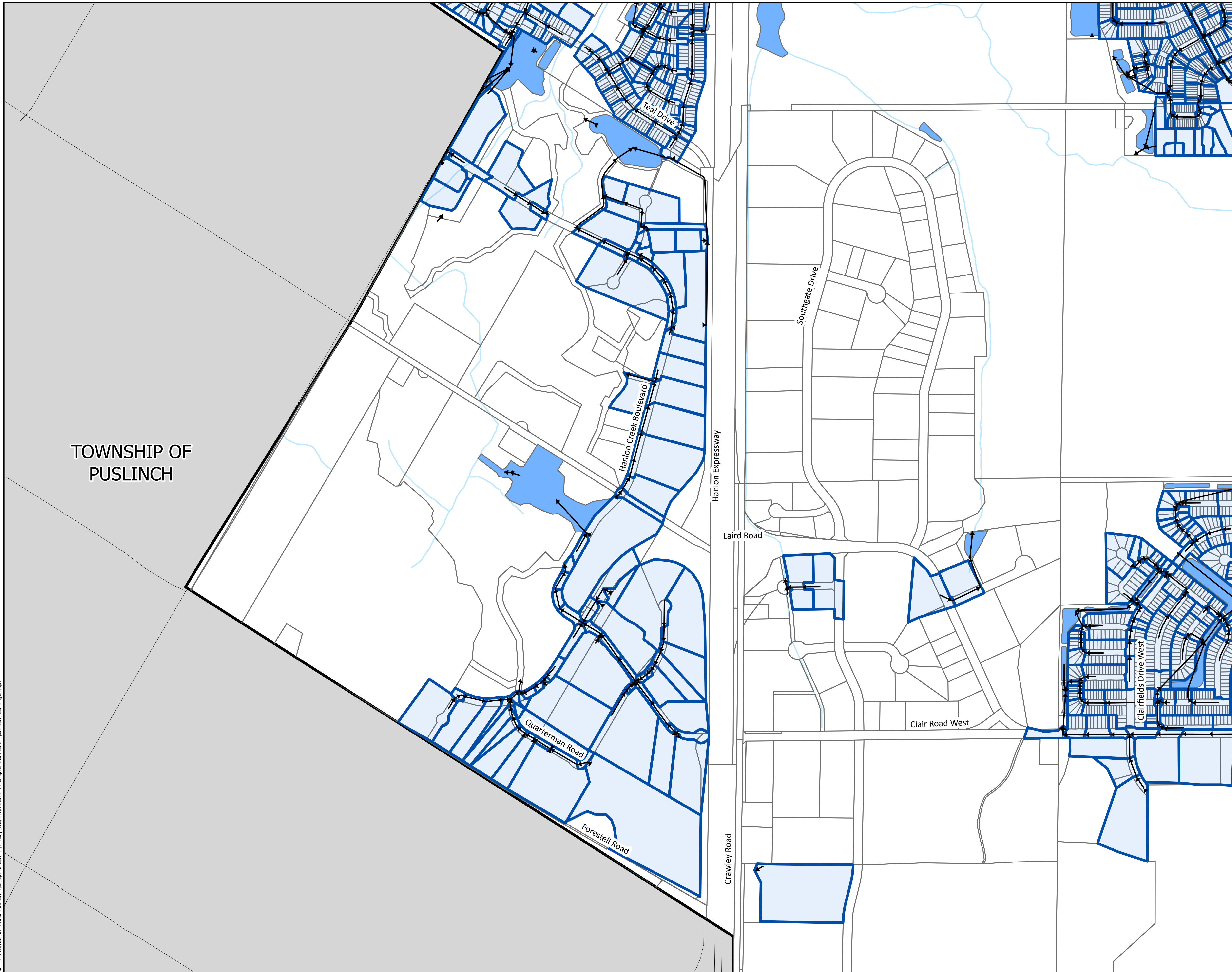


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 105 210 420
Meters



CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

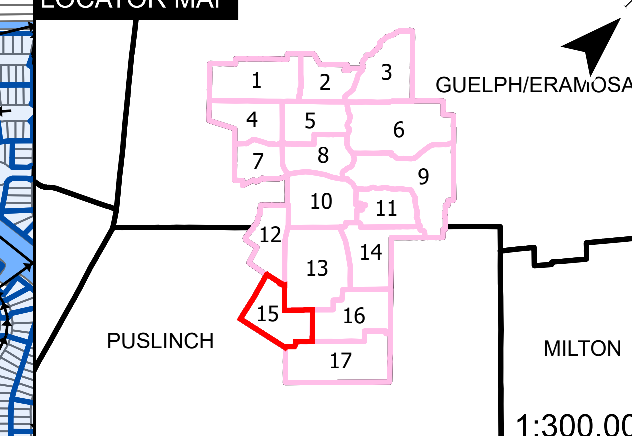


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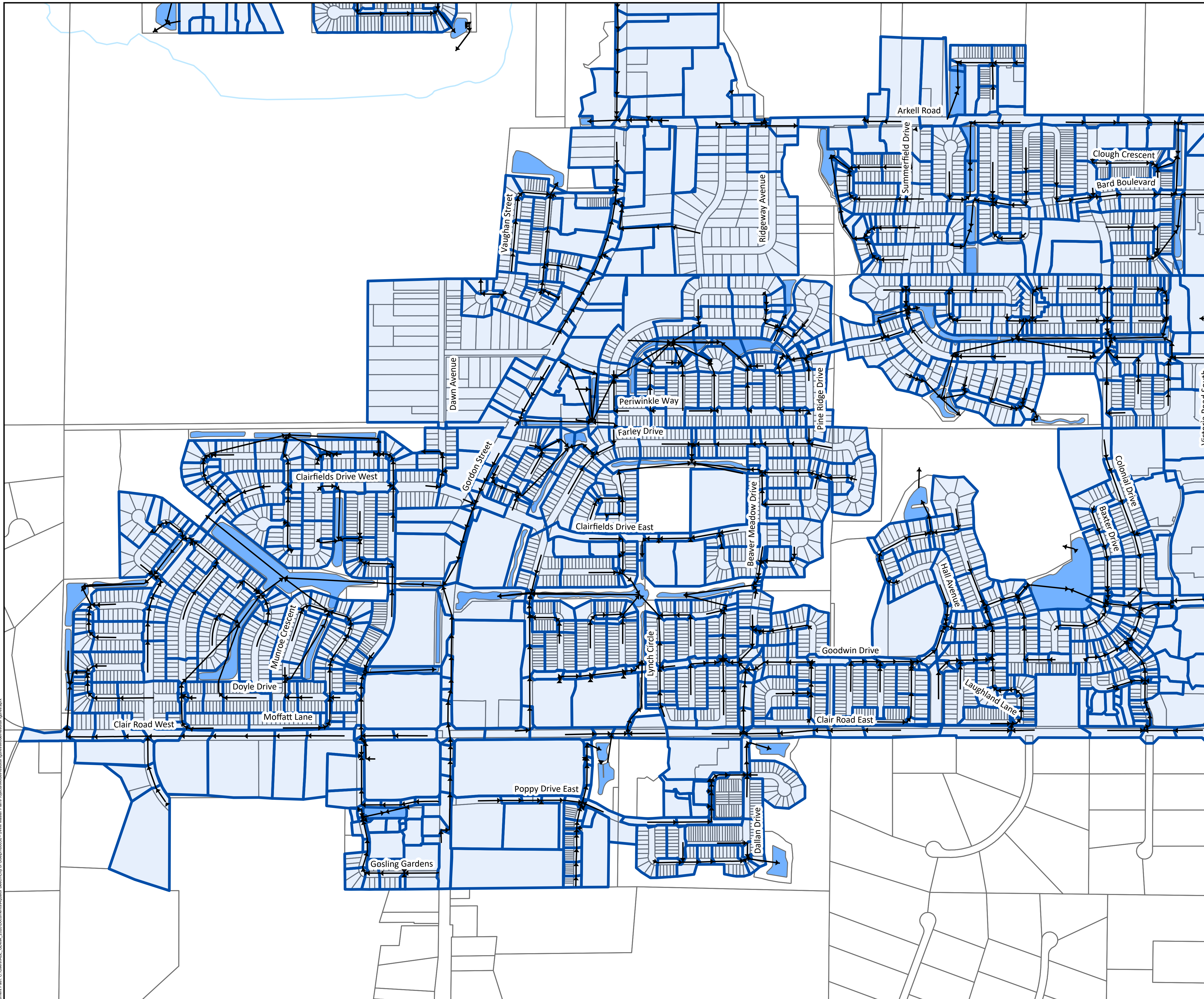
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 112.5 225 450
Meters

Aquafor Beech Limited

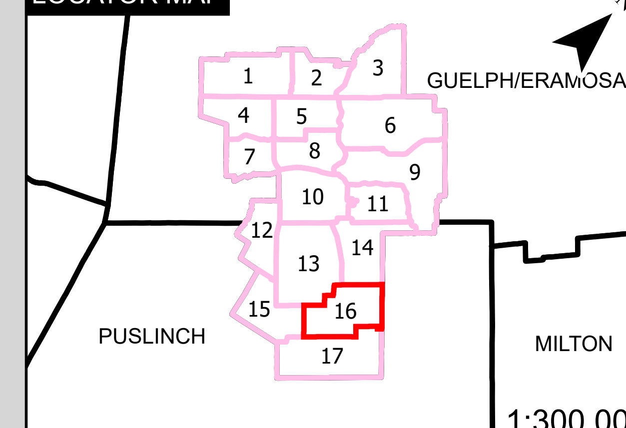


CITY OF Guelph
Making a Difference

Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP



1:300,000

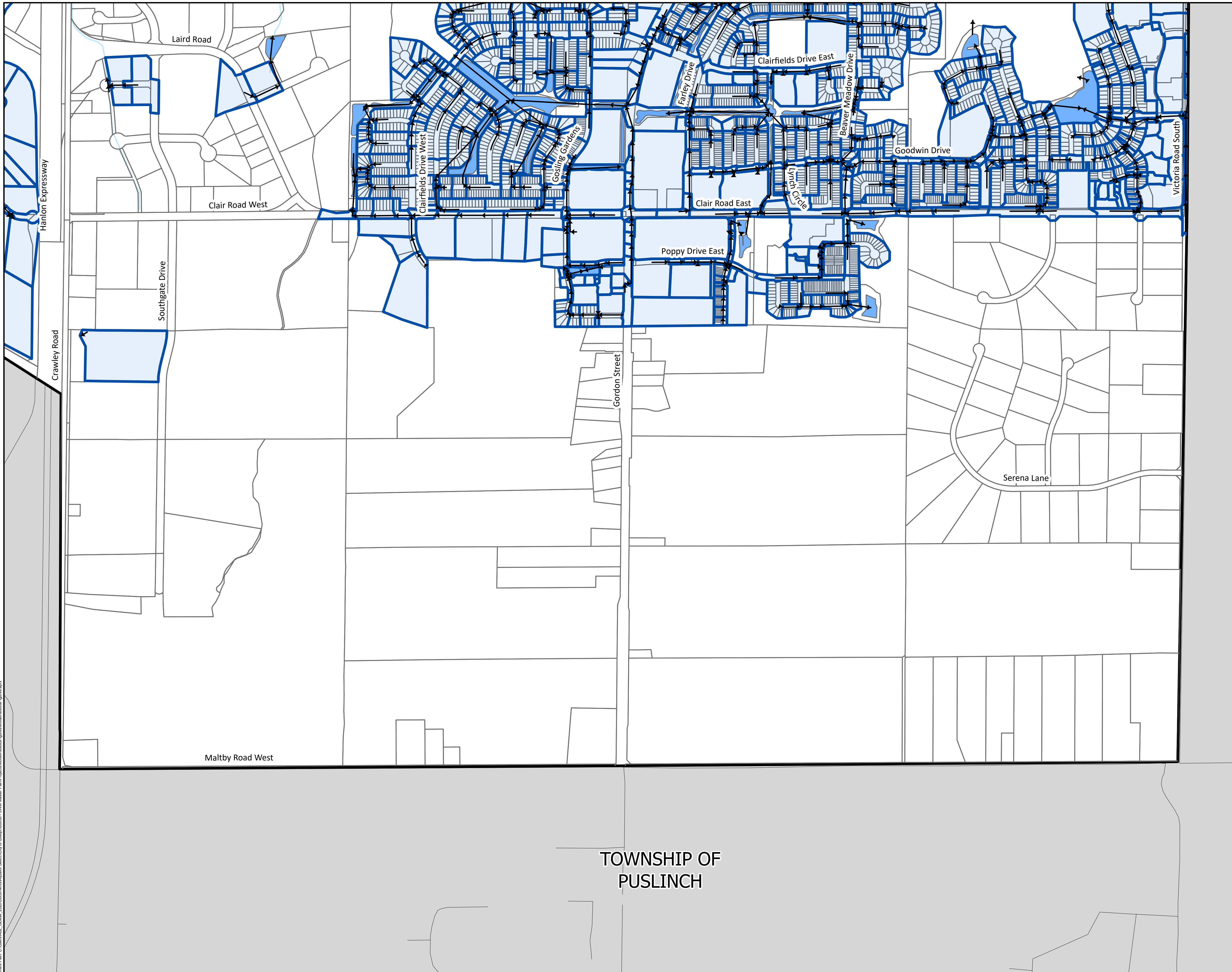
Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 95 190 380
Meters

Aquafor Beech Limited



Legend

- Municipal Boundary
- Watercourse
- Stormwater Management Facility
- Storm Sewer
- Subcatchment

LOCATOR MAP

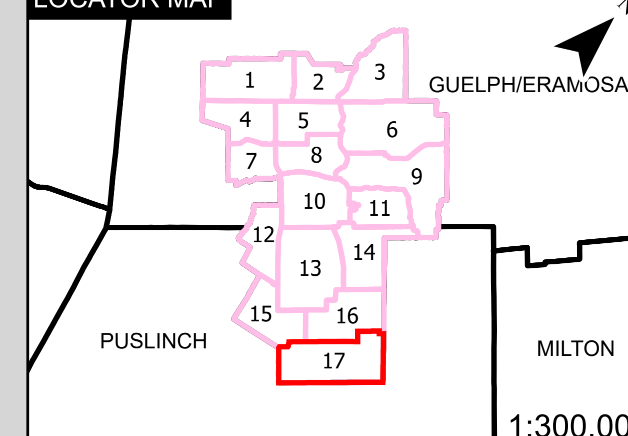


Figure 2.2

Subcatchment Delineation

Date: 2023-01-26
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

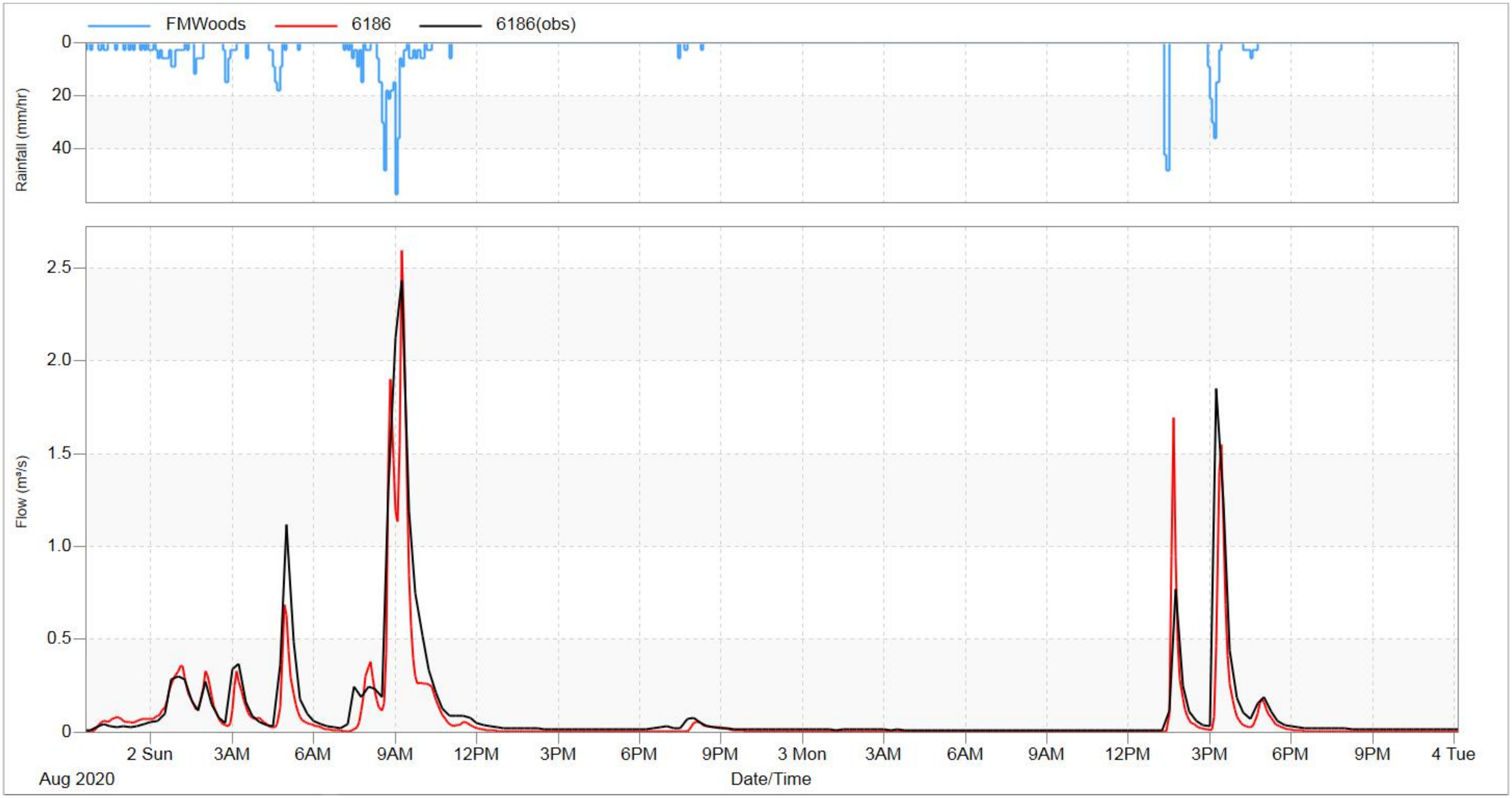
0 125 250 500
Meters

Appendix A2: PCSWMM Model Calibration Plots

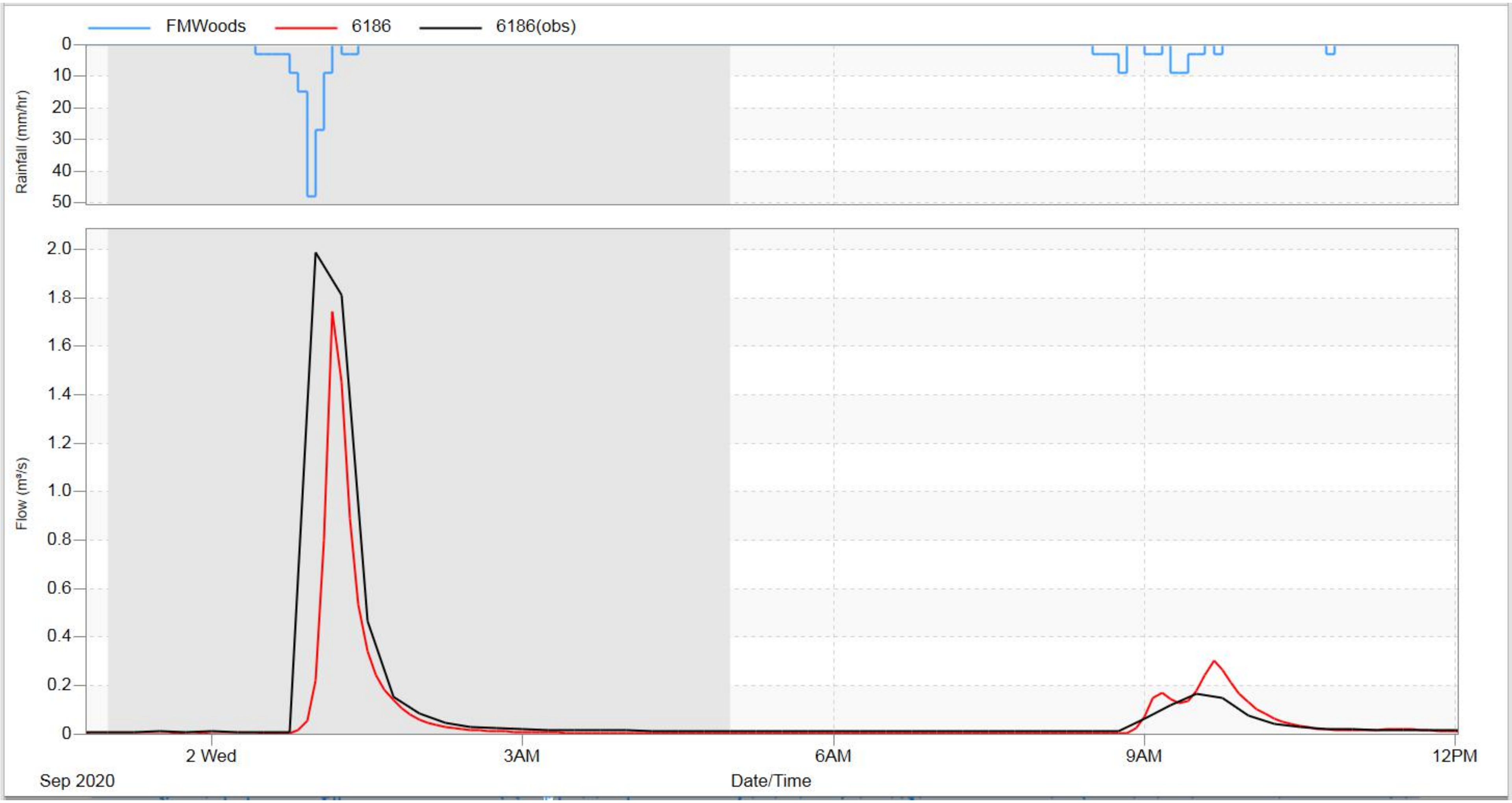
City of Guelph PCSMMM Model Calibration & Calibration Plots

