DILLON CONSULTING

CITY OF WINDSOR

Technical Report Volume I - Sewer Model Development and Existing Conditions

Sewer and Coastal Flood Protection Master Plan

November 2020 – 17-6638

Table of Contents

Figures

Tables

Appendices

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1.0 Introduction

In November 2016, the Flow Monitoring and Hydraulic Modeling of the Sewer System report (Dillon Consulting Limited & Aquafor Beech Limited) was completed. This report summarizes the methodology and findings for the development of a City-wide calibrated model including the sanitary, storm and combined sewer systems. The recommended next step from this project was the development of Phase 2 of the Sewer Master Plan to address basement and surface flooding. Further, the project deliverables from the November 2016 report serve as the basis to identify and implement comprehensive sewer system improvements.

Following the City of Windsor Council resolution CR660/2017, on November 6, 2017, Dillon Consulting Limited (Dillon) was retained as the lead consulting firm to develop the Sewer Master Plan. To complete the Master Plan project, Dillon partnered with Aquafor Beech Limited (Aquafor) and AMG Environmental Inc. (AMG). The Sewer Master Plan will be completed in accordance with Master Plan Approach No. 2 of the Municipal Class Environmental Assessment (EA) process in order to satisfy the EA requirements for Schedule B projects.

AMG's role was to complete a flow-monitoring program of the City's sanitary, storm and combined sewer systems between April and October 2018. Dillon and Aquafor's role include expanding the previously developed City-wide sewer model, evaluating the sewer and overland drainage network, and developing alternative basement and surface flooding solutions. In addition, Dillon led the public and agency engagement portion of the Sewer Master Plan.

This document is the first volume summarizing the technical and engineering work completed as part of the Master Plan. This report, *the Sewer and Coastal Flood Protection Master Plan – Technical Report Volume I*, includes the following:

- Identification of new sewer and drainage data collected in 2018;
- Summary of data used from the *Flow Monitoring and Hydraulic Modeling of the Sewer System* report (Dillon & Aquafor, 2016);
- Process and methodology for expanding the existing City-wide sewer model including calibration; and,
- Identification of existing baseline sewer and overland drainage conditions within the City, including the characterization of rain-derived inflow and inflation (RDII).

Technical Report Volume II includes:

- Identification of level of service criteria for basement and surface flooding solutions including development, discussion with the technical committee and comparisons to other municipalities;
- Delineation of the existing level of service for existing condition basement and surface flooding;

- An overview of the development process for basement and surface flooding solutions, including source control programs, conveyance/storage measures, and end of pipe (outlet) improvements. A summary of alternatives solutions considered; and,
- A background review of coastal flooding risk and level of service criteria. A summary of the development process for coastal flooding solutions.

Technical Report Volume III includes:

- For the preferred solutions, a summary of the preliminary functional design process and recommendations for the proposed storm and sanitary sewer improvements;
- For the preferred coastal flooding solutions a summary of the functional design process and recommendations;
- A summary of the assumptions and methodology in developing unit prices and cost estimates for the preferred solutions; and,
- The development process for the flooding solution recommended implementation plan. The plan was established considering multiple metrics identified in the report, including discussions with City Administration, prioritization of projects with external funding, consideration for both past flooding records and the potential for flooding based on modelled findings, cost-benefit of solutions, and a focus on the incorporation of source control measures.

1.1 Background

In the past decade, Windsor has experienced significant rainfall events with prevalent surface and basement flooding. These significant rainfall events include June 4th, 5th and 6th 2010, November 29th and 30th, 2011, August 11th, 2014, September 28th, 2016, and August 28th, 2017. The City received over 2200, 2800, and 6000 reports of basement flooding from the 2010, 2016 and 2017 rainfall events.

Although, the precipitation from these events was not uniformly distributed over the whole City, recorded rainfall totals from numerous gauging stations had 24-hour precipitation total depths greater than the locally accepted amount for a 1: 100-year occurrence for the August 28th, 2017 event and just under a 1:50 year occurrence for the September 28th, 2016 event. The June 2010 rainfall event was estimated to be between a 1:50 year and 1:100 year occurrence.

Following the August 29th, 2017 rainfall event the City of Windsor Mayor developed an 8-point plan to address flooding in the City; this included expediting the completion of the Sewer Master Plan, as outlined in the Flow Monitoring and Hydraulic Modeling of the Sewer System report (Dillon & Aquafor, 2016).

1.2 Previous Work: Flow Monitoring and Hydraulic Modelling of the Sewer System

In 2013, Dillon and Aquafor were retained by the City of Windsor to undertake the *Flow Monitoring and Hydraulic Modelling of the Sewer System* (Dillon & Aquafor, 2016) study which included the City-wide sewer system of the sanitary, storm and combined sewers. The study which was completed in 2016, did not follow the Municipal Class Environmental Assessment (EA) process. Still, the report and data were ultimately intended to be used by the City as the foundation to complete Phase 2 of the Sewer Master Plan that would address basement flooding, consider the Ministry of Environment, Conservation and Parks (MECP) F-5-5 guidelines, and serve as a basis to identify and implement comprehensive sewer system improvements.

The study was supported by a 2-year sewer flow monitoring program completed in 2013 and 2014. For the first year of flow monitoring, the program included 28 flow monitors installed at locations determined in conjunction with City staff. In the second year of the monitoring program, flow monitors were moved to alternative locations where further investigation was warranted.

The monitoring program focused on wet weather responses of the storm and combined sewers, as well as the dry weather (diurnal) flow patterns in the sanitary and combined sewer systems. The dry weather diurnal flows consist of both domestic wastewater and non-rainfall derived groundwater infiltration. For wet weather events, records of precipitation were provided from a network of up to fourteen rain gauges maintained by the City. The results of the flow monitoring program were used to develop a baseline calibrated model for the City's storm, sanitary, and combined sewer systems.

A calibrated model representing the City's sewer systems was developed, using the information from the flow monitoring program and the rain gauge network data. The calibration process, which was completed, improved the representation of the existing sewer system's conditions. The calibration process for this study resulted in a reasonable agreement between flow monitor data and model predictions. The model included only approximately 50 % of the City's sewers and did not include a representation of surface drainage. Refer to **Figure F.1.1,** which identifies the sewer segments included in the expanded model developed for this study.

1.2.1 City of Windsor Interceptor Maintenance Hole/Overflow Sewer Data Gap Assessment

A data gap assessment and field program was completed in December 2017 to fill in missing information related to the City's interceptor maintenance holes (MH) and overflow sewers. Interceptor MHs are flow diversion structures within the sewer system, where the flow direction in the chamber is defined by the control structure(s). Under low flow conditions, inflow entering the chamber is directed to the main outflow pipe (typically a sanitary or combined sewer). Under higher flow events, water levels within the structure reach a certain height and flow is directed to both the main sewer and the overflow sewer.

The City of Windsor took on the task of surveying the interceptor and overflow sewer data that was missing in the sewer model. The survey of the data was completed at 46 locations where field access to the overflow and interceptor maintenance holes was feasible. This field work provided the necessary information to develop a more accurate model calibration.

1.3 Coastal Flood Protection

Following extreme high water level conditions in the Detroit River and Lake St. Clair in the Summer of 2019, the scope of the Master Plan was expanded to include:

- Review of possible 1:100 year high water level conditions in the Detroit River and Lake St. Clair, including the potential impact of Climate Change;
- Identification and evaluation of potential short and long term solutions to mitigate the risks of coastal flooding;
- Development of preliminary designs and cost estimates for the recommended infrastructure improvements; and,
- Recommendation of an implementation strategy to reduce this flooding risk.

This assessment focused on the coastal flood risk within the Riverside and East Riverside Areas, between Ford Blvd. and the East City of Windsor Limits. It has been identified that there are additional low lying areas, at risk of coastal flooding, along the Detroit River Shoreline, East of Huron Church, this is further detailed in Technical Volume 2 report (Appendix E). Assessment of the west Windsor Area is not included in this scope of this project and will be reviewed under other City initiatives.

This Riverside Dr. E. and East Riverside assessment was completed based on the East Riverside Flood Risk Assessment (September 2019) (ERFRA) study, by Landmark Engineering Inc. (Landmark). Landmark and partnered with the MP consulting team, including Essex Region Conservation Authority (ERCA), to provide support related to the 2019 coastal flooding assessment and development of solutions alternatives for coastal flood protection. The functional design of the landform barrier used in this study is based on the recommendations of the ERFRA. This includes the placement of the landform barrier or build-up of the existing barrier along Riverside Dr. E. which has been established based on a number of considerations further defined in Technical Volume 2 and 3 of this MP study (Appendix E and F). The barrier will not provide coastal flood protection to those properties, north of the structure, along the river/lake shoreline. However, it will provide protection for those low lying properties from overland flow/ponding along Riverside Dr. caused by extreme rain events.

Where coastal flood protection measures exist, such as the existing earth berm (Ganatchio Trail) along the south side of Riverside Dr. E. between the Little Rive Drain and the East City limits, the recommendations include the build-up and reinstatement of the berm. These berms are within City-owned lands or are covered under existing easement agreements; therefore, the construction and maintenance associated with these berm sections are under the City's jurisdiction. In locations where the newly proposed berm is required within private property areas, the City will need to acquire necessary easement agreements to have access for construction and regular inspection and maintenance of the berm. Where existing properties along the shoreline have existing grades sufficient enough to provide the necessary coastal flood protection, the City will need to develop a legal method of regulating that elevation such as easements or placement of min. lot grades under the property title.

The City will address coastal flood risk for properties, along the Detroit River and Lake St. Clair shoreline, through other City initiatives including emergency protection and preparedness measures. The assessment of flood protection for those properties is beyond the scope of this study.

The proposed coastal flood protection intends to provide protection to low lying in-land areas that are at risk of flooding due to high lake/river water levels and spillover caused by instantaneous water level increases during storm events. Additional study to assess the extent of flood risk associated with the existing coastal flood protection measures has been completed by Landmark Engineering (November 2020). This study will confirm the level of benefit the proposed coastal flood protection measures will provide. A copy of this study is included in the Technical Volume 2 report (Appendix E) to the City of Windsor.

Additional details related to the coastal flooding risk assessment, solution alternatives, evaluation process, preliminary design, costings, and recommendations are provided in *Technical Report Volume II* and *Volume III*.

2.0 Problem, Opportunity and Objectives

2.1 Problem and Opportunity Statement

The City of Windsor has experienced **basement and surface flooding** that resulted in property damage and disruption to the community. Refer to **Figure F.2.1**, which provides a heat map of basement flooding records from the September 28th, 2016 and August 28/29, 2017 storms. This flooding generally results from significant storm events, which brings more water than City sewers, roadways, and open drains have the capacity to manage. The City is undertaking this Sewer Master Plan to identify specific problems and explore achievable measures to reduce the risks and impacts of flooding by identifying and evaluating the following:

- **Shorter-term** solutions that can reduce the amount of water going into the City's drainage systems, including partnering with homeowners to protect against the impacts of flooding; and,
- **Longer-term** solutions to improve the sewer systems by reducing inflow at the sources, increasing conveyance capacity and/or identifying temporary storage measures.

Problems and opportunities associated with this project are outlined in the following:

- Storm, sanitary and combined sewer capacity issues. The existing sewer systems are not capable of providing an adequate level of service during wet weather flow conditions. This could lead to flooding damages with economic losses.
- Public health issues/nuisances. This is caused by the inability of the sanitary sewer system to handle excessive extraneous flows, resulting in:
  - The backup of raw sewage into basements; and,
  - During high periods of weather, by-passing of partially-treated sanitary sewage flows from City sewage treatment plants to the open bodies of water.
- Surface water directed to habitable structures. Low or poor lot grading can lead to what otherwise would be considered normal roadway ponding being directing to habitable structures. Excess ponding beyond normal conditions may also lead to the same.
- Excessive surface water ponding limiting access. Under extreme wet-weather events, the depth of surface water ponding in roads beyond normal conditions (i.e. more than 0.30 m deep) can prevent road traffic (including emergency vehicles) from traversing a section of roadway and/or can cause damage to parked vehicles.
- Confirm mitigation measures for future development that will accommodate additional loading on the existing sewer and drainage systems.
- The problem and opportunities related to Coastal Flooding risk and mitigation are presented in Technical Report Volume II.

2.2 Project Objectives

The objectives for the first technical study (*Technical Report Volume I*) include the following:

- **Document and characterize existing drainage and sewer conditions** within the City of Windsor focusing on factors that contribute to basement and surface flooding;
- **Expand the existing City-wide sewer model,** including:
    - Development of surface/overland flow conveyance and storage with two-dimensional modelling using the City's topographic LiDAR information; and,
    - Incorporation of additional storm, sanitary and combined sewers to represent a greater portion of the existing sewer systems.
- Collect additional flow monitoring and precipitation data to calibrate further and confirm the validity of the City model;
- **Calibrate the expanded model** with flow monitoring data and flooding records from past wet weather events; and,
- **Complete model simulations assessing the problems,** including sewer hydraulic conveyance, surface ponding, and sanitary sewer wet-weather inflow and infiltration.

In addition to the objectives identified above, the other major objectives of the Sewer Master Plan include the following:

- Complete a comprehensive public and agency engagement program following the Municipal Class Environmental Assessment Master Planning process, including collecting technical and non-technical stakeholders input;
- Identify high water level conditions in the Detroit River/Lake St. Clair system including inland properties at risk of coastal flooding, provisions for the impact of climate change will also be considered;
- Develop in coordination with the City, Ministry of Environment, Conservation and Parks (MECP), and the Essex Region Conservation Authority (ERCA), a framework for guidelines and criteria to support the solutions developed as part of this project;
- Design and model alternative solutions at a functional design level of detail;
- Complete a desktop environmental inventory as part of the evaluation of the alternative solutions and identification of mitigation strategies for the preferred solutions; and,
- Complete budgetary project cost estimates to develop a long-term capital improvement program, including a recommended implementation strategy for City Council's consideration.

3.0 Background Document Review

The Sewer Master Plan encompasses the entire City of Windsor as defined by the current Municipal Boundaries as of March 2019. A background document review was completed that compiled information from over 110 available background reports related to sewers and drainage conditions within the Municipality.

The review includes a summary of the scope of work and recommendations made within the reports. The reports that were reviewed are organized by stormwater watersheds and the Little River or Lou Romano sanitary drainage areas.

Select reports which are anticipated to influence the recommendations for the project solutions are provided below. The complete review is provided in **Appendix A**. The summaries of the select studies are organized by the City's major storm and sanitary service areas, as follows:

- Turkey Creek Drainage Area
- Little River Drainage Area
- Detroit River Drainage Area
- City-Wide Study Area
- Lou Romano Water Reclamation Plant Service Area
- Little River Pollution Control Plant Service Area

3.1 Turkey Creek Drainage Area

Lennon Drain:

A recent stormwater management review and assessment of recommended improvements for the Lennon Drain service area was completed following two recent reports from AECOM 2017 and 2012, and a 2017 Drainage Report from Rood Engineering. The stormwater management review included an examination of the Lennon Drain to determine whether the drain in its current configuration has sufficient capacity for runoff from an improved Cabana Road and Detroit River Tunnel Partnership (DRTP) Railway east of Provincial Road to Huron Church Road. Further, the overall performance of the Drain was reviewed. The works recommended from these studies was constructed in 2017.

Recommendations included solutions for existing flooding issues within the Lennon Drain service area with the construction of new or expansion of existing stormwater management quantity control facilities. Further, the solutions included provisions that the Lennon Drain be cleaned to provide improved conveyance capacity in select locations.

The identification of both existing flooding issues in the service area and Municipal Drain flow conveyance capacity limits restricted the pool of available alternative options to improve flooding conditions. Solutions were limited to alternatives where additional volume was not sent downstream. This was based on concerns that additional volume may worsen flooding extents within the service area.

The Sewer Master Plan review of the drainage area was limited to the outlet of the Lennon Drain as it enters the Ontario Ministry of Transportation (MTO) Herb Gray Parkway property. No assessment of downstream lands was conducted.

Grand Marais Drain:

A recent study of the Grand Marais Drain was completed by Landmark Engineers Inc. (Landmark) entitled Grand Marais Drain Hydrologic and Hydraulic Models (2019), which included the development of a joint hydrologic-hydrodynamic PCSWMM model and a hydraulic HEC-RAS model of the watercourse. The study updated estimate of flooding inundation and water levels for the watercourse. In addition, Landmark also completed a study of the Grand Marais Drain under the Drainage Act, entitled Drainage Report for the Grand Marais Drain in the City of Windsor, County of Essex, October 2019.

In 2012 Landmark completed a Class Environmental Assessment for channel improvements to the Grand Marais Drain, and in the preceding years, Dillon and Landmark Engineering jointly completed technical and other supporting studies for this waterway. Various improvement alternatives were reviewed, and in this study, it was identified that under the 1:100 year design event, the hydraulic grade line elevation in the drain is lower than the two-thirds full depth of the receiving sewers.

In 1993 MacLaren Engineers reviewed the upper portion of the Grand Marais Drain between Walker Road and Pillette Road. The scope of the study was to identify measures to reduce flooding potential. Turkey Creek improvements downstream were based on controlling 1:100 year flood flows to the downstream area to the existing 1:100 year flow which was based on the 1989 extent of development. This report recommends the need for a stormwater management strategy for lands south of the CPR east of Walker Road and lands north of the CPR and east of Central to manage peak flow discharge to existing levels. Design of future flooding solutions must be developed considering this requirement.

The Sewer Master Plan review of the drainage area was limited to the outlet of the Grand Marais Drain as it enters the Ontario Ministry of Transportation (MTO) Herb Gray Parkway property. No assessment of downstream lands was conducted.

3.2 Little River Drainage Area

Pontiac and St. Paul Pump Station:

In 2018 Dillon completed an assessment of the existing stormwater infrastructure for the Pontiac and St. Paul pump station drainage areas. The assessment also included the stormwater infrastructure, which drains by gravity to Detroit River just north of the intersection of Riverside Drive and St. Rose Ave. The report identified storm sewer solutions to increase the sewer level of service and reduce the risk of flooding. Further, it was identified that the recommended flooding solutions would be validated with all of the sewers (sanitary, combined and storm) and two-dimensional surface mesh model developed as part of Phase 2 of the Sewer Master Plan (this project).

Upper Little River Watershed Area:

In 2017, Stantec completed a draft Master Drainage Study for the Upper Little River drainage area, which included all lands within the Little River Watershed upstream of the E.C. Row Expressway. Recommendations included providing stormwater management facilities for all future development within the study area to limit stormwater outflow to existing levels and/or a rate equal to the Municipal Agricultural Drain design coefficient approach. Design of future flood control solutions must be developed considering this requirement. Based on these recommendations, there is no anticipated negative impact from future development within the Upper Little River drainage area on the existing lands and stormwater infrastructure downstream of the E.C. Row Expressway.

The study also recommended a limited release of stormwater discharge for the Upper Little River area be considered to mitigate impact to existing development (downstream of E.C. Row Expressway) to inform the design of future flood control solutions.

3.3 Detroit River Drainage Area

Combined Sewer Pollution Prevention Plan and Riverfront Retention Treatment Basin:

In 2008, Stantec completed an Environmental Assessment study for the design of the Riverfront retention treatment basin (RTB) which collects and treats wet-weather combined sewer overflow from all the lands generally west of Walker Road and east of Victoria Avenue. Various supporting studies and works were completed previously, which included design for a new collector sewer and identification of the RTB solution feasibility and approximate location. Designs were based upon consideration of the "average year" and following the MECP's F-5-5 procedure. The on-going strategy for managing sewage from this catchment area has been to separate the combined sewer where feasible, with the RTB providing treatment and limiting untreated discharge to the Detroit River.

Further, Stantec is currently completing an Environmental Assessment for management of the combined sewer system overflow for land generally to the west of Victoria Avenue. The Notice of Completion for this study will be posted in 2020.

Woodlawn/Ypres/Memorial Storm Area:

In 2000 CH2M Gore & Storrie Limited completed a study within the Woodlawn/Ypres/Memorial drainage area, which was initiated following the wet weather derived flooding following a heavy storm event in 1997. The lands were serviced by multiple sewer types including combined, sanitary, and storm sewers with over/under (dual) maintenance holes. Improvements and new storm relief infrastructure were designed to achieve a sewer hydraulic grade line below the basement elevations for the 1:5 storm event.

The previously applied design criteria of having the hydraulic grade line for a 1:5 year storm event below the basement elevation must be considered in future solutions for this area.

Prince Road Sewer Area:

In 2001 Stantec completed a study of Prince Road sewage system which is composed of a mixture of combined and partially separated sanitary and storm sewers servicing residential, commercial and industrial land uses. This area has had a common occurrence of basement flooding following severe storms. The recommendations included continued separation of flows, with the construction of new trunk storm and sanitary sewer systems. Upgrading and separation of local combined sewers were to follow the installation of the new trunks.

Campbell and University Area:

A recent study completed by Stantec entitled Campbell/University Combined Sewer Separation and Stormwater Management Strategy (May 2019) reviewed the existing hydraulic system in the Campbell/University Area. It provided recommendations for partial separation of the combined sewage systems.

3.4 Little River Water Treatment Plant

Sanitary Sewer Servicing Study - Lands Annexed from Tecumseh:

In 2002 Stantec completed a study to review potential land use and utility servicing for approximately 2,600 hectares of land (Annexed Lands) from the Town of Tecumseh and Essex County. The Annexed Lands would require sanitary sewer services prior to any new development occurring. Expansion of the Little River Pollution Control Plant Sanitary Service Area was the recommended alternative with a trunk sanitary sewer on Banwell Road servicing the annexed lands and adjacent lands in the Town of Tecumseh. The potential impact of this future development must be considered when reviewing future sanitary service conditions.

4.0 Existing Conditions

In 2016, Phase 1 of the Study existing conditions were established by completing a City-wide inventory of background information. In Phase 2 of the Study, and as outlined in this report, the existing condition information was updated, refined and expanded as required to develop a model of the City to represent surface and basement flooding. The information compiled and used for input into the sewer model and development of solutions is based on data available throughout this study. The final existing condition model has been updated to reflect the City of Windsor System and known boundary conditions up to and including December 2019.

The following sections outline the findings of the inventory in terms of economic environment (existing land use parameters, existing populations, etc.), drainage and sewage infrastructure (sewers, catch basin, backflow preventers, etc.) and records of flooding.

4.1 Land Use

Representative land use areas were developed in the Phase 1 Study and used in Phase 2 to define the combined, sanitary and storm subcatchments for the expanded sections of the sewer network in the sewer network model.

The Official Plan Land Use map, as well as Zoning By-Law 8600, were provided by the City of Windsor Planning Department to determine initial land uses throughout the City. The zoning maps, respective By-Laws and 2017 aerial imaging were referenced to identify and confirm each land use category for existing and future uses. Districts taken from Zoning By-Law 8600 were summarized throughout the City based on each overall category. The land uses throughout the City used for this exercise are summarized below with their representative zoning district:

Table 4.1: City of Windsor Land Use Designations

Zoning	Associated Zoning Districts	Description
Low Density Residential	RD1.1 – RD1.7	Single Unit
Medium Density Residential	RD2.1 – RD2.6	Single Unit, Duplex, Semi-Detached
High Density Residential	RD3.1 – RD3.15	Multiple Dwellings, Townhomes, Residential Care Facility
Institutional	ID1.1 – ID1.6	Church, School, Day Nursery

Zoning	Associated Zoning Districts	Description
Commercial	CD1.1 – CD4.6	General/Highway Commercial, Neighbourhood Convenience, Restaurant, Grocery, Gas Bar, Auto Sales, Hotel
Light Industrial	MD1.1 – MD1.8	Light Manufacturing Districts, Business Park, Transportation/Shipping, Railway
Heavy Industrial	MD2.1 – MD2.8	Heavy Manufacturing, Aggregate Industrial, Automotive Assembly
Parkland	GD1.1 – GD1.3	Green Districts, Public Park, Golf Course, Cemetery

For wastewater flow contributions, the population within each subcatchment area was estimated based on the above zoning definitions and census data as discussed below in Section 4.2.

To define the appropriate surface runoff parameters for each of the representative areas, the overall impervious values were determined based on a percentage of steep roof (house) and percentage of flat surfaces (apartment, commercial and industrial roof, road, parking, driveway and sidewalk). They were determined by using aerial photographic and impervious surface shapefile information. The different parameters (percentage of impervious and pervious areas) were calculated by overlaying the impervious coverage information onto the catchment area map. Illustrations of the remaining distinctive land uses are provided in the Phase 1 Study.

4.1.1 Official Plan and Future Development

In the Phase 1 study, the official plan (2014) was used as a guiding document to assemble land use areas for modelling of the storm, sanitary and combined systems. The Official Plan Land Use map ,as well as Zoning By-Law 8600, were provided by the City of Windsor Planning Department to determine initial land uses throughout the City and are provided in the Phase 1 study. The land use areas were then updated to represent current conditions and are reflected in the dry weather flow and wet weather flow subcatchment parameters in the model.

Future development was not considered in the assessment summarized in *Technical Report Volume I* as this document summarizes the updates completed for calibration of the existing combined, sanitary and storm drainage systems. Considerations and model allocations were made for future development in Windsor, the Town of Tecumseh, and the Town of LaSalle and those details are provided in *Technical Report Volume II*.

4.2 Population Estimates

Population data for this existing conditions analysis is based on the Statistics Canada 2011 Census, which was provided and adapted by the City of Windsor Planning Department.

The City of Windsor provided areas associated with the census data, which was then used to determine initial population densities for the land uses identified above. This information was used as a basis to estimate population data within each subcatchment area.

4.3 Soil Conditions and Groundwater Conditions

Ground conditions can significantly impact the volume and rate of runoff produced from a rain event:

- Hard, impervious surfaces (like pavement) allow limited infiltration and have less depression storage; therefore, result in more runoff than pervious surfaces (like grass and soil).
- The amount of water that can soak into the ground (i.e. infiltration capacity) varies based on the type of soils. Geo-spatial data from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) delineates the soil distribution within Ontario. This mapping data identifies, the majority of Windsor consists of clay soils, which have low infiltration rates (see **Figure F.4.1**).
- Soil moisture conditions also affect the amount of water that can soak into the ground, affecting the volume and rate of runoff.

The majority of the soils within the study area are heavy clays with slow to very slow infiltration rates. Areas in south and western sections of the study area have sections of moderate to high infiltration rates characteristic of sandy soils.

4.4 Topography and Overland Flow

The City of Windsor's relatively flat topography lies within the Little River, Turkey Creek and Detroit River watersheds. The central portion of the City is approximately 15 m (about 50 ft) higher than lands to the east and west. Gravity measures can generally manage stormwater runoff from higher elevation areas. Figure F.4.2 presents a heat map showing the ground elevations across the study area. Figure F.4.3 shows the main receiving watercourses and waterbodies for overland flow. The main receiving watercourses that will influence the range of flood relief solutions available include:

- Detroit River
- Little River
- Grand Maris Drain
- Lennon Drain
- Cahill Drain

4.5 Sewer Systems

The project study area is serviced by a mix of combined, sanitary and storm sewers. A majority of the existing homes in the core City area are serviced with combined sewers, which carry both wastewater and stormwater runoff flows to the sanitary treatment plant and storm outlets.

In the fully-separated areas, sanitary flows area conveyed to the sanitary sewer while storm flows are directed to an independent storm sewer. In older areas that are fully separated, inflow and infiltration (I&I) into the sanitary sewers reduces the capacity of the sanitary sewers to convey wastewater flows effectively and impacts the treatment capacity of the wastewater treatment plants. Sources of I&I include groundwater leakage into the sanitary sewer from cracks or breaks in existing sewers, non-sealing manhole lids, broken sanitary private drain connection caps and flows from improperly-connected foundation drains and roof downspout connections to the sanitary system.

In the partially-separated areas, storm sewers were introduced to divert stormwater runoff from the road to the storm sewer via catch basins. At the same time, private drains, roof downspouts and foundation drains would still generally be connected to the combined sewer. Sources of I&I include leakage into the system through cracks and breaks, damaged laterals, etc.