	Flow Monitor		Peak flow (cms)				Total Volume (m3)			
	Location	Event Date	observed	model	% Difference	Average %	Observed	model	% Difference	Average %
1	HD02 (Schroder)	Aug 1st,2020 9pm	2.4	2.6	7%		14650	11000	-25%	
	Mostly Residential	Sep 2nd,2020 12am	2.0	1.7	-12%	**-3%**	4226	2141	-49%	**-25%**
	FMWoods Raingage	Oct 21st,2020 2:30am	0.3	0.3	-3%		2082	2073	0%	
2	US03 (Waverly)	July 10,2020 6pm	3.9	4.9	26%		10950	10200	-7%	
	Mostly Residential	July 19,2020 11am	2.5	4.0	62%	**27%**	7205	5390	-25%	**-29%**
	FMWoods Raingage	Sep 2nd,2020 12am	3.0	2.8	-6%		8695	4013	-54%	
3	US10 (Woodlawn)	Aug 1st,2020 8pm	1.5	1.5	5%		14500	13540	-7%	
	Industrial & Commercial	Aug 3rd,2020 12pm	0.6	1.2	93%	**25%**	2690	3882	44%	**-4%**
	CityHall Raingage	Sep 1st,2020 11pm	1.5	1.1	-24%		4686	2323	-50%	
4	LS05 (Stone Road)	July 19,2020 12pm	4.0	4.4	10%		11670	11940	2%	
	Residential & Com/Inst	July 22,2020 2:30pm	3.9	3.7	-4%		11960	11570	-3%	
	WWTP Raingage	Aug 1st,2020 9pm	3.7	4.4	18%	**9%**	35720	33840	-5%	**3%**
		Sep 2nd,2020 12am	1.8	2.0	14%		5699	6754	19%	
5	LS02 (NW01 Railway)	Aug 1st,2020 9pm	5.1	6.6	30%		46230	55530	20%	
	Mostly Residential	Aug 3rd,2020 1pm	6.4	7.8	22%	**12%**	14430	19060	32%	**11%**
	WWTP Raingage	Sep 1st,2020 11pm	6.4	5.3	-17%		15150	12440	-18%	
6	NW04 (Nortwest Channel)	Aug 1st,2020 9pm	1.8	2.4	31%		41600	30250	-27%	
	WECC Raingage	Sep 1st,2020 11pm	1.6	3.0	88%	**60%**	11850	10660	-10%	**-19%**
7	WW06 (Willow west)	July 10,2020 6pm	8.4	7.1	-15%		20310	18750	-8%	
	Industrial with Ditching	July 19,2020 11am	7.5	8.0	6%	**-8%**	21480	24880	16%	**-3%**
	WECC Raingage	Sep 1st,2020 11pm	4.3	3.7	-14%		14990	12470	-17%	

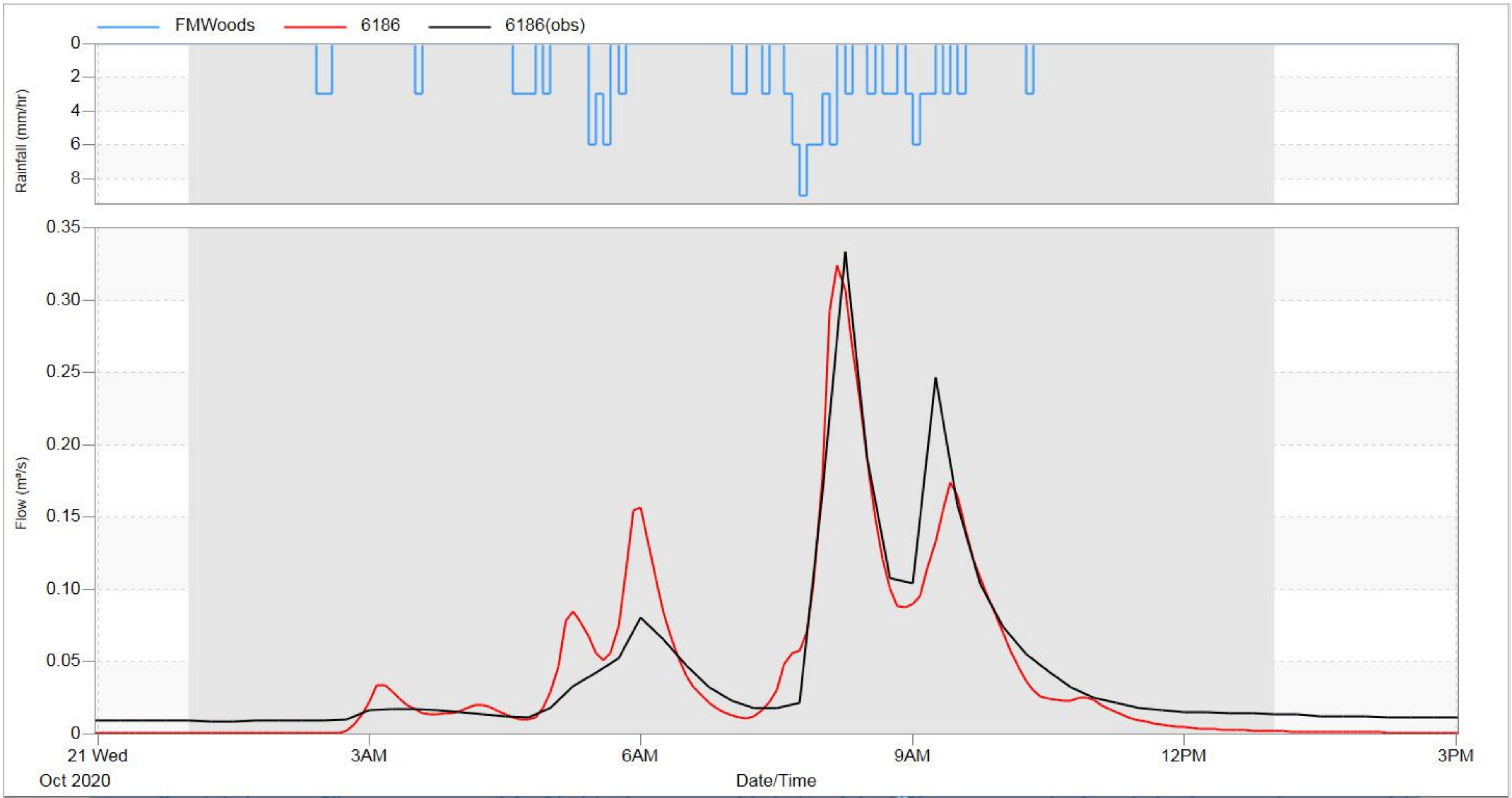
1. HD02 Monitoring location



Calibration Plot for August 1st 2020 Event

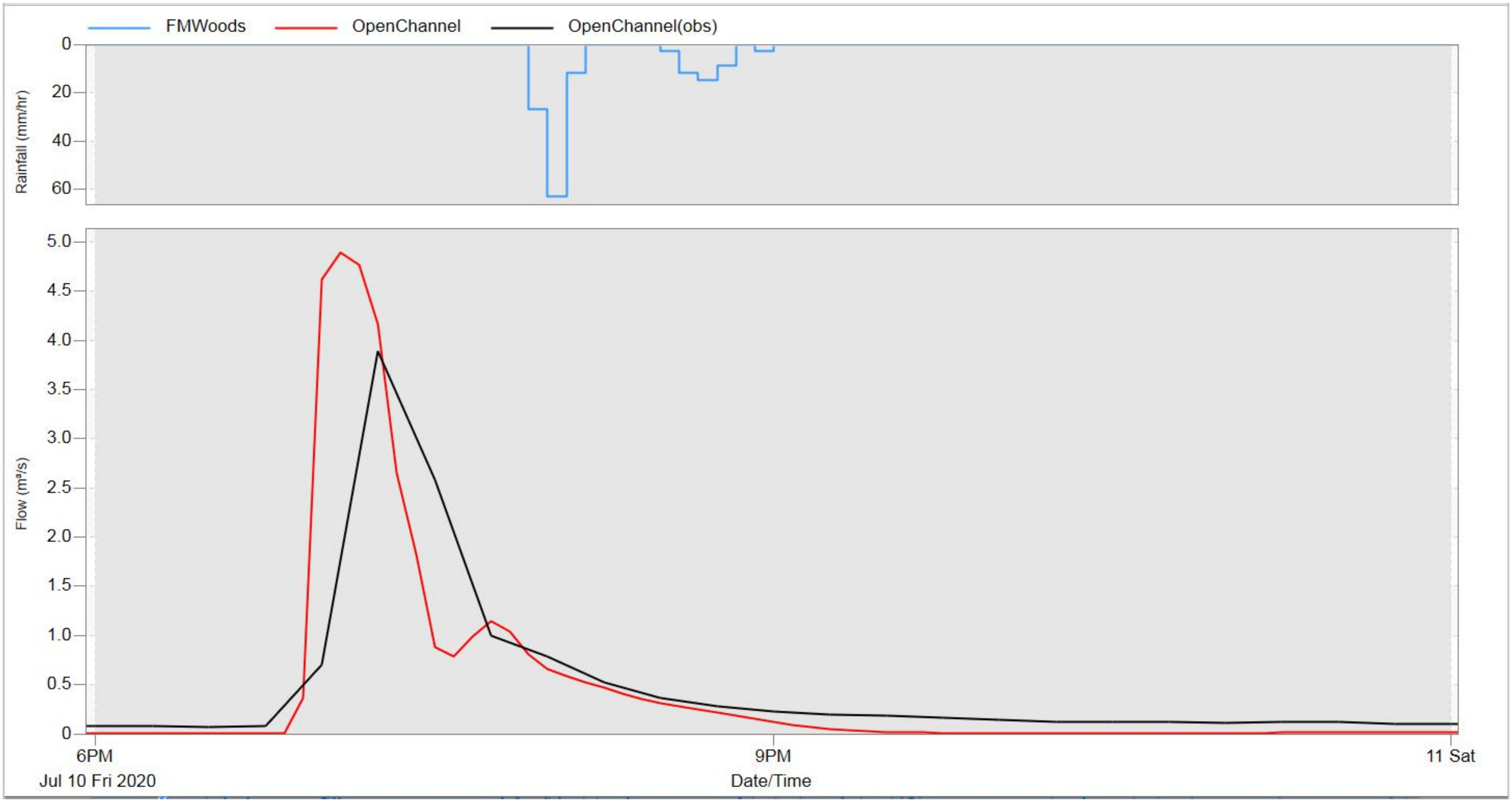


Calibration Plot for September 2nd 2020 Event

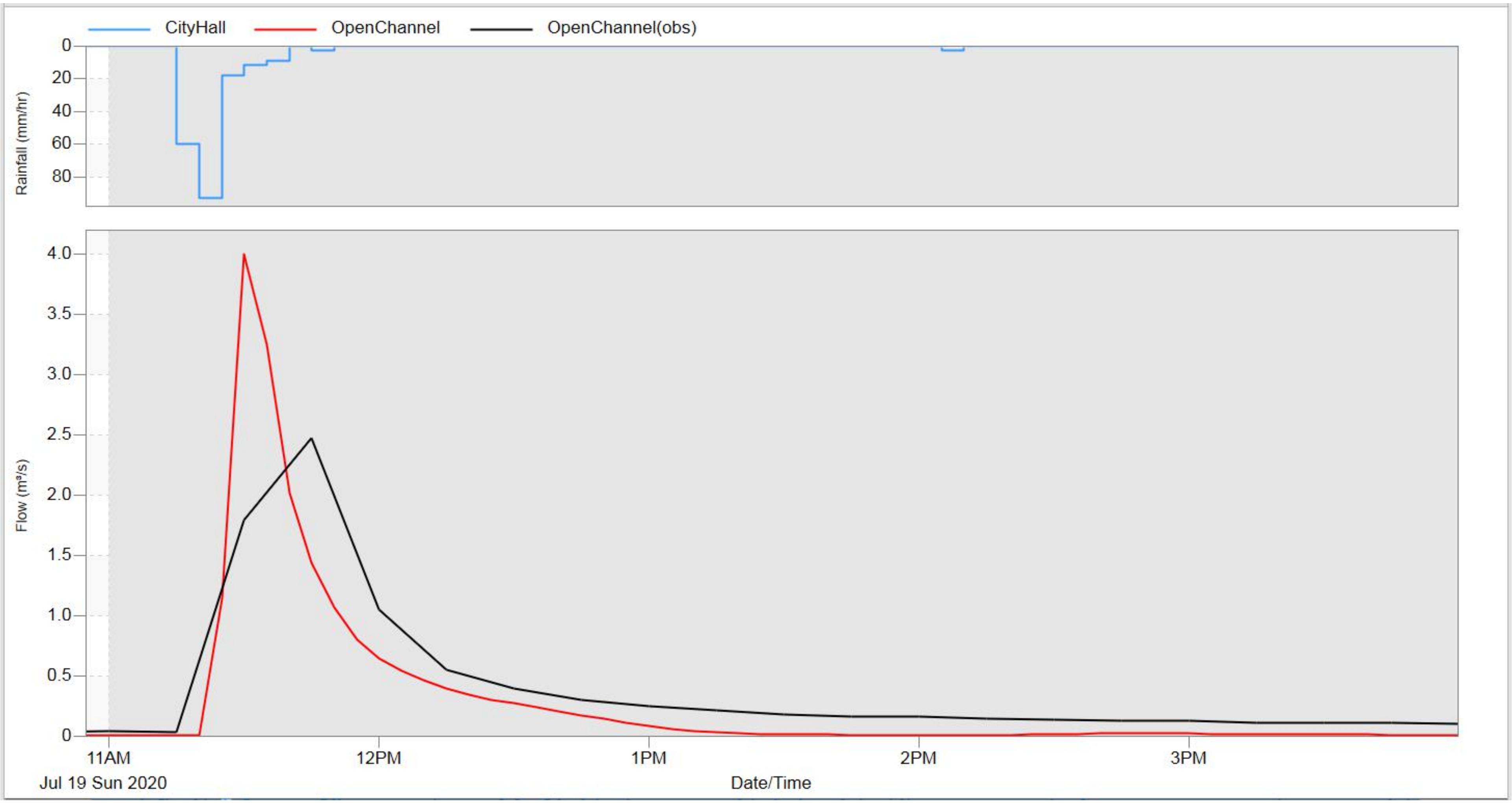


Calibration Plot for October 21st 2020 Event

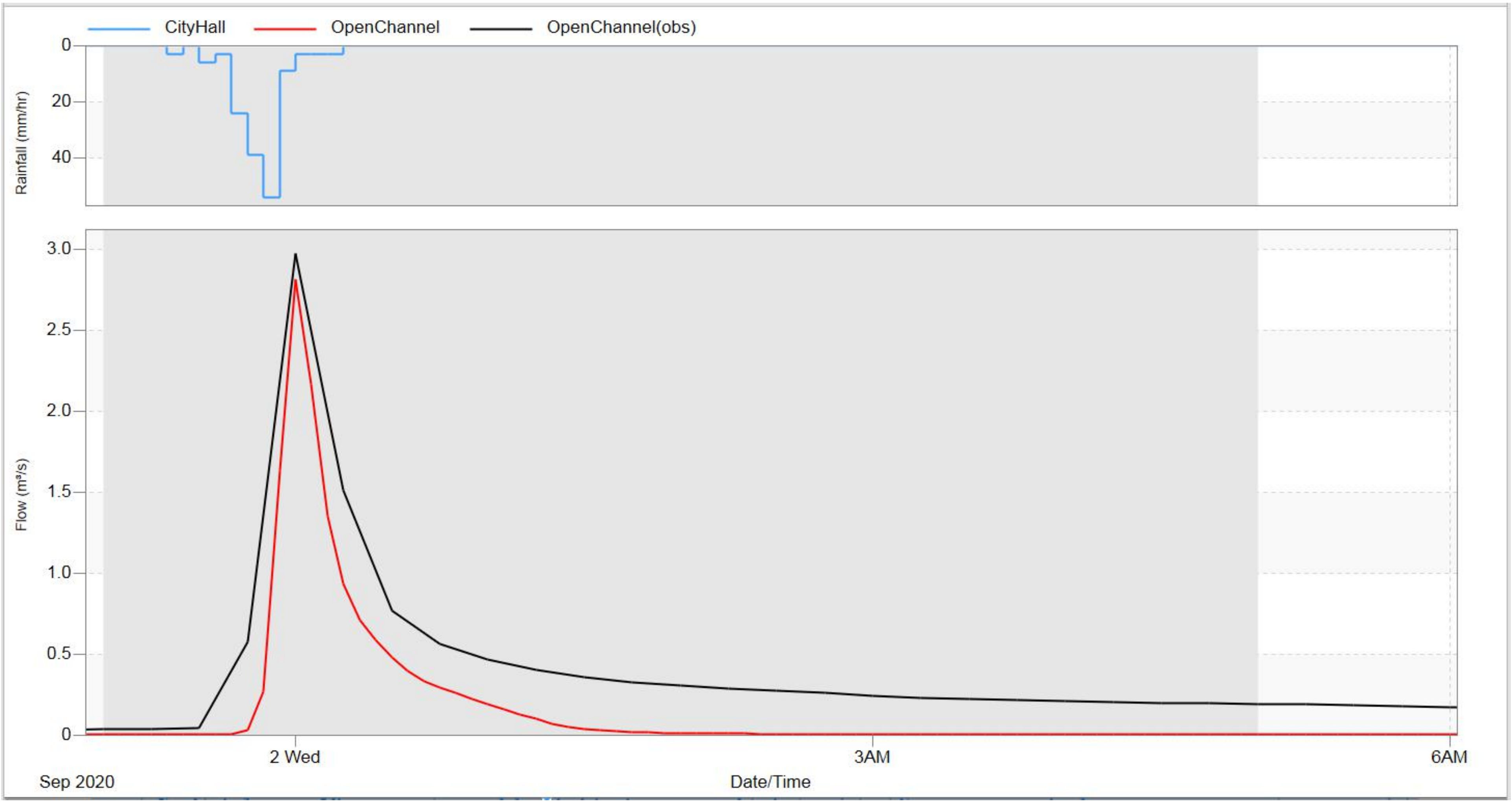
2. US03 Monitoring location



Calibration Plot for July 10th 2020 Event

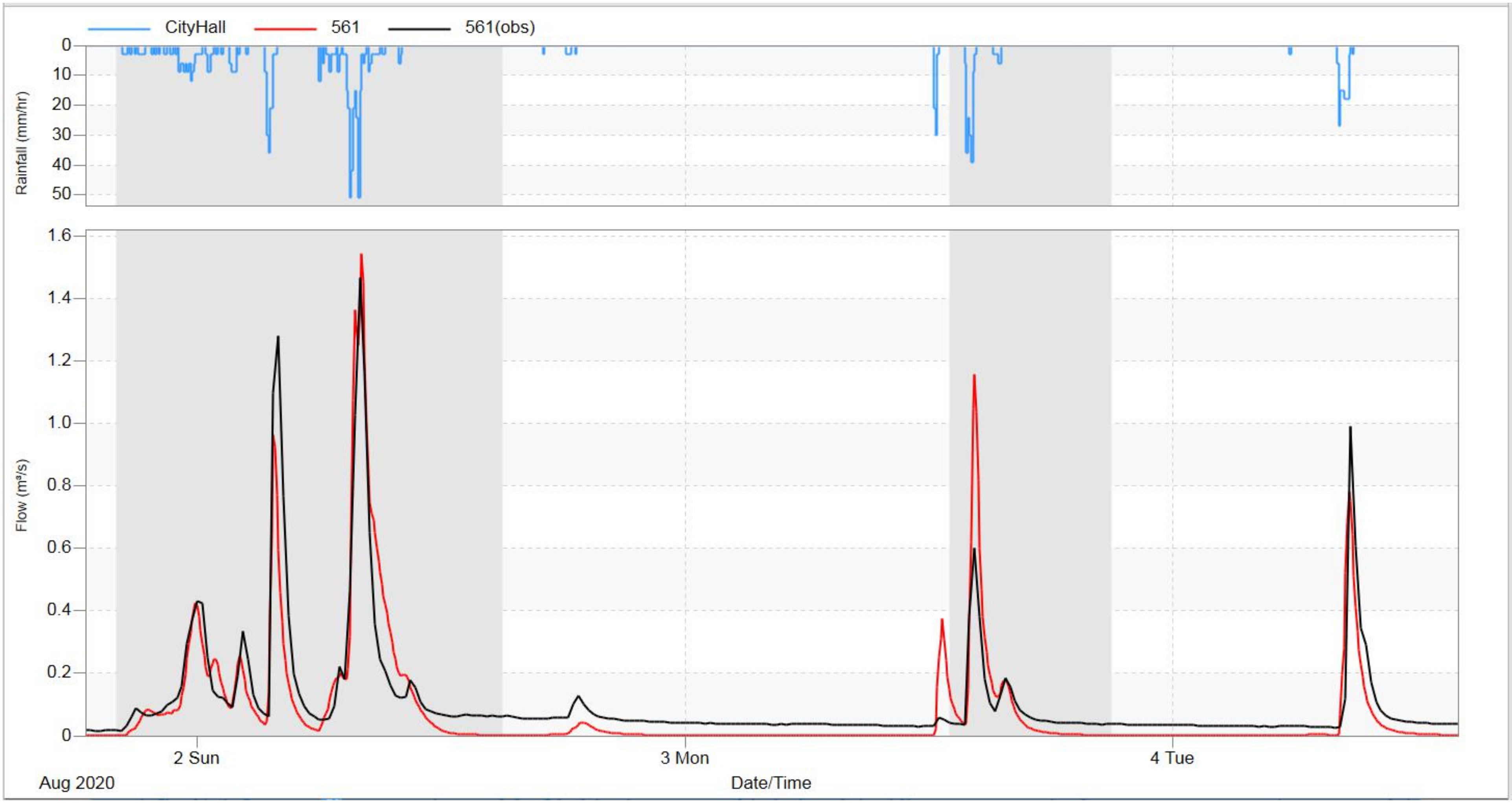


Calibration Plot for July 19th 2020 Event