Combined sewer areas have limited to no storm sewers; combined sewers receive both wastewater and stormwater flows. Sources of I&I also include leakage into the system through cracks and breaks, damaged lateral connections, etc.

Figure 4.1 shows the typical connection profiles between a house and sewer system in a fully separated area, partially separated area and combined area. **Figure F.4.4** shows an overview of the combined, sanitary and storm sewer system

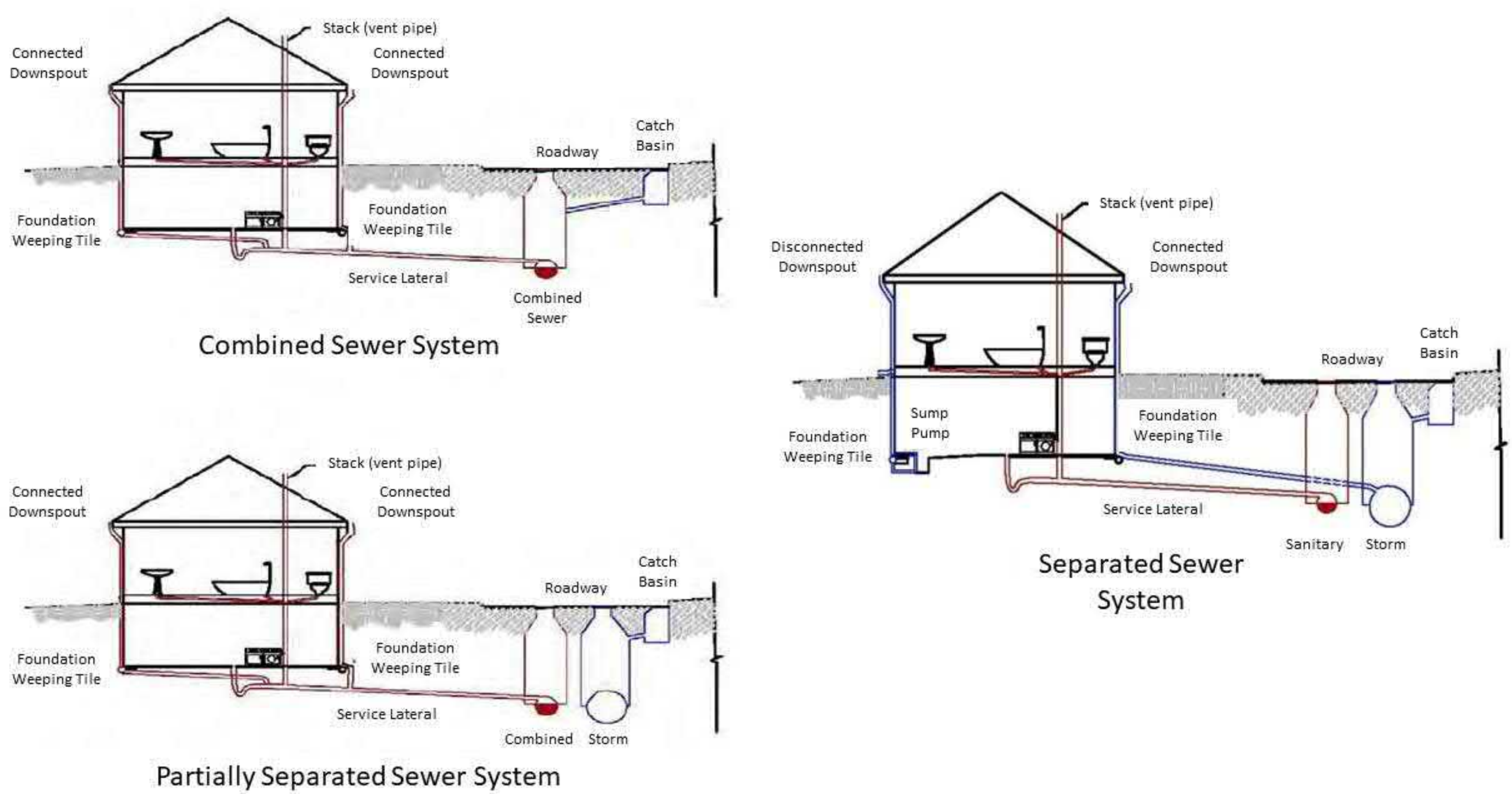


Figure 4.1: Sewer System Profiles

4.5.1 Sanitary Sewers

The sanitary sewer systems convey domestic sewage via local service connections from residential, commercial, industrial, institutional and other land uses to a wastewater treatment plant where it is filtered, treated and discharged. There is over 645 km of sanitary sewers modelled for this project which consisted of sewers ranging in diameters from 150 mm through 2100 mm. The existing sewer network in Phase 1 was expanded to include all pipe segments where there were clusters of flooding calls into the City. These segments were imported into the model from the Geographic Information (GIS) asset data provided by the City to accurately reflect pipes, overflow devices, pumping stations and/or other elements of the sewer system. Within the City of Windsor, the two major sanitary outlets are as follows:

- Lou Romano Water Reclamation Plant; and,
- Little River Pollution Control Plant.

The location of sanitary sewers represents the area of separated sewers (separate sewers for domestic wastewater flow with storm sewers collecting rainfall runoff).

4.5.1.1 Domestic Flow

Hourly diurnal dry weather flow (DWF) patterns were extracted for weekdays and weekends from the sanitary and combined sewer flow monitoring data. Conceptually, sanitary dry weather flow (DWF) is identified in the hydrograph below.

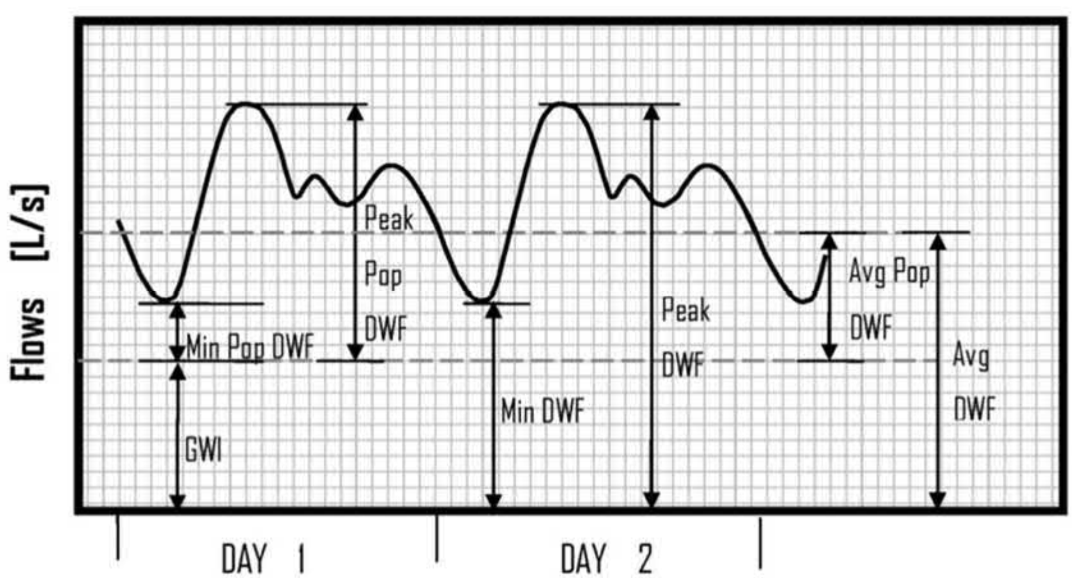


Figure 4.2: Domestic Flow Hydrograph Components

As shown in **Figure 4.2**, DWF can be described as follows:

a) DWF (Total):

Peak DWF = Peak Dry-Weather Flow

Avg. DWF = Average Dry-Weather Flow

Min. DWF = Minimum Dry-Weather Flow

GWI = Non-Rainfall Derived Groundwater Infiltration

b) Population DWF:

Peak Population DWF = Peak Domestic Wastewater Dry-Weather Flow

Avg. Population DWF = Average Domestic Wastewater Dry-Weather Flow

Min. Population DWF = Minimum Domestic Wastewater Dry-Weather Flow

The following steps summarize the procedure used to determine the domestic flow patterns:

Step 1: Dry weather days are defined if no rainfall occurred within the previous 72 hours.

Step 2 Separate weekday and weekend flow patterns.

Step 3: A series of diurnal flows were established for each station and from a series of diurnal flows, approximately 5 typical days were selected. The selection of the 5 representative days was based on visually examining the data and excluding flow patterns with outliers.

Step 4: The typical day flows that were selected were then normalized to determine a pattern for each day.

Step 5: The normalized patterns were averaged to get a typical hourly diurnal DWF pattern.

Steps 3-5: Carry out steps 3 through 5 for weekday and the weekend flow patterns separately.

A weighted average of weekday and weekend patterns ({5 weekdays + 2 weekends}/7) was used for the diurnal flow pattern for that specific flow monitor. The difference between the flow patterns between weekday and weekends were not significant.

An example of an hourly diurnal DWF pattern for combined sewer flow monitor C300 (primarily residential) is illustrated below in **Figure 4.3**.

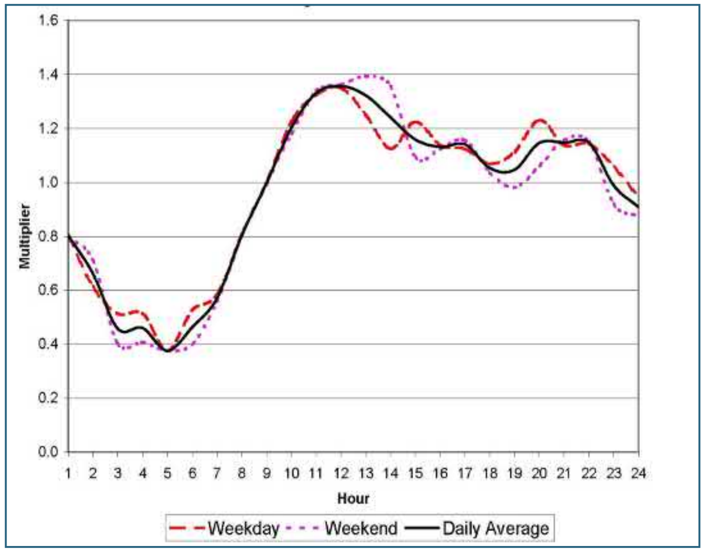


Figure 4.3: Diurnal Flow Pattern - Weekday and Weekend

4.5.1.2 Wet Weather Flow

Quantification of the wet weather flow hydrograph in a sanitary sewer requires 'separation' of the measured dry-weather hydrograph from the total measured hydrograph. The hydrograph below illustrates the various components of dry and wet weather flows in a sanitary sewers system.

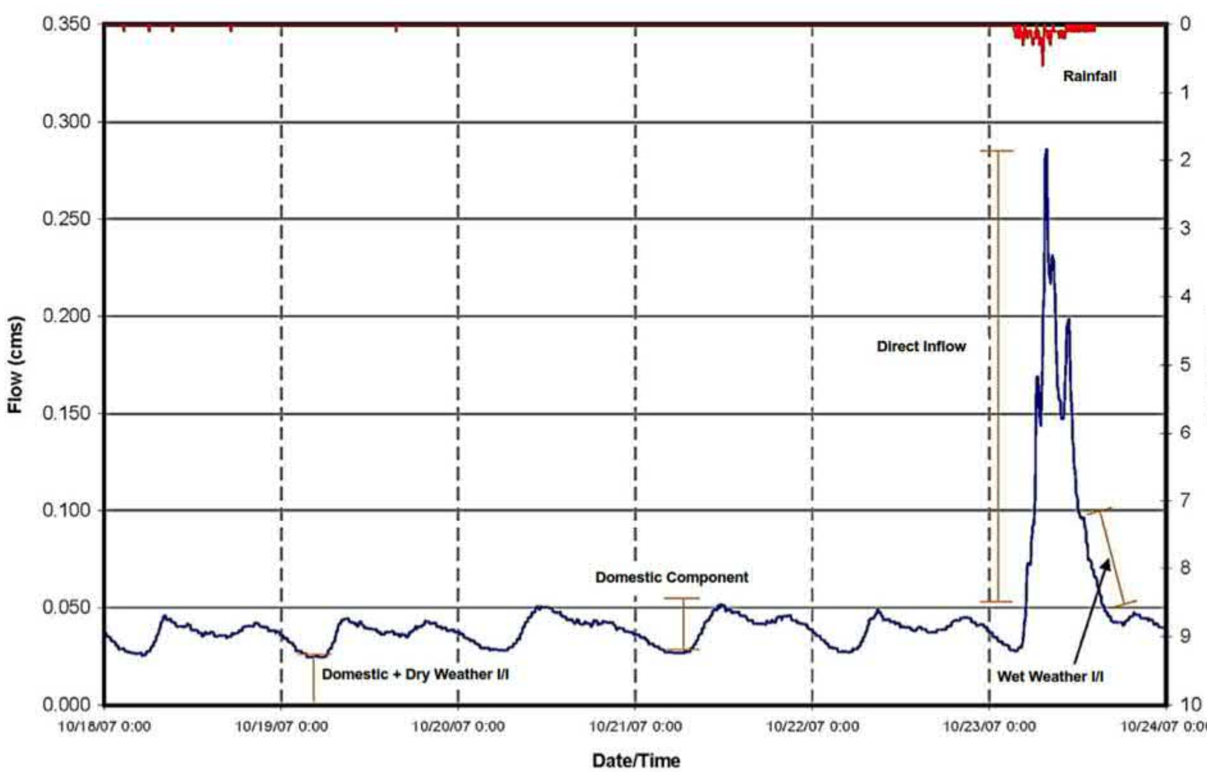


Figure 4.4: Wet Weather Hydrograph Components

As shown, the WWF hydrograph can be described in parts or using the following terms:

a) WWF:

WWF = DWF + Direct Inflow + Wet Weather I&I

b) DWF:

DWF = Dry Weather I&I + Domestic Component

c) Direct Inflow:

Direct inflow = Rapid Inflow (i.e. short-term response from directly connected downspouts, foundation drains or illegal connections).

d) Wet Weather Infiltration:

Wet Weather Infiltration = Moderate Infiltration (i.e. medium-term response from inflow through sanitary maintenance hole lids) and Slow Infiltration (i.e. long-term response from groundwater infiltration).

Wet weather flow analysis was completed for the sewer system networks based on the precipitation data that could cause significant flow within the sewer systems. The flow monitoring data identified peaks in conveyance flow during these events, which was used to adjust parameters within the model for proper calibration. The sum of both direct inflow and wet weather infiltration is known as rain-derived inflow and infiltration (RDII).

Wet weather flow includes dry-weather flow plus the additional extraneous flow contribution from rain or snowmelt. It is comprised of the sum of the following:

- Population derived flow (wastewater);
- Groundwater infiltration (GWI); and,
- Inflow and infiltration (I&I) due to rainfall or snowmelt runoff entering the sewer system through maintenance hole covers, cracks in the pipes, foundation drains or illegal connections.

4.5.1.3 Extraneous Flow

Sanitary sewers are designed to carry the population derived flow (sewage) to wastewater treatment plants, including a nominal amount of extraneous flows, e.g., groundwater infiltration. Extraneous flows, from either groundwater or direct runoff inflows (rain or snowmelt), are undesirable, as it is typically not accounted for in sewer system capacity calculations for conveyance and treatment.

Basement flooding can result from RDII resulting from three major causes:

- Overland flooding caused by intense rainfall events that exceed the capacity of the drainage system resulting in surface flooding that reaches the building through improper grading, entering the internal plumbing system and municipal sewer system;
- Groundwater infiltration caused by groundwater leakage through basement walls or by weeping tiles/foundation drain flows that exceed the capacity of the sump pump; and,

- Sewer back-up caused by excess flows from I&I that contribute more flows than the sanitary and combined sewer systems were designed for resulting in surcharging through the building plumbing.

Flows based on the above list should be excluded as much as possible from the wastewater system. Extraneous flows occur due to the following:

Inflow

Sources of stormwater flows entering the sanitary system directly are summarized below:

- Connected roof rainwater downspouts;
- Surface drains (window wells, catch basins, broken cleanout caps, etc.);
- MH covers in the right-of-way during ponding of stormwater flows; and,
- Improper plumbing connections.

Downspouts which discharge to the ground reduce inflow to sewer systems. Downspout disconnection was estimated from desktop analysis using available open-source data (such as Google Earth) and field surveys from the front of the property to determine if the roof drains were partially or fully disconnected. The survey was summarized in the Field Conditions Survey and Desktop Analysis Memorandum (**Appendix B**). Fog testing was conducted in the areas of highest flood vulnerability to confirm downspout connections to the sanitary sewer system and is summarized in Section 4.5.4 below. The areas where downspout disconnection rates could be confirmed are summarized in **Figure F.4.5**.

Infiltration

Sources of infiltration have a higher potential in older areas. Sources of rain-derived infiltration include groundwater that enters the sanitary sewage system are summarized below:

- Cracks or leaks in sewer pipes including public and private infrastructure caused by age-related infrastructure deterioration, loose joints, improper installation, damage and root penetration; and,
- Flow from foundation drains that receive water from infiltration of rainfall within the area immediately surrounding the building.

Discussions with the project technical committee and a review of historic residential subdivision construction drawings were completed, to estimate foundation drain connection to the sanitary sewer system. It was agreed for modelling purposes that houses constructed before and up to 1980 would have a connection to the sanitary sewer and construction after 1980 would not have foundation drainage connections to the sanitary sewer. Based on GIS parcel data received from the City, lot parcels with buildings older than 1980 are shown in **Figure F.4.6**. It should be noted that approximately 30% of parcel data did not contain a date of construction.

4.5.1.4 External Areas

External flows from surrounding lands outside of the City of Windsor limits were reviewed to confirm connections to the storm and sanitary networks. The external systems currently conveying flows to either the Lou Romano WRP or the Little River PCP system include:

1. Contributions to the Lou Romano WRP

a. Town of LaSalle

An 800 mm diameter sanitary flows enter the City limits at the intersection of Ojibway Parkway and Morton Drive from the Town of LaSalle. This is a direct connection from the Town of LaSalle's Sewage Pumping Station No. 1 outlet forcemain. As identified in the pumping station's Environmental Compliance Approval (ECA), the works include 2 variable speed pumps (one duty, one standby) each rated at 252 to 592 L/s at a total dynamic head of 6.7 to 14.9 m. Records of pumped flow from the Town of LaSalle and the Ontario Clean Water Agency (OCWA) provided key information for modelling the inflows from the pump station.

b. Town of Tecumseh

Based on the sewer data provided by the City of Windsor, a 600 mm diameter sanitary pipe enters the City limits from North Talbot Road under Highway 401 from the Town of Tecumseh. The North Talbot Road sewer from Tecumseh has a maximum flow allowance of 85 L/s as identified in the Town's Water and Wastewater Master Plan (2008). Flows from the Town of Tecumseh provided a minor contribution to the downstream Lou Romano WRP within the City of Windsor during the monitoring periods for the project under both dry and wet weather flow conditions.

2. Contributions to the Little River PCP

a. Town of Tecumseh

A number of external flows from the Town of Tecumseh contribute to the City's sanitary sewer system and the Little River PCP. The agreed maximum flow allowances for each external area into the sanitary system, which include future development allowances, are outlined below as identified in the Town's Water and Wastewater Master Plan (2008):

i. Northeast Windsor Trunk Sanitary Sewer Outlet (1200 mm diameter) @ County Road 22 and Banwell Road = 983 L/s.

ii. Eighth Concession Road Sanitary Sewer Outlet (900 mm diameter) @ Highway 401 and Eighth Concession Road = 325 L/s.

iii. Cedarwood Sanitary Pump Station Outlet (900 mm diameter) at Gauthier Drive = 935 L/s.

The three sanitary outlet locations from the Town of Tecumseh to the Little River PCP contribute flow to the downstream sanitary systems within the City of Windsor during the monitoring periods for the project under both dry and wet weather flow conditions. These flows were have been accounted for during calibration of the model.

During the study period, no monitors were installed at the direct inlet locations of any external flow areas. Flow data from the Town of LaSalle and the Town of Tecumseh was based on historical flow data provided by the City. Flows entering the study area were defined using predefined hydrograph for future conditions or under existing conditions based on lumped simple sub-catchment areas.

External flows to both the Lou Romano WRP and Little River PCP would be reflected in the flow monitoring results. During calibration and validation of the model, sub-catchment parameters within the City limits and downstream of the outlets from external areas were adjusted to reflect the monitoring results. Therefore, took into consideration any flow from the external areas to calibrate to a reasonable accuracy.

4.5.2 Combined Sewers

Combined sewer systems were designed to convey both sanitary and storm flows to sanitary treatment plants. The combined sewer representation in the model includes approximately 200 km of combined sewers, which consisted of sewers form sizes 200 mm diameter to 2250 mm diameter trunks as well as underground storage retention at key points in the system.

Combined sewer systems occasionally lead to combined sewer overflows (CSO) during wet weather flow events based on the available conveyance capacity of the combined sewer system. These combined sewer overflows occur at locations throughout the system where overflow/interconnection structures have been provided. A high-rate Retention Treatment Basin Facility was recently completed within the City of Windsor under the existing riverfront parking lot to assist with CSO treatment for the contributing area of the City. The retention treatment basin provides a storage volume of 8,000 m^3 as outlined within the final design brief for the Riverfront RTB dated October 5, 2009, and was considered within the baseline model calibration.

A second RTB unit is planned to be constructed adjacent to the Lou Romano WRP to support the City's current strategy for management of CSO. It is estimated this new treatment unit will have a flow through capacity up to 9.1 m^3/s, providing treatment for combined sewage before discharge to the Detroit River. The RTB was not considered in the existing conditions model but was incorporated in the proposed conditions model.

4.5.3 Storm Sewers

Storm sewer systems are designed to convey rainfall runoff and other drainages (excess rain and ground water from impervious surfaces such as paved streets, parking lots, sidewalks and roofs). There are approximately 700 km of storm sewers modelled for this project, which consisted of sewers from 200 mm diameter to 3600 mm rectangular boxes. The storm sewer system conveys stormwater to a series of storage systems and river outfalls, as well as overflow structures. Within the City of Windsor, the major storm sewer outlets are summarized below:

- Grand Marais Drain;

- Cahill Drain;
- Lennon Drain;
- Little River Drain; and,
- Detroit River.

4.5.4 Additional Data Sources

The City provided additional data for the Phase 2 study from the Infrastructure Management Systems (IMS) department that included the following:

- Fog testing results;
- Catch basin records;
- Parcel Date ;
- Sewer and maintenance hole records;
- Backflow prevention devices (i.e. WaStop units);
- Water quality data; and,
- Interceptor/ Overflow data.

4.5.4.1 Fog Testing Results

Fog testing results were provided by the City, which identified the following:

- Downspout work orders confirming the connection to the sanitary sewer system; and,
- Clean-out cap work orders confirming broken clean-out caps and repairs completed.

Based on the fog testing results, it was determined that some of the roof area in the City was directly connected to the sanitary sewer. In addition to the desktop survey findings; the number of homes fog-tested was limited to a few areas with clusters of basement flooding complaints.

While inflow through broken sanitary service caps was identified through the fog testing and associated repair work orders, this was considered a more indirect source of inflow as most of the sanitary service caps are buried under lawns and gardens as opposed to direct inflow to the sanitary sewer from connected downspouts.

4.5.4.2 Catch Basins

The City of Windsor provided two files defining the existing catch basin inventory, including a shapefile with a georeferenced location, and an excel sheet with catch basin meta data. Each catch basin in the City has a unique "Unit ID" which is identified in both the shapefile and the excel file. The catch basin shapefile had an incomplete assessment of its identification of unit type, and data was filled in to characterize existing conditions better. With the updated data source, the points from the shapefile could properly be separated by the type of catch basin.

Catch basin lead repair work orders were delivered in a spreadsheet which included; spatial identifier, date of work completed, and if available, description of pre-repair damage. Much of that data indicated which catch basins were cleaned though it was unclear if this was a result of a continuous maintenance program or reactive repairs. Current catch basin inventory with inlet types was also identified in GIS shape file and was mapped to determine the number of catch basins draining to each sewer segment.

4.5.4.3 Sewer Records and Maintenance Hole Condition Rating

Sewer and maintenance hole condition ratings (structural and O&M) were provided by the City in the form of a spreadsheet summarizing the condition obtained from CCTV records through a rating system from both an infiltration perspective and service perspective. The condition rating data was extracted for 60% of the data where the sewer asset ID's could be matched in the model network.

From an infiltration perspective, the rating system described the structural condition of the sewer segment found from CCTV from very good to very poor as shown in **Figure F.4.7** and provided guidance as to which areas where I&I potential was the greatest. Those sewers that were rated poor to very poor conditions were considered areas of critical needs for repair and upgrade.

4.5.4.4 Backflow Prevention Devices

The City provided spreadsheet records indicating the presence of backflow prevention valves in the sanitary and storm sewer system main lines known as "WaStops". The data included identified the maintenance hole locations, the sewer segment, as well as the date the device was installed. WaStops were added to the model network and represented using flap valves between maintenance holes. WaStops in catch basins were not included in the model. The majority of the WaStops in the model network is located in the central portion of the study area in the combined and partially separated areas of the City shown in **Figure F.4.8**.

4.5.4.5 Interceptor and Overflow Data

Data for the interceptors and overflows were provided in the Phase 1 study for the model. It was refined in the Data Gap Assessment and verified/updated in this study from the IMS data provided by the City. The documentation of overflow and interceptor data included the drawing of each interceptor/overflow provided through operations field investigation. Over 340 interceptor and overflow control structures are in the model with the majority in the older areas (combined and partially separated areas) of the City. Figure F.4.9 shows the location of existing slice gates and weirs. In addition to these structures, there are a number of overflow points that exist within the City's system. A list of those areas will be provided to the City's Engineering Department as part of the final Model submission.

Interceptor maintenance holes are flow diversion structures within the sewer system, where the direction of flow within the chamber is defined by each control structures. Under low flow conditions, inflow entering the chamber is directed to the main outflow pipe (typically to the sanitary or combined sewer located downstream). Under higher flow events, water levels within the structure reach a certain height and flow is directed to more than one outlet through a spill over. During high flow events, the majority of the flow is conveyed to the storm sewer system.

Accurate representation of the structures in the Info Works model is critical as the values (e.g., weir length and height) strongly influence the direction and volume of flow being conveyed to downstream sewers. Representative input parameters for an interceptor maintenance hole are identified below:

- Sluice Gate Height Width;
- Overflow Weir Height, Length;
- Baffle Plate Height, Length; and,
- Overflow Sewer Size, Invert.

Overflow sewers divert flow beyond a certain water level within a maintenance hole structure. Different from diversion structures within an interceptor maintenance hole, flow diversion occurs without the use of a weir or sluice gate. During the field investigation, it was determined that certain interceptor maintenance holes did not have diversion structures, but instead overflow sewers. The overflow sewers in the study area based on background data provided by the City. As noted above for the interceptor maintenance holes, collection of suitable data which describes the specifics of the overflow chamber is critical in order to predict flow patterns during both dry and wet weather conditions. The input parameters generally required for the overflow sewer include:

- Overflow sewer size; and,
- Overflow sewer invert.

4.6 Records of Flooding

The City of Windsor has experienced significant rainfall events in recent years which have led to both localized and wide-spread surface flooding within the study areas. One of the two most prominent events included the September 28, 2016 storm where the City’s east-side received nearly 100 mm of rainfall over 24 hours and caused significant surface and basement flooding. The rainfall amount recorded at the Little River PCP/Pontiac Pump Station rain gauge confirms that the majority of the Pontiac Pump Station area experienced the worst of the storm.

Another significant storm event occurred in the Windsor area in August 2017, in which the storm lasted approximately 28 hours. A maximum measured rainfall amount of 212 mm was logged southwest of the study at the Huron Estates Pump Station and 189 mm at the Howard Grade Separation Pump Station. The rain gauge measurements within and around the current study area were taken at 89 mm, 105mm and 149 mm at the Little River PCP/Pontiac Pump Station, Twin Oaks Pump Station and Drouillard Pump Station rain gauges respectively. East Windsor, although not severely as hit area, significant surface flooding was observed along Riverside Drive and Wyandotte Street. An estimated 60% of the rainfall during this storm occurred within a three-and-a-half-hour time frame, which most likely caused the majority of the surface flooding. It was estimated that the August 2017 event was more severe than the 1:100 year event for many locations within the City; as identified above, the severity varied spatially.

During the Phase 1 study, an assessment of self-reported flooding (June 5-6, 2010 Flooding Event) determined that 90% of homeowners observed water backing up through basement floor drains, shower tubs, toilets, sinks or laundry.

Flooding records were provided by the City of Windsor to review the areas with high flood vulnerability. The data was analyzed to correlate areas of frequent flooding over multiple years. The flooding record data was used to determine additional flow monitoring locations for the separated area for the 2018 monitoring period. Below is the record data provided:

Phase 1 Study

- GIS Basement Flooding Data - 2000 & 2007;
- GIS Basement Flooding Data – 2010 (Receding and Standing Water Complaints);
- City of Windsor Basement Flooding Report (June 5-6, 2010 Flooding Event);
- City of Windsor Basement Flooding Presentation to City Council (June 5-6, 2010 Flooding Event); and,
- GIS Basement Flooding Data – 2011.

Phase 2 Study

- GIS Flooding Calls – 2000 to 2019.

The historical rainfall data was collected from City-owned monitoring stations. Incremental rainfall depths were collected at 5 or 15-minute intervals at each station. Peak annual rainfall events for the period of record (2016 – 2017) were examined for the major flood events. **Table 4.2** below summarizes peak annual rainfall event depths for the period of record and includes the 2016 and 2017 flood events.

Table 4.2: Summary of Flood Events 2016 & 2017

Event Date	Maximum Total Rainfall Accumulation (mm)	Approximate Storm Duration (hrs)
September 28, 2016	100	37
August 28, 2017	212	28

It is noted that the accumulated rainfall amounts represent the gauge that recorded the maximum value, and this does not reflect the spatial variation of rainfall amounts that impacted each part of the City.

5.0 Model Expansion and Development

5.1 Modelling Platform

InfoWorks ICM 8.5.4 was used to simulate the existing flow conditions of the minor (sewer) and major (overland) systems. The minor system was modelled using a 1-dimensional (1D) linear model network while the major (overland) system was modelled using a 2-dimensional (2D) approach.

The InfoWorks ICM sewer existing conditions model includes approximately 3,000 combined sewer sections, 9,100 storm sewer sections, and 7,800 sanitary sewer sections. There are also over 340 control structures within the system, which includes overflow sewers and interceptor maintenance holes connecting the sanitary/combined sewers to the storm sewer system. The locations and types of sewers that were included in the InfoWorks ICM sewer model are provided in the sections below. Existing pump stations are represented in the model based on pump curves and pump information provided by City Operations.

The hydraulic model completed for the 2016 Flow Monitoring and Hydraulic Modelling Study for the City of Windsor (Phase 1 Study) was expanded for the purposes of the Sewer Master Plan. The model network for the Phase 1 Study included storm sewers with diameters greater than or equal to 600 mm, and sanitary sewers and combined greater than 375 mm in diameter.

Subcatchment delineation in the 2016 model was completed on a maintenance hole to maintenance hole basis. For areas where storm sewers were not modelled, the subcatchment areas were aggregated and connected to the nearest upstream maintenance hole. Pump stations and Stormwater Management (SWM) facilities the current physical collection system, specifically the representation of the expanded network and the associated overflow/flow diversion structures and backflow control valves (WaStops) throughout the city-wide system.

To develop the model expansion, the sewer network from the Data Gap Assessment completed in 2017 was exported into GIS. The model was expanded using the minor system network on file in GIS where flooding records indicated clusters of flooding complaints between 2016 and 2017. The sewer network was then updated using the City's GIS Asset Database. The updated sewer network from the City's GIS database contains sewer network and maintenance hole as-built information for all combined, sanitary and storm sewer systems. This includes pipe diameters, invert elevations, pipe lengths, and maintenance hole ground elevations. The symmetrical difference was used to eliminate duplication of nodes and pipes as well as to eliminate redundant pipes, particularly in areas of recent road reconstruction. The network sewer pipe network was then re-imported back into InfoWorks.

To confirm the accuracy of the data once imported, extensive quality checks were completed, and data gaps were filled in through review of as-built information and field drawings and use of best professional judgement to develop an accurate model. Updated and revised data were flagged and documented in the model for future reference.

LiDAR data was obtained for the entire City of Windsor boundary in April 2017. It was used to develop a 1 m x 1 m grid resolution bare earth digital elevation map (DEM); this data was imported into InfoWorks as a ground model. All maintenance hole cover elevations were updated, and the ground model was used to develop the 2D mesh elements for the overland system. Any missing invert and ground elevations were filled in using the inference

(ponds) were also incorporated into the 2016 model based on information provided by the City. The major system/overland flow routes were not incorporated in the 2016 model. Still, they were developed as part of the 2D overland system and linked to the 1D minor system in the expanded model used for this current project. This section provides further details on the model expansion completed.

5.2 Network Development

Proper network development of the model was critical to ensure that each sewer system element was representative of a tool in InfoWorks and corrected using as-built information where there were validation errors.

5.3 Catchment Areas

Subcatchment areas that were initially lumped together (aggregated) in the 2016 model for the Phase 1 Study were further delineated once the additional sewers were incorporated into the model. The subcatchments developed in Phase 1 were exported from InfoWorks into GIS prior to delineating the aggregated areas. Newly delineated subcatchments were based on the sewer segment, closest land parcel and were assigned to the upstream node of the sewer segment. Subcatchments were parametrized based on similar land use classifications in the original model. To simplify subcatchment parametrization, the previously assigned land use classification was generally applied to the newer, smaller subcatchments if they had the same land use. In some cases, new subcatchments were assigned another land use classification as appropriate. Land use types include residential, commercial, industrial and open space, among others, as discussed in Section 4.

Once the delineations were completed, the subcatchments were imported back into InfoWorks and validated.

Four types of sub-catchments were set up in Phase 1. **Table 5.1** below summarizes the possible sewer types of a catchment area and its subcatchment "runoff area" connection to the minor system.

Table 5.1: Subcatchment Runoff Area Connections

Sewer System Type	Subcatchment #1 (DWF including wastewater and baseflow)	Subcatchment #2 (Quick Response)	Subcatchment #3 (Slow Response)	Subcatchment #4 (WWF including disconnected roof and surface runoff via CBs)
Separated System (Sanitary & Storm)	To sanitary sewer			To storm sewer
Partially Separated (Combined & Storm)	To combined sewer			To storm sewer
Combined Only	To combined sewer			

Subcatchment #1 - Dry Weather Flow (DWF) represents wastewater from residential and industrial, commercial, and institutional (ICI) areas plus baseflow (i.e., groundwater infiltration or GWI) draining directly to the corresponding sewer. This subcatchment area ID was given the prefix “DWF” in most cases. Several subcatchments did not have this prefix in the model but were defined in the subcatchment type;

Subcatchment #2 – Quick Response (inflow) represents the area from surfaces that provide an immediate type flow to draining to the corresponding sewer (sanitary or combined sewer). The flow from these types of subcatchments usually peaks during the precipitation event with flow ending relatively shortly after the rainfall stops. The surfaces represented by this subcatchment include direct sources, connected roofs, improper surface drainage, cross-connections with storm sewers, and foundation drains. This subcatchment area ID was given the prefix “CR”;

Subcatchment #3 – Slow Response (infiltration) represents a delayed type hydrograph with a peak flow rate and an extended duration of flow, lasting well beyond the peak rainfall intensity and the end of the precipitation event, respectively. The slow response represents inflow sources such as foundation drains, ground water infiltration, and leaks in maintenance holes, service connections and sewer pipes. This subcatchment area ID was given the prefix “FD”; and,

Subcatchment #4 - Surface Runoff (WWF) represents disconnected roof areas, as well as tributary paved and non-paved (i.e. pervious) areas over private and public properties, drain to the major system or catch basin. This subcatchment area ID was given the prefix “WWF” in most cases. Several subcatchments did not have this prefix in the model but were defined in the subcatchment type.

Runoff surfaces were defined in the model for the disconnected roof, corridor, driveway and pervious area, similar to those used in the Phase 1 study. The runoff coefficient for each surface was assigned based on the land use type and was adjusted during model calibration. Initial loss values for each runoff surface were also adjusted to reflect more representative losses.

Surface infiltration was simulated using the Horton equation, which is a widely accepted method. Three input parameters are required: the maximum infiltration rate, minimum rate, and a decay rate parameter which determines how quickly infiltration rate declines during a storm event. The Horton parameters used in the existing conditions model are presented in **Table 5.2**.

Table 5.2: Previous Surface Horton Equation Parameters

Parameter	Pervious Surface, High to Moderate Infiltration Rate Soils	Pervious Surface, Slow to Very Slow Infiltration Rate Soils
Maximum Infiltration Rate (mm/hr)	125.0	75.0
Minimum Infiltration Rate (mm/hr)	25.2	6.6
Decay Rate (1/hour)	2.0	2.0

Foundation drains connected to the sanitary sewer system exhibit both inflow and infiltration type hydrologic responses and consequently were modelled with a combination of both types of subcatchments. Prior to sanitary sewer model calibration, the slow response of residential lots older than 1980 was set to an area equivalent to 10% of the building area. The contributing area and hydrograph shape parameter (dimension) were further adjusted following calibration, as discussed in detail in Section 7.

Lot-Level Surface Runoff Separation

The subcatchment delineations quantified the amount of contributing roof area, impervious surfaces (roads, driveways, sidewalks) and pervious surfaces (grass, open space). These areas were defined in the Phase 1 study and may be served by fully separated, partially separated or combined sewer systems. Examples of each type of system are illustrated in ***Figure 5.1 through Figure 5.3*** and outlined below.

Fully Separated Systems

Runoff within fully separated areas makes its way to the storm sewer by overland drainage to inlet structures. It is important to define flow path lengths for rainfall that falls on hard surfaces but may be conveyed across pervious areas before reaching the sewer inlet (also referred to as impervious to pervious surface runoff). These areas include roof downspouts that discharge to the grassed surface instead of directly into the storm sewer system. Portions of flow will infiltrate into the ground, thereby reducing the amount of surface flow that makes its way into the storm sewer system.

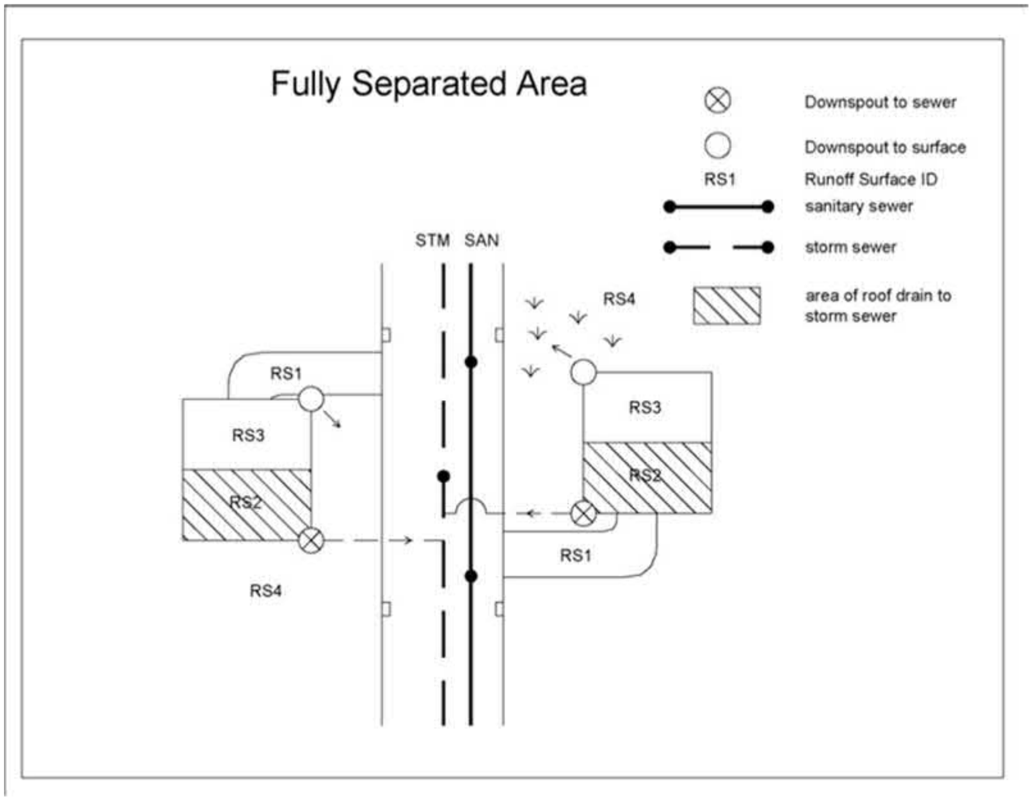


Figure 5.1: Runoff Flow Path in Fully Separated Area

Partially Separated Systems

For partially separated systems, flow patterns are more varied. Roof downspouts that are directly connected are likely to convey flows to the combined sewer, while downspouts that discharge to the ground would convey flows overland to the storm sewer. Runoff from driveways, grassed areas and the road would also discharge to the storm sewer through surface inlets.

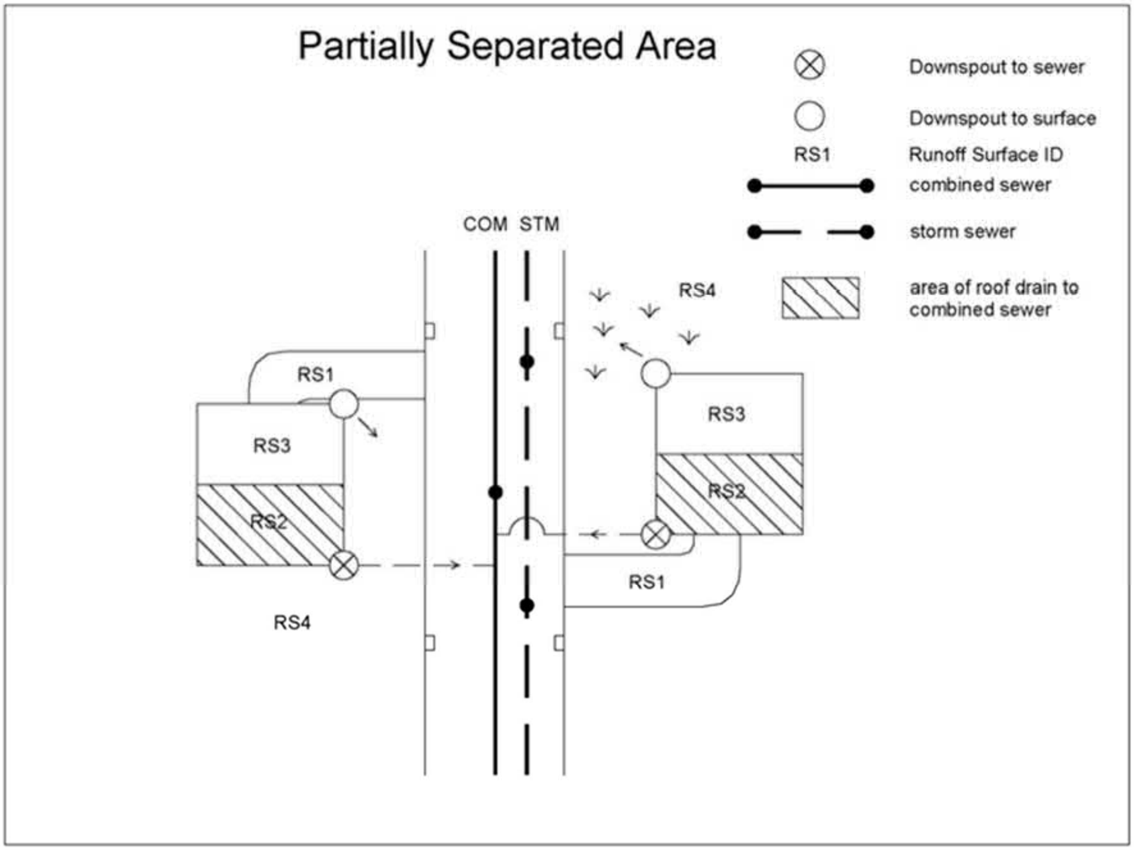


Figure 5.2: Runoff Flow Path in Partially Separated Area

Combined Systems

Flow patterns for combined sewer systems are similar to those shown for the fully separated storm sewer system, but all flows are conveyed to the combined sewer system. The connection policies for roof downspouts are important, as portions of flow will infiltrate into the ground, thereby reducing the amount of overland flow which makes its way to the combined sewer system.

The three runoff separation approaches were used to establish flow patterns for the three types of sewer systems that exist within the City of Windsor.

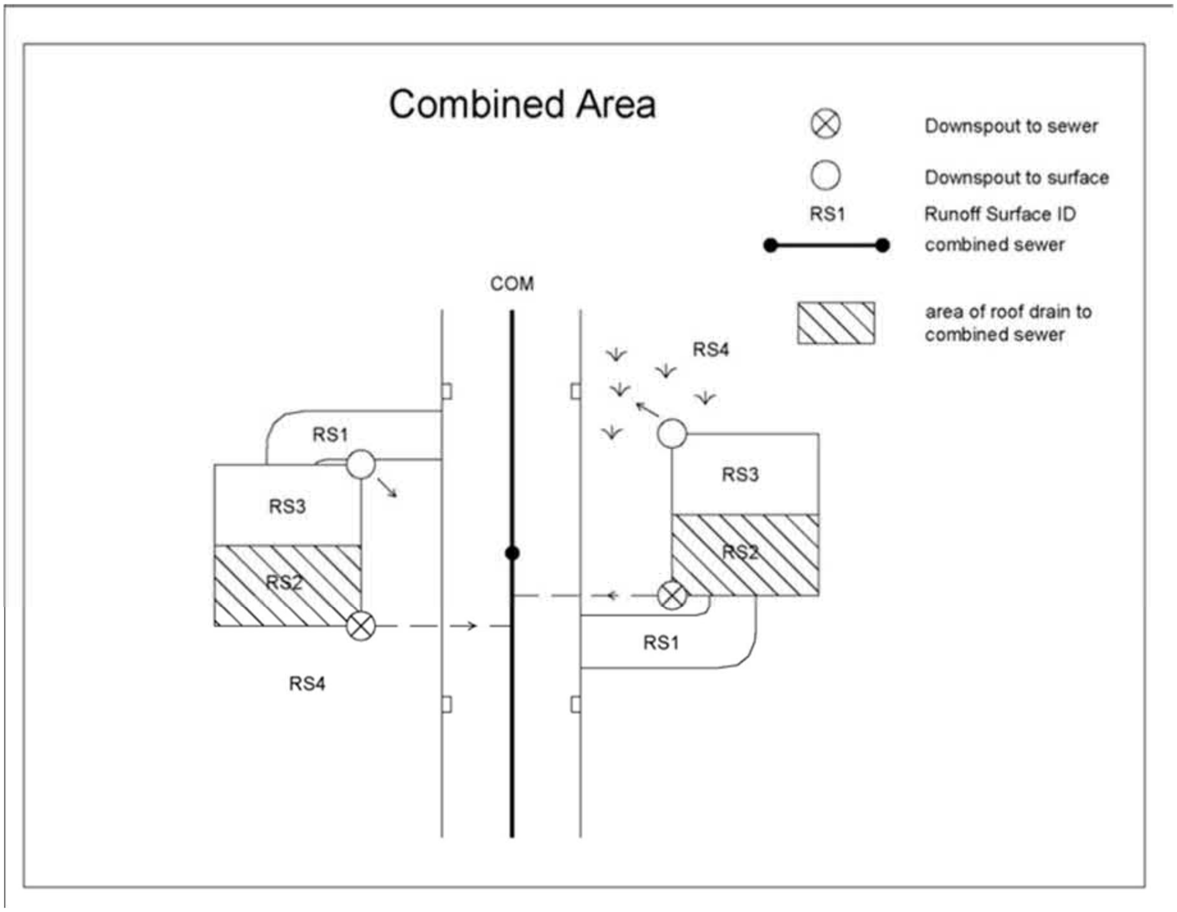


Figure 5.3: Runoff Flow Path in Combined Area

5.4 Catch Basins

Catch basin data sets that included the location and type were provided in GIS format by the City at the beginning of the project. For modelling purposes, a typical catch basin inlet capacity curve was applied for use in the InfoWorks model.

Road drainage throughout the City consists of surface drainage and conveyance elements which are representative of pipes and ditches. The number of sewer inlets within a pipe section affects both the rate of runoff removal from the road surface and the degree of utilization of the conveyance elements. It is necessary to incorporate inlet controls for the sewer system analysis in order to characterize the existing storm sewer and surface drainage performance.

Storm sewer systems are typically designed for the 1:2 to 1:5 year storm event. During smaller storm events, under the assumption that all surface runoff enters the sewer system unimpeded, the capacity of the sewer system should be sufficient to carry flows from these events. During larger storm events, inlet flows will typically exceed the capacity of catch basin inlets. For modelling purposes, a limit is typically set to limit the capacity of the inlets to limit issues which could arise relating to associated flooding and unrealistic surcharging of the system if the inflows are not be appropriately represented.

Standard parallel slot catch basins provide an inflow rate of 28 L/s to 46 L/s (1.0 ft^3/s to 1.5 ft^3/s) depending upon many factors such as cross grade, type of inlet, depth of flow, and curb and gutter type. The volume that is not captured by the inlet of the catch basin is either stored along the road surface until the inlet rate drops below the maximum allowable capacity of the catch basin or is bypassed to the next downstream inlet. The inlet capacity curve for a standard combined sewer catch basin within inflow rate of 46 L/s used in Phase 1 is shown below in **Figure 5.4.**

	Head (m)	Discharge (m3/s)	Power (kW)
1	-0.3000	-0.0467	0.0000
2	-0.1500	-0.0467	0.0000
3	-0.1000	-0.0467	0.0000
4	-0.0900	-0.0383	0.0000
5	-0.0800	-0.0304	0.0000
6	-0.0700	-0.0229	0.0000
7	-0.0600	-0.0149	0.0000
8	-0.0500	-0.0077	0.0000
9	-0.0400	-0.0038	0.0000
10	-0.0350	-0.0026	0.0000
11	-0.0320	-0.0023	0.0000
12	-0.0300	-0.0020	0.0000
13	-0.0200	-0.0007	0.0000
14	-0.0100	-0.0001	0.0000
15	0.0000	0.0000	0.0000
16	0.0100	0.0001	0.0000
17	0.0200	0.0007	0.0000
18	0.0300	0.0020	0.0000

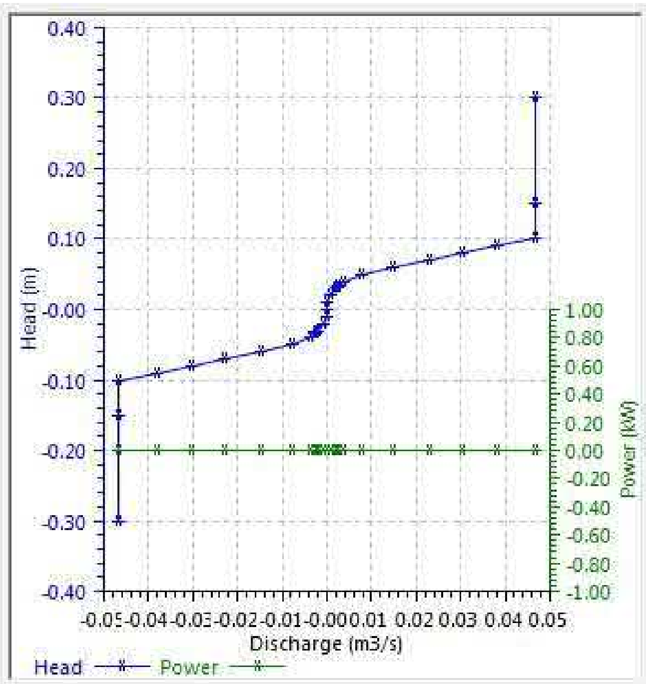


Figure 5.4: Standard Catch Basin Inlet Capacity Curve for Parallel Slot

At the beginning of the Phase 2 study, the City provided data that indicated the typical size of the storm leader pipe connecting the catch basin to the storm sewer system was between 150 mm and 200 mm in diameter. In comparison, the model assumes a minimum lead size of 200 mm diameter. The inlet capacity is governed by the catch basin lead as opposed to the inlet capacity of the catch basin grate, particularly at sags. The orifice equation was applied at the gullies to represent the inlet capacity curve.

$$Q = \frac{\pi}{4} C_d d^2 \sqrt{2gh}$$

Additionally, to estimate inflow through the sanitary maintenance hole covers, the equivalent diameter of two pick holes was calculated and the above equation applied at all sanitary maintenance hole nodes except where the covers were sealed.

Figure 5.5 shows the inlet capacity curve applied at the storm sewer maintenance holes in the model considering the lead size. At the same time, **Figure 5.6** identifies the updated inlet capacity curve at catch basins for when a large head is trying to let water drain to the surface (See 1D-2D schematic below in next sub-section).