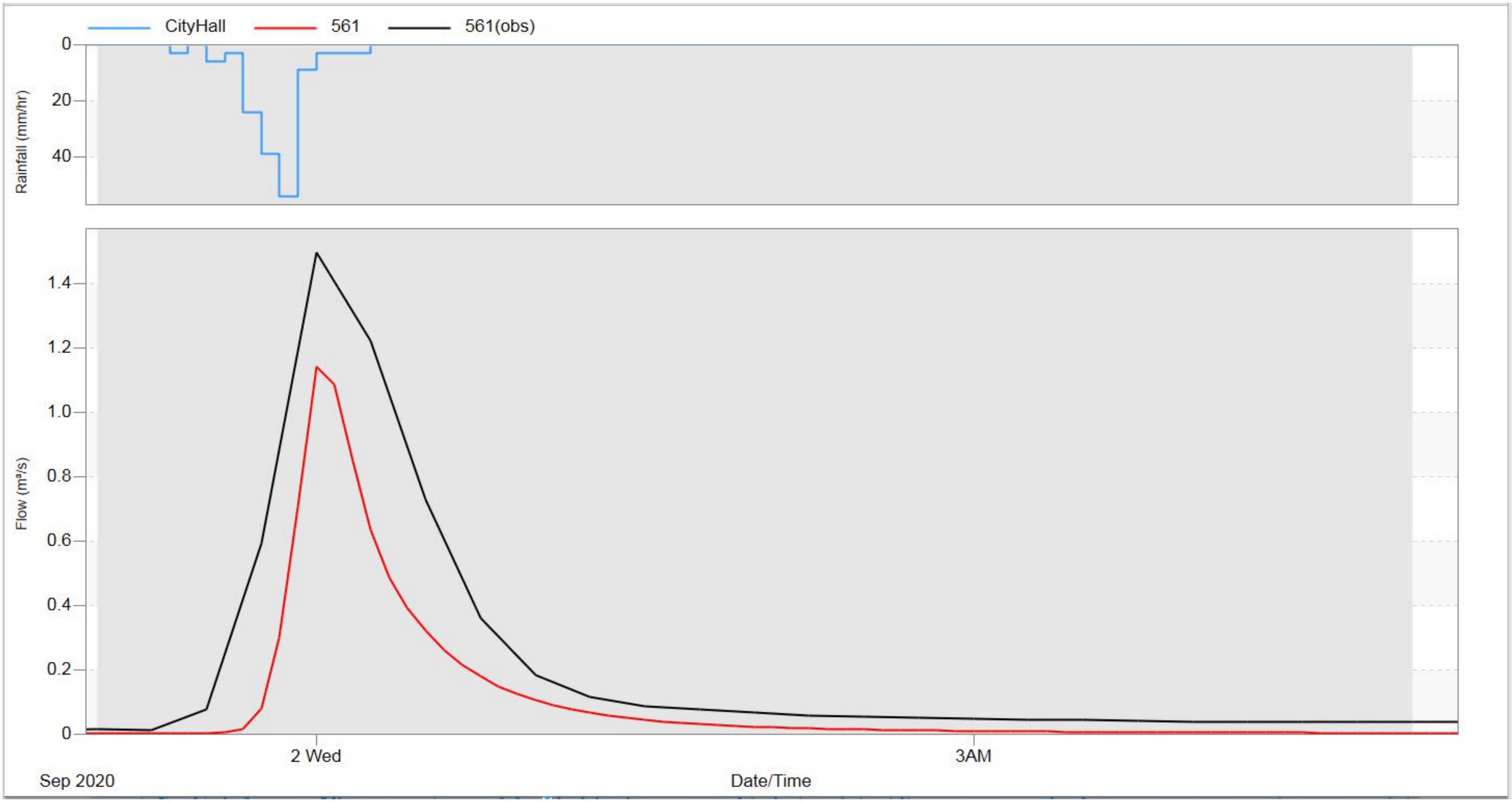


Calibration Plot for September 2nd 2020 Event

3. US10 Monitoring location

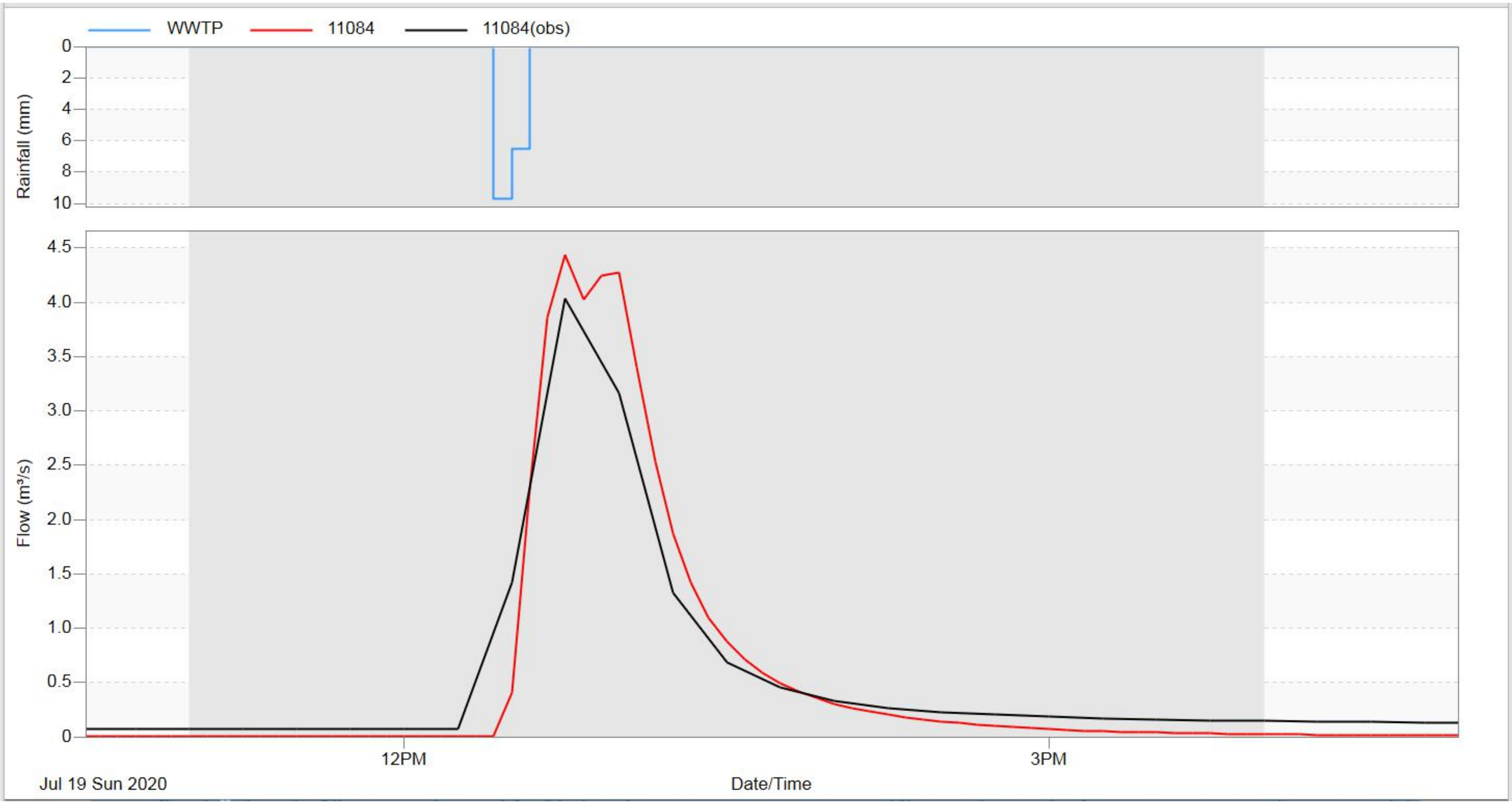


Calibration Plot for August 1st & August 3rd 2020 Event

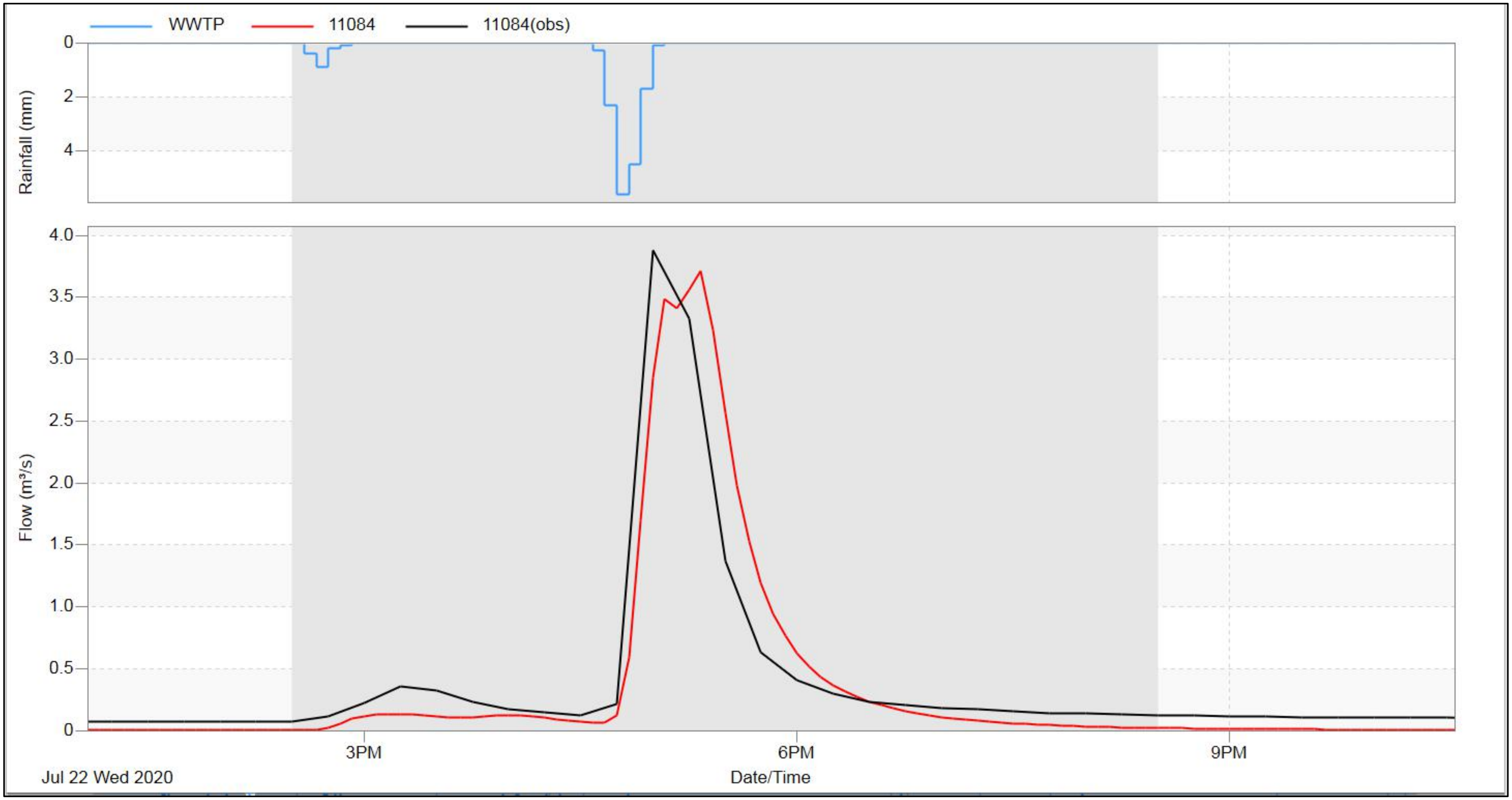


Calibration Plot for September 1st 2020 Event

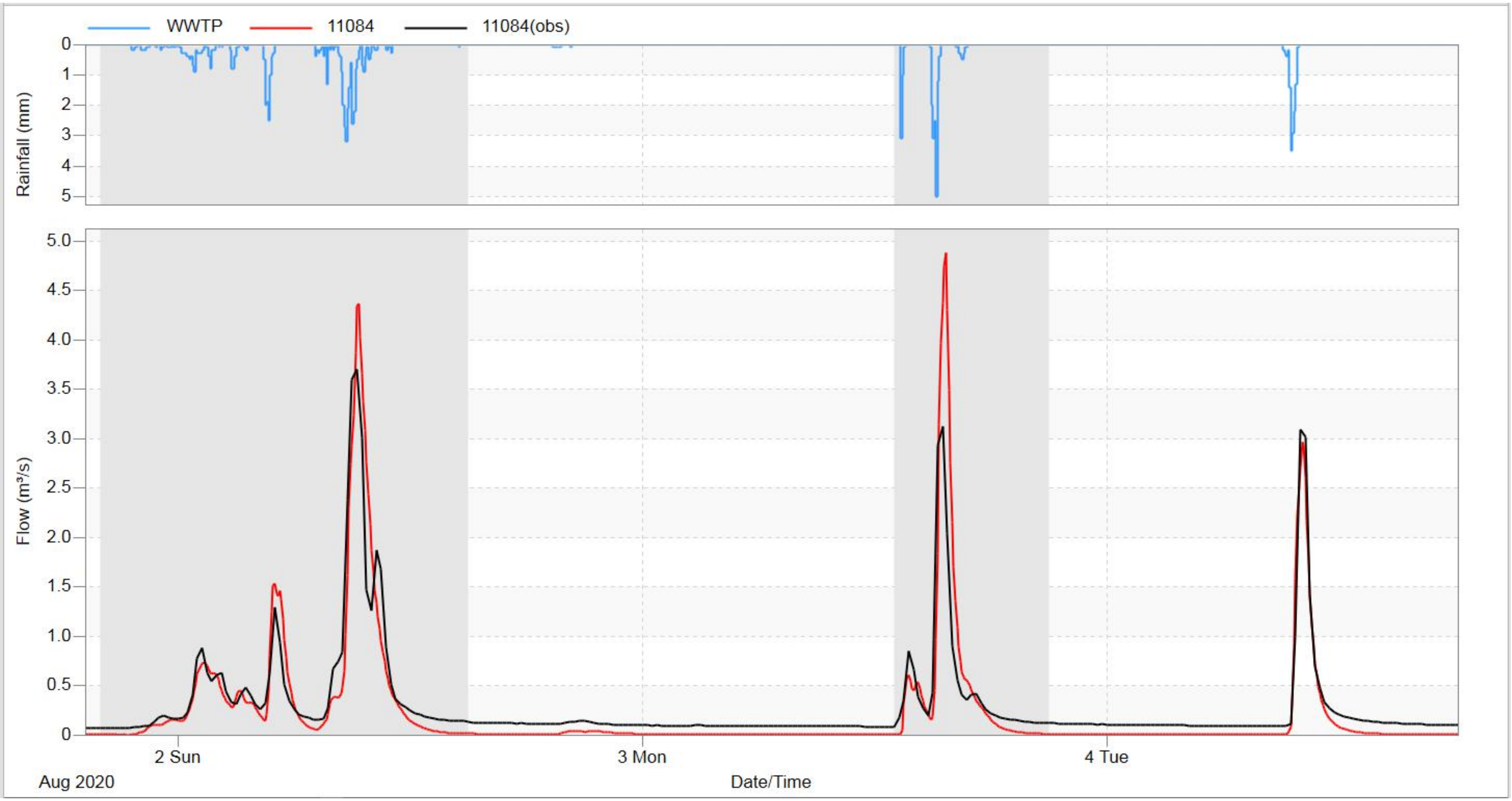
4. LS05 Monitoring location



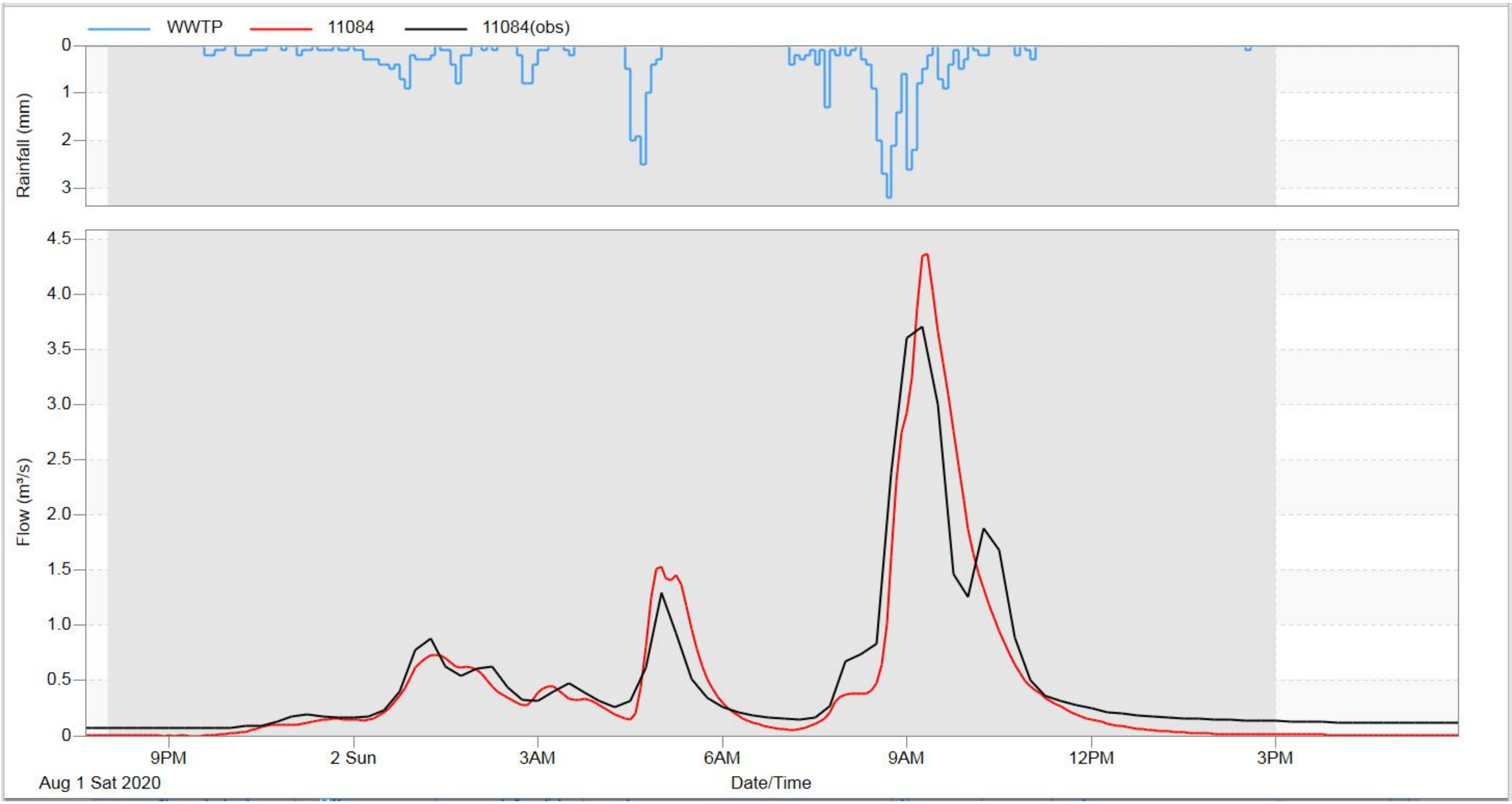
Calibration Plot for July 19th 2020 Event