	Head (m)	Discharge (m3/s)	Power (kW)
1	-0.3000	-0.0670	0.0000
2	-0.1500	-0.0610	0.0000
3	-0.1000	-0.0467	0.0000
4	-0.0900	-0.0383	0.0000
5	-0.0800	-0.0304	0.0000
6	-0.0700	-0.0229	0.0000
7	-0.0600	-0.0149	0.0000
8	-0.0500	-0.0077	0.0000
9	-0.0400	-0.0038	0.0000
10	-0.0350	-0.0026	0.0000
11	-0.0320	-0.0023	0.0000
12	-0.0300	-0.0020	0.0000
13	-0.0200	-0.0007	0.0000
14	-0.0100	-0.0001	0.0000
15	0.0000	0.0000	0.0000
16	0.0100	0.0001	0.0000
17	0.0200	0.0007	0.0000
18	0.0300	0.0020	0.0000

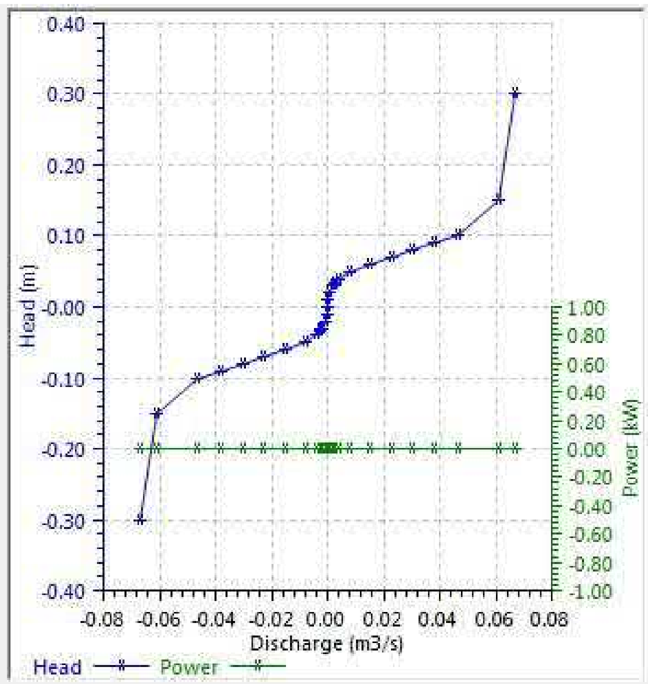
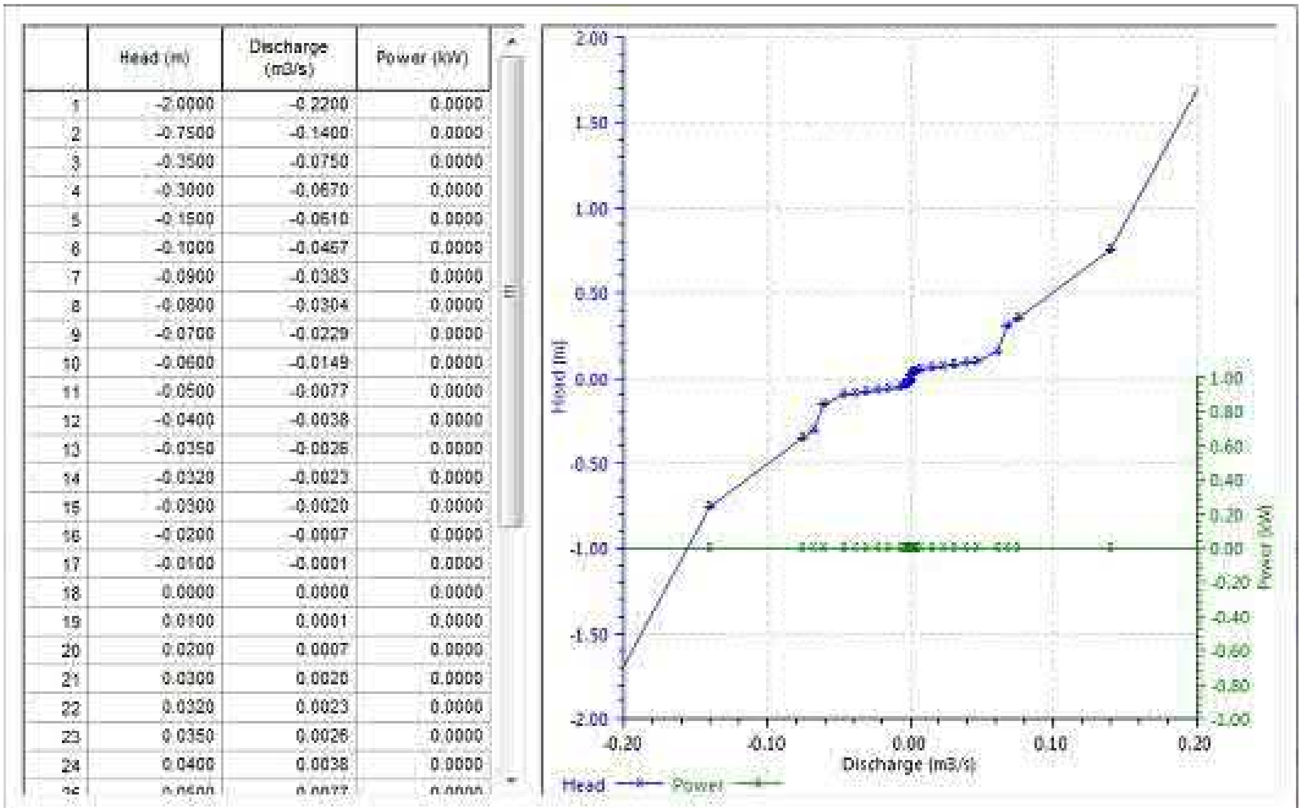


Figure 5.5: Inlet Capacity Curve for 200 mm diameter Lead Pipe



	Head (m)	Discharge (m3/s)	Power (kW)
1	-2.0000	-0.2200	0.0000
2	-0.7500	-0.1400	0.0000
3	-0.3500	-0.0750	0.0000
4	-0.3000	-0.0670	0.0000
5	-0.1500	-0.0610	0.0000
6	-0.1000	-0.0467	0.0000
7	-0.0900	-0.0383	0.0000
8	-0.0800	-0.0304	0.0000
9	-0.0700	-0.0229	0.0000
10	-0.0600	-0.0149	0.0000
11	-0.0500	-0.0077	0.0000
12	-0.0400	-0.0038	0.0000
13	-0.0350	-0.0026	0.0000
14	-0.0320	-0.0023	0.0000
15	-0.0300	-0.0020	0.0000
16	-0.0200	-0.0007	0.0000
17	-0.0100	-0.0001	0.0000
18	0.0000	0.0000	0.0000
19	0.0100	0.0001	0.0000
20	0.0200	0.0007	0.0000
21	0.0300	0.0020	0.0000
22	0.0320	0.0023	0.0000
23	0.0350	0.0026	0.0000
24	0.0400	0.0038	0.0000

Figure 5.6: Inlet Capacity Curve for CB with Additional Head

Figure 5.7 (below) shows the inlet curve applied at the sanitary model nodes to account for inflow from surface ponding through maintenance hole covers.

	Head (m)	Discharge (m3/s)	Power (kW)
1	-0.5000	-0.0070	
2	-0.3050	-0.0060	
3	-0.2440	-0.0050	
4	-0.2000	-0.0050	
5	-0.1820	-0.0050	
6	-0.1210	-0.0040	
7	0.0000	0.0000	
8	0.1210	0.0040	
9	0.1820	0.0050	
10	0.2000	0.0050	
11	0.2440	0.0050	
12	0.3050	0.0060	
13	0.5000	0.0070	
*			

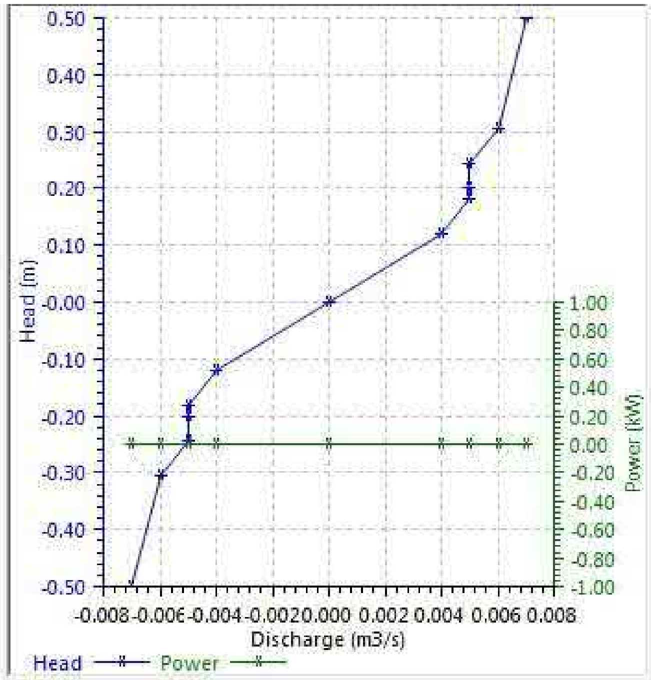


Figure 5-7: Inlet Curve at Sanitary MH Cover

5.5 Overland Drainage

A two-dimensional (2D) mesh was developed using a digital elevation map of the ground surface to represent the major system network, which was coupled with the one-dimensional (1D) sewer system model. This approach allows for the analysis of surface ponding depths within depressed areas, localized roadway low points while accounting for the movement of overland flow through the study area. This modelling approach included integration of 1D and 2D model computing as follows:

- Sewer pipes, maintenance holes, catch basins structures, stormwater management facilities and larger drainage channels (i.e. watercourses, municipal drains) represented as 1D elements; and,
- Roadways, private property drainage, localized depression storage areas and undeveloped land represented in a 2D mesh.

The 1D elements within the InfoWorks model were then connected to the 2D mesh elements to ensure that once the capacity of the 1D system is exceeded, the mesh will begin to dynamically compute overland flow routing and surface ponding throughout the duration of the simulated storm event as depicted in the figure below. Each 2D mesh element has a minimum size of 28 m^2 and a maximum size of 144 m^2. Mesh elements defined larger than 144 m^2 area automatically split into smaller mesh elements with individual centroids. The total surface area accounted for in the 2D mesh grid is approximately 11,500 ha, which is represented by over 2.5 million triangular elements with an average area of 46 m^2. A schematic of the coupled 1D-2D model elements is provided in **Figure 5.8**.

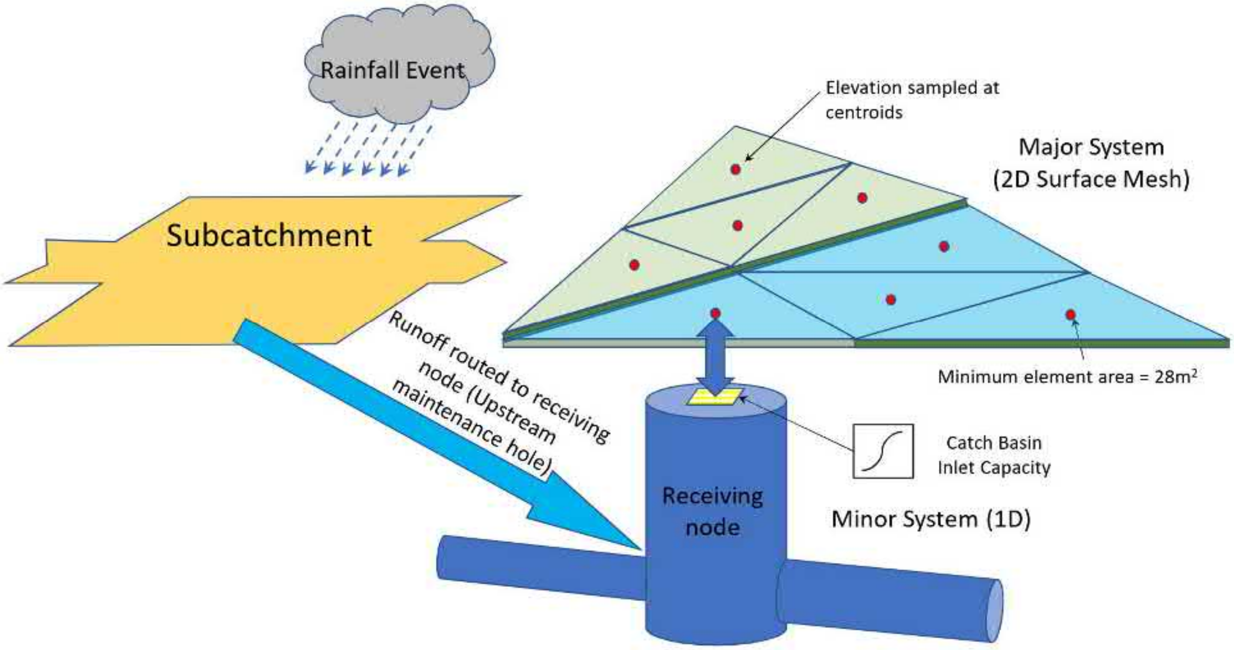


Figure 5.8: 1D-2d Model Linkage Schematic

In this coupled model of the minor (1D) and major (2D) systems, the major system is represented as a multi-triangular element mesh where triangular elements exchange water with neighbouring elements and the 1D conveyance links. Simulation times are considerably longer than those of 1D surface flow models with the increased complexity of physical processes being calculated. If limited data is available for calibration, this can lead to high uncertainty in the model results. The extreme events in September 2016 and August 2017 provided key input for the surface model calibration, thus improving the accuracy of the simulation results.

6.0 Flow Monitoring & Precipitation Data

To reasonably represent the flow characteristics of the City's sanitary, combined and storm sewer systems, both precipitation (rainfall) and flow monitoring data are required. This data is used to characterize and understand dry-weather (no rainfall) and wet-weather (rainfall) sewer flows. During dry-weather periods the sanitary and combined sewers convey only sewage from households, commercial, institutional and industrial land uses plus non-rainfall derived groundwater infiltration.

During and following wet-weather events, otherwise dry storm sewers, convey rainwater that runs off overland into catch basins, and then to an underground sewer which ultimately drains into the Detroit River or Lake St. Clair. In Windsor, sanitary sewers are designed primarily to convey sewage plus a nominal allowance for infiltration based on total service area. However, through a review of the City's flow monitoring data, a response to wet-weather rain events was observed in all sanitary flow monitoring gauges with noticeable increases inflow.

The compiled flow monitoring and precipitation records within the City of Windsor allow designers and engineers to understand flow characteristics. The key data sources used for this project are recent records from generally 2012 or later, as identified below:

- The City of Windsor had a network of rain gauges that record precipitation patterns within the Municipality. The rain data from this network was provided as a continuous record from October 2012 to 2018 and formed the primary source of precipitation data for the study;
- During 2013 and 2014, sewer flow monitor data was collected as part of a temporary program to characterize better the City's storm, sanitary and combined sewer systems;
- In 2017, 5 months of temporary sewer flow monitor data were collected in the Pontiac, St. Paul and St. Rose stormwater service areas. This program focused only on the storm sewer systems;
- In 2018, 6 months of temporary sewer flow monitor data were collected at locations throughout the City, focused on understanding sanitary sewer wet-weather response. Two temporary rain gauges were set up to support the program; and,
- Starting in 2013 and currently on-going, the City is collecting sanitary sewer flow monitoring data at 13 locations throughout the Municipality. These gauges collect data from relatively large service areas providing information at a global scale.

Additional details about each program and the supporting precipitation data are identified in the subsequent sections.

6.1 Precipitation Data

The City of Windsor owns and maintains an active network of rain gauges that collect continuous records of rainfall volumes. Data provided from the City included up to 14 gauges with records starting from October 2012. Within this seven-year period gauges have been moved and removed from service.

As part of the 2018 temporary flow monitoring program, an additional two rain gauges were deployed to supplement the wet-weather analysis further. AMG Environmental Inc. provided the two additional gauges (No. 101 and 102). A map of all rain gauges used in the study is presented in **Figure F.6.1**.

The rainfall records were used in the project to help characterize and understand the City's sewer and drainage systems. Prior to using the records for individual wet-weather events, a quality screening process was completed where gauged event records with missing data, or potentially incorrect information were removed. **Table 6.1** summarizes the wet-weather event rainfall total volumes used in the study.

Where "QA/C" values are identified in the table, data was partially missing, or the records were considered to have a significant discrepancy when compared to neighbouring monitors. These precipitation records were not used. If gauges were inactive or not yet installed, a "N/A", is provided in the table to identify information is not available. City rain gauges 13 and 14 were not active during the 2018 flow monitoring program. City rain gauge 10 was moved in 2018 from the 6th Concession pumping station to Provincial Square pump station (Lowe's Home Improvement Store).

Table 6.1: Rain Gauge Total Wet-Weather Event Precipitation Volumes (mm)

Gauge No.	Event									
	8/30/13	6/18/14	8/11/14	9/10/14	9/28/16	8/28/17	5/2/18	5/12/18	9/20/18	9/24/18
1	31.2	38.4	92.7	39.9	64.9	90.9	21.8	12.3	58.0	73.4
2	20.7	29.0	56.1	57.4	77.9	142.0	25.4	10.9	50.3	57.1
3	22.6	6.5	55.7	54.4	100.2	84.4	18.2	15.9	46.5	42.3
4	27.0	44.8	72.2	55.4	QA/C	185.3	19.7	20.3	QA/C	76.4
5	24.9	17.1	87.8	37.9	80.1	81.6	19.4	12.8	QA/C	QA/C
6	38.1	13.6	79.7	59.3	QA/C	138.2	19.2	QA/C	QA/C	QA/C
7	28.5	44.4	76.8	53.0	62.3	211.8	22.7	16.0	43.5	68.8
8	20.5	30.0	53.9	54.4	74.0	185.4	20.3	11.2	56.8	62.2
9	16.1	32.2	91.9	QA/C	70.6	110.6	22.3	10.0	35.6	47.3
10	QA/C	QA/C	QA/C	QA/C	53.2	83.2	QA/C	QA/C	QA/C	QA/C
11	QA/C	QA/C	QA/C	QA/C	90.9	96.2	24.9	QA/C	40.2	39.8
12	25.6	30.6	73.1	48.9	70.8	138.0	22.4	11.3	62.5	87.7
13	N/A	N/A	53.2	62.3	69.0	134.9	N/A	N/A	N/A	N/A
14	N/A	N/A	N/A	55.7	N/A	N/A	N/A	N/A	N/A	N/A
101	N/A	N/A	N/A	N/A	N/A	N/A	24.4	14.7	QA/C	40.9
102	N/A	N/A	N/A	N/A	N/A	N/A	25.7	15.2	47.2	55.6

6.2 Previous Flow Monitoring

6.2.1 2013 & 2014

This flow monitoring program was completed between July 1st, 2013 and November 30th, 2014 as part of Phase 1 of the Sewer Master Plan. This study's monitoring data were used to calibrate and validate the baseline InfoWorks model for the City's storm, sanitary and combined sewer systems. The first year of monitoring was aimed at providing a high level overview and understanding of the system. The second year of monitoring focused on smaller sub-watersheds and potential locations where concerns had been identified. During this program between 28 and 30, temporary flow monitors were actively recording flow.

The flow monitoring devices were equipped with two depth sensors, two Doppler ultrasonic velocity sensors, one float switch and an antenna. Exact sensor configurations were determined based on site inspections. Sensor readings were taken every 5 minutes. Selection for the locations of the storm, sanitary and combined sewer flow monitors were based on the drainage area characteristic and discussions with City staff. Specifically, a selection of the monitoring sites was based on the following:

Year 1 Flow Monitoring Location Selection Criteria:

- At strategic locations within the study area where bottlenecks or flooding events have been previously identified;
- At representative homogenous catchment areas, such that the hydrologic component of the hydraulic model can be calibrated;
- At representative critical diversion and overflow locations;
- In representative sub trunk/trunk sewers, to confirm the model's hydraulic response to Infiltration and Inflow (I&I) and peak flows to correlate with results from other studies; and,
- At representative locations to assist in confirming existing pumping station capacity and response to wet weather events.

Year 2 Flow Monitoring Location Selection Criteria:

- I&I rates were identified;
- Areas where known flooding had occurred; and,
- Critical overflow (CSO) locations.

The locations of the flow monitors used in this study are identified in **Figure F.6.2**. The Phase 1 Sewer Master Plan used a total of six wet-weather events to characterize the City's sewers. However, as additional data was available to support his study, only four of those six events were considered in model calibration and validation for Phase 2. Summary data for those four events are presented in **Tables 6.2** to **6.4**. For the storm sewer records, total event runoff volume and event peak flow are provided. For the sanitary sewer and combined sewer records in the table total volume above dry conditions from the rain-derived inflow and infiltration (RDII) are provided. The sanitary sewer and combined sewer event maximum peak flow rate includes the RDII component and dry-weather diurnal base flow component. Blank values in the tables represent data points that were removed following a quality review of available information, where either all flow information or a large portion of the event was missing.

Table 6.2: Summary of 2013 & 2014 Flow Monitor Data – Storm Sewers

Gauge No.	Event			
	8/30/2013	6/18/2014	8/11/2014	9/10/2014
	Total Event Volume, in mm (Event Peak Flow, in L/s)			
ST300 (8R494)	4.4	6.4		
	(328)	(269)		
ST400 (3R203)	3.2	2.1	14.1	9.0
	(2,798)	(1,542)	(6,442)	(3,518)
ST500 (1R131)	1.2	0.0		
	(1,024)	(73)		
ST501 (1R3587)			10.3	4.1
			(127)	(56)
ST600 (6R908)	1.0	1.1		
	(990)	(581)		
ST700 (7R3)	5.1	4.3		
	(2,541)	(1,659)		
ST700 (7R1218)			10.1	16.1
			(208)	(179)
ST800 (7R978)	2.9	8.3		
	(2,035)	(935)		
ST900 (7R957)	6.8	4.1		
	(1,769)	(254)		
ST901 (7R1331)			12.2	14.8
			(109)	(74)
ST1000 (1R1451)	1.2	3.7		
	(1,030)	(1,557)		
ST1001 (1R3272)			12.1	16.0
			(78)	(110)
ST1100 (6R949)	6.4	1.0		
	(7,713)	(823)		
ST1101 (6R549)			9.6	7.8
			(259)	(135)
ST1200 (8R3577)	2.0	1.7		
	(1,369)	(991)		
ST1300 (7R5016)	2.8	1.1		
	(124)	(31)		

Gauge No.	Event			
	8/30/2013	6/18/2014	8/11/2014	9/10/2014
	Total Event Volume, in mm (Event Peak Flow, in L/s)			
ST1301 (6R3889)			13.6	16.6
			(99)	(74)
ST1400 (7R288)	5.5	4.0		
	(1,973)	(2,335)		
ST1500 (7R9848)		4.6	8.4	8.9
		(1,400)	(1,862)	(1,539)
ST1600 (8R9081)	5.5	14.7		
	(1,474)	(1,893)		
ST1601 (8R608)			7.3	13.2
			(134)	(130)

Table 6.3: Summary of 2013 & 2014 Flow Monitor Data – Sanitary Sewers

Gauge No.	Event			
	8/30/2013	6/18/2014	8/11/2014	9/10/2014
	Total Event Rain-Derived Inflow & Infiltration Volume, in mm (Event Peak Flow, in L/S)			
S100 (8S1650)	0.1	0.4	0.5	1.3
	(557)	(699)	(1,060)	(1,661)
S200 (1S3374)	1.2	0.5	1.6	2.6
	(494)	(198)	(421)	(497)
S300 (1S89)		0.3	0.1	0.1
		(41)	(36)	(55)

Table 6.4: Summary of 2013 & 2014 Flow Monitor Data – Combined Sewers

Gauge No.	Event			
	8/30/2013	6/18/2014	8/11/2014	9/10/2014
	Total Event Volume, in mm (Event Peak Flow, in L/s)			
C100 (6S311)	2.7	1.1		
	(625)	(388)		
C200 (7S17)	2.0	1.7		
	(280)	(264)		
C201 (7C4504)			11.2	12.2
			(98)	(101)
C300 (5C443)	1.6	3.4	4.8	4.1
	(247)	(281)	(302)	(283)
C400 (2C375)	2.1	1.5	3.9	2.4
	(1,231)	(637)	(1,406)	(1,190)
C500 (5C82)	5.3	6.4	26.5	11.9
	(2,437)	(1,886)	(4,490)	(2,477)
C600 (4C268)	2.1	2.2		
	(619)	(393)		
C601 (4CJ939)			15.4	8.4
			(536)	(306)
C700 (1C910)		4.34		
		(973)		
C701 (1C143)			7.4	6.2
			(117)	(90)
C800 (4C73)	1.8	2.6		
	(1,233)	(1,097)		
C900 (2C748)	4.0	2.0		
	(138)	(84)		
C901 (2C748)			1.2	0.7
			(48)	(42)
C1100 (3C77)	4.3	3.9	12.8	11.7
	(744)	(534)	(1,210)	(1,048)

For additional details related to the 2013 & 2014, temporary flow monitoring refer to *Flow Monitoring and Hydraulic Modeling of the Sewer System* report (2016).

6.2.2 2017 – Pontiac and St. Paul

A flow monitoring program was completed between April 1, 2017, and August 31, 2017, to support the Pontiac and St. Paul storm sewer study (2018). A total of 7 flow monitors were installed, and data was collected for the 5 month period to monitor the storm sewer system.

Selection for the locations of the storm sewer system flow monitors was based on the previous locations, calibration results from the Phase 1 Sewer Master Plan, the general characteristics of the study drainage areas, discussions with City staff, and previously reported complaints of basement and surface flooding.

The locations of the flow monitors used in this study are identified in **Figure F.6.3**. The Pontiac and St. Paul storm sewer study (2018) used a total of four wet-weather events in model calibration and validation. Only data from one of the four events, the August 28, 2017 storm event was used in this study. Summary data for this event is presented in **Table 6.5**.

Table 6.5: Summary of 2017 Pontiac and St. Paul - AMG Temporary Flow Monitor Data

Gauge No.	**Event**	
	August 28, 2017	
	Total Event Volume, in mm	(Event Peak Flow, in L/s)
FM 01 (6R1022)	4.4	(1,145)
N_FM 02 (6R3847)	5.5	(2,113)
FM 03 (6R3899)	28.6	(2,208)
FM 04 (6R4191)	2.0	(489)
FM 05 (6R865)	27.5	(3,970)
N_FM 06 (6R424)	5.7	(543)
FM 07 (6R914)	23.9	(1,940)

6.2.3 City's Flow Monitoring

The City's sanitary flow monitoring program which started in 2013 includes six permanent flow monitors within the Lou Romano Water Reclamation Plant (WRP) service area and seven monitors installed within the Little River Pollution Control Plant (PCP) service area. Data from these monitors was fundamental in characterizing the City's large-scale sanitary sewer wet-weather response. The locations of these flow monitors are identified in **Figure F.6.4**. A summary description of the flow monitor service areas is provided in **Table 6.6**.

Table 6.6: Summary of Sanitary Sewer Flow Monitor Service Areas

Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Description of Service Area
Lou Romano Water Reclamation Plant Service Area			
1S3342	480	825	This sanitary sewer in the combined sewer system area has a mostly separated service area, 80% or more. It includes a significant portion of the City's dual MH system. The sewer conveys dry-weather flow and a fraction of the wet-weather flow from rain events.
5S724	3,140	1950	This sewer conveys wastewater from nearly the whole combined sewer system to the plant. This inflow characterizes globally how the Lou Romano combined sewer system operates; in particular how much combined sewage is conveyed to the plant.
5S728	500	1050	This sanitary sewer in the combined sewer system area has partial separated upstream lands. Service area includes the Prince Road combined sewer system, where previous studies recommended continuation of sewer separation.
8S1309	2,450	1675	This sanitary sewer in a separated area conveys flow from lands north of Cabana Rd.
8S1838	4,580	1950	This sanitary sewer in a separated area conveys nearly all the separated sanitary sewer system flow to the plant. This inflow characterizes globally how the Lou Romano separated sewer system operates.
8S2133	1,250	1050	This sanitary sewer in a separated area conveys flow from lands south of Cabana Rd and west of Walker Rd.
Little River Wastewater Treatment Plant Service Area			
6S2037	340*	1500	This sanitary sewer in a separated area conveys flow from the far northeast of Windsor and sanitary flow from the Town of Tecumseh's Gauthier (Cedarwood) pump station.
6S2249	160	900	The service areas from these four sewers overlap, where overflow between the networks, can provide conditions where all four pipes act as a single system. The serviced lands include a majority of older homes with most properties having a separated sewer system. A few isolated pockets of combined sewer exist, generally south of South Nation St between Jefferson Blvd and Pillette Rd.
6S3033	400	675	
6S3841	980	900	
6S875	820	900	
7S5641	1,040	1200	This sewer conveys flows from a separated system. The service area includes the forest Glade subdivision and the industrial/commercial lands extending west to Jefferson Blvd.
7S6353	440*	2100	This sewer conveys flows from a separated system. The service area includes existing industrial lands south of E.C. Row, the Town of Tecumseh's Oldcastle Hamlet and other small residential areas. Further, this area has a significant planned capacity for future development in both Windsor and Tecumseh.

Note: The service areas for 6S2037 and 7S6353 identified in the table, only represents the service area within the City of Windsor borders.

For these monitors, a total of eleven wet weather flow events are included in the study. Summary data for those events are presented in Table 6.7. The data in the table includes total volume above dry conditions from the rain-derived inflow and infiltration (RDII). The event maximum peak flow rate includes the RDII component and dry-weather diurnal base flow component.