Calibration Plot for July 22nd 2020 Event

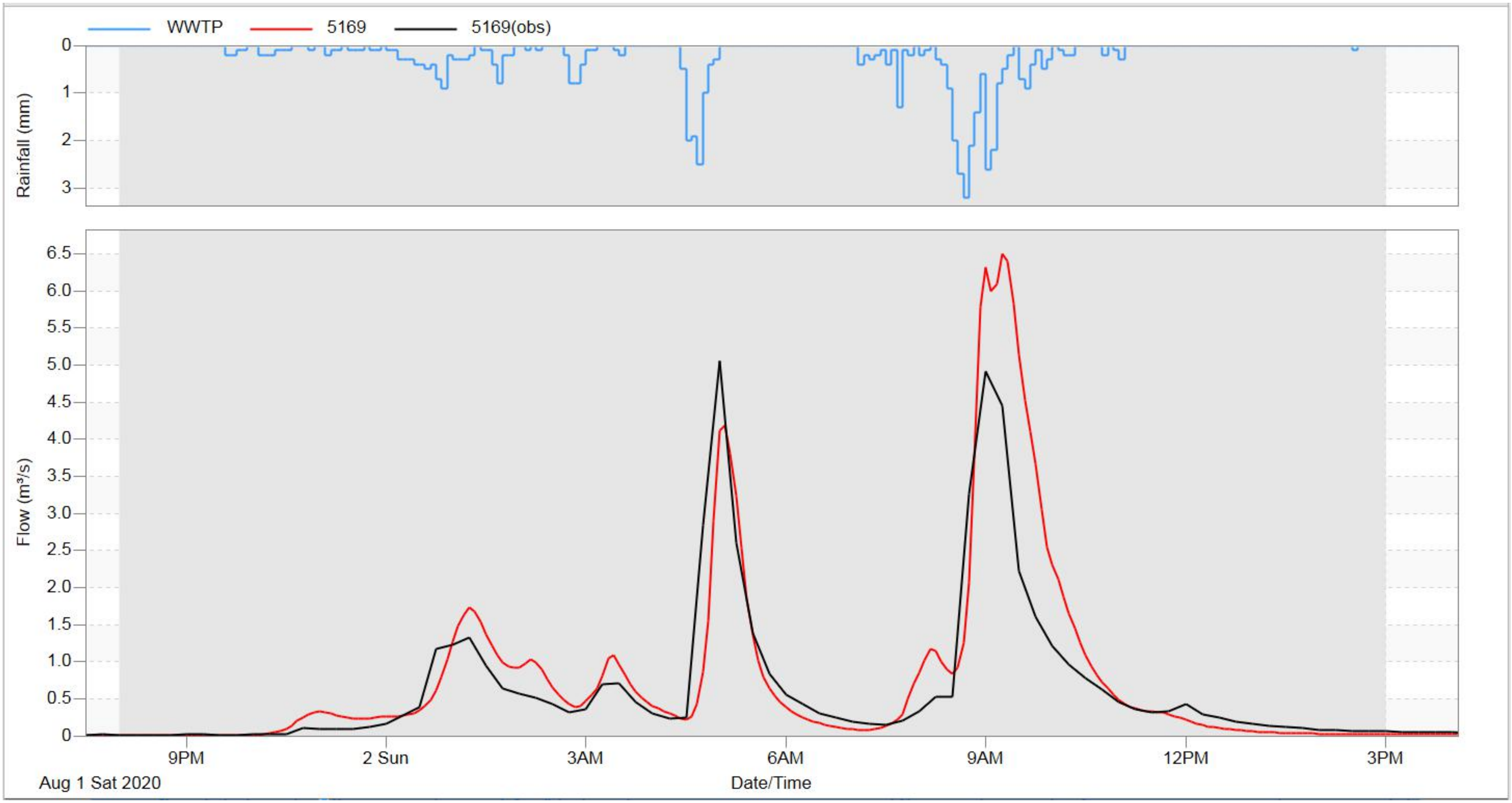


Calibration Plot for August 1st 2020 Event

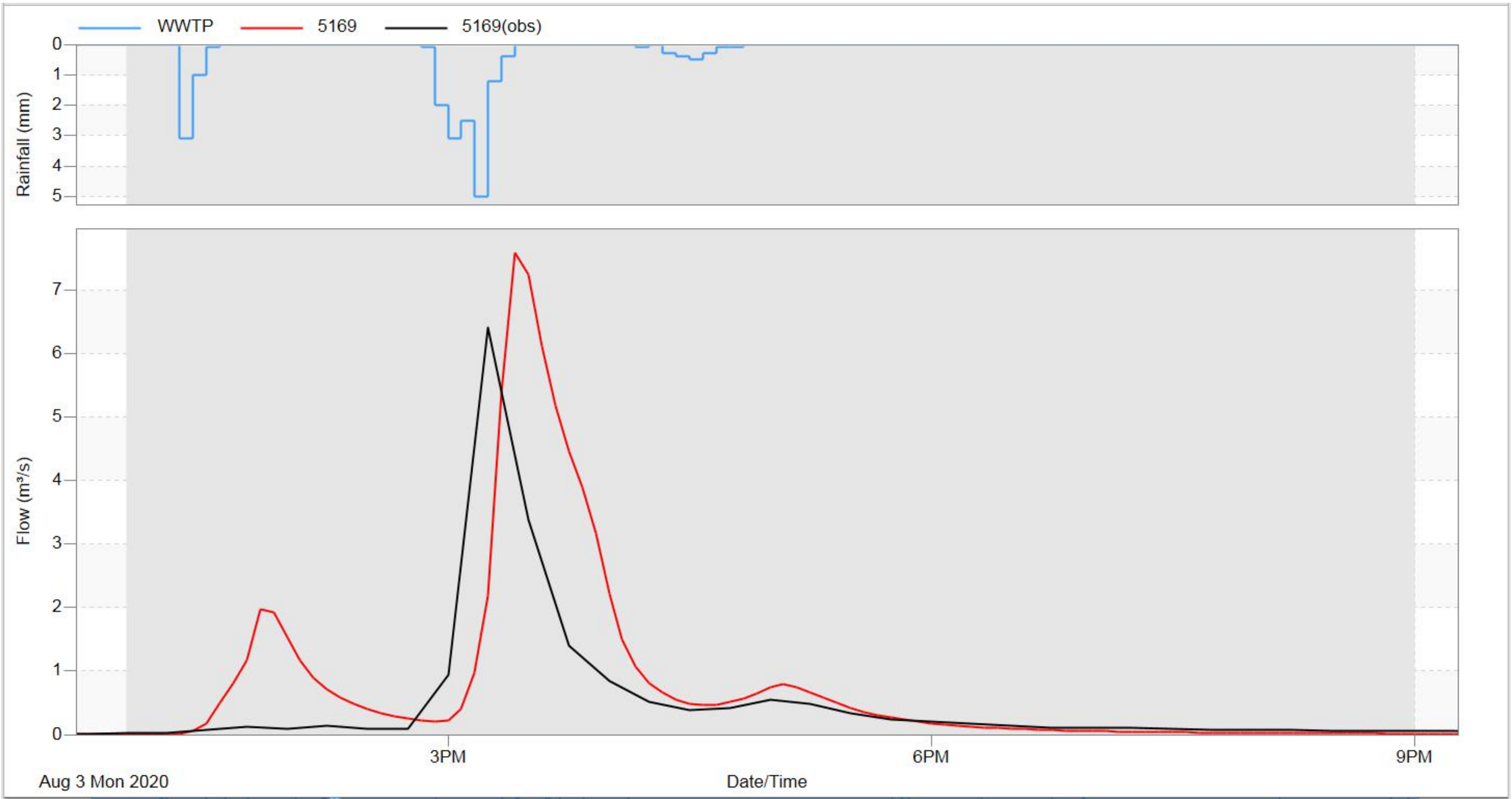


Calibration Plot for September 2nd 2020 Event

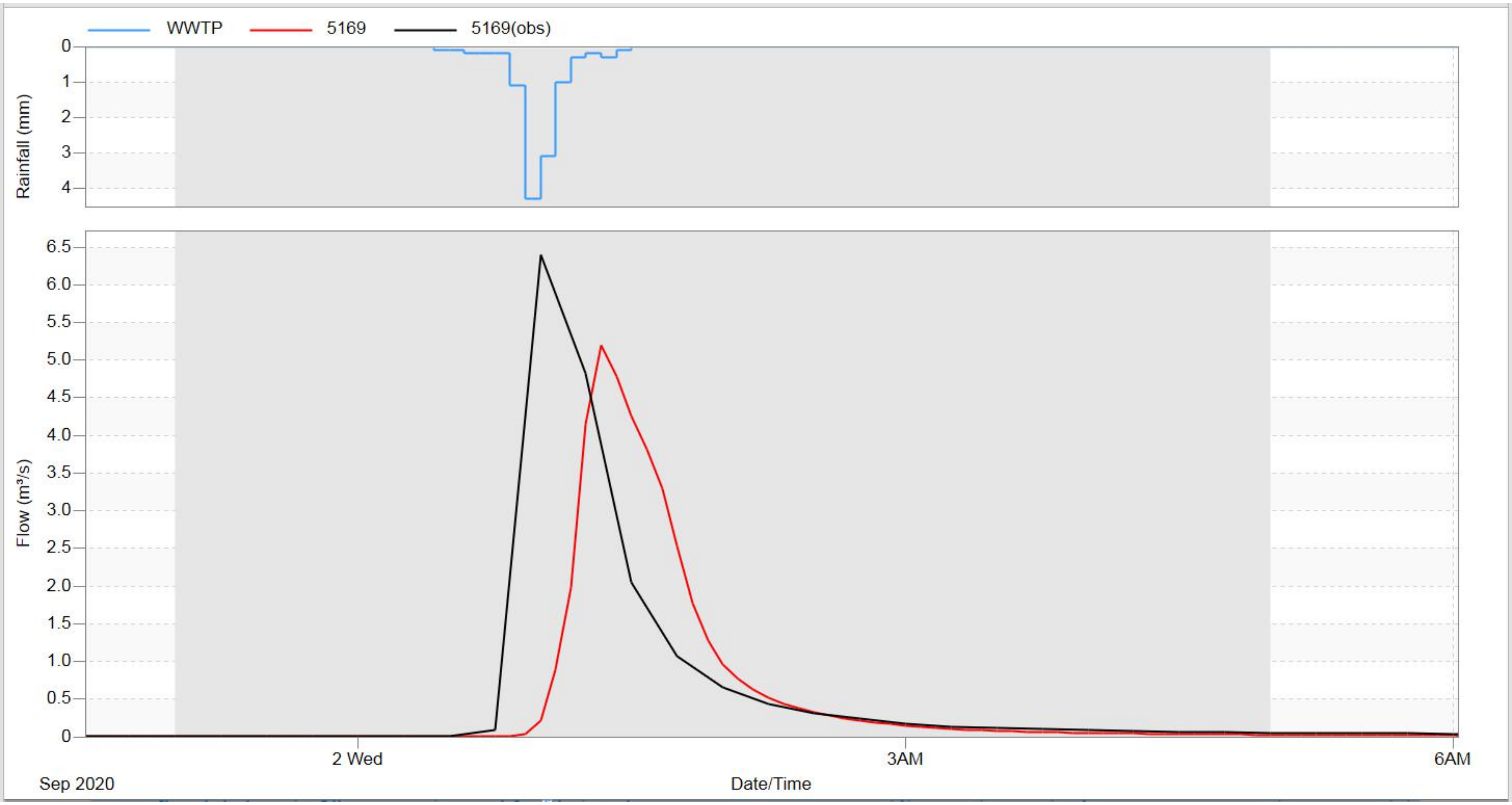
5. LS02 Monitoring location



Calibration Plot for August 1st 2020 Event

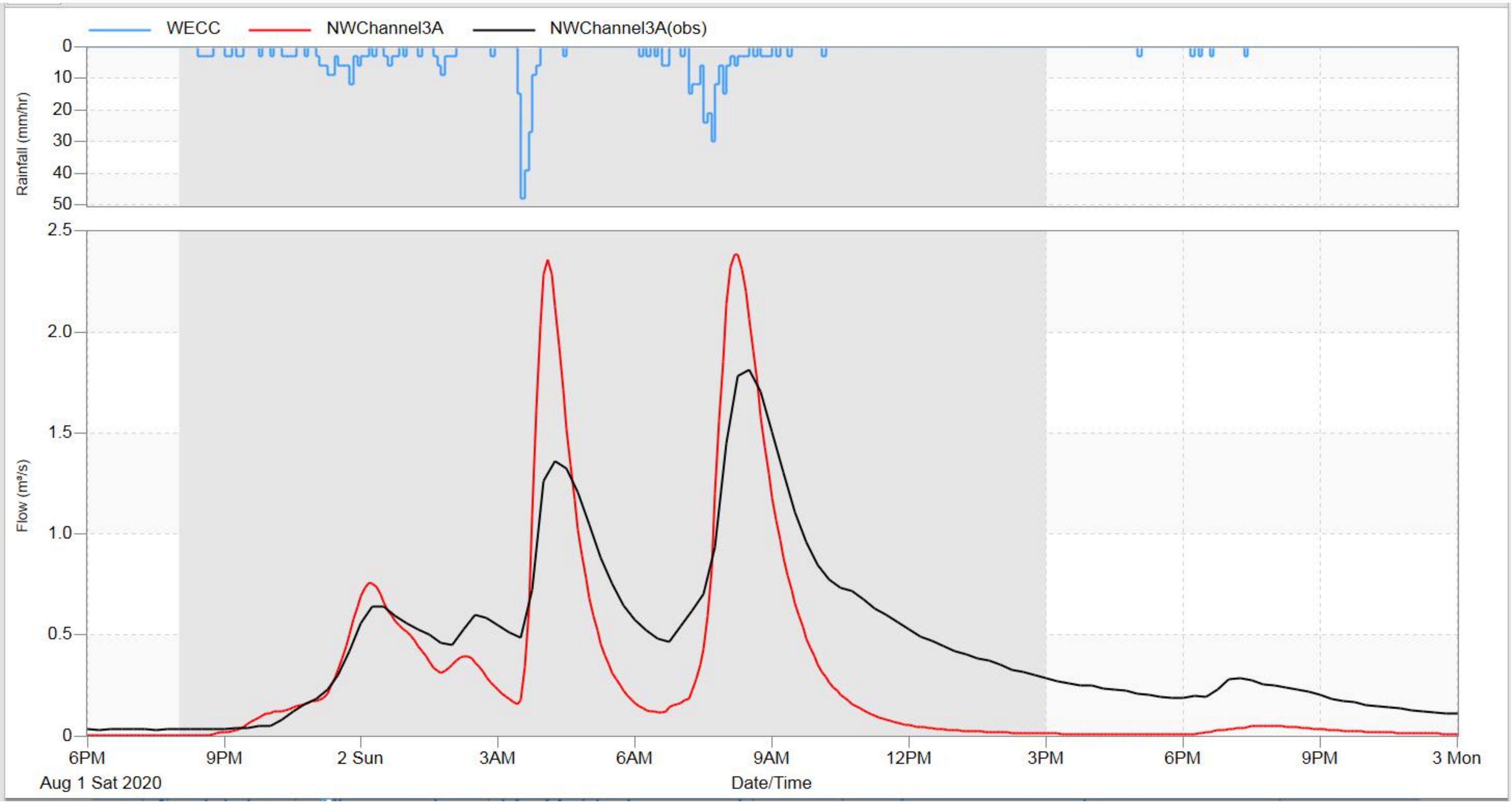


Calibration Plot for August 3rd 2020 Event

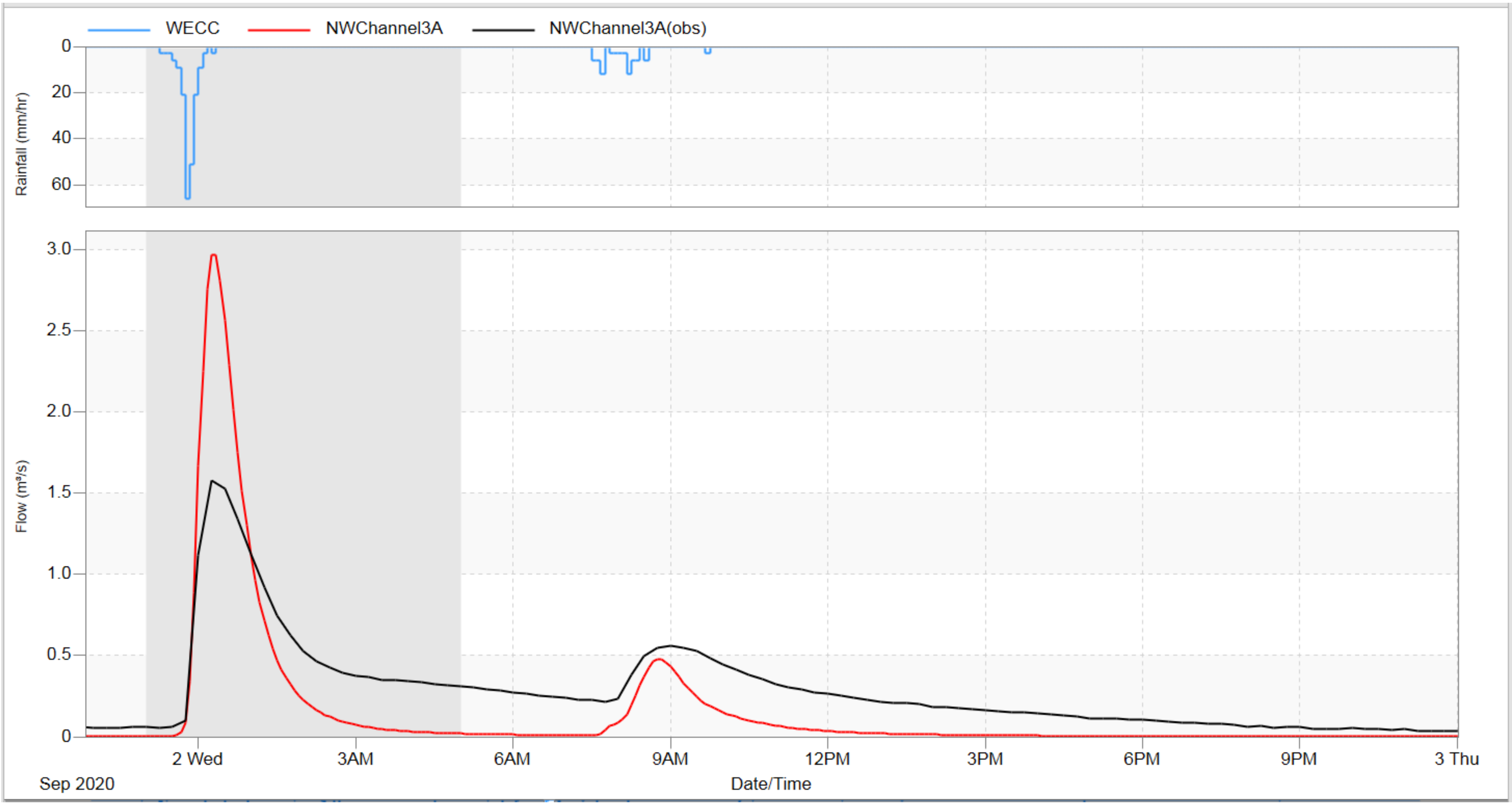


Calibration Plot for September 1st 2020 Event

6. NW04 Monitoring location

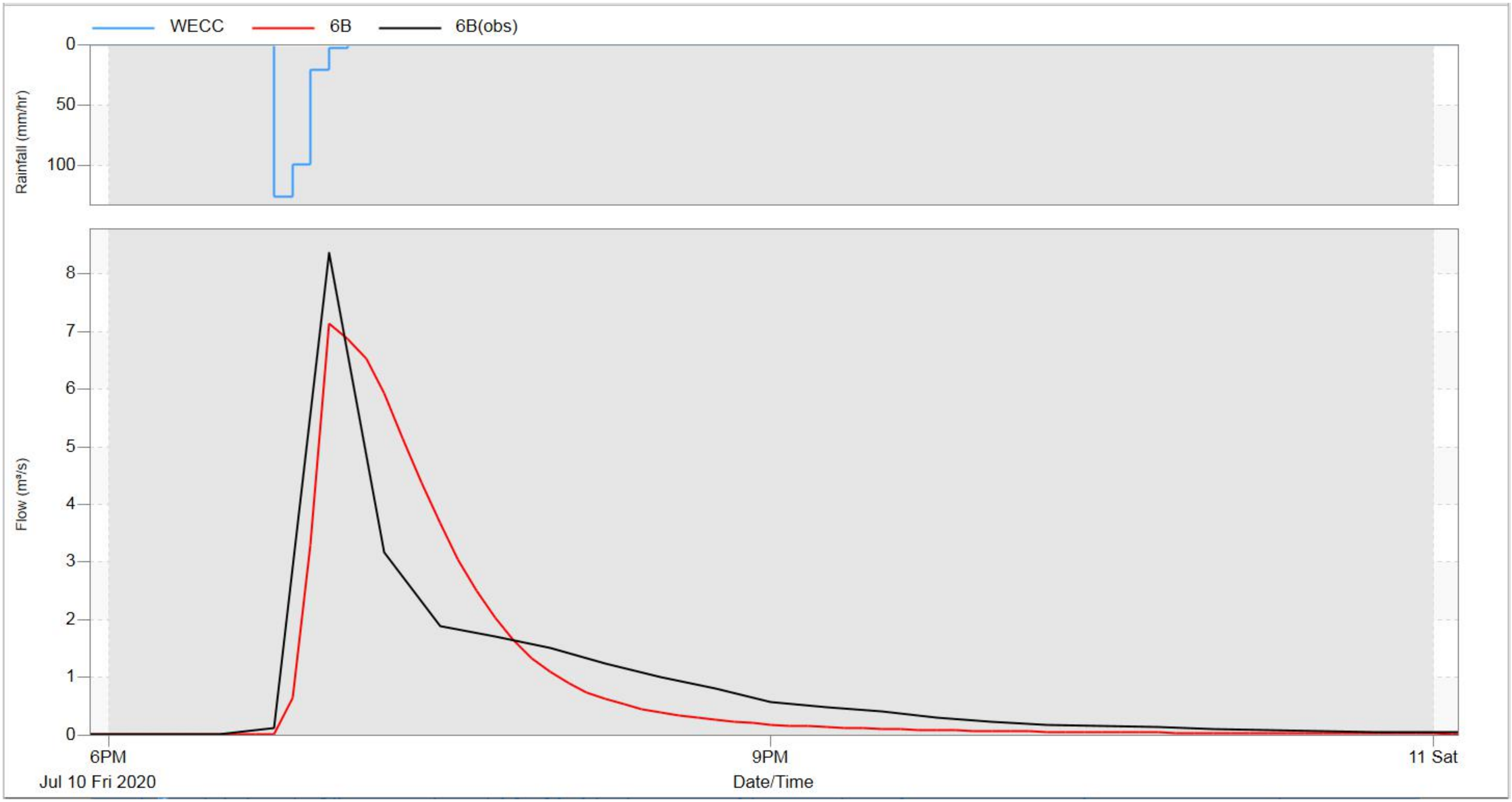


Calibration Plot for August 1st 2020 Event

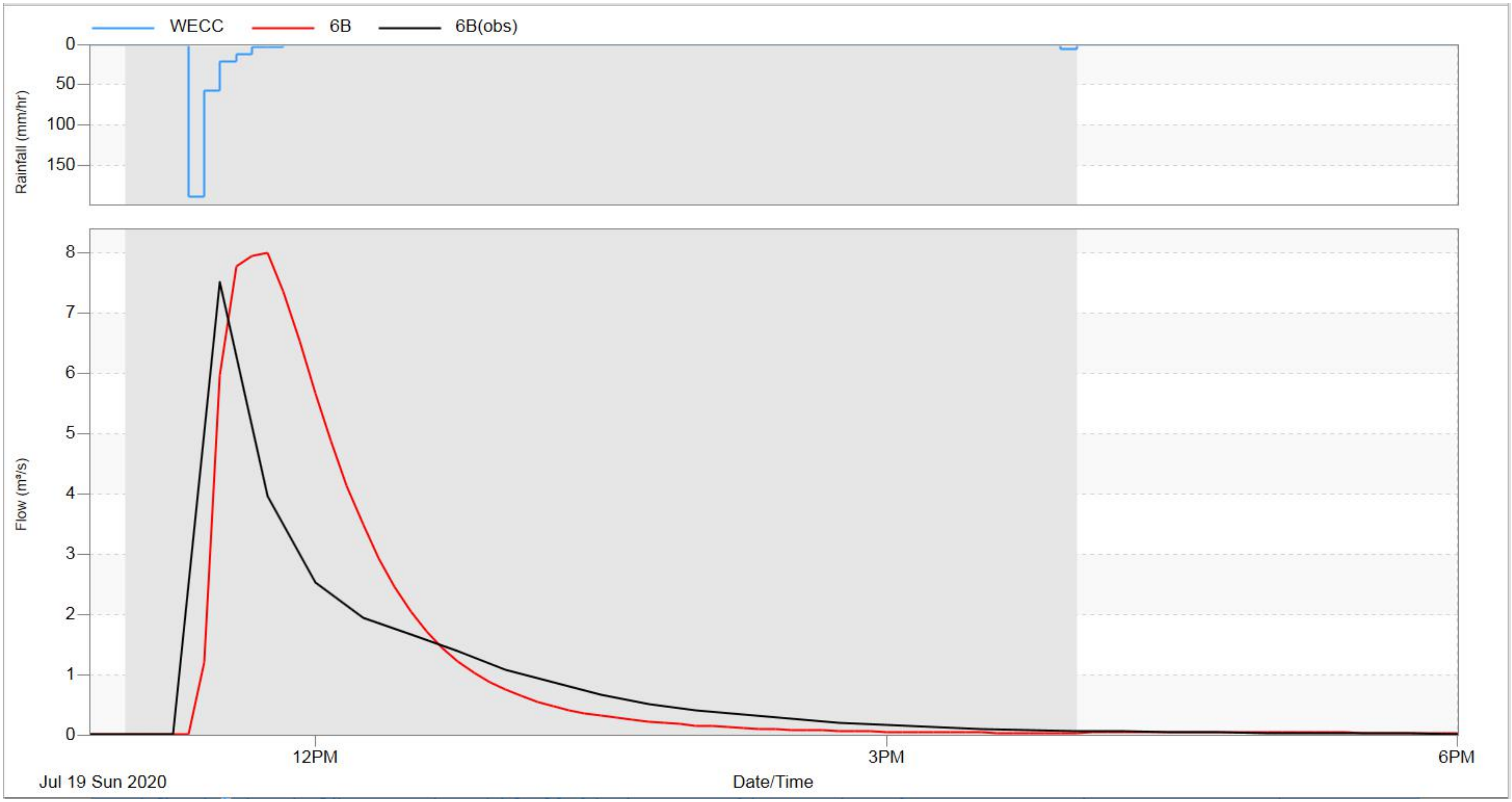


Calibration Plot for September 1st 2020 Event

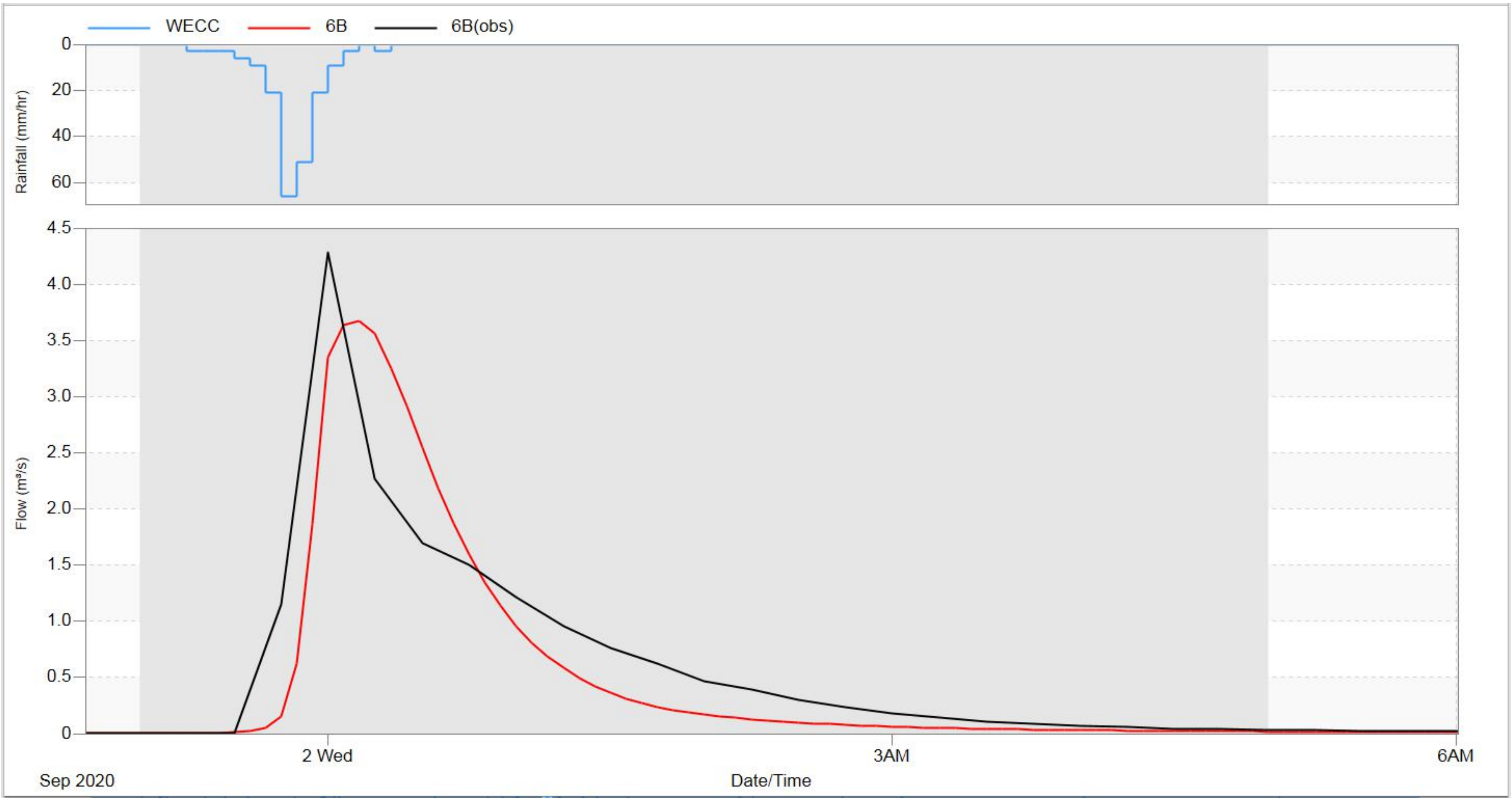
7. WW06 Monitoring location



Calibration Plot for July 10th 2020 Event



Calibration Plot for July 19th 2020 Event



Calibration Plot for September 1st 2020 Event

Appendix A3: Neighbourhood Characteristics

To: **Colleen Gammie, P.Eng**
Infrastructure Planning Engineer
City of Guelph

From: **Alison Gingrich Regehr, MASc**
Chris Denich, M.Sc., P.Eng.
Aquafor Beech Limited

Project: **Guelph Stormwater Management Master Plan**

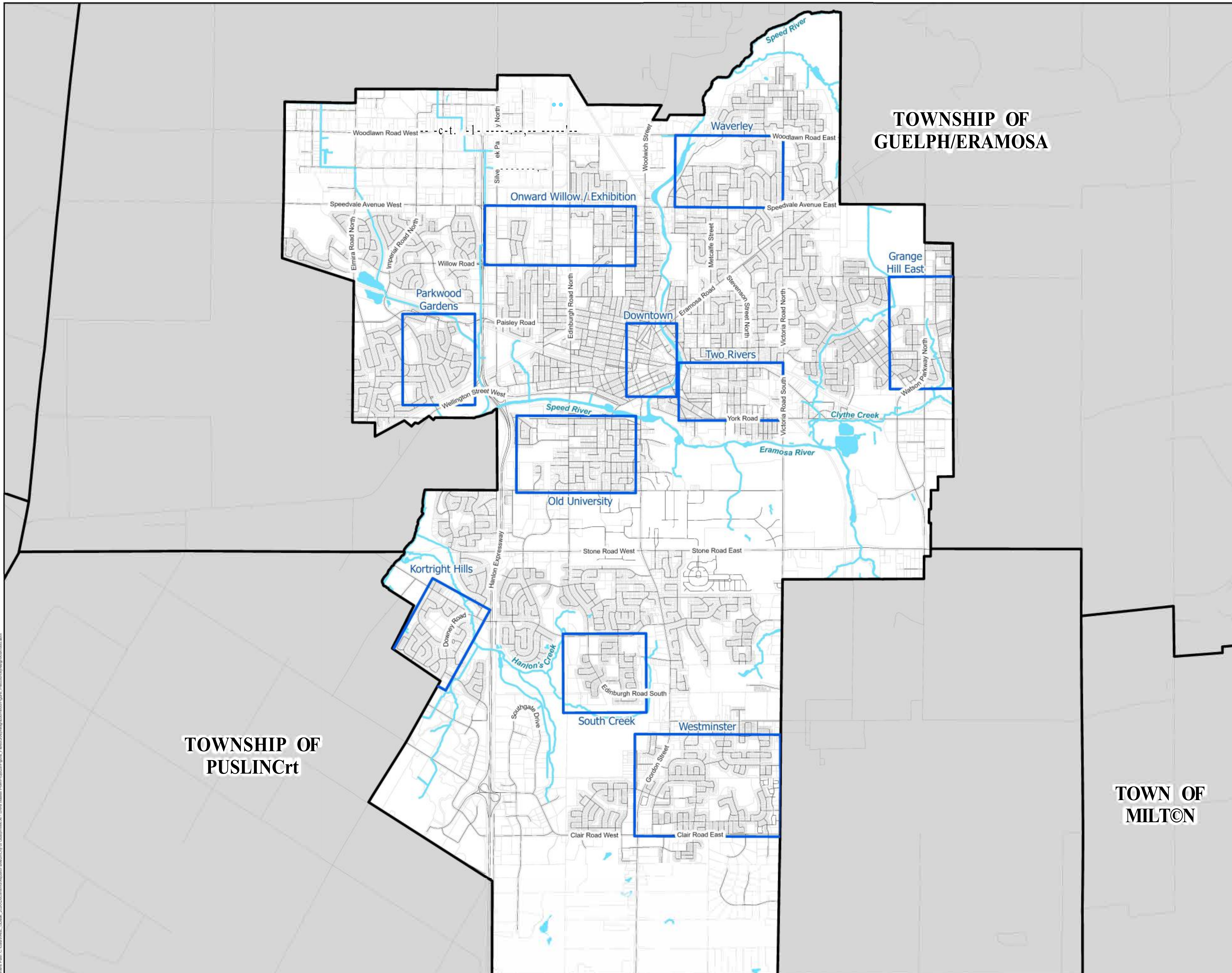
Subject: **Neighbourhood Field Assessments**

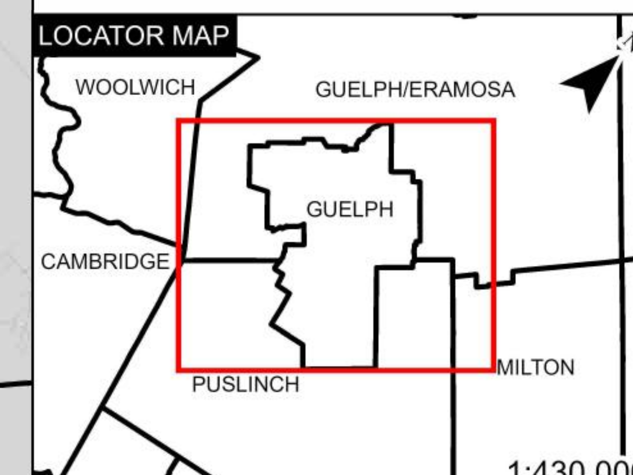
As part of the Stormwater Management Master Plan for the City of Guelph, Aquafor Beech is updating and expanding the City's PCSWMM model of its stormwater network. This process included the completion of neighbourhood field assessments to characterize neighbourhoods of varying ages and land uses. Key characteristics included: catch basin type, downspout disconnection, reverse slope driveways, and lot grading. Ten neighbourhoods were selected, as presented in **Table 1** and **Figure 1**. Results from these neighbourhoods will be extrapolated to neighbourhoods of similar age and land use. These similar neighbourhoods are also listed in **Table 1**; note that some areas are best represented by a combination of representative neighbourhoods.