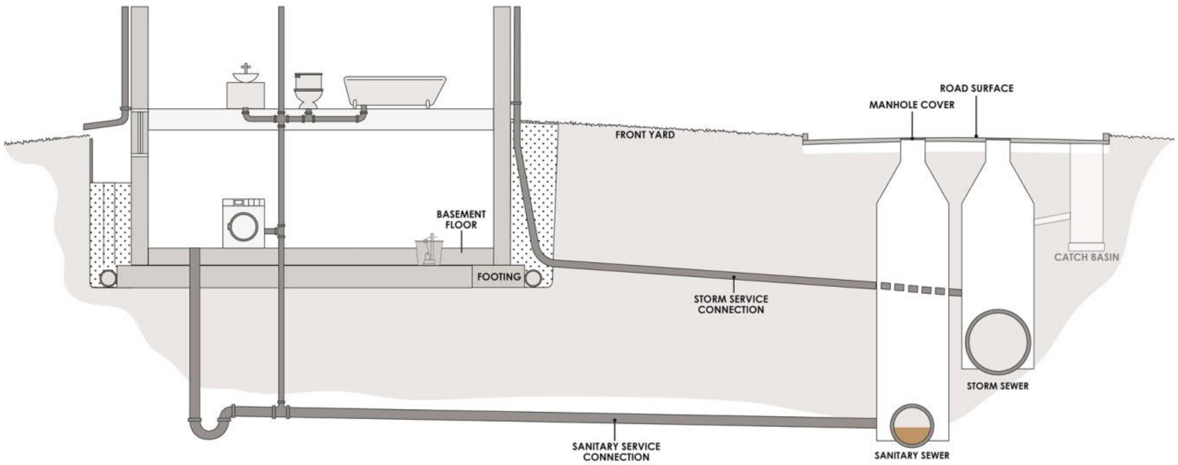
Table 6.7: Summary On-Going Sanitary Sewer Flow Monitor Data

Gauge No.	Event									
	8/30/13	6/18/14	8/11/14	9/10/14	9/28/16	8/28/17	5/2/18	5/12/18	9/20/18	9/24/18
	Total Event Rain-Derived Inflow & Infiltration Volume, in mm (Event Peak Flow, in L/s)									
1S3342	2.4	3.1				8.6				
	(629)	(520)				(682)				
5S724	2.4	7.5	9	5.6	12.5	7.8	3.8	6.8		
	(5,468)	(4,791)	(5,674)	(5,110)	(4,000)	(9,885)	(3,569)	(5,025)		
5S728	1.6	7	7.5		20.7	8.7	2.5		2.7	5.4
	(968)	(858)	(1,642)		(924)	(1,408)	(737)		(1,224)	(1,376)
6S2037		10.1	10.5	14.7		27.0	4.1			
		(527)	(667)	(802)		(933)	(278)			
6S2249							7.6	11.4	6.9	11.9
							(210)	(378)	(801)	(835)
6S3033		2.1	6.4	6.1		12.5	1		2.2	3
		(349)	(404)	(472)		(515)	(208)		(425)	(561)
6S3841						2.1	0.4	1.9		
						(561)	(148)	(238)		
6S875							1.4		1.3	2.2
							(260)		(438)	(527)
7S5641		2.2	2.9	2.7	10.8	3.4				
		(337)	(853)	(984)	(1,296)	(3,330)				
8S1309	0.8	4.9	4.5	3.8		12.2	1.9	3.9	1.1	4.3
	(1,022)	(1,385)	(1,975)	(1,995)		(2,622)	(932)	(1,356)	(1,713)	(6,344)
8S1838	0.7	5.2	5.6	3.6	11.5	10.3	1.4	2.6	1.2	
	(4,393)	(2,326)	(3,399)	(3,361)	(3,241)	(4,379)	(1,557)	(2,913)	(2,393)	
8S2133	1.8	6.7	8.7	4.6		10.4				
	(446)	(796)	(1,299)	(1,232)		(1,119)				

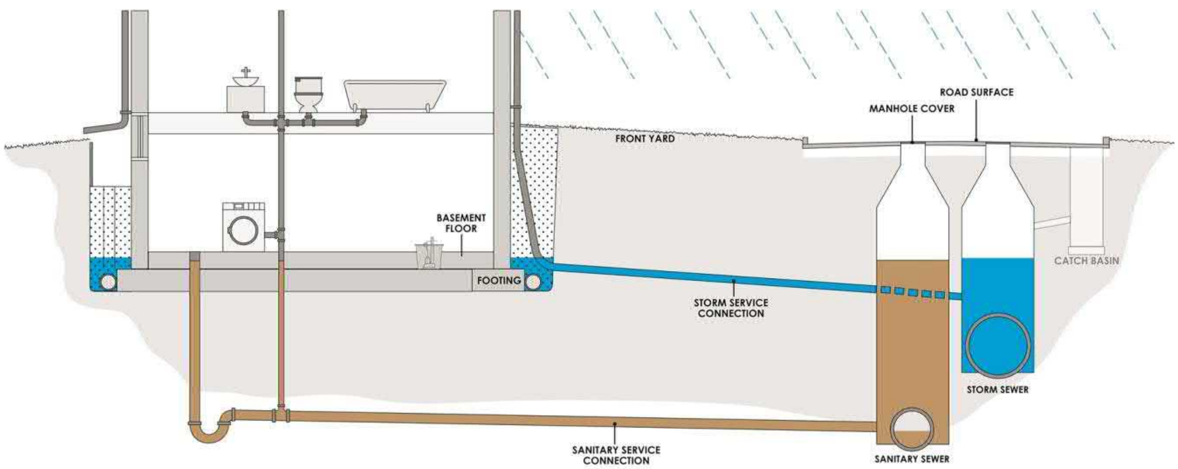
One of the thirteen flow monitor gauges, 7S6353, has limited use in the flow monitoring analysis for characterizing residential RDII. This gauge represents flow from primarily industrial and rural lands in the City of Windsor, and rural residential lands from the Town of Tecumseh's subdivision Oldcastle Hamlet. Unlike the remainder of the City's flow monitors, residential lands are not included in the service area. Consequently, information from this gauge is not used for calibration. Blank values in the table represent data points that were removed following a quality review of available information, where either all flow information or a large portion of the event was missing.

6.3 2018 Flow Monitoring Program

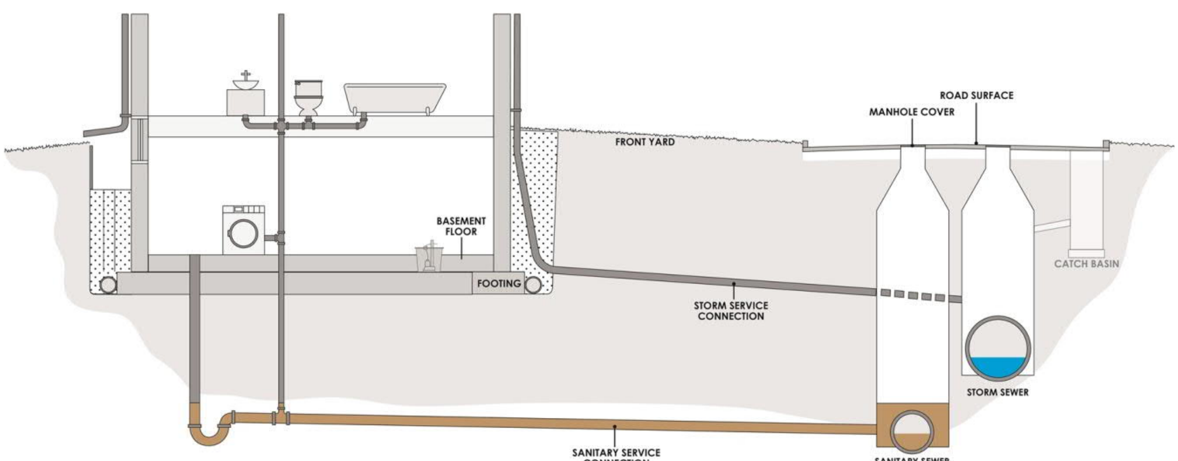
The 2018 flow monitoring program focused on developing a better understanding of City's sanitary sewers' wet-weather response. To accomplish this, the monitoring program used a "coupled" flow monitor concept, where storm and sanitary sewers in parallel were each gauged. The information gathered from this type of flow monitoring helps develop an understanding of the characteristics of the sanitary sewer rain-derived flow by comparing with a neighbouring storm sewer. This comparison of response focuses on hydrograph shape and timing between the two parallel systems. This concept is shown in **Figure 6.1** and **6.2**.



(A) Right before rain event: Dry-weather flow in Sanitary, no flow in Storm

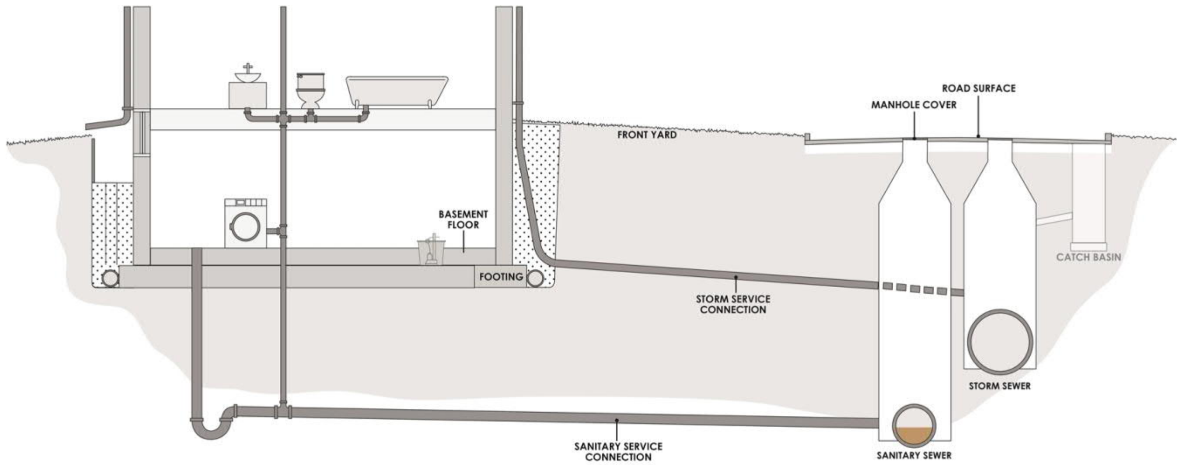


(B) During rain event: Sanitary and Storm sewers have similar responses

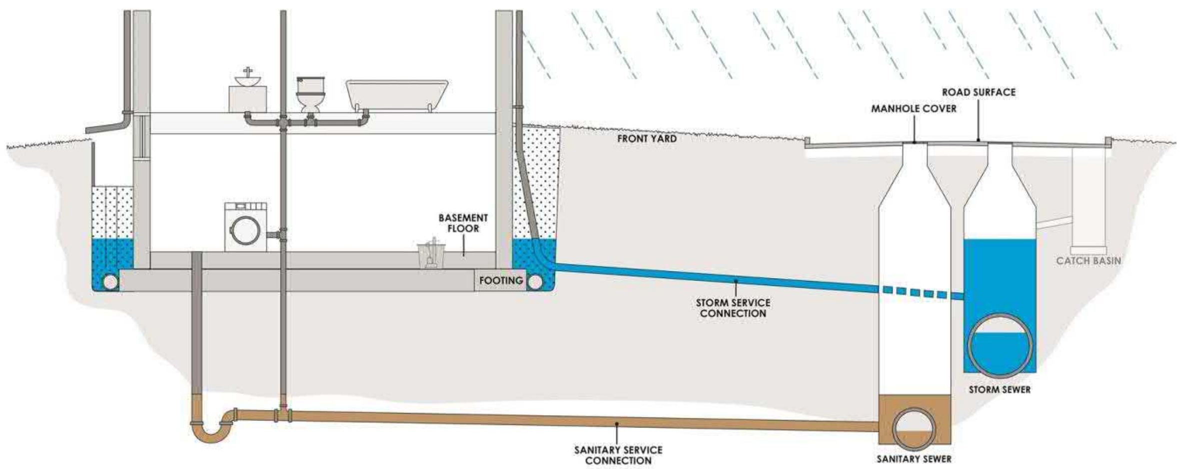


(C) Shortly after rain event: Sanitary HGL much lower than peak and Storm nearly empty

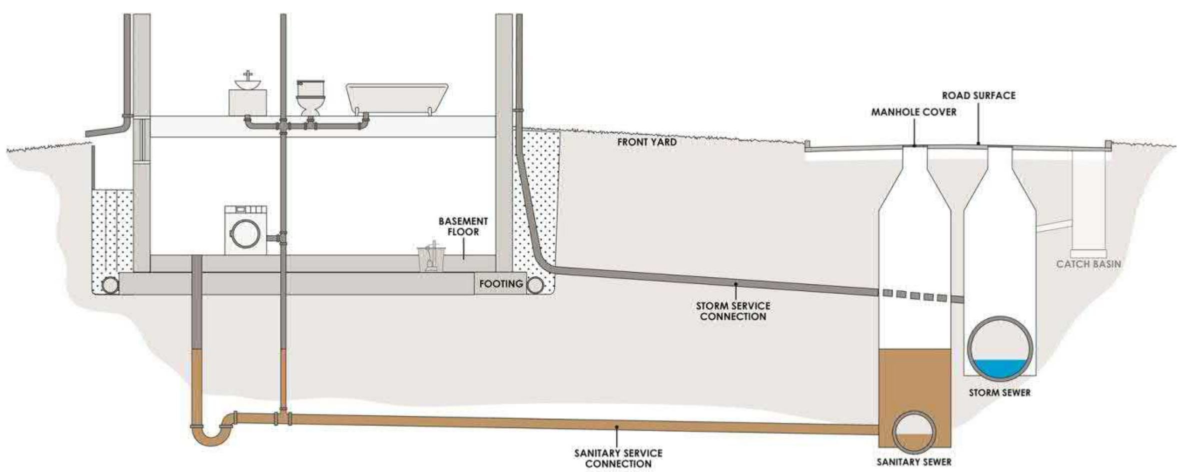
Figure 6.1: Quick and Direct-Connection Type Rainfall-Derived Inflow and Infiltration Response



(A) Right before rain event: Dry-weather glow in Sanitary, no flow in Storm



(B) During rain event: Storm sewers have faster HGL peak than Sanitary sewer



(C) Shortly after rain event: Sanitary HGL may continue to increase while Storm nearly empty

Figure 6.2: Slow Type Rainfall-Derived Inflow and Infiltration Response

AMG Environmental Inc. was retained to undertake this flow monitoring program completed between April and October 2018. A summary of the flow monitor service areas is provided in **Table 6.8**. Refer to **Appendix C** for photos of the flow monitor installations. This temporary program was focused on improving the characterization of local systems and is complemented by the City's sanitary flow monitoring data which characterizes a more global scale. The 2018 flow monitor locations are identified in **Figure F.6.5**.

Table 6.8: Summary of 2018 Flow Monitor Service Areas

Coupled Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Description of Service Area
Lou Romano Water Reclamation Plant Service Area			
SA01 (8S3587) ST01 (8R4234)	SA01: 82 ST01: 102	SA01: 450 ST01: 1500	The sewers are in the combined sewer system and have separated upstream service areas, but ultimately drain to combined sewers. This system is within the Prince Road combined sewer area.
SA02 (8S490) ST02 (8R8923)	SA02: 99 ST02: 7	SA02: 400 ST02: 750	The sewers are in the separated sewer system area. The storm sewer drains directly to the Grand Marias Drain and the sanitary drains to the West Grand trunk sewer. Both the trunk sewer and the Grand Marias Drain are less than 400 m south of the monitors.
SA03 (7S4052) ST03 (7R4036)	SA03: 60 ST03: 15	SA03: 450 ST03: 1050	The sewers are in the separated sewer system area. The storm sewer drains to the Grand Marias Drain and the sanitary drains to the West Grand trunk sewer. Both the trunk sewer and the Grand Marias drain are more than 1 km to the north of the monitors.
SA04 (2S3364) ST04 (2R3269)	SA04: 4 ST04: 3	SA04: 250 ST04: 300	The sewers are in the combined sewer system and have separated upstream service areas. The storm sewer pipe is separated, flows northerly, and further downstream "u-turns" southerly to outlet into the Grand Marias Drain. Downstream of the sanitary sewer monitor flow continues northerly and then westerly to the treatment plant.
SA05 (1S3294) ST05 (1R3300)	SA05: 8 ST05: 4	SA05: 250 ST05: 375	The sewers are in the combined sewer system and use dual maintenance holes. The storm sewer system is separated and flows northerly, ultimately to the Detroit River near Strabane Ave. Downstream of the sanitary sewer flow continues northerly and then westerly to the treatment plant.
SA06 (1S3580) ST06 (1R3587)	SA06: 6 ST06: 4	SA06: 250 ST06: 525	The sewers are in the combined sewer system area and have separated upstream service areas. The storm sewer system is separated and flows northerly to the Detroit River at Pillette Rd. The sanitary sewer flows northerly draining through the combined sewer system before reaching the treatment plant.
Little River Pollution Control Plant Service Area			
SA07 (6S172) ST07 (6R131)	SA07: 5 ST07: 9	SA07: 250 ST07: 750	The sewers are in the separated sewer system area. The storm sewer system flows northerly to the Detroit River at Ford Blvd. The sanitary sewer flows northerly then easterly to the treatment plant.
SA08 (6S359) ST08 (8R335)	SA08: 4 ST08: 4	SA08: 300 ST08: 375	The sewers are in the separated sewer system area. The storm sewer system flows northerly to the Detroit River from the St. Paul pump station. The sanitary flows northerly then easterly to the treatment plant.

Coupled Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Description of Service Area
SA09 (6S3097) ST09 (6R3130)	SA09: 17 ST09: 36	SA09: 300 ST09: 1500	The sewers are in the separated sewer system area. The storm sewer drains to the Blue Heron Pond. The sanitary sewer flows southerly then westerly to the treatment plant.
SA10 (7S2104) ST10 (7R1522)	SA10: 29 ST10: 33	SA10: 300 ST10: 1350	The sewers are in the separated sewer system area. The storm sewer system flows westerly to Little River at Forest Glade Dr. The sanitary sewer flows westerly then northerly to the treatment plant.

For these monitors, a total of four wet weather flow events are included in the study. Summary data for those events are presented in **Table 6.9** and **6.10** for the storm and sanitary sewers, respectively. The storm sewer data in the table includes total event runoff volume and event peak flow.

The sanitary sewer data in the table includes total volume above dry conditions from the rain-derived inflow and infiltration (RDII). In the same table, the sanitary sewer event maximum peak flow rate represents the combined effect of the RDII component and the dry-weather base flow component. Blank values in **Table 6.9** and **6.10** represent data points that were removed following a quality review of available information, where all or a large portion of flow information was missing.

Table 6.9: Summary 2018 Flow Monitor Data – Storm Sewers

Gauge No.	Event			
	5/2/2018	5/12/2018	9/20/2018	9/24/2018
	Total Event Volume, in mm			
	(Event Peak Flow, in L/s)			
ST01 (8R4234)	5.9	8.1	14.1	30.4
	(393)	(396)	(2,595)	(3,676)
ST02 (8R8923)	2.0	3.6		1.5
	(21)	(22)		(49)
ST03 (7R4036)	2.2	6.4	8.1	8.7
	(67)	(63)	(362)	(547)
ST04 (2R3269)	4.6	2.6	4.1	7.9
	(15)	(10)	(21)	(21)
ST07 (6R131)			2.4	3.8
			(144)	(110)
ST09 (6R3130)	3.3	5.6	11.7	13.6
	(185)	(472)	(915)	(858)
ST10 (7R1522)	7.8	12.4	8.6	14.1
	(512)	(525)	(734)	(1,521)

From the 2018 temporary monitoring program flow records for ST05, ST06, and ST08 were inconsistent and/or had missing information for the events identified above. Therefore, they were not included in the table.

Table 6.10: Summary 2018 Flow Monitor Data – Sanitary Sewers

Gauge No.	Event			
	5/2/2018	5/12/2018	9/20/2018	9/24/2018
	Total Event Volume, in mm (Event Peak Flow, in L/s)			
SA01 (8S3587)	0.3	0.8	1.1	3.5
	(6)	(17)	(78)	(100)
SA02 (8S490)	1.9	3.1	1.4	4.7
	(38)	(73)	(79)	(146)
SA03 (7S4052)	3.2	5.8	2.5	5.8
	(41)	(82)	(67)	(144)
SA04 (2S3364)	1	2.2		
	(2)	(4)		
SA05 (1S3294)	2.2	5.3		7.4
	(14)	(19)		(18)
SA06 (1S3580)	0.8	2.5		
	(3)	(10)		
SA07 (6S172)	1.1	4.1	5.9	11.7
	(5)	(11)	(34)	(49)
SA08 (6S359)	2.2	4.3		
	(5)	(7)		
SA09 (6S3097)	0.6	3.6	1.6	2.9
	(3)	(16)	(12)	(16)
SA10 (7S2104)	2.4	3.6	1.9	5.3
	(10)	(25)	(24)	(46)

6.4 Climate Change – Potential Impact on Precipitation

Climate change is the shift in weather patterns associated with an increase in global average temperatures. In Windsor, Environment and Climate Change Canada's trend analysis on annual maximum rainfall up to 2016 show no significant change in rainfall intensities and volume, consistent with other long-term gauges in southern Ontario. Nonetheless, intense, localized storms have been observed, resulting in widespread flooding. Though climate change shifts may not be well-defined, the Sewer Master Plan will recommend methods to make the City's drainage infrastructure more resilient to potential changes in more frequent and significant storms. Estimating potential changes in future conditions is an inexact science; however, practitioners need to incorporate both current and reliable information related to climate change predictions.

Significant research is being completed in this area of study. For the reader's benefit, a short discussion is provided below related to potential changes and increases in local precipitation patterns. Four primary sources of information were considered to help better define current and potential future local precipitation patterns. A summary of the rainfall studies and tools is provided in **Table 6.11**.

Table 6.11: Summary of Potential Climate Change Impacts on Precipitation Patterns

Source	**Summary Notes**
Windsor Essex Region Stormwater Management Standards Manual (ERCA, 2018)	• This document is a local stormwater management design manual, finalized at the end of 2018. Includes discussion about climate change, studies completed to date and recommendations to practically account for a changing climate. • Recommends a single design storm event to assess drainage infrastructure's resiliency and vulnerability. This design storm is "stress test" event, is not based on theory or return period, but meant to represent recent extreme storms. o This event has a 24-hour precipitation depth of 150 mm and a 15-minute peak rainfall intensity of 145.3 mm/hr.
Environment Canada - Short Duration Rainfall Intensity-Duration-Frequency Data for Windsor Airport (2012)	• Intensity-Duration-Frequency (IDF) statistics in the form of tables and graphs are provided by the Government of Canada, Environment Canada. The Windsor A Climate Station (6139525) is located within the Municipality of Windsor and has represented the most current Environment Canada data for the City at the time of the study (1946-2007). • A select summary of the Windsor A IDF statistics are provided below: o 1:100 year storm 24 hour volume = 107.9 mm o 1:100 year storm 15 minute peak intensity = 142.5 mm/hr
A Comparison of Future IDF Curves for Southern Ontario (Dr. Coulibaly et al, 2015)	• This study reviews the limitations and applicability of different techniques for updating IDF statistics to represent potential impacts of climate change and focused on the Windsor-Essex area. This included analyzing data using multiple methods to estimate future condition IDF statistics. Multiple climate model outputs are compared, including two global climate models and three regional climate models. • Predictions of IDF statistics for a 1:100 return period included: o 15-minute peak intensities between 183 mm/hr to 329 mm/hr o 24-hour volumes between 101 mm and 274 mm
The MTO IDF Curve Lookup System/Web Tool	• Online tool developed in coordination with the University of Waterloo and the MTO. • Provides a method to interpolate precipitation intensity-duration-frequency (IDF) statistic between Environmental Canada Stations and extrapolate predictions of future precipitation statistics. The time trend analysis was done using observations from 1960 to 2014. A linear trend was observed and extrapolated from this period to 2060. • For the Windsor Area, the year 2060 predictions are: o 1:100 year storm 24 hour volume = 144.0 mm o 1:100 year storm 15 minute peak intensity = 141.4 mm/hr

The stress test storm identified in the ERCA (2018) Manual represents a 40% increase in volume, but effectively the same intensity of rainfall (mm/hr) is as a 1:100 year Chicago Design storm. This stress test storm was assessed using the InfoWorks City-wide sewer model. It found results related to peak flooding conditions were approximately the same or sometimes less severe when compared with the 1:100 year (15-minute intensity interval) Chicago Design storm. Therefore, to represent a condition more severe than the current 1:100 year design storm and following discussion with the technical committee it was agreed for this project to represent the potential impact of climate change with a design storm that has both a 40% increase to volume and intensity. The 1:100 year 4 hour Chicago distribution design storm with 15-minute intensity intervals was adjusted by multiplying the ordinates by 1.40, with the following characteristics:

- Peak 15 minute intensity = 203 mm/hr; and,
- Total 4 hour storm volume = 114 mm.

This design storm referred to as the climate change storm for the project was used to assess conditions in the InfoWorks model.

7.0 Model Calibration

7.1 Overview

Model calibration is a procedure used to improve the ability of the software tool to represent hydrologic and hydraulic conditions better. For sewer and hydrologic model calibration, this involves the altering of input parameters representing land surfaces and sewers until a reasonable match between model estimates, and observed flows are achieved. Previous iterations of the InfoWorks ICM model were calibrated following this process, during Phase 1 of the Sewer Master Plan. This preceding calibration work focused on the storm and combined sewers' wet-weather response to rainfall events and the combined and sanitary sewers' dry-weather diurnal flow patterns. The previous efforts resulted in a good to moderate calibration match, reducing the effort for this model update.

This project's calibration focused on improving the representation of basement and surface flooding. Emphasis was placed on the sanitary sewers' wet-weather response to inflow and infiltration, under larger storm events to improve the model's representation of basement flooding conditions. To represent surface flooding conditions in the model, a two-dimensional mesh was implemented to account for overland drainage in the City. The dry-weather diurnal flow patterns developed as part of Phase 1 of the Sewer Master Plan did not need to be updated, and model calibration for these parameters were not adjusted in this study.

The first part of calibration for this study focused on the largest of recorded events, the August 28 and 29, 2017 storm event. The key parameters for calibration include depression storage/initial infiltration loss for different runoff surfaces, catchment dimension parameter and the contributing area of runoff surfaces. The calibration process was considered complete once a reasonable agreement between the observed and simulated runoff volumes and peak flows was achieved. Further, an intentional bias was included in the calibration process with a preference for model estimates of volume and peak flow to be slightly higher than observed. The preference in the calibration process was included to develop model estimates that represent conservative flooding conditions.

7.2 Calibration Events

The InfoWorks ICM model calibration for this project relied on observed flow and precipitation monitoring data, as identified in Section 6. Observed rainfall data was used to simulate the response of the sewer systems. The spatial distribution of the gauged rainfall was estimated using the Thiessen polygon approach. A sample graphic identifying the Thiessen polygon approach used for the modelling of the August 28, 2017 event is presented in **Figures F.7.1.**

A summary of the rainfall events used to calibrate modelled components of the drainage system are identified in **Table 7.1**. As the 2018 flow monitoring program focused on the storm and sanitary sewer systems, the re-calibration for the combined sewer system was completed using records compiled from Phase 1 of the Sewer Master Plan.

Table 7.1: Summary of Calibration Rainfall Events

Event	Calibration Data Sources	Rainfall Conditions
Storm and Sanitary Sewers (Minor System)		
September 24, 2018	Temporary flow monitors were installed throughout the City and the on-going sanitary flow monitoring program.	Conditions represent a moderate event similar to a 1:5 year. The event was more extreme in the west and south ends of the City, varying between a 1:10 and 1:25 year.
September 20, 2018		Intensity and volume of rain varied throughout the City. At select gauges conditions approached a milder event similar to a 1:2 year occurrence.
August 28, 2017	Temporary storm sewer flow monitors in the Pontiac and St. Paul area, the on-going sanitary flow monitoring program, and 311 reported records of basement flooding.	Conditions represent an extreme wet weather event similar to or exceeding a 1:100 storm year for volume; however, the event was most severe in the South end of the City.
Combined Sewers (Minor System)		
September 10, 2014	Temporary flow monitors were installed throughout the City and the on-going sanitary program collected data.	Intensity and volume of rain varied throughout the City. At select gauges conditions approached a milder event similar to a 1:2 year occurrence.
August 11, 2014		Intensity and volume of rain varied throughout the City. The intensity of the rainfall was similar to a 1:2 year, and event total volume ranged between a 1:10 and 1:25 year.
Surface Drainage (Major System)		
August 28, 2017	Photos of surface flooding and input from City Staff confirming known areas of surface flooding concerns.	Same as above.
September 28, 2016		Conditions represent an extreme wet weather event similar to or exceeding a 1:50 storm year for volume. The event was generally more severe in the east end of the City.

Following the calibration process, model validation was completed. Model validation is a process that commonly follows calibration and is completed as a check or confirmation of the model's validity to represent real-life conditions. Additional precipitation and flow monitoring records are used. A summary of the rainfall events used to validate the modelled drainage system is identified in **Table 7.2**. Only the minor system was validated, as only limited data were available for the major system which was used in the model calibration process.

Table 7.2: Summary of Validation Rainfall Events

Event	Calibration Data Sources	Rainfall Conditions
Storm and Sanitary Sewers (Minor System)		
May 12, 2018 (Storm System Only)	Temporary flow monitors were installed throughout the City and the on-going sanitary flow monitoring program.	Conditions represent a very mild event, less than a 1:2 year occurrence.
May 2, 2018		
September 28,2016 (Sanitary System Only)		Conditions represent an extreme wet weather event similar to or exceeding a 1:50 storm year for volume. The event was generally more severe in the east end of the City. Flow monitor data for this event was only available for the sanitary sewer system.
August 11, 2014		Intensity and volume of rain varied throughout the City. The intensity of the rainfall was similar to a 1:2 year, and event total volume ranged between a 1:10 and 1:25 year.
Combined Sewers (Minor System)		
June 18, 2014	Temporary flow monitors were installed throughout the City and the on-going sanitary program collected data.	Intensity and volume of rain varied throughout the City. At select gauges conditions approached an event similar to a 1:2 year occurrence, less severe in other parts of the City.
August 30, 2013		Conditions represent a very mild event, generally less than a 1:2 year occurrence.

7.3 Storm Sewer – Wet Weather Calibration

7.3.1 Storm Sewer – Calibration Process

Storm sewers are generally dry during periods of little to no rain, and are designed to convey surface water runoff generated from rainfall events. Initial calibration efforts were completed for the storm sewer's wet weather response during Phase 1 of the Sewer Master Plan. This calibration was focused on the sewer system only, as a major system (surface drainage) component was not modelled. These initial efforts reduced the time and calibration iterations required during Phase 2.

As identified in Section 5, model development for Phase 2 included expanding the representation of the City's storm sewer network in the upstream direction. Corresponding subcatchments draining to the expanded storm sewer network were re-delineated (i.e., discretized into new smaller subcatchments) and hydrologic parameters including total area and dimension were recalculated. Within the sewer network, an updated number of contributing catchbasins needed to be reassigned, to represent a connection to the major system in the model.

Once the new expanded model was completed, the re-calibration process of the storm sewer system was started. This process to develop a representation of the wet weather response of the storm system is summarized below:

- **Wet-weather response** from the ground surface and building roof stormwater runoff in the sewer and surface drainage system is estimated with subcatchment model elements. The calibration procedure for these components are summarized as follows:
  - Initial model values were taken from Phase 1, wherein select expanded areas, inputs for the new subcatchments were estimated. Phase 1 work included identification and model verification of lands that do not contribute to the storm sewer.
  - All lands throughout the City with the potential to be connected or drain to the public sewer service connections were given a representation of this component.
  - The dimension, contributing area, and impervious surfaces area parameters were adjusted uniformly within gauged service areas to improve the match with observed data. As the Phase 1 storm sewer calibration was a reasonable representation the Phase 2 final calibration numbers were similar, as follows:
    - The Phase 2 storm calibration resulted in catchments with a contributing area ranging from **0** to **100 %**, with an average of **75 %**. This is the same average as Phase 1.
    - The Phase 2 storm calibration resulted in catchments with a % impervious area from **0** to **100 %**, with an average of **35 %.** This average is 1 % less than Phase 1.

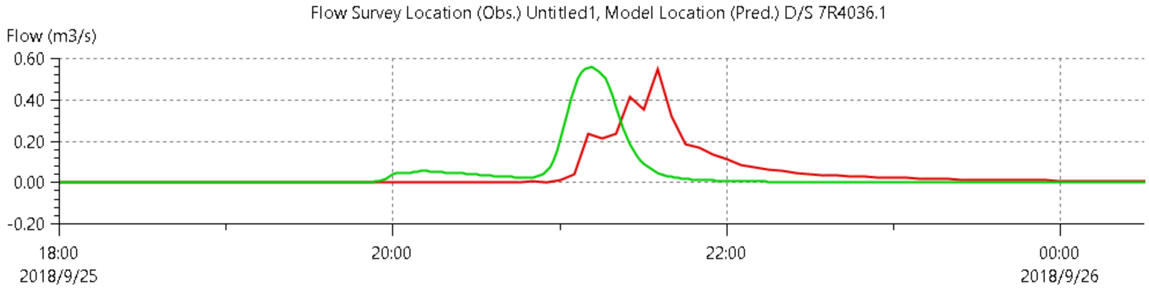
7.3.2 Storm Sewer – Calibration Results

The results of the storm sewer model calibration are presented in **Table 7.3**. Each flow monitor gauge's match with the model estimates is compared for three storm events. The table identifies the modelled match for both event maximum peak flow and total event volume. Where the quality of observed data was determined to be inadequate for model calibration, the term "Data – QA/C" is provided. The differences between the observed data and model estimates are described using the following:

- **Good –** model estimates are within 20%, above or below the observed value;
- **Moderate –** model estimates are within 34%, above or below the observed value; and,
- **Poor –** model estimate is beyond 34% of the observed value.

Examples of good, moderate and poor hydrograph matches are provided in **Figure 7.1**.

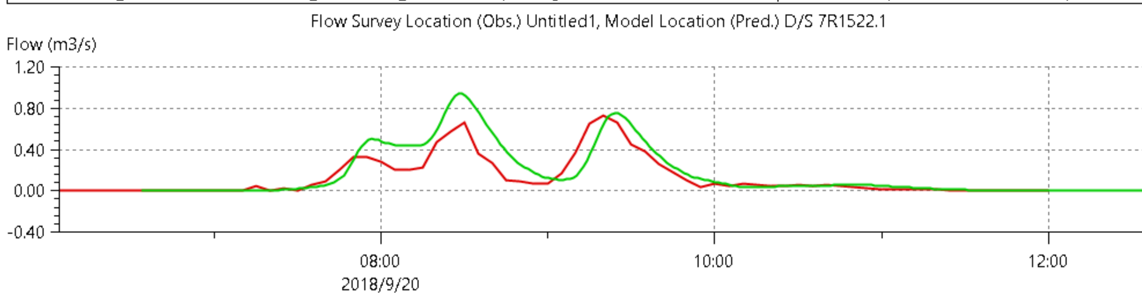
Observed / Predicted Report Produced by 32idw (2019-02-09 3:48:33 PM) Page 1 of 1
Flow survey: >Model_Results>Observed FM Data>2018 AMG Observed FM>24-Sept-2018>ST03_7R4036_24-Sep-2018 (2018-10-25 3:38:07 PM)
Sim: >Model_Results>Runs>20172018_Simulation_Events>2018 - 32 Hr - Jan 27!>24-Sept-2018 - 31 Hr (2019-02-03 6:26:00 PM)



	Flow		
	Min (m3/s)	Max (m3/s)	Volume (m3)
Observed	0.000	0.547	1125.844
...an 27!>24-Sept-2018 - 31 Hr	0.000	0.558	925.394

Good – Match both Peak Flow and Volume

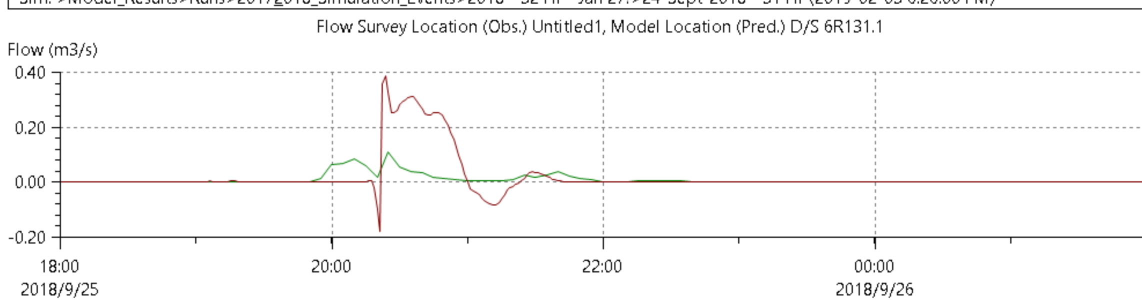
Observed / Predicted Report Produced by 32idw (2019-02-09 3:56:26 PM) Page 1 of 1
Flow survey: >Model_Results>Observed FM Data>2018 AMG Observed FM>20-Sept-2018>ST10 - 7R1522 (2018-11-12 3:44:26 PM)
Sim: >Model_Results>Runs>20172018_Simulation_Events>2013, 2014 _2018 - 24 Hr - Jan 27!>20-Sept-2018 -8 Hr (2019-01-27 8:01:37 PM)



	Flow		
	Min (m3/s)	Max (m3/s)	Volume (m3)
Observed	0.000	0.734	2808.426
...- Jan 27!>20-Sept-2018 -8 Hr	-0.000	0.941	3692.464

Moderate – Match both Peak Flow and Volume

Observed / Predicted Report Produced by 32idw (2019-02-09 4:05:08 PM) Page 1 of 1
Flow survey: >Model_Results>Observed FM Data>2018 AMG Observed FM>24-Sept-2018>ST07_6R131_24-Sep-2018 (2018-10-25 4:07:41 PM)
Sim: >Model_Results>Runs>20172018_Simulation_Events>2018 - 32 Hr - Jan 27!>24-Sept-2018 - 31 Hr (2019-02-03 6:26:00 PM)



	Flow		
	Min (m3/s)	Max (m3/s)	Volume (m3)
Observed	0.000	0.110	250.422
...an 27!>24-Sept-2018 - 31 Hr	-0.181	0.386	496.239

Poor – Match both Peak Flow and Volume

Figure 7.1: Example Hydrograph Calibtration Matchs

Table 7.3: Storm Sewer Wet-Weather Calibration Summary Results

Gauge	Event			
	September 24, 2018		September 20, 2018	
	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match
ST01 (8R4234)	Good	Moderate	Good	Moderate
ST02 (8R8923)	Poor	Poor	Data - QA/C	
ST03 (7R4036)	Good	Good	Good	Good
ST04 (2R3269)	Good	Poor	Poor	Poor
ST07 (6R131)	Poor	Poor	Poor	Poor
ST09 (6R3130)	Good	Good	Good	Good
ST10 (7R1522)	Good	Good	Moderate	Moderate

Gauge	Event	
	August 28, 2017	
	Volume Match	Volume Match
FM 01 (6R1022)	Good	Moderate
N_FM 02 (6R3847)	Moderate	Moderate
FM 03 (6R3899)	Poor	Moderate
FM 04 (6R4191)	Moderate	Poor
FM 05 (6R865)	Moderate	Poor
N_FM 06 (6R424)	Poor	Poor
FM 07 (6R914)	Moderate	Moderate

From the 2018 temporary monitoring program flow records for ST05, ST06, and ST08 were inconsistent and/or had missing information for the events identified above. Therefore, they were not included in the table.

For the September 24, 2018 event the volume match between the observed and modelled estimates was generally good. The September 24 peak flow matches were varied with an overall average of moderate. For the September 20, 2018 event, the volume match between the observed and modelled estimates was varied with an overall average of good to moderate. Further, the September 20 peak flow matches were varied with an overall average of moderate. The August 28 matches were varied with an overall average of moderate to poor.

Flow monitor ST07 (6R131) had consistently poor matches for the September 20 and 24 events. The normalize runoff volume from this gauge had significantly lower values than all other gauges, refer to **Table 6.9**. The poor match may be a function of an overestimated service area size or poor flow monitoring records. The quality control process of the flow monitor records included the removal of very small runoff volume values, less than 2 mm. The volumes from ST07 were small (2 to 4 mm), but could not be solely removed as the low values may have been possible.

From a review of the calibration results, the storm sewer model estimates were found to be a moderate to good representation of observed conditions.

Further, to confirm the reasonability of the model to represent conditions in the storm sewer, a validation process was completed. The results of the validation are presented in **Table 7.4**. The validation considers two sets of data, observations from the 2018 program and the 2014 program. Flow monitoring records from 2014 were used as additional verification that previous model calibration work for the storm sewer system was still correctly accounted for in the model.

Table 7.4: Storm Sewer Wet-Weather Validation Summary Results

Gauge	Event			
	May 12, 2018		May 2, 2018	
	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match
ST01 (8R4234)	Poor	Poor	Good	Good
ST02 (8R8923)	Poor	Poor	Good	Poor
ST03 (7R4036)	Poor	Poor	Moderate	Good
ST04 (2R3269)	Poor	Good	Moderate	Good
ST09 (6R3130)	Poor	Poor	Moderate	Good
ST10 (7R1522)	Moderate	Moderate	Moderate	Poor

Gauge	Event	
	August 11, 2014	
	Volume Match	Peak Flow Match
ST400 (3R203)	Good	Moderate
ST500 (1R3587)	Poor	Poor
ST701 (7R1218)	Poor	Moderate
ST901 (7R1331)	Good	Good
ST1001 (1R3272)	Moderate	Poor
ST1101 (6R949)	Poor	Good
ST1301 (6R3889)	Poor	Moderate
ST1500 (7R9848)	Moderate	Poor
ST1601 (8R608)	Poor	Good

For the 2018 validation observed flow records for ST07 were also inconsistent and/or had missing information for the events considered. Therefore, they were not included in the validation assessment.

The model validation results identify that the May 12, 2018 event predictions generally had poor to moderate matches with observed data. The precipitation records from this event characterize this storm as a mild event less than a 1:2 year occurrence. The May 2, 2018 and August 11, 2014 model estimates both had varied matches with an overall average of good to moderate with observed data. These two storm events had intensities similar to a 1:2 year occurrence, with August 11, 2014 having intensities greater than a 1:2 year and May 2, 2018 have intensities less than a 1:2 year, and both had variable event total volumes up to a 1:25 year occurrence.

From a review of both calibration and validation matches, the model storm sewer estimates were found to have a good to moderate representation for storm events similar to or more intense than the 1:2 year occurrence. Mild storms less than the 1:2 year occurrence were found to have moderate to poor matches with observed data. The model is considered a reasonable representation for storm events equal to or greater than the 1:2 year storm event.

7.4 Sanitary Sewer – Wet Weather (RDII) Calibration

7.4.1 Sanitary Sewer – Calibration Process

During rainfall events separated sanitary sewers convey both a dry-weather diurnal wastewater component and rainfall derived inflow and infiltration. The dry-weather diurnal wastewater component consists of domestic sewage and groundwater infiltration that would occur under dry conditions. This domestic flow component was calibrated in Phase 1 of the Sewer Master Plan. As the domestic flow component had a good calibration, the same input parameters were used in this study.

To develop a representation of rainfall derived inflow and infiltration, three major sources were accounted for in the model, as follows:

- Direct Inflow – modelled using two components, through subcatchments connected directly to the sanitary sewer and through surface water entering via sanitary maintenance hole covers.
    - Inflow - Subcatchments – These model elements were included to represent stormwater flows through direct connections including roof rainwater downspouts, basement foundation drains, surface drains (window wells, catch basins, broken cleanout caps, etc.) and improper plumbing connections. The model development procedure for these components are summarized as follows:
        - To model these more instantaneous and higher peak flow response, subcatchment parameters similar to weather-wet subcatchments were used.
        - All lands throughout the City with sanitary sewer service connections were given a representation of this component.
        - Prior to calibration, the initial model parameters for these catchments were taken from Phase 1 of the Sewer Master Plan. Updated parameters that were adjusted prior to calibration, as part of the model expansion included total area and dimension.
        - The dimension parameter, which has a significant impact on peak flow value and hydrograph shape, was calculated the same way as wet-weather catchments.
            - This value was in select service areas uniformly changed by up to a factor of 2, either increasing or decreasing to better match observed data.
        - The final calibration resulted in catchments with a 0 to 10.0 % contributing area. The average for catchments with non-zero values was 2.2 %.
    - Inflow - Surface Water through Maintenance Holes – These model elements were included to represent stormwater flows entering directly through sanitary sewer

maintenance hole cover pick holes in the public right-of-way. The model development procedure for this component is summarized as follows:

    - To model this flow response, hydraulic elements representing public sanitary sewer maintenance hole cover pick holes were connected to the overland drainage system, where excess storm sewer water ponding on the ground may enter the sanitary system.
    - All sanitary sewer maintenance hole covers throughout the City were accounted for as a potential inflow source except for the covers identified as sealed.
    - The inflow and outflow relationship (outflow occurs under sewer surcharge condition) was developed using the orifice equation, assuming two pick holes per cover.
    - Direct calibration for these model elements was not completed. Estimates of this inflow type are a function of surface water ponding from the storm and combined sewer systems.

- Infiltration – modelled using subcatchments connected directly to the sanitary sewer.
  - Infiltration - Subcatchments – These model elements were included to represent a relatively delayed, longer duration flow pattern. Sources of rain-derived infiltration include groundwater that enters the sanitary sewage system through cracks or leaks in sewer pipes, including public and private infrastructure and flow from foundation drains. Cracks or leaks may be caused by age-related infrastructure deterioration, loose joints, improper installation, damage and root penetration. The model development procedure for this flow contribution is summarized as follows:
    - Sources of infiltration have a higher potential in older areas, including foundation drains connected to the sanitary system and both public and private leaky pipes. Catchments were used to model this contribution; however, the approach to represent this differed from that used for the direct sanitary sewer inflow and wet-weather for the storm and combined sewer systems.
    - Prior to calibration, the initial contributing area for infiltration catchments was estimated using the building surface area of residential structures with a construction date from 1980 or earlier. This estimate is based on the assumption that 1980 is the approximate date foundation drain connections switched from the sanitary sewer to the storm sewer system.
    - A relatively high initial abstraction of 18 mm was applied to these catchments to account for soil holding capacity absorbing the first part of a rain event before infiltration contributes to the sanitary sewer.
    - Prior to calibration, the dimension parameter, which has a significant impact on hydrograph shape, was reduced by a factor of 5 to extend the initial flow duration and reduce the peak rate.
    - To calibrate the infiltration catchments, the dimension parameter values and contributing area were adjusted uniformly within each gauged service area to

improve the match with observed data. The final calibration resulted in catchments with a 0 to 70 % contributing area. The average for catchments with non-zero values was 10.7 %.

Refer to **Figure 7.2** for a schematic of the elements considered in the sanitary sewer wet weather flow modelling. The calibration process was first completed using the gauges with the largest service area, the sub-service areas within the larger areas were then calibrated. Calibration started first with the most extreme storm event, the August 28, 2017 event, where model parameters were adjusted later for the less extreme events. A preference was given to obtaining a good calibration match for the August 28, 2017 event, where if smaller events required calibration changes that would worsen the match for August 28, 2017, then no further changes were made.

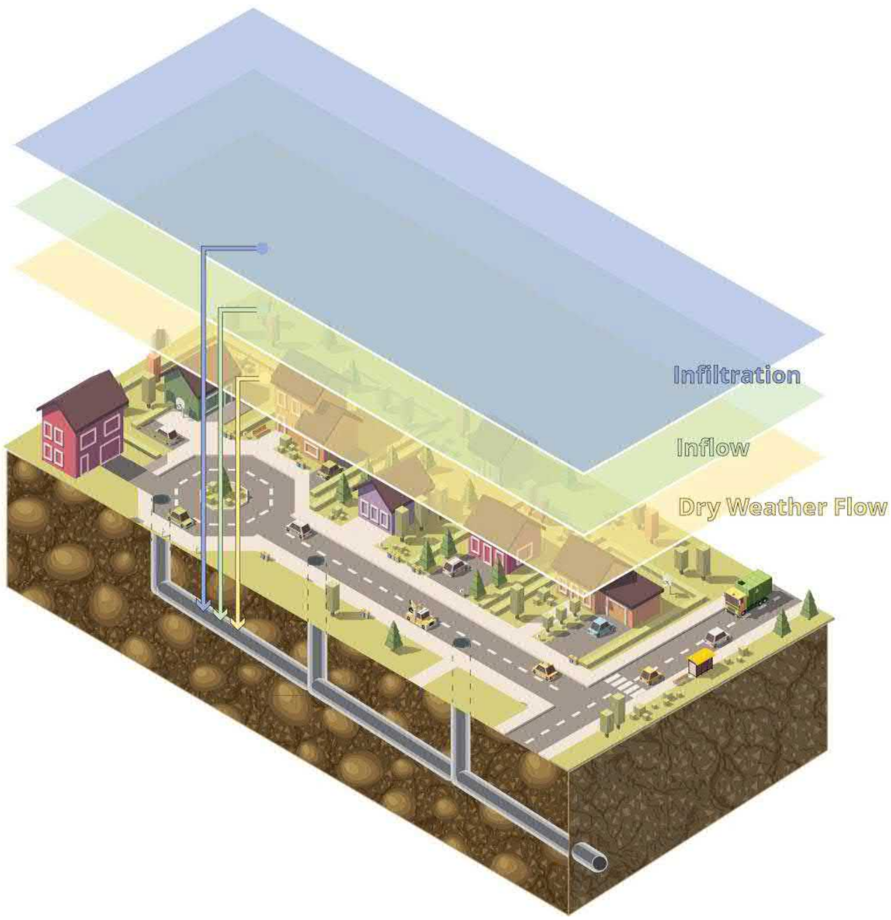


Figure 7.2: Sanitary Sewer – Inflow Model Representation

7.4.2 Sanitary Sewer – Calibration Results

The results of the sanitary sewer model calibration are presented in **Table 7.5**. For three storm events, each flow monitors' observed data is compared with the model estimates. The table identifies the match for both the event maximum peak flow and total event volume. The same terminology used to define the storm sewer calibration is used for the sanitary sewer.

Table 7.5: Sanitary Sewer Wet-Weather Calibration Summary Results

Gauge	Event					
	September 24, 2018		September 20, 2018		August 28, 2017	
	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match
1S3342	Data - QA/C		Data - QA/C		Good	Moderate
5S728	Good	Poor	Poor	Poor	Poor	Moderate
6S2037	Data - QA/C		Data - QA/C		Good	Good
6S2249	Poor	Moderate	Poor	Good	Data - QA/C	
6S3033	Moderate	Moderate	Poor	Good	Good	Good
6S3841	Data - QA/C		Data - QA/C		Good	Moderate
6S875	Poor	Moderate	Poor	Poor	Data - QA/C	
7S5641	Data - QA/C		Data - QA/C		Good	Poor
8S1309	Good	Poor	Poor	Good	Good	Good
8S1838	Data - QA/C		Moderate	Moderate	Good	Good
8S2133	Data - QA/C		Data - QA/C		Good	Good
SA01 (8S3587)	Poor	Poor	Poor	Moderate	Data - N/A	
SA02 (8S490)	Good	Good	Poor	Poor	Data - N/A	
SA03 (7S4052)	Good	Moderate	Poor	Poor	Data - N/A	
SA05 (1S3294)	Good	Poor	Data - QA/C		Data - N/A	
SA07 (6S712)	Moderate	Moderate	Moderate	Poor	Data - N/A	
SA09 (6S3097)	Poor	Moderate	Good	Poor	Data - N/A	
SA10 (7R1522)	Good	Poor	Poor	Poor	Data - N/A	

From the 2018 temporary monitoring program, records for SA04, SA06, and SA08 were inconsistent and/or had missing information for the events identified above. Therefore, they were not included in the table. From the on-going sanitary sewer monitoring the gauge at 1S3342 also had inconsistent and/or had missing information, and was accordingly not included.

Calibration for the August 28 and 29, 2017 event was good for most gauges, except for 5S728 and 7S5641. Calibration results for the September 24, 2018 event were good to moderate, and results for the September 20, 2018 event were moderate to poor. These overall calibration results were intended to develop a model that better represents larger or more intense rainfall conditions with the mildest storm, September 20, 2018, having the weakest match of the three events.

As identified in **Table 7.1**, based on precipitation records, the August 28, 2017 event represents extreme conditions (similar or greater to a 1:100 year return), the September 24, 2018 event represents moderate storm event conditions (similar or greater to a 1:5 year return). The September 20, 2018 event represents mild conditions (less than a 1:2 year return). The calibration process was focused to achieving a strong match for extreme conditions and a reasonable match with moderate storm events.

Once this was achieved, there was less concern for mild events which generally cause limited to no flooding. Alternatively put, the model's sanitary sewer systems were preferentially calibrated to represent conditions ranging between a 1:5 year event to beyond a 1:100 year event (August 28, 2017).

For the August 28, 2017 event, the calibration results for 5S728 had a strong hydrograph shape match between observed and modelled. The peak flow had a moderate match and was approximately 25% greater than observed. The volume had a poor match and was approximately 45% greater than observed. This overestimate was still considered acceptable with the strong match to hydrograph shape, and is considered to be a conservative overestimate of conditions at the gauge.

For the August 28, 2017 event, the calibration results for 7S5641 were poor for peak flow and good for volume. There is a poor match for peak flow which may be related to limited or missing data (limited precipitation records in the southeastern part of Windsor, or more likely error with the flow monitor, etc.). For approximately half of an hour the observed hydrograph has a vertical jump from approximately 1.6 m^3/s to 3.3 m^3/s, following this jump a vertical fall occurs to 1.4 m^3/s, with the remainder of the observed hydrograph having more smooth transitions, generally anticipated inflow monitoring data. Further, this flow monitor did not provide a response to the second half of the storm peaking around 4 pm on August 29, 2017. This second peak was not considered in the calibration. The best effort was made to calibrate with the available information and the hydrograph trends between observed and modelled match well, with the exception of the above.

In addition to using the flow monitoring data to calibrate the model results, the calibration process also considered records of observed basement flooding. Records of reported basement flooding were compared to modelled sanitary and combined sewer hydraulic grade line (HGL). It was assumed basements are approximately 1.5 to 2.0 metres below ground elevation in the right-of-way; a representative value of 1.80 metres was used throughout the city. This calibration test compared reported basement flooding from the August 2017 storm event with estimated sanitary sewer HGLs 1.80 metres or deeper below ground.

A validation process was completed to confirm the reasonability of the model to represent conditions in the sanitary sewer. The results of the validation are presented in **Table 7.6**. The validation considers three sets of data, observations from the 2018 program, observations from the 2014 program, and the September 28, 2016 event records from the City's continuous sanitary monitoring program. Flow monitoring records from 2014 were used as additional verification that previous model calibration work for the storm sewer system was still correctly accounted for in the model.

Table 7.6: Sanitary Sewer Wet-Weather Validation Summary Results

Gauge	Event					
	May 2, 2018		September 28, 2016		August 11, 2014	
	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match
5S724	Data - QA/C		Good	Poor	Poor	Poor
5S728	Good	Good	Moderate	Poor	Poor	Good
6S2037	Data - QA/C		Data - QA/C		Good	Good
6S2249	Poor	Good	Data - QA/C		Poor	Poor
6S3033	Moderate	Good	Data - QA/C		Good	Good
6S3841	Data - QA/C		Data - QA/C		Data - QA/C	
6S875	Poor	Poor	Data - QA/C		Data - QA/C	
7S5641	Data - QA/C		Good	Good	Poor	Poor
8S1309	Good	Moderate	Poor	Poor	Good	Moderate
8S1838	Data - QA/C		Good	Good	Good	Good
8S2133	Data - QA/C		Data - QA/C		Good	Good
SA01 (8S3587)	Poor	Poor	Data - N/A			
SA02 (8S490)	Poor	Poor	Data - N/A			
SA03 (7S4052)	Moderate	Good	Data - N/A			
SA04 (2S3364)	Good	Poor	Data - N/A			
SA05 (1S3294)	Moderate	Good	Data - N/A			
SA06 (1S3580)	Moderate	Moderate	Data - N/A			
SA07 (6S712)	Poor	Poor	Data - N/A			
SA08 (6S359)	Poor	Poor	Data - N/A			
SA09 (6S3097)	Moderate	Moderate	Data - N/A			
SA10 (7R1522)	Poor	Moderate	Data - N/A			
S100 (8S1650)	Data - N/A				Poor	Moderate
S200 (1S3374)	Data - N/A				Good	Good
S300 (1S89)	Data - N/A				Poor	Poor

The model validation results identify that the May 2, 2018 event predictions generally had poor to moderate matches with observed data. This storm event had intensities similar to but less than a 1:2 year occurrence. The model validation result matches for August 11, 2014, were similarly varied but had a better overall average of good to moderate with observed data. The August 11 event was more intense than the May 2 and as identified in calibration better matches of model flow estimated with observed data is achieved under heavier rainfall events.