Table 1: Neighbourhoods Included in Survey

Neighbourhood	Age	Primary Land Uses	Similar Neighbourhoods
Onward Willow / Exhibition	Pre-1950	Low density residential; mixed-use corridor; service commercial; major institutional; industrial; high density residential	Guelph Junction; Old City
Downtown	Pre-1950	Mixed Use; Institutional or Office; Major Transit Station	NA
Two Rivers	Pre-1950	Low density residential; mixed office/commercial; mixed business; industrial	St. George's
Old University	Pre-1950; 1950-1984	Low density residential; utility area; medium density residential; high density residential	NA
Waverley	1950-1984	Low density residential; neighbourhood commercial centre	Grange Road
Parkwood Gardens	1950-1984	Low density residential; medium density residential	West Willow Woods
Kortright Hills	1984-2000	Low density residential	Kortright West

Neighbourhood	Age	Primary Land Uses	Similar Neighbourhoods
South Creek	1984-2000	Low density residential; medium density residential; neighbourhood commercial centre	Clairfields; Kortright East
Grange Hill East	Post-2000	Low density greenfield residential; medium density residential	West Willow Woods; Brant
Westminster	Post-2000	Low density residential; low density greenfield residential; medium density residential; community mixed-use centre	Clairfields





Legend

- Survey Area
- Municipal Boundary
- Property
- Rivers
- Watercourse
- Road Centreline

Figure 1

Survey Locations

Date: 2020-12-03
Projection: NAD83_UTM_Zone_17N
Data Source: City of Guelph, GRCA
Created by: A.V.

0 0.5 1 2
Kilometres

Catch Basins

Aquafor Beech staff visited each neighbourhood during the last two weeks of October to complete these surveys by car and on foot. From the 3,718 catch basins surveyed in the road right of way, a total of 11 types were observed, many of which could be found with or without a side inlet. These catch basin types are summarized in **Appendix A**. Inlet flow rates available in the literature are also presented in **Appendix A**, and are distinguished between the catch basin located in a sag (road low point) or not. Many of the older catch basin types were not found in the literature, so the flow rates were estimated based on similar types.

Results from each neighbourhood illustrating the proportions of each catch basin present can be found in **Table 2**. The majority (83.9%) of the catch basins found through the study areas are one of the five catch basin types whose flow rates could be obtained from the literature.

The dual drainage system model will incorporate the catch basin type by applying the appropriate rating curve.

Downspout Disconnection

Varying rates of downspout disconnection were observed throughout the different neighbourhoods (**Table 2**). For this survey, it was assumed that a downspout that went underground at the house was not disconnected. Only downspouts where the outlet was visible were classified as disconnected.

The 1993 Stormwater Disposal Bylaw allows for direct connections from single detached or semi-detached dwellings to the storm sewer or discharge to the ground such that it reaches the Storm Water Disposal System through catch basins, while downspouts in Hanlon Creek or Torrance Creek Watersheds must drain to the surface of the ground. In all cases, rooftop runoff from other building types is to be discharged to the storm sewers. Similarly, all foundation drain pipes are to be discharged to the storm sewers. Kortright Hills, South Creek, Grange Hill East and Westminster neighbourhoods were constructed in the 1990s or 2000s, and therefore after the implementation of this bylaw. Downspout disconnection rates in these neighbourhoods ranged from 73% to 98%.

The Downtown Servicing Study acknowledges the presence of historical cross-connections to the sanitary sewer from roof drainage and foundation drains, but indicates that the sources of RDII are not known. City staff confirmed that downspouts within the Downtown connect to the sanitary sewers. With only 47.7% of the Downtown downspouts disconnected, this provides a significant opportunity to reduce stormwater inflows to the sanitary system.

The 2012 Stormwater Master Plan assessed downspout disconnections for the entire city (**Appendix B**). The results from the current downspout disconnection assessment generally validate those from the previous assessment, so it is therefore recommended to use the City-wide results from 2012.

Downspout disconnection rates will be used in the interpretation of the model results. For example, if the model indicates sewer surcharging, downspout disconnections may be proposed as a mitigation strategy.

Reverse-Slope Driveways

Few reverse-slope driveways were observed through the surveyed neighbourhoods, with none observed in the neighbourhoods constructed since 1984 (**Table 2**). Properties with reverse-slope driveways are at a higher risk of flooding if the overland flow depth exceeds the right-of-way.

Reverse slope driveways will be used in the interpretation of model results. For example, if the model indicates major flows expand beyond the road right-of-way, neighbourhoods with more reverse-slope driveways will be at a higher risk of property damage.

Lot Grading

While most lots sloped to the street throughout the surveyed neighbourhoods, some neighbourhoods had a higher proportion of flat lots or lots that slope away from the street. The Downtown, Two Rivers, Old University, and Onward Willow/Exhibition neighbourhoods were most likely to have flat lots or ones which slope to the house (**Table 2**).

Lot grading will be used in the interpretation of model results. For example, if the model indicates major flows expand beyond the road right-of-way, neighbourhoods with flat lots, or lots graded away from the road, will be at a higher risk of property damage.

Table 2: Neighbourhood Survey Results

		Neighbourhood									
		Onward Willow / Exhibition	Downtown	Two Rivers	Old University	Waverley	Parkwood Gardens	Kortright Hills	South Creek	Grange Hill East	Westminster
Catch Basin Type	1	32.0%	44.9%	19.5%	19.2%	9.7%	36.6%	19.3%	30.8%	22.0%	8.2%
	1B	-	-	-	0.3%	-	-	-	-	-	-
	2	25.4%	21.0%	29.3%	31.0%	18.9%	56.2%	76.5%	66.1%	69.6%	73.4%
	2B	-	-	-	0.3%	-	-	-	-	-	-
	3	-	-	-	0.5%	-	-	-	-	-	-
	4	0.7%	0.4%	0.3%	0.3%	0.7%	-	-	-	-	-
	4B	8.0%	1.5%	6.3%	15.4%	16.2%	-	-	-	-	-
	5	0.9%	-	0.6%	2.6%	-	-	-	-	-	-
	6	13.5%	3.0%	19.5%	10.3%	29.9%	-	-	-	-	-
	6B	3.0%	0.7%	2.0%	1.5%	0.9%	-	-	-	-	-
	7	9.4%	9.7%	17.8%	5.6%	7.6%	-	4.2%	0.5%	-	3.1%
	8	-	-	-	-	1.8%	-	-	-	-	-
	8B	1.1%	-	0.6%	0.8%	3.1%	-	-	-	-	-
	9B	3.0%	17.2%	3.7%	0.5%	10.1%	-	-	-	8.5%	15.3%
	10	3.0%	1.5%	0.3%	10.8%	1.1%	7.2%	-	2.7%	-	-
	11	-	-	-	1.0%	-	-	-	-	-	-
Downspout Disconnected		66.9%	47.7%	98.0%	37.3%	53.3%	45.0%	73.9%	98.2%	92.8%	73.0%
Reverse-Slope Driveway		3.8%	1.9%	0.2%	0.3%	0.1%	0.8%	-	-	-	-

		Neighbourhood									
		Onward Willow / Exhibition	Downtown	Two Rivers	Old University	Waverley	Parkwood Gardens	Kortright Hills	South Creek	Grange Hill East	Westminster
Lot Grading	Slope Away from Road	12%	3%	14%	7%	1%	-	5%	-	11%	-
	Flat	20%	30%	28%	22%	12%	-	20%	-	1%	19%
	2-5% Slope to Road	58%	60%	58%	69%	81%	96%	70%	100%	88%	81%
	Steep Slope to Road	10%	6%	1%	3%	6%	4%	5%	-	-	-

Appendix A: Catch Basin Types and Flow Rates

CB Grate Types	Standard	With Side Inlet	Prevalence within Study Area (%)	Maximum Literature Flow Rate at 0.3m head (L/s)	
				Not Sag	Sag
1 Fish Bone	 1 (OPSD 400.02)	 1B (OPSD 400.08)	1: 21.19% 1B: 0.03%	1: 64[1] 1B: 64*	1: 213[1] 1B: 213*
2 Grate 4x7	 2 (OPSD 400.10)	 2B	2: 47.20% 2B: 0.03%	2: 54[1] 2B: 54*	2: 234[1] 2B: 234*
3 Grate 2x9	 3		3: 0.05%	3: 64*	3: 213*
4 Eight Bar	 4	 4B	4: 0.24% 4B: 5.19%	4: 64* 4B: 64*	4: 213* 4B: 213*
5 Convex ½ Size	 5		5: 0.43%	5: 32*	5: 106*

CB Grate Types	Standard	With Side Inlet	Prevalence within Study Area (%)	Maximum Literature Flow Rate at 0.3m head (L/s)	
				Not Sag	Sag
6 Seven Bar	 6	 6B	6: 8.28% 6B: 0.86%	6: 64* 6B: 64*	6: 213* 6B: 213*
7 Fish	 7 (OPSD 400.02)		7: 5.92%	7: 64*	7: 258[2]
8 Grate 3x7	 8	 8B	8: 0.22% 8B: 0.65%	2: 40* 2B: 40*	2: 175* 2B: 175*
9 Side Inlet Only		 9B	9B: 7.24%	9B: 50[3]	9B: 100[2]
10 Grate 2x10	 10		10: 2.37%	10: 64[1]	10: 203[1]

CB Grate Types	Standard	With Side Inlet	Prevalence within Study Area (%)	Maximum Literature Flow Rate at 0.3m head (L/s)	
				Not Sag	Sag
11 Grate 2x8	 11		11: 0.11%	11: 64*	11: 203*

[1] City of Toronto Infoworks Basement Flooding Model Studies Guideline, 2020.
[2] Canada Municipal and Construction Castings
[3] City of Guelph, Downtown Servicing Study, 2020.
* Flow rate is assumed based on similar catch basins.

Appendix B: Synthetic Storm Events

5-Year Event				
Time (H:M)	Intensity (mm/hr)			
	Climate Change	Climate Change + 5mm Volume Control	Climate Change + 14mm Volume Control	Climate Change + 28mm Volume Control
0:00	3.016	0.1	0.1	0.1
0:05	3.258	0.1	0.1	0.1
0:10	3.547	0.1	0.1	0.1
0:15	3.899	0.1	0.1	0.1
0:20	4.338	0.1	0.1	0.1
0:25	4.901	0.1	0.1	0.1
0:30	5.652	0.1	0.1	0.1
0:35	6.706	5.9	0.1	0.1
0:40	8.296	7.96416	0.1	0.1
0:45	10.98	10.5408	0.1	0.1
0:50	16.48	15.8208	0.1	0.1
0:55	33.816	32.46336	0.1	0.1
1:00	161.573	155.11008	0.1	0.1
1:05	65.859	63.22464	21.1	0.1
1:10	34.601	33.21696	142.18424	0.1
1:15	22.134	22.134	57.95592	0.1
1:20	16.24	16.24	30.44888	0.1
1:25	12.843	12.843	22.134	14
1:30	10.644	10.644	16.24	80.7865
1:35	9.108	9.108	12.843	32.9295
1:40	7.974	7.974	10.644	17.3005
1:45	7.103	7.103	9.108	22.134
1:50	6.413	6.413	7.974	16.24
1:55	5.853	5.853	7.103	12.843
2:00	5.388	5.388	6.413	10.644
2:05	4.997	4.997	5.853	9.108
2:10	4.662	4.662	5.388	7.974
2:15	4.373	4.373	4.997	7.103
2:20	4.12	4.12	4.662	6.413
2:25	3.897	3.897	4.373	5.853
2:30	3.698	3.698	4.12	5.388
2:35	3.521	3.521	3.897	4.997
2:40	3.361	3.361	3.698	4.662
2:45	3.217	3.217	3.521	4.373
2:50	3.085	3.085	3.361	4.12
2:55	2.965	2.965	3.217	3.897
3:00	0	0	0	0

100-Year Event				
Time (H:M)	Intensity (mm/hr)			
	Climate Change	Climate Change + 5mm Volume Control	Climate Change + 14mm Volume Control	Climate Change + 28mm Volume Control
0:00	4.423	0.1	0.1	0.1
0:05	4.964	0.1	0.1	0.1
0:10	5.636	0.1	0.1	0.1
0:15	6.488	0.1	0.1	0.1
0:20	7.597	0.1	0.1	0.1
0:25	9.083	0.1	0.1	0.1
0:30	11.155	6.7	0.1	0.1
0:35	14.191	14.191	0.1	0.1
0:40	18.943	18.943	0.1	0.1
0:45	27.115	27.115	16.9	0.1
0:50	43.32	43.32	41.154	0.1
0:55	84.459	84.459	80.23605	0.1
1:00	211.941	211.941	201.34395	8
1:05	137.427	137.427	130.55565	20.33625
1:10	87.241	87.241	82.87895	32.49
1:15	58.747	58.747	58.747	63.34425
1:20	42.724	42.724	42.724	158.95575
1:25	32.755	32.755	32.755	103.07025
1:30	26.095	26.095	26.095	65.43075
1:35	21.406	21.406	21.406	58.747
1:40	17.966	17.966	17.966	42.724
1:45	15.36	15.36	15.36	32.755
1:50	13.332	13.332	13.332	26.095
1:55	11.72	11.72	11.72	21.406
2:00	10.414	10.414	10.414	17.966
2:05	9.339	9.339	9.339	15.36
2:10	8.442	8.442	8.442	13.332
2:15	7.684	7.684	7.684	11.72
2:20	7.038	7.038	7.038	10.414
2:25	6.481	6.481	6.481	9.339
2:30	5.997	5.997	5.997	8.442
2:35	5.574	5.574	5.574	7.684
2:40	5.2	5.2	5.2	7.038
2:45	4.87	4.87	4.87	6.481
2:50	4.575	4.575	4.575	5.997
2:55	4.31	4.31	4.31	5.574
3:00	0	0	0	0

Appendix D: Enhanced Storm Sewer Flow Monitoring Program

Submitted to:

The City of Guelph

ENHANCED STORMWATER RUNOFF MONITORING PROGRAM

CITY OF GUELPH SWM MASTER PLAN

A report submitted by:

Aquafor Beech Ltd.

July 14, 2022

1. Introduction

Aquafor Beech Limited has been retained to complete consultant services for the development of a Stormwater Management Master Plan (SWMMP) for the City of Guelph. These services will update the 2012 SWMMP (completed by AMEC) to meet the current needs of the City, following the Municipal Class Environmental Assessment (EA) process, and, in doing so, develop a long-term plan for safe and effective management of stormwater runoff from urban areas while improving the ecosystem health and ecological sustainability of the Eramosa and Speed Rivers and their Tributaries.

A key component of the SWMMP is the development of a comprehensive City-wide integrated hydrologic, hydraulic, and water quality simulation model using PCSWMM for the purpose of study area characterization and impact assessment.

An important element in the development of any comprehensive model is the incorporation of a thorough monitoring plan that details techniques, equipment and industry standards related to real-time, cloud and linked monitoring systems and approaches to obtain representative data of real-life scenarios.

A monitoring program provides important information in regards to key characteristics of the stormwater water system within a study area; and the results obtained from flow monitoring programs are then utilized for the proper calibration of the stormwater network hydrologic and hydraulic computer models. The calibration process results in more accurate model representations of the existing stormwater network, which acknowledges the adaptive environmental management process.

The following sections provide:

- A general overview of stormwater runoff monitoring
- A review of the 2012 SWMMP monitoring program
- Discussion of the measurement of precipitation relating to stormwater monitoring
- Summary of the means and methods for flow monitoring, calibration and validation
- Discussion and comparison of two (2) alternative monitoring approaches for use in this SWMMP
- The financial implications

2. General Stormwater Runoff Monitoring Overview

Stormwater flow monitoring programs provide valuable information to better understand the functionality of existing stormwater infrastructure. They generate information that allows for a better understanding of the existing level of service, definition of problem areas together with direction as to where subsequent efforts should be spent as means of mitigating risks and enabling fast decision making.

The development and implementation of a flow monitoring program involves several activities, including:

1. Supply of flow monitoring devices and rain gauges (if required), and installation at the specified locations;
2. Field verification and calibration of installed equipment;
3. Collection and analysis of data;
4. Completion of monitoring reports;
5. Removal of flow monitoring equipment after completion of monitoring period;

The purpose of the monitoring program is to obtain real-life data in regards to both precipitation and the associated stormwater runoff. In order to obtain representative data that can be used for calibration purposes, it is recommended that the monitoring extend for a period of time sufficient to capture a minimum of six (6) significant storm events, which are typically defined as storm events with total rainfall depth of 10mm or greater, over a storm duration of three (3) hours or less. Ideally one of either the 2-year or 5-year storm event shall be captured.

In order to obtain representative data, it is recommended that the monitoring period extends from early Spring until late Fall, typically from March to December, for a total of nine (9) months of continuous monitoring for each location selected.

The duration is weather dependent and may require more than nine (9) months to collect the necessary information. A provision of an additional nine (9) months of monitoring is recommended to be included in any program to account for the possibility of dry conditions being predominant during monitoring period, impeding the capture of the required significant storm events.

3. 2012 Monitoring Study

A stormwater flow monitoring program was carried out as part of the City of Guelph Stormwater Management Master Plan, developed by AMEC in 2012. The monitoring program included continuous water level and rainfall monitoring, as well as discrete in-situ stream velocity monitoring for the purpose of calibrating and verifying the hydrologic drainage network modelling. All monitoring points were located in creeks throughout the City.

Monitoring activities started on June 25, 2010 and ended on December 3, 2010. The details of the various monitoring locations and dates are summarized below in **Table 3-1**, and shown in **Figure 3.1**. Two rounds of water level/flow monitoring were conducted, with four sites per round.

Table 3-1 - 2012 Monitoring Program Location Details

Round 1 (June 25 – September 1, 2010)		**Round 2 (September 21 – December 3, 2010)**	
Location Name	**UTM (Approximate)**	**Location Name**	**UTM (Approximate)**
Willow West (WW06)	17 T 556509 m E 4820128 m N	NW Channel (NW04)	17 T 557123 m E 4821784 m N
Waverly (US03)	17 T 559610 m E 4824492 m N	Woodlawn (US10)	17 T 558550 m E 4823994 m N
Railway (LS02)	17 T 559208 m E 4820411 m N	Ward 1 (HD02)	17 T 562043 m E 4822544 m N
Stone Road (LS05)	17 T 560727 m E 4817618 m N	Schroder (HD02)	17 T 562572 m E 4823077 m N

Data Loggers at these locations (Solinst Leveloggers) recorded water levels at 5-minute increments, with barometric correction data applied from another of AMEC's monitoring program site. A geodetic survey was conducted to obtain a cross-section and channel profile at all locations. Periodic in-stream velocity measurements were also taken throughout the monitoring program to enable the calculation of observed flow – surface water level elevations. These elevations were then used to fit a rating curve, based on the previously noted surveyed cross-sections and the hydraulic modeling program HEC-RAS v.4.0.