The validation results for the August 28, 2016 event had varied matches with an overall average of a moderate match with observed data. The exception for this event was gauge 8S1309, which had both a poor volume and peak flow match. The model predictions for 8S1309, for the other five validation and calibration events, had a least one good match with volume or peak flow. This outlier at 8S1309 may be caused by incorrect data from the flow monitor or from the rainfall records; or alternatively from other real phenomena not accounted for in the model (i.e., the effect of basement storage of sanitary surcharge). This outlier with a poor match had higher model estimates than observed data, which is preferred.

From a review of both calibration and validation matches, the model sanitary sewer estimates were found to have a good to moderate representation for storm events similar to or more intense than the 1:2 year occurrence. Mild storms less than the 1:2 year occurrence were found to have moderate to poor matches with observed data. The model is considered a reasonable representation for storm events equal to or greater than the 1:2 year storm event.

7.5 Combined Sewer – Wet Weather Calibration

7.5.1 Combined Sewer – Calibration Process

Combined sewers may be relatively dry during periods of little to no rain, or they may convey domestic wastewater dry-weather flow. Combined sewers are intended to convey both surface water runoff generated from rainfall events and domestic waste flow. Similar to the storm sewers, initial calibration efforts were completed for the combined sewer's wet weather response during Phase 1 of the Sewer Master Plan. A major system (surface drainage) component was not modelled at that time. These initial efforts reduced the time and calibration iterations required during Phase 2. However, calibrating the combined sewer system is more complex than the storm sewer system with many overflow structures diverting flow and impacting hydraulics.

The representation of wet weather response in the combined system has more model elements than the storm sewer. For example, a combined sewer may have half the service area separated and the other half contributing stormwater directly; this would result in a large peak flow hump during the storm with an extended delay following the event. The most dominate component influencing flow conditions is generally the stormwater directly connected to the sewer. Therefore, calibration was focused solely on modifying wet-weather catchments using the same process as identified for storm sewers.

As the Phase 1 combined sewer calibration was a reasonable representation, the Phase 2 final calibration numbers were similar, as follows:

- The Phase 2 calibration resulted in catchments with a contributing area ranging from 0 to 100 %, with an average of 75 % for all wet-weather subcatchments. The Phase 2 average for combined wet-weather subcatchments is 85 %.
- The Phase 2 wet-weather combined sewer calibration resulted in catchments with a % impervious area from 0 to 100 %, with an average of 45 %.

7.5.2 Combined Sewer – Calibration Results

Phase 2 of the Sewer Master Plan flow monitoring program focused on understanding local sanitary sewer RDII. It did not include new local (street level) flow monitoring for the combined sewer system. Therefore, flow monitoring records from the Phase 1 study were used. The combined sewer system was calibrated using the August 11, 2014 and September 10, 2014 events. The validation check was completed with the August 30, 2013 and June 18, 2014 events.

The results of both the combined sewer model calibration and validation check are presented in **Table 7.7**. The table identifies the modelled match for both event maximum peak flow and total event volume. The same terminology as defining the storm sewer calibration is used for the combined sewer system.

Table 7.7: Combined Sewer Model Wet Weather Calibration and Validation Results

Gauge	Event							
	Calibration Events				Validation Events			
	August 11th, 2014		September 10th, 2014		August 30th, 2013		June 18th, 2014	
	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match	Volume Match	Peak Flow Match
C100 (6S311)	Data - N/A				Good	Good	Poor	Moderate
C200 (7S17)	Data - N/A				Poor	Good	Good	Moderate
C201 (7C4504)	Poor	Poor	Good	Poor	Data - N/A			
C300 (5C443)	Good	Good	Good	Good	Good	Good	Good	Good
C400 (2C375)	Poor	Good	Poor	Moderate	Good	Poor	Moderate	Poor
C500 (5C82)	Good	Poor	Moderate	Good	Moderate	Poor	Moderate	Poor
C600 (4C268)	Good	Good	Good	Good	Good	Good	Poor	Good
C700 (1C910)	Data - N/A				N/A	N/A	Good	Moderate
C701 (1C143)	Moderate	Moderate	Moderate	Moderate	Data - N/A			
C800 (4C73)	Data - N/A				Moderate	Moderate	Moderate	Moderate
C801 (4CJ559)	Moderate	Good	Good	Good	Data - N/A			
C900 (2C748)	Data - N/A				Moderate	Poor	Good	Good
C901 (2C748)	Poor	Poor	Poor	Poor	Data - N/A			
C1100 (3C77)	Moderate	Moderate	Moderate	Good	Moderate	Poor	Moderate	Poor

The model calibration results reasonably reflect the monitored flow for 8 of the 10 monitor locations for the combined sewer system. The model calibration and validation results identify that the majority of flow monitors, with the exception of C500 and C901, have a moderate to good match with observed data. The storm events range from mild events less than a 1:2 year occurrence to storm conditions similar to 1:10 year occurrence.

Discussion related to why only poor calibration for flow monitors C500 and C901 was achieved is provided below.

C500

Flow monitor station C500 is located downstream of several interceptor maintenance holes and overflow sewers where the dimensions of the structures were either taken from as built drawings or schematics provided from the City's IMS department. The model outputs for hydraulic conditions are sensitive to overflow weir, sluice gate and/or overflow sewer parameters, and this is likely the reason for the difference between the monitoring and modelling result. The poor match with peak flows may be a result of the Caron Avenue Pumping Station upstream of the flow monitor which cycles continuously pumping flow into the interceptor sewer along Riverside Drive carrying flows to the LRWRP. It should be noted that while the calibration to the peak flow rate was poor, the total flow volumes were reasonable compared to the observed data.

C901 and C900

The flow monitor station was moved in July 2014 upstream of the previous location due to flow monitor failure. The C901 location captured a smaller drainage area and did not capture the flows from two overflow structures captured with the C900 flow monitor. The August 11, 2014 and September 10, 2014 storm events had poor calibration for both peak flows and volumes on events larger than the events captured at C900 for August 30, 2013, and June 18, 2014.

7.6 Major System – Calibration

Major system calibration was completed using records of observed flooding from the August 28, 2017 and September 28, 2016 storm events. These records were compiled with the help of City staff, both photos and descriptions of flooding were provided. The major areas identified and considered in the calibration are presented in **Figure F.7.2**. Photos of observed flooding provided by City staff are included in **Appendix D**.

A sample of the major system calibration results is presented below, in **Figure 7.3**. This includes a photo (above) of observed flooding at the Lauzon Parkway access to Tecumseh Mall from the September 2016 flooding event and model estimates (below) of flooding conditions at the same location.

Figure 7.3: Major System – Surface Flooding Calibration Example

The calibration process for the major system differed from the process for the sewer system calibration as exact details or numbers for surface flooding were not recorded. Areas with observed significant surface flooding were documented and compared with the model estimates of surface flooding, model parameters including percent impervious and dimension were adjusted to increase flooding potential until a reasonable representation was developed.

7.7 Outlet Boundary Conditions

Outlet boundary conditions represent the hydraulic state at locations where the model extents terminate. For example, in this project, sewers within the City are modelled and outlet to ditches, watercourses, or the Detroit River. These open bodies of water are not directly modelled and are represented with outlet boundary conditions. Using appropriate conditions to represent these open bodies of water is essential to develop valid model outputs. To hydraulically account for the outlet boundary conditions, the following approach was used:

- For relatively minor storm events both observed and design storm less than the 1:100 year occurrence:
    - A normal outlet boundary condition was applied. Under these conditions, the water level at the outlet is estimated without any additional restriction of flow, or water causing a backup.
    - This approach was selected to represent the average to low water levels expected under these less severe events.
- For major storm events including design storms equal to exceeding the 1:100 year occurrence, including the climate change stress test storm (with increased rainfall intensity and volume):
    - Constant fixed high water level conditions were used at outfalls and were taken from other existing studies and modelling exercises.
    - This approach was selected to represent conservative and high water level conditions under extreme or severe conditions.

7.8 Calibration Summary

After expanding the baseline sewer model developed for Phase 1 of the Sewer Master Plan, re-calibration was required to ensure the software tool provides a reasonable representation of sewer and surface flooding conditions. This calibration focused on the representation of basement and surface flooding with an emphasis on the sanitary sewers wet-weather response inflow and infiltration. To represent surface flooding conditions, a two-dimensional mesh was implemented to account for overland drainage systems in the City. The calibration and validation results indicate the following:

- The modelled sanitary sewer wet weather response was found to have a good to moderate match for storm events similar to or more intense than the 1:2 year occurrence, and further for the larger sanitary sewer service areas under extreme wet weather events matches were good.
- The modelled storm sewer estimates were found to have a good to moderate match for storm events similar to or more intense than the 1:2 year occurrence.
- The modelled combined sewer estimates were found to have a good to moderate match for storm events less intense than the 1:2 year up to a 1:10 year occurrence.
- Major system (surface drainage) calibration was completed using observed records of surface flooding.

The model is considered a reasonable representation in the storm, sanitary and combined sewer systems for storm events similar to or more intense than the 1:2 occurrence. Therefore, the baseline conditions model is an appropriate tool to evaluate existing flooding conditions and to develop, review and compare solutions to alleviate surface and basement flooding.

8.0 Existing Conditions Assessment

8.1 Overview

The following section outlines the existing conditions sewer and surface drainage assessment completed with the calibrated model, including the combined, partially separated and fully separated areas of the City. Once the model was completed and calibrated, it was used to estimate hydraulic conditions in the major and minor systems for selected design storm events to assess the capacity restrictions, to simulate the primary causes of basement flooding, to assess the current level of service, and to develop potential solutions to mitigate flooding. Additionally, beyond the design storm events, a stress test storm event was applied to evaluate the potential impacts of climate change on the major and minor systems.

Colour-coded figures were used to illustrate the modelled hydraulic performance of the City's sewer systems during the different design storms events.

8.1.1 Design Storms

Precipitation or rain event depth (volume), duration, and precipitation intensity (i.e. mm/hr) are related to frequency (i.e. return period of a storm event). These storm event characteristics have established frequency relationships (i.e. intensity-duration-frequency [IDF] curves); however, the rainfall distribution is not characterized in a similar relationship. Therefore, the selection of storm distribution must be made carefully and conservatively as this input affects the subcatchment hydrograph shape and the estimate of peak flow.

The Essex Region Conservation Authority (ERCA) released the Windsor/Essex Region Stormwater Management Standards Manual (December 2018) that recommended the design storm return periods and frequency distributions to be used to assess urban and rural drainage systems. The Chicago 4-hour distribution represents a high-intensity thunderstorm and is recommended as the design storm type to assess the conveyance capacity of urban systems. The selection of the design storm time step, and consequently peak rainfall intensity, has a significant impact on estimates of peak sewer HGL and surface ponding conditions.

Further, the Stormwater Management Standards Manual has recommended time steps as a function of percent impervious and consequence of flow conveyance capacity being exceeded. The City of Windsor is large and diverse encompassing significant variability. The calibrated model average contributing percent impervious was 35 % and 45 % for stormwater and combined sewer subcatchments, respectively. Under medium consequence of exceedance conditions and these average impervious percentages, a 20 and 15 minute step time would be recommended for the storm sewer area and the combined sewer area. Conservatively, to assess the sewer system's resiliency and vulnerability, the design storms for the study use a Chicago Storm distribution, with 4-hour duration and 15 minute time steps. The use of smaller time steps (5 or 10 minutes) or larger time steps (20 or 30 minutes) was not considered appropriate.

Additionally, a climate change stress test was applied to assess climate change risk across the study area for surface conveyance (overland flow) and storage infrastructure, and further to help develop a realistic level of service as discussed in the next section. The ERCA Stormwater Management Standards Manual (2018) recommends an urban stress test storm with 24-hour distribution and a peak rainfall intensity similar to the 1:100 year event. However, as discussed in Section 6.4 to represent a climate change condition more severe than the current 1:100 year design storm, a modified stress test design storm that has both a 40% increase to volume and intensity was used. Details of the design storm events used in the assessment are provided in **Table 8.1**.

Table 8.1: Summary of Design Storm Events

Design Storm Event	Duration (Hours)	Total Volume (mm)	Peak Intensity (mm/hr)
1:5 Year	4	49.5	88.4
1:25 Year	4	67.0	118.4
1:100 Year	4	81.6	144.7
Climate Change Stress Test	4	114.2	202.6

It should be recognized design storms, including the Chicago distribution design storm event are not based on actual storm events and are developed using statistics from single location (or point) rain gauges. The statistics are from past events and may or may not be representative of future conditions. Further, when using these design storm events, the observed conditions at a single point are extrapolated over a much larger area and, unlike real storms that are spatially varied, are assumed to occur uniformly.

8.1.2 Level of Service – Discussion

Minor System

The minor system was assessed using the one-dimensional sewer elements from the model comparing the depth of the sewer hydraulic grade line (HGL) to the ground surface. Typically, the depth of a residential basement from the ground surface to the bottom of the foundation is 1.80 m. The basement depth was established as the metric to compare the modelled HGL in the sanitary sewers and combined sewers identifying where basement flooding had a potential to occur. Depth of the HGL was measured at each node in the model. Nodes were the HGL was less than 1.80 m below the ground surface were considered surcharged and shown in the accompanying figures under the various design storms.

The following colour coding was used in the assessment for each design storm to evaluate the level of service for **sanitary** and **combined sewer infrastructure**:

- For the sanitary sewer, nodes in red indicate the **maximum estimated depth of the HGL is less than 1.80 m below ground**; and,
- For the combined sewer, nodes in green indicate the **maximum estimated depth of the HGL is less than 1.80 m below ground**.

Commonly separated sewer systems in Windsor consist of storm pipes significantly shallower than the sanitary system, and consequently, gravity residential service connections to the storm sewer system are uncommon. Therefore, the design consideration and colour coding used in the assessment varies from that of sanitary and combined sewers. The following colour coding was used in the assessment for each design storm to evaluate the level of service for **storm sewer infrastructure**:

- Under the **1:5 year** event nodes in blue indicate the **estimated HGL is greater than or equal to the ground elevation**;
- Under the **1:25 year** event nodes in blue indicate the **estimated HGL is greater than or equal to 0.15 m above the ground elevation**; and,
- Under the **Climate Change** and **1:100 year** events nodes in blue indicate the **estimated HGL is greater than or equal to 0.3 m above the ground elevation**.

The sanitary, storm and combined sewer nodes that are not identified in the mapping were not found to exceed the above levels of service.

The minor system assessment considers system performance and HGL at model nodes. A model node generally represents a single MH structure, with more than 90% of nodes representing one MH. However, there are exceptions, including nodes that represent ponds or underground storage, and further MH structures with overflow controls (weirs, etc.) may be represented with more than one node in the model.

Major System

Through the integration of the major system two-dimensional mesh with the sewer pipes, a single integrated network was completed. This single network's surface drainage represents overland flow routes and surface storage, where water would be conveyed to the surface when the excess flow from surcharged sanitary, combined and storm sewers, reaches the ground elevation. Surface water will then follow the topographic of the land and may end up as ponding water or re-enter the sewer pipes at another location or at the same location at a later time when the water level in the sewer pipes subside. Dynamic simulation of routing of surcharged flow conditions is provided by the model, allowing more accurate determination of their destination and understanding of surface.

The two-dimensional mesh elements were colour coded in the assessment using the following approach:

- Blue indicating surface flooding less than 0.30 m above the ground surface; this generally represents conditions under good grading condition where water remains within the road right-of-way. Under less ideal grading conditions, this could indicate spills across low-lying properties. The light blue extents identified on the maps are to scale, following the model estimates.
- Red mesh elements indicate that surface flood depth is greater than 0.3 m; this generally represents the condition where water may go beyond the road right-of-way, even under ideal grading. The light blue extents identified on the maps are slightly exaggerated beyond the scale from the model estimates to improve visibility for the reader.

Under either of the conditions identified above, there is potential for flows to enter the sanitary system with water over-topping sanitary maintenance holes in the model. Further, in certain cases based on local topography, but not accounted for in the model, these flow conditions could result in water entering basements through window wells, wall cracks, etc.

8.2 Assessment

8.2.1 1:5 Year Design Storm Assessment

The City-wide model results for the sanitary and combined sewer under the 1:5 year design storm event conditions are presented in **Figure F.8.1.** The figure identifies a significant number of the combined sewer model nodes have an estimated maximum HGL higher than 1.80 m below ground. The majority of the combined sewer nodes were found to be above these criteria for the 1:5 year storm event.

In the separated sewer areas, there are large clusters of sanitary sewer nodes with HGLs less than 1.80 m below ground found in the western and central area of Riverside and Fontianbleu east of Pillette Road. Further, there were smaller clusters identified within the model; a pocket in central Forest Glade and Parkwood Ave and Woodlawn Ave, south of E.C. Row.

The City-wide model results for the storm sewer under the 1:5 year design storm event conditions are presented in **Figure F.8.2.** The vast majority of the modelled storm nodes were found to have estimated maximum HGL elevations below the ground elevation. However, there were clusters of nodes where the maximum HGL exceeded ground elevation, spread throughout the City, some of the major clusters include:

- The Riverside area;
- A pocket in the center of the East Riverside area;
- The Fontainebleau area east of Pillette Road; and,
- Southwood Lakes area.

Summary statistics for the existing condition sewer performance estimates are provided in **Table 8.2**. The table identifies for each sewer system type the total number of nodes included in the model and the percent of nodes that exceed the HGL criteria for the 1:5 year design storm event.

Table 8.2: Summary of Sewer Performance under 1:5 Year Design Storm

System Type	Total Number of Model Nodes	Percent of Nodes with HGL above Criteria	System-wide Average Depth of HGL below Ground
Storm	8800	14.0%	1.72 m
Sanitary	7647	16.3%	3.28 m
Combined	2952	56.5%	1.51 m

Further, it should be noted some shallow sanitary and combined sewers in the model are less than 1.80 m below ground. Therefore, they will always exceed the threshold and be included in the percent of nodes with HGL above criteria. In the model, there are approximately 350 sanitary nodes and 130 combined nodes. If these low lying nodes were removed from the assessment above the percentages for sanitary and combined nodes would be reduced to 12.3% and 54.5%.

8.2.2 1:25 Year Design Storm Event

The City-wide model results for the sanitary and combined sewer under the 1:25 year design storm event conditions are presented in **Figure F.8.3.** The figure identifies a significant number of the combined sewer model nodes have an estimated maximum HGL higher than 1.80 m below ground. Under the 1:25 year storm event conditions, even more prevalent than the model results from the 1:5 year event, the majority of the combined sewer nodes were found to have an estimated maximum HGL higher than 1.80 m below ground.

In the separated sewer areas, sanitary sewer nodes with maximum HGLs less than 1.80 m below ground were generally found throughout the City. Areas with sanitary sewer nodes with maximum modelled HGLs more than 1.80 m below ground include:

- The south-west corner of East Riverside;
- The northwestern portion of Forest Glade and lands further east;
- Large pockets in the Devonshire and Remington Park areas; and,
- Lands south of Cabana Rd, generally west of Roseland Golf Course.

The City-wide model results for the storm sewer under the 1:25 year design storm event conditions are presented in **Figure F.8.4.** The majority of the modelled storm nodes were found to have estimated maximum HGL elevations less than 0.15 m above ground elevation. However, there were small clusters with higher elevations above ground spread throughout the City. Larger clusters of nodes where the maximum HGL exceeded 0.15 m above the ground elevation, included:

- The Riverside area;

- A pocket in the center of the East Riverside area;
- The Fountainbleu area generally north of Grand Blvd;
- The western portion of the Remington Park area; and,
- Southwood Lakes developments in the Roseland area.

Summary statistics for the existing condition sewer performance estimates are provided in **Table 8.3**. The table identifies for each sewer system type the total number of nodes included in the model and the percent of nodes where performance indicates a flood risk and that exceed the HGL criteria for the 1:25 year design storm event.

Table 8.3: Summary of Sewer Performance under 1:25 Year Design Storm

System Type	Total Number of Model Nodes	Percent of Nodes with HGL above Criteria	System-wide Average Depth of HGL below Ground
Storm	8800	6.1%	1.27 m
Sanitary	7647	49.6%	1.85 m
Combined	2952	70.3%	1.01 m

Some shallow sanitary and combined sewers in the model are less than 1.80 m below ground. Therefore, they will always exceed the threshold and be included in the percent of nodes with HGL above criteria. In the model, there are approximately 350 sanitary nodes and 130 combined nodes with this characteristic. If these low lying nodes were removed from the assessment above the percentages for sanitary and combined nodes would be reduced to 47.2% and 68.9%.

8.2.3 1:100 Year Design Storm Event

The City-wide model results for the sanitary and combined sewer under the 1:100 year design storm event conditions are presented in **Figure F.8.5.** The figure identifies a significant number of the combined sewer model nodes have an estimated maximum HGL higher than 1.80 m below ground. Under the 1:100 year storm event conditions, approximately 85% of combined sewer nodes were found to have an estimated maximum HGL higher than 1.80 m below ground.

In the separated sewer areas, sanitary sewer nodes with maximum HGLs less than 1.80 m below ground were found throughout the City. Similar to the combined sewer nodes but less severe, approximately 75% of sanitary sewer nodes were found to have an estimated maximum HGL higher than 1.80 m below ground.

The City-wide model results for the storm sewer under the 1:100 year design storm event conditions are presented in **Figure F.8.6.** The majority of the modelled storm nodes were found to have estimated maximum HGL elevations below 0.30 m above ground elevation. However, there were small clusters spread throughout the City where HGL was more than 0.30 m above ground. Larger clusters of nodes where the maximum HGL exceeded 0.30 m above the ground elevation, included:

- The Riverside area;
- The Fontainebleau area;
- The western portion of the Remington Park area; and,
- Southwood Lakes developments in the Roseland area.

Summary statistics for the existing condition sewer performance estimates are provided in **Table 8.4**. The table identifies for each sewer system type the total number of nodes included in the model and the percent of nodes that excide the HGL criteria for the 1:100 year design storm event. The system-wide average depth for the sanitary sewer system indicates under peak or maximum conditions the majority of sanitary sewer nodes within the model have an average HGL of 0.69 m below ground. The model was calibrated to match conditions similar to extreme storm event; however, the effect of storage from flood basements is not accounted for in the simulations which would lower the actual potential for surcharge in some locations. This results in the model estimate higher sanitary sewer HGL than would occur under real or actual conditions.

Table 8.4: Summary of Sewer Performance under 1:100 Year Design Storm

System Type	Total Number of Model Nodes	Percent of Nodes with HGL above Criteria	System-wide Average Depth of HGL below Ground
Storm	8800	13.1%	0.63 m
Sanitary	7643	75.0%	0.69 m
Combined	2952	84.8%	0.44 m

Some shallow sanitary and combined sewers in the model are less than 1.80 m below ground. Therefore, any will always exceed the threshold and be included in the percent of nodes with HGL above criteria. In the model, there are approximately 350 sanitary nodes and 130 combined nodes. If these low lying nodes were removed from the assessment above the percentages for sanitary and combined nodes would be reduced to 73.8% and 84.1%.

The model estimated maximum surface flooding extents and depths for the 1:100 year are provided in **Figure F.8.7**. Much of the surface flooding is less than 0.30 m above ground on the two-dimensional mesh and generally follows the road right-of-way. Ponding depths greater 0.30 m above ground identify that flows are anticipated to go beyond the right-of-way, even under ideal grading conditions. Some of the surface floodings identified above 0.30 m (red) are ponding in swales or drains. A summary of the maximum surface flooding in the two-dimensional mesh is provided below:

- Approximately 709 ha of surface area was estimated to have surface flooding between 0.01 m and less than 0.30 m; and,
- Approximately 32 ha of surface area was estimated to have surface flooding depths greater than or equal to 0.30 m.

The model results from the two-dimensional surface mesh should only be considered surface flooding caused by conveyance restrictions. In the model, surface flooding on the two-dimensional mesh is by conditions with a model node HGL (representing catch basins or maintenance hole lids) equal to or greater than the HGL of ponding water on the ground surface. The HGL in the sewer and on the surface are interdependent, but do not have to be the same during simulations, and are infrequently the same. When the HGL in the sewer is higher than the ground, water will be conveyed to the ground at a rate defined by the inlet-capacity curves. As the surface storage on the ground allows surcharged water from the sewer to spread, generally during the peak of the storm, the ground HGL will be less than the HGL in the sewer.

8.2.4 Stress Test Design Storm

The City-wide model results for the sanitary and combined sewer under the stress test design storm event conditions are presented in **Figure F.8.8.** The figure identifies a significant number of the combined sewer model nodes have an estimated maximum HGL higher than 1.80 m below ground. Under the climate change stress test design storm event conditions, the vast majority (over 90%) of the combined sewer nodes were found to have an estimated maximum HGL higher than 1.80 m below ground.

In the separated sewer areas, sanitary sewer nodes with maximum HGLs less than 1.80 m below ground were found throughout the City. Nearly 93% of sanitary sewer nodes were found to have an estimated maximum HGL higher than 1.80 m below ground.

The City-wide model results for the storm sewer under the climate change stress test design storm event conditions are presented in **Figure F.8.9.** The majority of the modelled storm nodes were found to have estimated maximum HGL elevations below 0.30 m above ground elevation. However, there were small clusters for each sewer system type the total number of nodes included in the model and the percent of nodes that excide the HGL criteria for the stress test design storm event. The negative system-wide average depth for the sanitary sewer system indicates under peak or maximum conditions the majority of sanitary sewer nodes within the mode have an HGL above ground, with an average of 0.65 m above ground. The spread throughout the City. Larger clusters of nodes where the maximum HGL exceeded 0.30 m above the ground elevation, including:

- The Riverside area;
- The Fontainebleau area;
- The western portion of the Remington Park area; and,
- Southwood Lakes development in the Roseland area.

Summary statistics for the existing condition sewer performance estimates are provided in **Table 8.5**. The table identifies model was calibrated to match conditions similar to an extreme storm event; however, the effect of storage within flooded basements that can moderate extreme surcharge is not accounted for in the simulations. This results in the model estimating higher sanitary sewer HGL than would occur under real or actual conditions.

Table 8.5: Summary of Sewer Performance under the Climate Change Stress Test Design Storm

System Type	Total Number of Model Nodes	Percent of Nodes with HGL above Criteria	System-wide Average Depth of HGL below Ground
Storm	8800	31.0%	0.19 m
Sanitary	7643	92.6%	(-)0.65 m
Combined	2952	90.7%	(-)0.09 m

Some shallow sanitary and combined sewers in the model are less than 1.80 m below ground. Therefore, any will always exceed the threshold and be included in the percent of nodes with HGL above criteria. In the model, there are approximately 350 sanitary nodes and 130 combined nodes. If these low lying nodes were removed from the assessment above the percentages, sanitary and combined nodes would be reduced to 92.3% and 90.3%.

The model estimated maximum surface flooding extents and depths for the climate change stress test design event are provided in **Figure F.8.10**. Much of the surface flooding is less than 0.30 m above ground on the two-dimensional mesh and generally follows the road right-of-way. Ponding depths greater 0.30 m above ground identify that flows are anticipated to go beyond the right-of-way, even under ideal grading conditions. Some of the surface floodings identified above 0.30 m (red) is ponding in swales or drains. A summary of the maximum surface flooding in the two-dimension mesh are provided below:

- Approximately 1206 ha of surface area was estimated to have surface flooding between 0.01 m and less than 0.30 m; and,
- Approximately 105 ha of surface area was estimated to have surface flooding depths greater than or equal to 0.30 m.

8.2.5 Design Storm Assessment – Summary

The modelled storm sewer system results identify relative good performance (hydraulic conveyance capacity) when compared to the sanitary and combined sewer systems. The comparison may not be equal as the storm sewer HGL criteria is anywhere from 1.80 to 2.10 m higher than the other two systems. This difference in the criteria is based on the assumption that properties do not have gravity service connections from foundation drains to the storm sewer. In the absence of this flow connection, high HGL conditions in the storm sewer won't cause backwater flowing through service connections into basements. Foundations may discharge to the storm sewer via non-gravity connections such as sump pumps that may prevent back-up into the property. The model results identified between the 1:5 year and the 1:100 return period design storms between 6% and 14% of the storm sewer system exceed the HGL performance criteria, and 31% exceeds the criteria under the climate change stress test.