A rainfall gauge was installed on the roof of the new City Hall for the entire duration of the monitoring program. Twelve (12) significant storm events with total rainfall depth ranging from 11.4mm to 38mm were observed between June 25, 2010 and December 3, 2010.

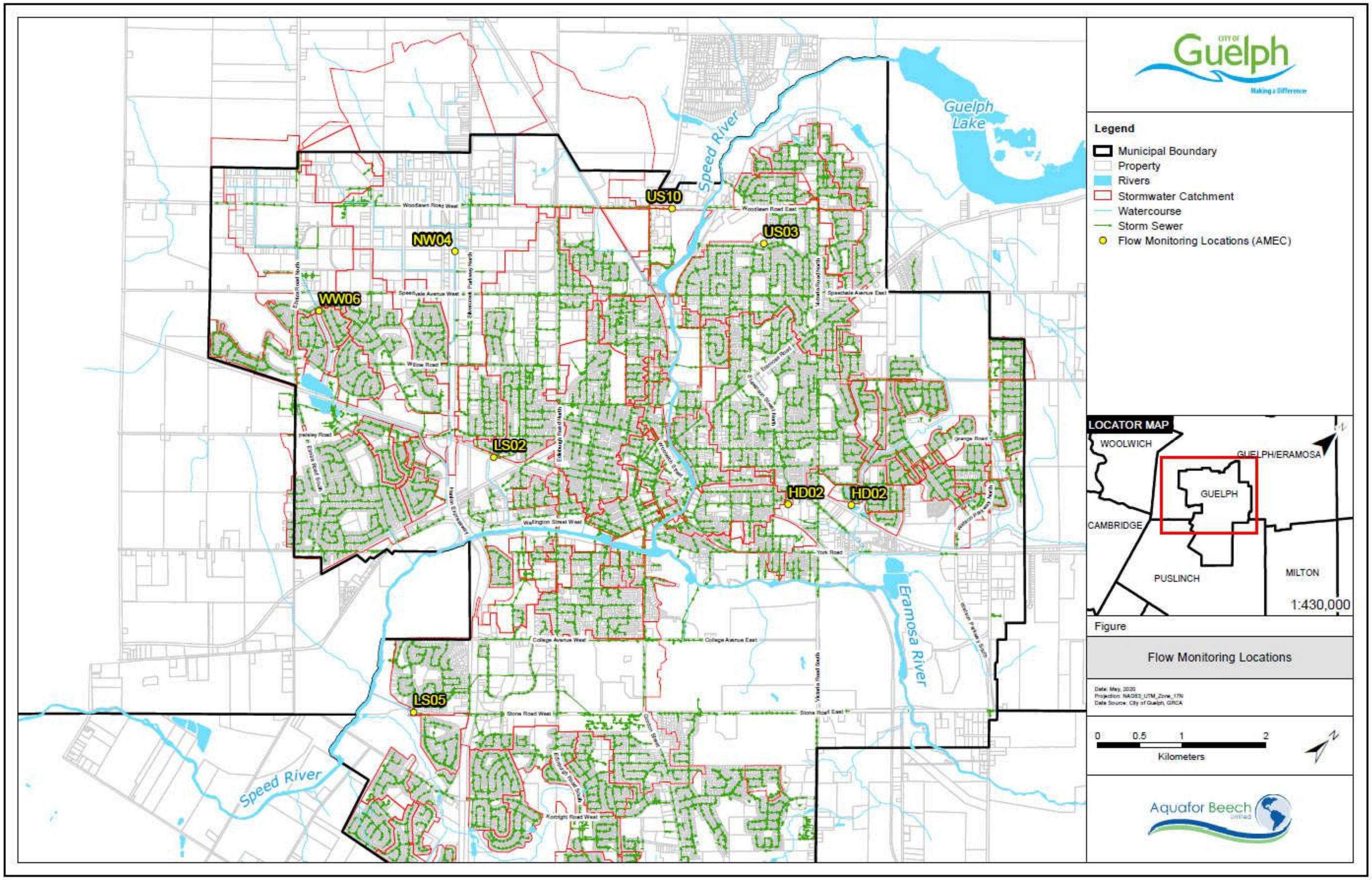


Figure 3.1 - 2012 Flow Monitoring Locations

4. Measurement of Precipitation

Total rainfall can be measured by a network of rain gauges spread throughout the study area to provide a representative coverage of the whole area. Rain gauges are selected based on their proximity to each monitoring station. The City of Guelph currently has two (2) rain gauges reporting to FlowWorks:

1. West End Community Centre, and
2. Helmar Well.

The City operates four (4) additional rain gauges not connected to FlowWorks in other locations, including at:

1. FM Woods,
2. Waste Water Treatment Plant,
3. Arkell 15 Well, and the
4. Emergency Services Building

Additionally, the GRCA operates two (2) rain gauges near Guelph, including one at Guelph Lake and one where Wellington Road 32 crosses the Speed River. These gauges are shown in **Figure 4.1**.

This existing network of rain gauges provides good coverage to the City, with most of the City within a 4 km radius of a rain gauge. To improve the rain gauge coverage, the addition two rain gauges is recommended to increase the existing coverage to a 3 km radius for most of the City, as shown in **Figure 4.2**.

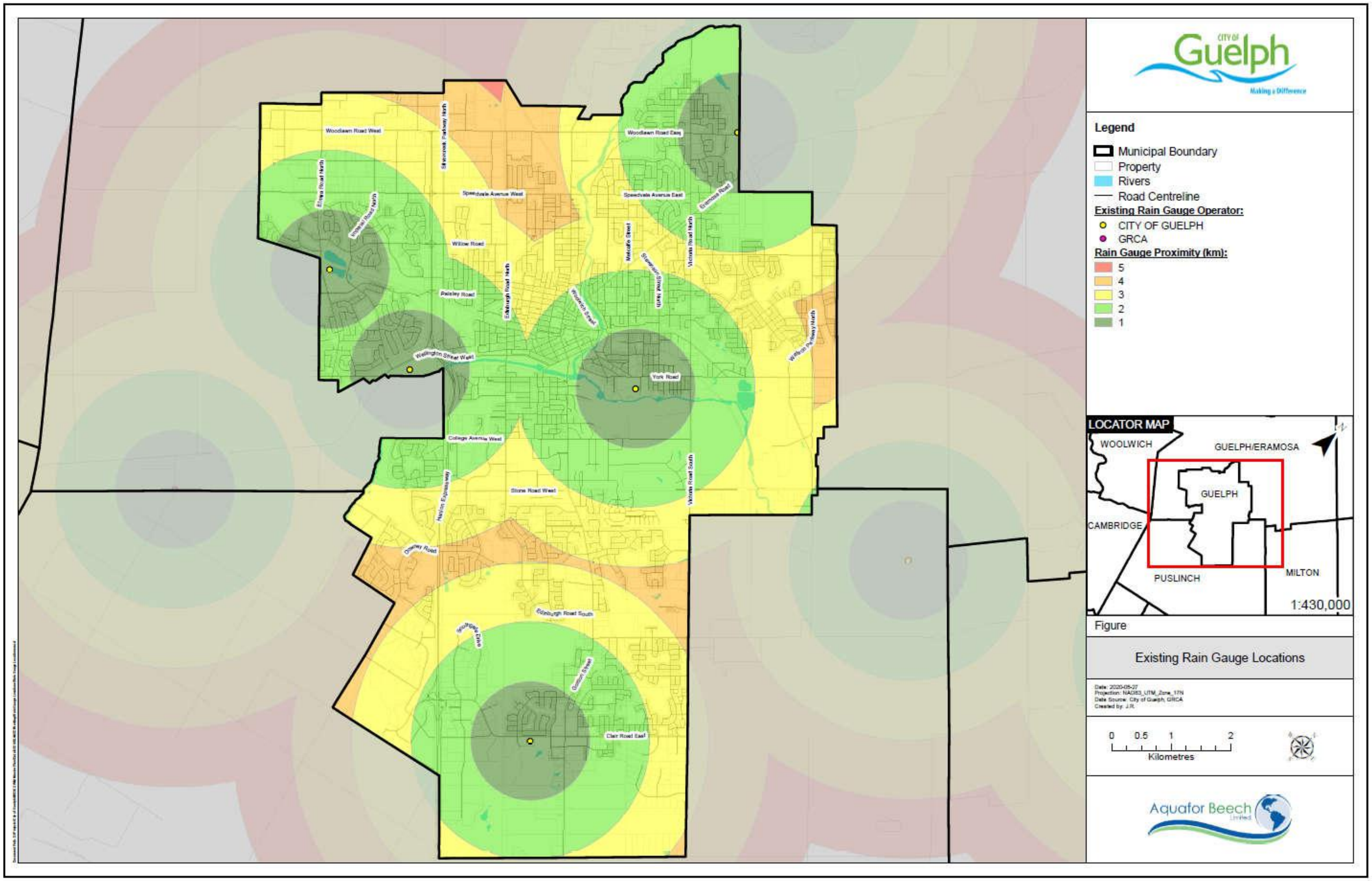


Figure 4.1 - Existing Rain Gauge Network

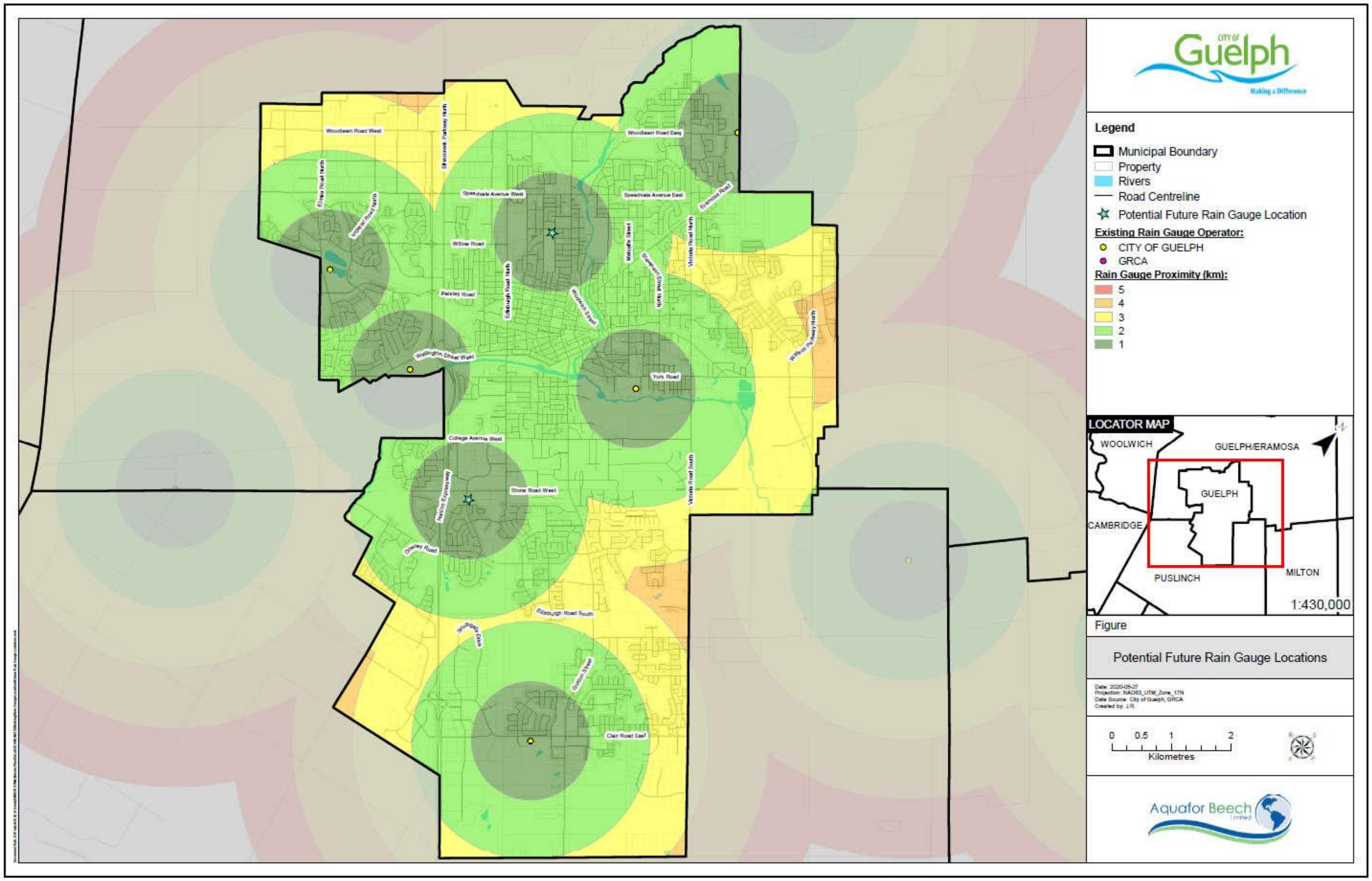


Figure 4.2 – Potential New Rain Gauges Locations

5. Measurement of Flow, Calibration and Validation

The monitoring locations shall be selected based on numerous factors, including:

1. Coverage of full range of land use types in the study area, isolating land use types where practical;
2. Coverage of system portions of various ages, both with and without stormwater management included in their original design;
3. Coverage of areas where the existing modeling predicts surcharging from relatively small storm events storm;
4. Coverage of strategic locations where bottlenecks or flooding events have been previously identified;
5. Coverage of key storm sewer outfalls (within 1 to 2 pipes of them);
6. Incorporation of areas where ground water tables are known to be high since these could have excessive base infiltration which would reduce their effective level of service;
7. Selected locations shall have satisfactory hydraulic sewer conditions in order to allow for the highest accuracy and reliability of measurements;
8. Selected locations are ideally easy to access, preferably away from areas requiring high-traffic control or locations of deep sewers;
9. Coverage of areas with known problems;
10. Selected monitoring points shall be located in representative catchment areas, such that the hydrologic component of the hydraulic model can be calibrated.

The selection of 8 to 10 sites, in accordance with the requirements outlined above, is considered sufficient for a good representation of the study area land use. After selection of the monitoring locations, site visits are typically undertaken to ensure that the hydraulics at the site are suitable for obtaining representative information.

The installation of the monitoring equipment is carried out following the selection and field evaluation of the monitoring locations. The monitoring equipment can vary depending on specific site conditions and the desired information to be collected. In general, the equipment shall be able to capture rainfall records, flow levels and velocity on a continuous basis, and also be able to address backwater issues and surcharging. Monitoring equipment shall be preferable installed within the sewer network itself, rather than of instream.

Model Calibration - The collected flow monitoring information will be used to calibrate and validate the new PCSWMM model developed for the City of Guelph. Calibration involves adjusting key parameters (percent impervious, drainage area, travel length, percent downspout disconnection, catch basin inlet capacity infiltration parameters as well as others) for typically three or more events that were recorded. Calibration should consider peak flow, volume and hydrograph shape. In general, for all studies it was found that the default values used to start the calibration process had to be lowered as the initial modelled flow volumes and peak flows far exceeded the monitored values due to factors such as split drainage from homes, poor road and property drainage and areas adjacent to parks. A similar adjustment may be required with the expanded model and the key parameters will be adjusted on a case by case basis once the runoff surfaces have been recalculated based on land use. For the calibration of the hydrological and hydraulic detailed model, the performance criteria, which is consistent with our approach, will be set at: **+/- 20% on runoff volumes and +/- 20% on peak flows.**

Model Validation - The model is then validated using three different events to confirm suitability of the results.

Once the calibration/validation process is carried out for the sewersheds where flow monitoring was provided then the appropriate key parameters are applied to the remaining sewersheds to provide flows for existing conditions as well as design events.

6. Proposed Monitoring Program

Two (2) alternatives are proposed as part of the stormwater flow monitoring program.

1. **Alternative 1: Consistent with the 2012 SWM-MP -** consists of additional flow monitoring conducted similarly as the 2012 monitoring program, and at the same locations, in order to allow for comparison of current flow levels with the results found as part of the 2012 Study. Minor adjustments are also proposed.

2. **Alternative 2: Enhanced Storm Sewer Monitoring Program -** consists of an enhanced monitoring program implemented following all the standards and considerations described in the previous sections, including site selection, installation of new rain gauges and the adoption of high capability flow monitors. The details of both phases are described in the following sections.

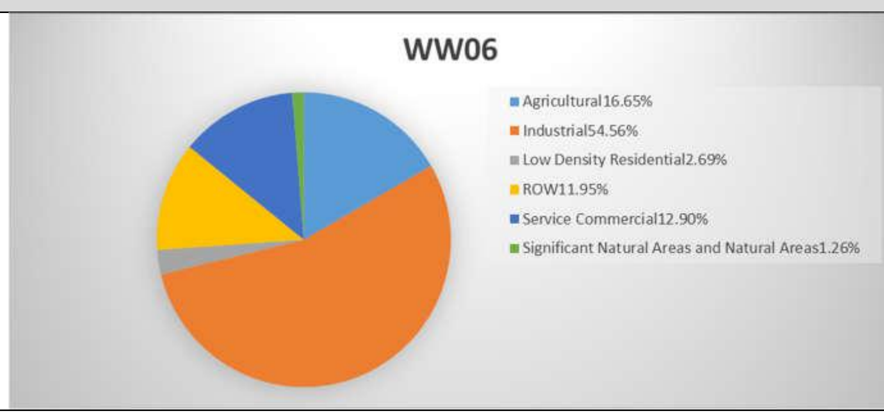
6.1. Alternative 1 – Consistent with the 2012 SWM-MP

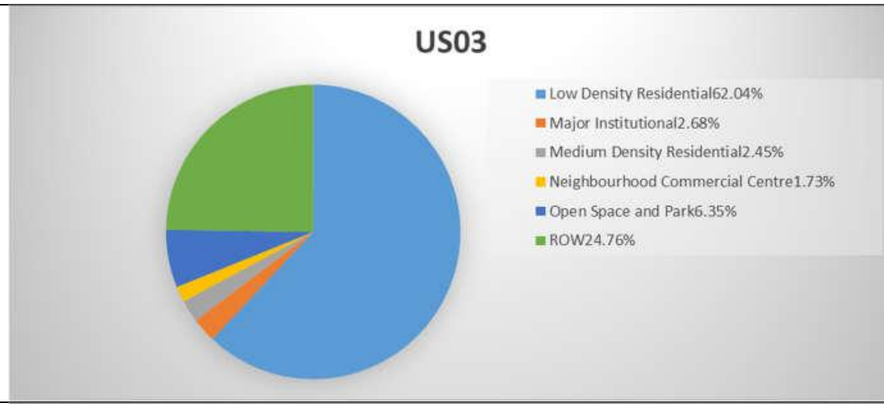
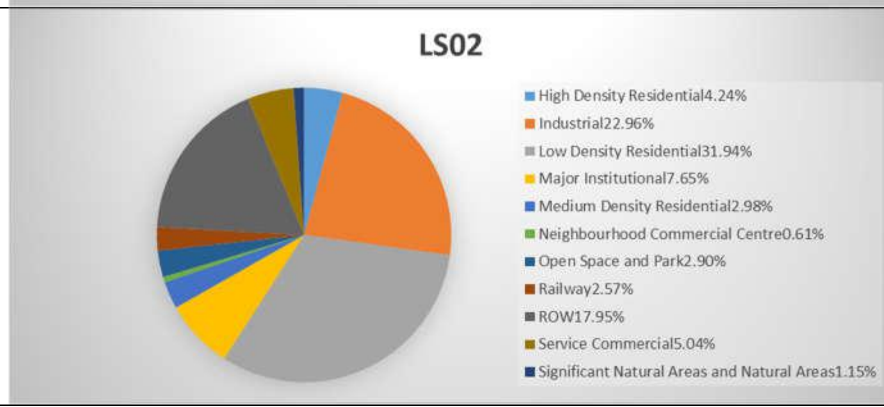
Monitoring alternative 1 is similar to the one developed as part of the 2012 SWMMP, including continuous water level and rainfall monitoring, as well as in-situ stream velocity monitoring in eight (8) different points throughout the City of Guelph. The selected monitoring locations are the same as the 2012 monitoring program, as described in Table 3-1. These locations are distributed among existing creeks within the city.

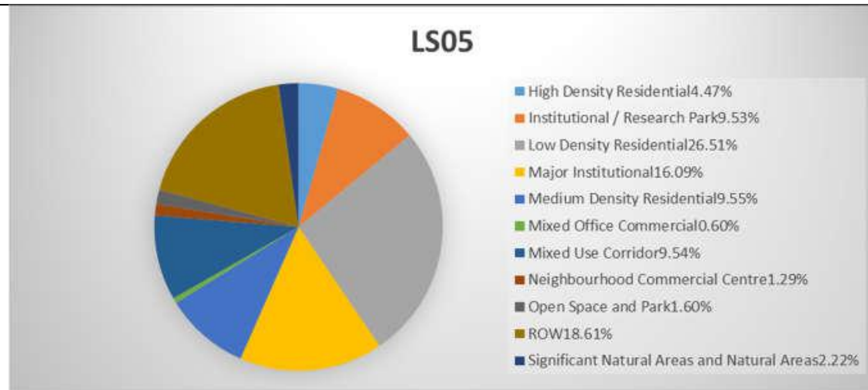
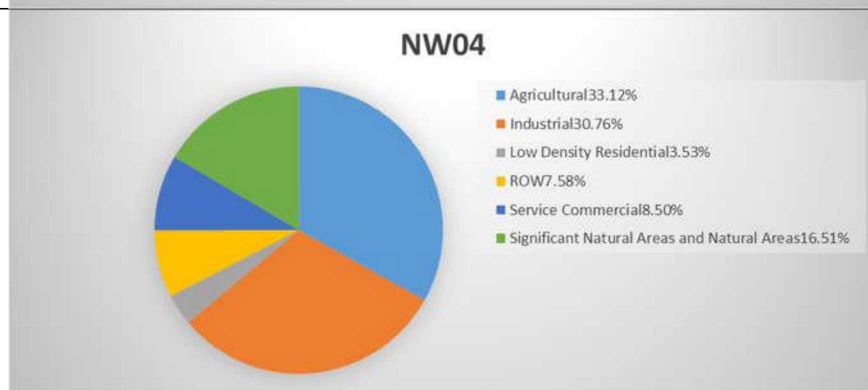
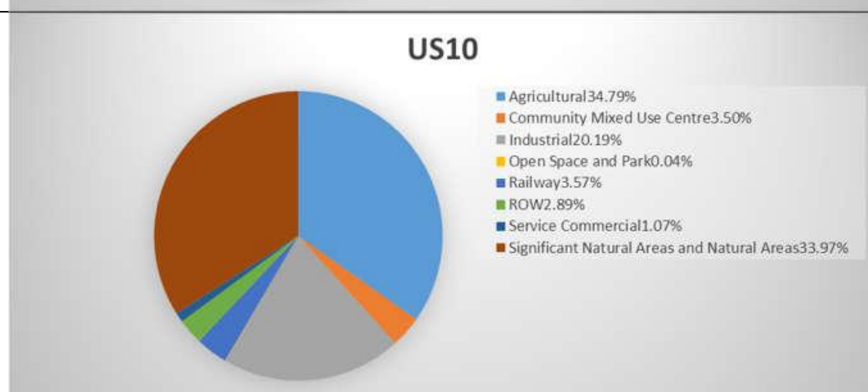
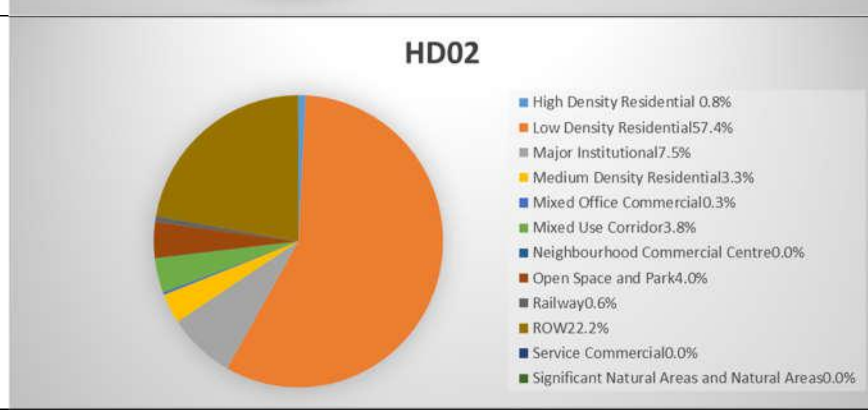
Assessment of Contributing Drainage Areas:

To better understand the characteristics of the contributing drainage area for the various monitoring locations from the 2012 SWMMP, an assessment of the land-uses was completed. Table 6-1 and Figure 6.1 provides a summary of all land-uses as well as the ranking of the top three (3) most prevalent land-uses in each contributing drainage area.

Table 6-1 - Drainage Area Land-uses (2012 SWWMP Monitoring Locations)

Location Name	Major Land uses (top 3)	
Willow West (WW06)	1. Industrial (54.65%) 2. Agricultural (16.65%) 3. ROW (11.95%)	

<table>
<tr>
<td>Waverly (US03)</td>
<td>1. Low Density Residential (62.04%)
2. ROW (24.76%)
3. Parks & Open Space (6.35%)</td>
<td>
</td>
</tr>
<tr>
<td>Railway (LS02)</td>
<td>1. Low Density Residential (31.94%)
2. Industrial (22.96%)
3. ROW (17.95%)</td>
<td>
</td>
</tr>
</table>

<table>
<tr><td>Stone Road (LS05)</td><td>1. Low Density Residential (26.51%)
2. ROW (18.61%)
3. Mixed Density Residential (9.55%)</td><td></td></tr>
<tr><td>NW Channel (NW04)</td><td>1. Agricultural (33.1%)
2. Industrial (30.76%)
3. Natural Areas (16.51%)</td><td></td></tr>
<tr><td>Woodlawn (US10)</td><td>1. Agricultural (34.79%)
2. Natural Areas (33.97%)
3. Industrial (20.19%)</td><td></td></tr>
<tr><td>Ward 1 (HD02) & Schroder (HD02)</td><td>1. Low Density Residential (57.4%)
2. ROW (22.2%)
3. Major Institutional (7.5%)</td><td></td></tr>
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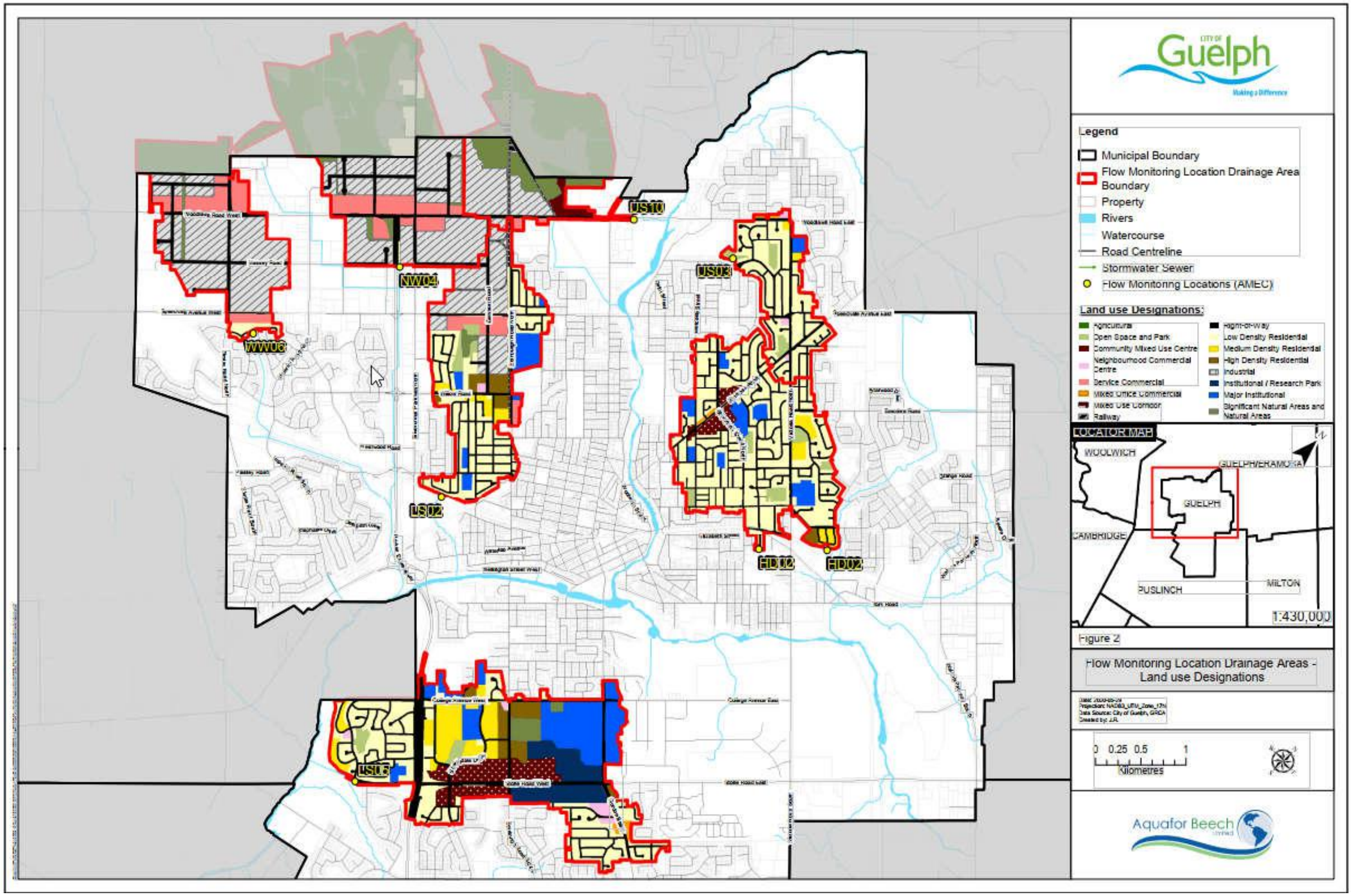

Figure 6.1 - Alternative 1 Contributing Drainage Areas Land Use

Monitoring Parameters and Equipment

The proposed works for Alternative 1 include the supply and installation of eight (8) monitoring stations, each consisting of the following:

- 1 Hobo U-20 Water Level and Temperature (pressure transducer) data logger;
- 1 staff gauge;
- 1 YSI Professional Plus Series multimeter
- 1 SonTek Flow Tracker;
- All associated hardware and housing required for proper functionality of monitoring equipment;

An additional Hobo U-20 logger will be installed at a central location for barometric compensation purposes.

Monitoring will start in July 2020, and is expected to extend during nine (9) months, split into two (2) continuous time periods. The initial monitoring period will undergo from July 2020 until December 2020. Equipment will be removed during the winter and reinstalled in March 2021 for the second monitoring period, which will extend until June 2021, for a total of nine (9) months. Should the City of Guelph decide to implement Alternative 2 prior to the end of the pre-established monitoring period, Alternative 1 will be interrupted and replaced with an enhanced monitoring program, as described in **Section 6.2**.

At a minimum, it is recommended that Alternative 1 be modified to undertake the monitoring of all eight (8) locations simultaneously for a nine-month period, with a provisional period of an additional nine months if required.

It has been observed in past studies of similar nature conducted by Aquafor, that 15-minute logging intervals accurately depict hydrologic responses to rainfall and runoff events. Therefore, Hobo U-20 loggers will be set to record water levels and temperature at 15-minute intervals in order to prolong data storage, battery life and remain consistent with industry standards.

Flow Trackers will be set to collect measurements at appropriate time intervals depending on the size of the watercourse. Water velocity measurements will be collected using the industry standard approach, specifically, for water levels less than 60 cm, velocity measurements will be taken at 60% of the flow depth and for water levels greater than 60 cm, the mean of two (2) water velocity measurements will be taken: one at 20% of the depth and the other at 80% of the depth.

At the time of the flow measurements, field measurements are to be conducted as part of quality control procedures and will include: pH, dissolved oxygen (DO), temperature and conductivity using YSI Professional Plus Series multimeter.

Data Collection and Deliverables

During the first month of the monitoring period, weekly visits will be carried out for inspection of the equipment and QA/QC of the measurements. Data will be collected once a month and will be made available to the City of Guelph in monthly reports.

6.2. Alternative 2 – Enhanced Storm Sewer Flow Monitoring

Monitoring alternative 2 consists of an enhanced monitoring program implemented following all the standards and considerations described in the previous sections, including site selection, installation of new rain gauges and the adoption of high capability flow monitors.

Assessment of Contributing Drainage Areas:

Monitoring alternative 2 consists of an enhanced monitoring program focused in obtaining data from the existing sewer network, rather than from water courses. A secondary assessment of the existing drainage areas will be completed for the selection of eight to ten (10) new monitoring locations within the existing storm sewer network, in accordance with the criteria outlined on Section 5. The layout of the activities conducted as part of alternative 2 are as follows:

- Review of background information in regards to storm sewer network and land use within the City of Guelph for the selection of eight to ten (10) potential monitoring locations;
- The proposed monitoring locations will be submitted to the City of Guelph for review and approval;
- Field inspections will be conducted to assess the suitability for accurate monitoring and proper equipment required for the installation of the monitoring equipment. If necessary, alternative locations can be added to the list of sites to be inspected;
- Following field inspection, eight to ten (10) locations will be selected to be included in the monitoring program;

Monitoring Parameters and Equipment

Monitoring stations will be installed for each location, each consisting of the following:

- Pipeline Model PSA-AV Area Velocity Smart Sensor in combination with a Ru-33 Recording Telemetry Units or equivalent (i.e. Telogs or Tritons). As an option, cellular enable units allowing real-time data can be installed.
- 1 SonTek Flow Tracker (used for discrete flow measurement for logger validation);
- Storm sewer weirs (primary devices) as required;
- All associated hardware and housing required for proper functionality of monitoring equipment;

Data Collection and Deliverables

Monitoring will start upon request of the City of Guelph, and it shall extend during the nine (9) months covering early Spring to late Fall. Depending on the starting date of the enhanced monitoring alternative, it might be necessary to break the monitoring period into two (2) continuous intervals to avoid winter conditions.

A/V smart sensors will be set to record water levels and temperature at 15-minute intervals in order to prolong data storage, battery life and remain consistent with industry standards. It has been observed in past studies of similar nature conducted by Aquafor, that 15-minute logging intervals accurately depict hydrologic responses to rainfall and runoff events. Flows in the sewers will be assessed using discrete measurements via a SonTek Flow Tracker or equivalent. The field program will consist of the following:

- Monthly visits will be conducted at each location for field checks, discrete flow sampling, and sensor cleaning;
- QA/QC will be carried out once a week during the first month of the monitoring program, followed by QA/QC visits monthly during the remainder of the monitoring period;

- Raw field data will be available on a daily basis on the Flow Works data platform. Finalized data will be made available on monthly reports to be submitted to the City;
- After the completion of the monitoring period, all monitoring stations will be removed and final report and documentation provided to the City of Guelph.

Rainfall Monitoring

For alternative 2, rainfall data will be collected from the existing City of Guelph rain gauge network, and correlated with corresponding runoff measurements according to the proximity of the rain gauge and each monitoring station. As discussed on **Section 4** of this report, the addition of two (2) extra rain gauges is recommended to refine the coverage of the City of Guelph rain gauge network.

The Meteorological Service of Canada has published siting standards for meteorological observing sites (MSC, 2001), including precipitation stations. The standards state that the site should be located:

1. On open, level ground with a primary area at least 15m x 15m covered with short grass or at least on natural ground with a secondary turf covered area of at least 30m x 30m, surrounded as by a single rail, cable, or chain link fence, and a protected area of 90m x 90m centered on the primary area.
2. Such that sensors shall be at a distance from vertical obstructions of four times the height of the obstruction for precipitation gauges.
3. In an area which provides ease of access for the observer and for maintenance of instruments and the installation of electrical ducts.

The standards state that locations that should be avoided for the installation of rain gauges include:

- the top of hills.
- in hollows, at the bottom of narrow valleys, and near hills or ridges, or cliffs.
- near isolated ponds or streams.
- near roads where snow from snow clearance operations, or dust, can affect the site.
- where there is excessive human or animal traffic.
- where excessive drifting snow accumulates.
- near vehicle parking areas.
- where heat is exhausted by vehicles or buildings

Although technical guidance generally suggests that siting precipitation and temperature sensors on rooftops should be avoided due to wind turbulence and rooftop temperature bias, rooftop installations are common in urban setting as a result of limited availability of accessible open space. Rooftops also have the advantage of being close to an electrical source to power heaters and telemetry (note: solar is another option), and are generally safe from accidental damage or vandalism by site users including the public.

There are several types of precipitation gauges, with the two most common being tipping bucket gauges and weighing bucket gauges. A tipping bucket precipitation gauge is recommended due to the low capital cost and minimal maintenance requirements apart from calibration. It consists of a funnel that collects and channels the onto a tipping device. After a pre-set amount of precipitation falls, the lever tips, dumping the collected water and sending an electrical signal. These devices should be equipped with telemetry and incorporated into the City's data delivery and data management system.

The two (2) recommended permanent or temporary locations as shown in **Figure 4.2** and include the rooftops of:

1. the Scottsdale Branch of the Guelph Public Library, and
2. the Exhibition Park Arena.

- Permanent Rain Gauges – can be supplied by the City of Guelph and installed by Aquafor Beech Ltd. as part of the monitoring program tasks.
- Temporary Rain Gauges – can be supplied and installed by Aquafor Beech Ltd. as part of the monitoring program tasks. Inspection and data collection of all temporary rain gauges to be part of this monitoring program will follow the same schedule as the inspection and data collection of the flow monitoring devices, including weekly visits during the first month of the monitoring period and subsequent visits monthly for further inspection and data collection. Rainfall data will be available on a monthly basis as part of the monthly monitoring reports.

7. Financial Implications

To accurately assess the financial implications, a full costing must be completed for Alternative 2. However, to provide a relative sense of the monitoring effort the following Class C cost estimate has been provided for Alternative 2 and compared to the costs of Alternative 1 as outline in the current scope of work. Should the City wish to proceed with an enhanced monitoring program, Aquafor will provide a detailed cost estimate for review and approval.

Alternatives	Base Cost	Additional Fees	Notes
Alternative 1 – 2012 SWM-MP	$19,890	$17,000	Additional fees required to undertake continuous monitoring at all 8 sites simultaneously
Rain Gauge (2)	n/a	$6,500	Assumes the Aqufor supplies the equipment as part of a temporary installation
TOTAL	**$19,890**	**$23,500**	
Alternative 2 – Enhanced Sewer Monitoring			
Monitoring Program Development	n/a	$15,000	Reallocation of the base costs can be used to negate this cost
Storm sewer Monitoring	n/a	$60,000	Assumes the City purchases equipment as part of a permanent installation
Storm sewer Monitoring	n/a	$140,000	Assumes the Aqufor supplies the equipment as part of a temporary installation
Rain Gauge (2)	n/a	$6,500	Assumes the Aqufor supplies the equipment as part of a temporary installation
TOTAL	**n/a**	**$81,500 - $161,500**	