The sanitary sewer system performance was found to be the most sensitive to increases in design storm rainfall intensities and volumes. The model results identified between the 1:5 year and climate change stress test design storms between 16% and 93% of the sanitary sewer system exceeds the HGL performance criteria.

The combined sewer system was found to have the worst performance relative to HGL criteria of the three sewer systems under both the 1:5 and 1:25 year design storm events. Under the 1:100 year storm event, the combined sewer system had a similar overall performance as the sanitary sewer and had slightly better results under the climate change stress test storm event. The model results identified under the 1:5 year to climate change stress test storms between 57% and 91% of the combined sewer system exceeds the HGL performance criteria. These results are likely a function of overflow elevations and pump stations restricting flow in the combined sewer system.

Summary of sewer system performance for the city-wide system, under various design storm events, is presented in **Table 8.6**.

Table 8.6: Summary of Sewer Performance – Percent of Nodes with HGL above Criteria

System Type	Design Storm			
	1:5 Year	1:25 Year	1:100 Year	Stress Test
Storm	14.0%	6.1%	13.1%	31.0%
Sanitary	16.3%	49.6%	75.0%	92.6%
Combined	56.5%	70.3%	84.8%	90.7%

In general, the system performance is worse with increasing more severe and less common events; with the notable exception being the storm sewer system under the 1:5, 1:25 and 1:100 year events. It should be noted the maximum HGL criteria is different for these events, and thus the trend may appear incorrect at first. However, system-wide average maximum HGL depth below ground increases as storm severity increases, refer to **Tables 8.2** to **8.5**.

8.3 Inflow and Infiltration Characterization

During significant wet-weather events, the sanitary sewer system experiences surcharging caused by excess infiltration and inflow. Sewers experiencing surcharging can cause backflow conditions for properties with service connections; this is one of the most common causes of basement flooding. Rainfall-derived infiltration and inflow (RDII) are defined as follows:

- Infiltration consists of groundwater that enters the sanitary sewage system through cracks or leaks in sewer pipes and/or improperly connected private drains. It may occur as a result of age-related infrastructure deterioration, loose joints, improper installation or maintenance, damage or root penetration. Infiltration is characterized by a constant base flow (during normal groundwater conditions) or a relatively delayed, longer duration flow pattern during wet weather conditions.

- Inflow is stormwater flows that are directly connected to a sanitary sewer system, including roof rainwater downspouts, basement foundation drains, surface drains (window wells, catch basins, broken cleanout caps, etc.), improper plumbing connections and maintenance hole covers. Inflows are typically characterized by more instantaneous, shorter duration and higher peak flow patterns.

8.3.1 Case Studies

The flow monitoring programs completed within the City helps characterize the total volume and peak flow RDII response in the sanitary sewer system, including developing a picture of quick (inflow) and slow (infiltration) contributions. These flow records define baseline RDII conditions. When these baseline conditions are used to develop a calibrated RDII sewer hydraulic model, designers can review potential benefits from various solutions to give recommendations to residents and policymakers.

As identified above, the flow monitoring data is extremely useful to understand the macro picture of RDII, determining the micro picture of RDII the contributing sources is exceptionally complex. To fully confirm the sources and relative contribution, either extensive field exploratory works and/or rehabilitation projects with monitoring are required. The exploratory works could include dye testing programs, video recordings of sanitary sewer connections during wet weather events, running water through connections under dry conditions, and other similar intensive programs. Rehabilitation projects could include foundation disconnection programs and/or high infiltration sewer repair with pre and post construction flow monitoring to quantify the reduction in RDII.

Without these types of programs to determine the actual sources and relative contributions, a review of other municipalities RDII investigation and programs was completed to understand Windsor's current conditions better.

It should be noted the City recently completed a City-wide sewer condition zoom-camera inspection and is still finalizing the asset data updates. Further, sanitary sewer fog testing was completed City-wide and repairs to damaged cleanout caps were completed.

8.3.1.1 Case Study 1: City of Revere, Massachusetts, USA

The City of Revere, MA determined that to achieve a 1:10 year level of protection against Sanitary Sewer Overflows (SSOs), approximately 40-50 percent of extraneous flow would need to be removed from sanitary sewers, over the entire city area. This project was supported with a 15 flow monitor gauging program and a sewer model representing wet weather sanitary sewer conditions.

The initial focus was on public infrastructure. A comprehensive repair and rehabilitation of sanitary sewers was undertaken, and post-construction flow monitoring was conducted at the same location as the pre-construction flow monitors. The repairs and rehabilitation tasks in the study included lining of mainline sewer pipes, replacement of collapsed sewers, lining of service laterals, and lining and rehabilitation of maintenance holes. Flows during night-time hours were compared and are considered a representation of dry weather groundwater infiltration. The repair and relining of public infrastructure removed 22% of extraneous flow during dry weather conditions.

The City initiated a Sump Pump Amnesty Program to identify and remove sources of private inflow. In addition, changes to local ordinances were made that required property owners redirect any illicit sources of inflow away from the sanitary sewer system. A flow monitoring analysis was conducted following a multi-year private inflow removal program. Flow in the sewers during similar rain events in both observation periods (prior to- and post- private inflow removal) were compared. Results showed that removal of 258 sources of private inflow in the study area, brought a 43% reduction inflow. This study identified the goal of reducing RDII by 50% or more could not be achieved by just rehabilitation works within the public right-of-way.

Source:
https://trenchlesstechnology.com/comprehensive-rehabilitation-measuring-the-effectiveness-of-public-vs-private-i-i-removal/

8.3.1.2 Case Study 2: City of Ann Arbor, MI, USA

The City of Ann Arbor completed a Sanitary Sewer Wet Weather Evaluation Project. The project involved monitoring and evaluation of sanitary sewer flows, hydraulic and hydrologic modelling of sanitary sewers and identification of sanitary sewer deficiencies. The City of Ann Arbor implemented a Foundation Drain Disconnection (FDD) Program, starting in 2002. The current study examines the effectiveness of the FDD program in reducing RDII flows in sanitary sewers.

Five priority districts were identified where pre- and post-FDD sanitary sewer flows were compared. **Table 8.7** lists the priority districts and, shows a comparison of the percentage of foundation drains disconnected among residential units in each priority district and percentage reduction in sanitary sewer flows.

Table 8.7: Ann Arbor Study - Reduction in Sanitary compared to Foundation Drain Disconnection

Priority Districts	% Reduction Sanitary Sewer Flows		% FDD Completed in Residential Units
	Peak Flow	Volume	
Bromley	85%	67%	99.0%
Orchard Hills	77%	77%	99.0%
Dartmoor	9%	56%	89.0%
Glen Leven	17%	13%	56.0%
Morehead	53%	78%	63.0%

Up to 85% reduction in sanitary sewer peak flows and up to 77% reduction in volume was observed when comparing sanitary sewer flows before and after completion of the FDD program in the five priority districts. One of the five districts, Glen Leven's FDD program was found to be significantly less effective for unknown reasons. A comparative analysis of flow monitoring data collected during rain events with similar volumes was used, before and after the completion of the FDD program. The analysis concluded that removal of direct wet-weather inflow from connected foundation drains significantly reduced flows in the sanitary sewers.

Source:
https://www.a2gov.org/departments/systems-planning/Documents/Full%20SSWWE%20Report.pdf

8.3.1.3 Case Study 3: Metro Vancouver

The *Metro Vancouver study: Private Lateral Foundation Drains and Semi-Combined Sewers as an Inflow and Infiltration Source under the Integrated Liquid Waste and Resource Management Plan* study was undertaken to establish the importance of private lateral foundation drain connections to the sanitary sewer as a major contributor to RDII. The current standard followed by the municipalities in the region is to limit wet-weather inflow and infiltration into sanitary sewers to 11,200 L/ha/day (1.12 mm/day) during a 1:5 year, 24-hour rainfall event.

The study identifies that upwards of 80% of I&I may originate from private laterals connected to the sanitary sewer system. Past standard construction practices allowed foundation drains to be connected to the sanitary sewer, especially in areas without a storm sewer. This was identified as a major potential reason why older areas show higher I&I than newer developments.

"An assessment by the City of North Vancouver's I&I in 2012 determined that groundwater derived inflow and infiltration (GDI&I) accounted between 10% and 16% of the total estimated I&I (City of North Vancouver, 2012), ranging from 2,425 to 17,000 L/ha/day (0.24 mm/day to 1.7 mm/day). In contrast, these catchments were found to experience significant RDII, which accounted for 84% to 90% of the total I&I (City of North Vancouver, 2012, p. 24)."

The study used GIS data to identify areas which correlated with the following parameters: older houses, having high RDII and the date of construction of storm sewers in the area. Areas were identified which had a high potential of foundation drain connections. A field investigation was carried out in these high potential areas.

The study highlights areas which have "semi-combined" sewers. These are areas where sewers have been separated into sanitary and storm sewers, but a large number of houses still have foundation drains connected to the sanitary sewer. This type of connection was the Canadian construction norm till the late 1970s. These sewers have high rates of I&I and exhibit similar hydrologic characteristics as fully combined sewers. Restricting these "semi-combined" sewers I&I rate to 11,200 L/ha/day (1.12 mm/day) with just sewer rehabilitation may not be feasible, without a comprehensive foundation drain disconnection program.

Source:
http://www.metrovancouver.org/services/liquid-waste/LiquidWastePublications/InflowInfiltrationFoundationDrainCrossConnectionsReport.pdf

8.3.1.4 Case Study 4: Ontario Inflow and Infiltration in New Subdivisions

The *Project to Address Unacceptable Inflow and Infiltration in New Subdivisions: Phase 1 Final Report* was a study initiated to review excessive (or unacceptable) I&I commonly in recently constructed subdivisions in Ontario. The report did not apply quantity specific public and private sources of I&I due to variability in an Ontario-wide review. Potential sources of I&I in new development were identified.

The report did identify current potential gaps for new public sewer pipes as follows:

- Consider potential impact from stormwater infiltration systems on shallower sanitary sewers that may be installed in the same or stepped trench;
- Improve understanding of potential sewer I&I with the use of electro-scan technology, in-lieu of CCTV, to identify leaks in nonconductive pipes;
- Review the use of Fernco (or equivalent) connections between PVC sewers and concrete maintenance holes; and,
- Improve consistency with leak testing, including calculation methods and interruption.

The report identified current potential gaps for new private sewer pipes as follows:

- Glued private property pipe joints can easily snap in with little settlement, especially when compared to the performance of gasketed joints, which represents a risk to long term I&I;
- Where inspection of laterals in older systems frequently identify leaking/root intrusion at joints, the inspection and proper installation of bedding and backfill is essential; and,
- Connections of lateral sewers at the property line without leakage are essential in resolving I&I in new subdivisions. This connection occurs after the mainline sanitary sewer and lateral sewer to property line have been accepted by the municipality. Staff resourcing for active inspection during this connection is required.

Source:
https://www.nortonengineeringinc.ca/I&I%20in%20NS%20Final%20Report%202017_Oct%2016%202017.pdf

8.3.1.5 Case Study Summary

RDII is not a unique challenge faced by the City of Windsor, with many other municipalities facing similar issues. Further, the undesired extraneous flows, although more common and/or prevalent in older areas, are also experienced in new development (20 years or younger). This was found to be true in both the case studies and from a review of Windsor's flow monitoring data.

In the case studies with available data, the findings indicated the majority of RDII was generated from private lands, with a smaller portion from public sewer infrastructure. The split of private-public contributing sources generally ranged between 80%-20% to 60%-40%. This upper 80% private contribution is considered to be more representative of older areas where foundation drains discharge to the sanitary sewer system. This range between 80%-20% to 60%-40% of a private-public split applied to both peak flow rate and total volume.

The actual split of private vs public of contributions in Windsor may vary beyond these ranges.

8.3.2 Flow Monitoring Data Assessment

The flow monitoring data described in section 6 of the report was used to characterize the RDII throughout the city. A summary of the findings is presented in **Tables 8.8** and **8.9**.

In the tables below, the term peak flow factor refers to the quotient of an "RDII peak flow rate" divided by the "average dry-weather flow rate". It is an integer value where a larger factor would represent a higher potential for sewer surcharging based on a sewer flow conveyance limitation. The total volume would represent a potential for surcharging over a longer period of time and areas that contribute more volume to the treatment plants. Both total volume and peak flow factor are compared to City-wide averages.

Table 8.8: RDII Characterization Summary of 2018 Flow Monitoring Areas

Coupled Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Separated Sanitary Sewer RDII Total Volume	Separated Sanitary Sewer RDII Peak Flow Factor
Lou Romano Water Reclamation Plant Service Area				
SA01 (8S3587) ST01 (8R4234)	SA01: 82 ST01: 102	SA01: 450 ST01: 1500	Lower than average	Lower than average
SA02 (8S490) ST02 (8R8923)	SA02: 99 ST02: 7	SA02: 400 ST02: 750	Lower than average	Average
SA03 (7S4052) ST03 (7R4036)	SA03: 60 ST03: 15	SA03: 450 ST03: 1050	Higher than average	Lower than average
SA04 (2S3364) ST04 (2R3269)	SA04: 4 ST04: 3	SA04: 250 ST04: 300	Lower than average	Lower than average
SA05 (1S3294) ST05 (1R3300)	SA05: 8 ST05: 4	SA05: 250 ST05: 375	• The quality of data from this sanitary monitor was inadequate to characterize RDII response	
SA06 (1S3580) ST06 (1R3587)	SA06: 6 ST06: 4	SA06: 250 ST06: 525	Lower than average	Higher than average

Coupled Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Separated Sanitary Sewer RDII Total Volume	Separated Sanitary Sewer RDII Peak Flow Factor
Little River Wastewater Treatment Plant Service Area				
SA07 (6S172) ST07 (6R131)	SA07: 5 ST07: 9	SA07: 250 ST07: 750	Average	Higher than average
SA08 (6S359) ST08 (8R335)	SA08: 4 ST08: 4	SA08: 300 ST08: 375	Higher than average	Higher than average
SA09 (6S3097) ST09 (6R3130)	SA09: 17 ST09: 36	SA09: 300 ST09: 1500	Lower than average	Lower than average
SA10 (7S2104) ST10 (7R1522)	SA10: 29 ST10: 33	SA10: 300 ST10: 1350	Lower than average	Lower than average

Table 8.9: RDII Characterization Summary of On-Going Sanitary Sewer Flow Monitoring Areas

Coupled Flow Monitor ID (MH Installed)	Service Area (ha)	Pipe Diameter (mm)	Separated Sanitary Sewer RDII Total Volume	Separated Sanitary Sewer RDII Peak Flow Factor
Lou Romano Water Reclamation Plant Service Area				
1S3342	482	825	• Combined sewer system, not considered for RDII	
5S724	3,140	1950		
5S728	502	1050		
8S1309	2,450	1675	Lower than average	Lower than average
8S1838	4,580	1950	Average	Lower than average
8S2133	1,250	1050	Higher than average	Average
Little River Wastewater Treatment Plant Service Area				
6S2037	337*	1500	Lower than average	Lower than average
6S2249	164	900	• The service areas from these sewers overlap, where overflow; provide conditions acting as a single system • Average response for total volume • Higher than the average response for peak flow factor	
6S3033	396	675		
6S3841	984	900		
6S875	816	900		
7S5641	1,040	1200	Lower than average	Higher than average

Note: The service area for 6S2037 identified only represents the service area within the City of Windsor borders

Based on the flow monitoring data from the separated sanitary sewer systems, two summary analysis comparing RDII inflow characteristics for the City were completed. These were completed as relative comparisons to event averages between the gauged service areas for different rainfall events. These comparisons were based on normalized volume (i.e., mm of RDII per ha or just mm) and the peak flow factor. Summary RDII analysis maps are presented in **Figure F.8.11** and **F.8.12**.

8.3.3 Model Representation

As identified above, RDII is represented in the model as three components with slow-response hydrographs, quick-response hydrographs, and estimated inflow to sanitary maintenance holes within the right-of-way. The actual sources of RDII in Windsor, like other municipalities, are difficult to fully confirm without doing extensive field work and/or rehabilitation programs coupled with flow monitoring.

When assessing potential future scenarios and improvements using the current model, it is recommended the findings from the case studies above and other similar reports, be used as the basis for confirming the range to lowering or reducing the RDII contributing flow. Areas contributing higher than average RDII flows are identified in **Figure F.8.11** and **F.8.12**. They may be considered the first or prioritization areas for programs to reduce inflow (i.e., foundation drain disconnection, etc.). In all review case studies, the majority of RDII was found to originate from private property. Further, it was found that foundation drains in older areas may be the primary contributor to RDII. The model was developed to represent these conditions.

8.4 Existing Conditions Summary

A review of the existing conditions storm, sanitary and combined sewer system performance was completed. It was found that under a 1:100 year storm at least 75% of the City's sewer may create conditions where there is potential for basement flooding, where the HGL in the sanitary and combined sewer was less than 1.80 m below ground.

The modelled storm sewer system results identify relative good performance (hydraulic conveyance capacity) when compared to the sanitary and combined sewer systems. The comparison may not be equal as the storm sewer HGL criteria is anywhere from 1.80 to 2.10 m higher than the other two systems. Between the 1:5 year and the 1:100 return period, design storms between 6% and 14% of the storm sewer system exceed the HGL performance criteria, and 31% exceeds the criteria under the climate change stress test.

The sanitary sewer system performance was found to be the most sensitive to increases in design storm rainfall intensities and volumes. The model results identified between the 1:5 year and climate change stress test design storms between 16% and 93% of the sanitary sewer system exceeds the HGL performance criteria.

The combined sewer system was found to have the worst performance relative to HGL criteria of the three sewer systems under both the 1:5 and 1:25 year design storm events. Under the 1:100 year storm event, the combined sewer system had a similar overall performance as the sanitary sewer and had better results under the climate change stress test storm event. The model results identified under the 1:5 year to climate change stress test storms between 57% and 91% of the combined sewer system exceeds the HGL performance criteria. These results are likely a function of overflow elevations and pump stations restricting flow in the combined sewer system.

9.0 Summary

9.1 Overview

In the past decade, Windsor has experienced significant rainfall events with prevalent surface and basement flooding. These significant rainfall events include June 4th, 5th and 6th 2010, November 29th and 30th, 2011, August 11th 2014, September 28th, 2016 and August 28th/29th, 2017. The City received over 2200, 2800, and 6000 reports of basement flooding from the 2010, 2016 and 2017 rainfall events.

Following the City of Windsor Council resolution CR660/2017, on November 6th, 2017, the Sewer Master Plan was initiated. It will be completed in accordance with Master Plan Approach No. 2 of the Municipal Class Environmental Assessment (EA) process to satisfy the EA requirements for Schedule B projects. This Master Plan will identify specific problems and explore achievable measures to reduce the risks and impacts of flooding by identifying and evaluating the following:

- **Shorter-term** solutions that can reduce the amount of water going into the City's drainage systems, including partnering with homeowners to protect against the impacts of flooding; and,
- **Longer-term** solutions to improve the sewer systems by reducing inflow at the sources, increasing conveyance capacity and/or identifying temporary storage measures.

Further, following extreme high water level conditions in the Detroit River and Lake St. Clair in the summer of 2019, the scope of the Master Plan was expanded to include:

- Review of year high water level conditions in the Detroit River and Lake St. Clair including the potential impact of Climate Change;
- Identification and evaluation of solutions to mitigate the risks of coastal flooding;
- Development of preliminary designs and cost estimates for the recommends; and,
- Recommendation of an implementation strategy to reduce this flooding risk.

Additional details related to the coastal flooding risk assessment, solution alternatives, evaluation process, preliminary design, costings, and recommendations are provided in *Technical Report Volume II*.

This document is the first volume summarizing the technical and engineering works completed as part of the Sewer Master Plan. This report, the Sewer Master Plan – Technical Report Volume I, includes the following:

- Identification of new sewer and drainage data collected in 2018;
- Summary of data used from the *Flow Monitoring and Hydraulic Modeling of the Sewer System* report (Dillon & Aquafor, 2016);
- Process and methodology for expanding the existing City-wide sewer model including calibration; and,

- Identification of existing baseline sewer and overland drainage conditions within the City including characterization of rain-derived inflow and inflation (RDII).

9.2 Background Work, Modelling and Findings

The Master Plan study area encompasses the whole City of Windsor. A review was completed that compiled information from over 110 available background reports related to sewers and drainage conditions within the Municipality.

In Phase 1 of the Study, existing conditions were established by completing a City-wide inventory of background information. In Phase 2 of the Study, the existing conditions information was updated, refined and expanded as required to develop a surface and basement flooding model of the City. InfoWorks ICM 8.5.4 was used to simulate flow conditions of the minor (sewers) and major (overland) systems. The minor system was modelled using a 1-dimensional (1D) linear model network while the major (overland) system was modelled using a 2-dimensional (2D) approach.

The compiled flow monitoring and precipitation records within the City of Windsor allow designers and engineers to understand flow characteristics. The key data sources used for this project are recent records from generally 2012 or newer, as identified below:

- The City of Windsor had a program with a network of rain gauges that record precipitation patterns within the Municipality.
- During 2013 and 2014, sewer flow monitor data was collected as part of a temporary program to better characterize the City's storm, sanitary and combined sewer systems;
- In 2017, 5 months of temporary sewer flow monitor data were collected in the Pontiac, St. Paul and St. Rose stormwater service areas. This program focused only on the storm sewer systems;
- In 2018, 6 months of temporary sewer flow monitor data were collected at locations throughout the City, focused on understanding sanitary sewer wet-weather response. Two temporary rain gauges were set up to support the program; and,
- Starting in 2013 and currently on-going, the City is collecting sanitary sewer flow monitoring data at 13 locations throughout the Municipality. These gauges collect data from relatively large service areas providing information at a global scale.

9.3 Calibration Summary

The model calibration focused on the representation of basement and surface flooding with an emphasis on the sanitary sewers wet-weather response inflow and infiltration. To represent surface flooding conditions, a two-dimensional mesh was implemented to account for the overland drainage system. The calibration and validation results indicate the following:

- The modelled sanitary sewer wet weather response was found to have a good to moderate match for storm events similar too or more intense than the 1:2 year occurrence, and further for the larger sanitary sewer service areas under extreme wet weather events matches were good.
- The modelled storm sewer estimates were found to have a good to moderate match for storm events similar too or more intense than the 1:2 year occurrence.
- The modelled combined sewer estimates were found to have a good to moderate match for storm events less intense than the 1:2 year up to a 1:10 year occurrence.
- Major system (surface drainage) calibration was completed using observed records of surface flooding.

The model is considered a reasonable representation in the storm, sanitary and combined sewer systems for storm events similar to or more intense than the 1:2 occurrence. Therefore, the baseline conditions model is an appropriate tool to evaluate existing flooding conditions and to develop, review and compare solutions to alleviate surface and basement flooding.

9.4 Existing Conditions Summary

A review of the existing conditions storm, sanitary and combined sewer system performance was completed. It was found that under a 1:100 year storm that up to 75% of the City's sewer may create conditions where there is potential for basement flooding, where the HGL in the sanitary and combined sewer was less than 1.80 m below ground.

The modelled storm sewer system results identify relative good performance (hydraulic conveyance capacity) when compared to the sanitary and combined sewer systems. The comparison may not be equal as the storm sewer HGL criteria is anywhere from 1.80 to 2.10 m higher than the other two systems. Between the 1:5 year and the 1:100 return period, design storms between 6% and 14% of the storm sewer system exceed the HGL performance criteria, and 31% exceeds the criteria under the climate change stress test.

The sanitary sewer system performance was found to be the most sensitive to increases in design storm rainfall intensities and volumes. The model results identified between the 1:5 year and climate change stress test design storms between 16% and 93% of the sanitary sewer system exceeds the HGL performance criteria.

The combined sewer system was found to have the worst performance relative to HGL criteria of the three sewer systems under both the 1:5 and 1:25 year design storm events. Under the 1:100 year storm event, the combined sewer system had a similar overall performance as the sanitary sewer and had better results under the climate change stress test storm event. The model results identified under the 1:5 year to climate change stress test storms between 57% and 91% of the combined sewer system exceeds the HGL performance criteria. These results are likely a function of overflow elevations and pump stations restricting flow in the combined sewer system.

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Figures

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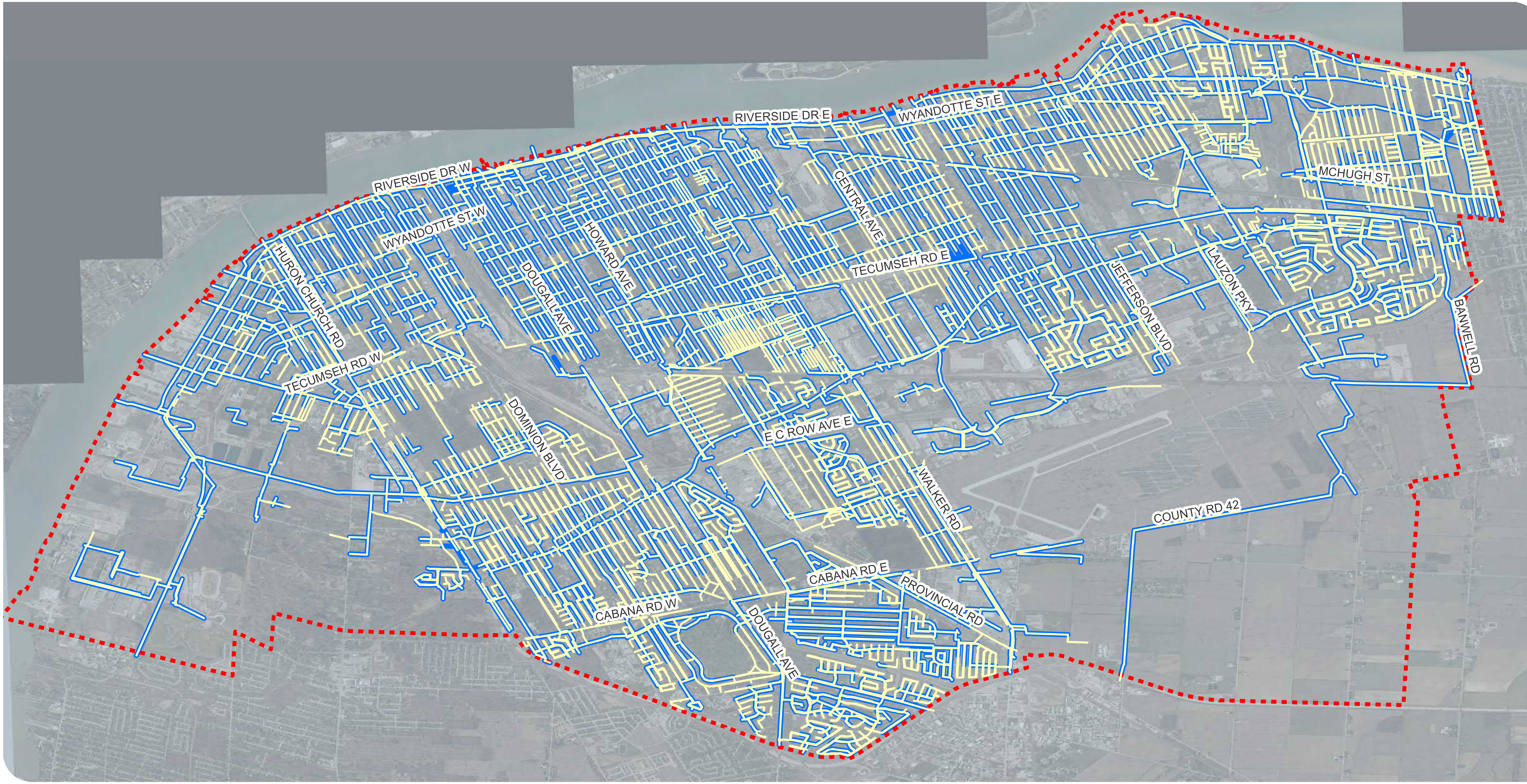

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

PHASE 1 & PHASE 2 SEWERS

FIGURE F.1.1

THE CITY OF WINDSOR

PHASE 1 SEWER

PHASE 2 SEWER

STUDY AREA

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

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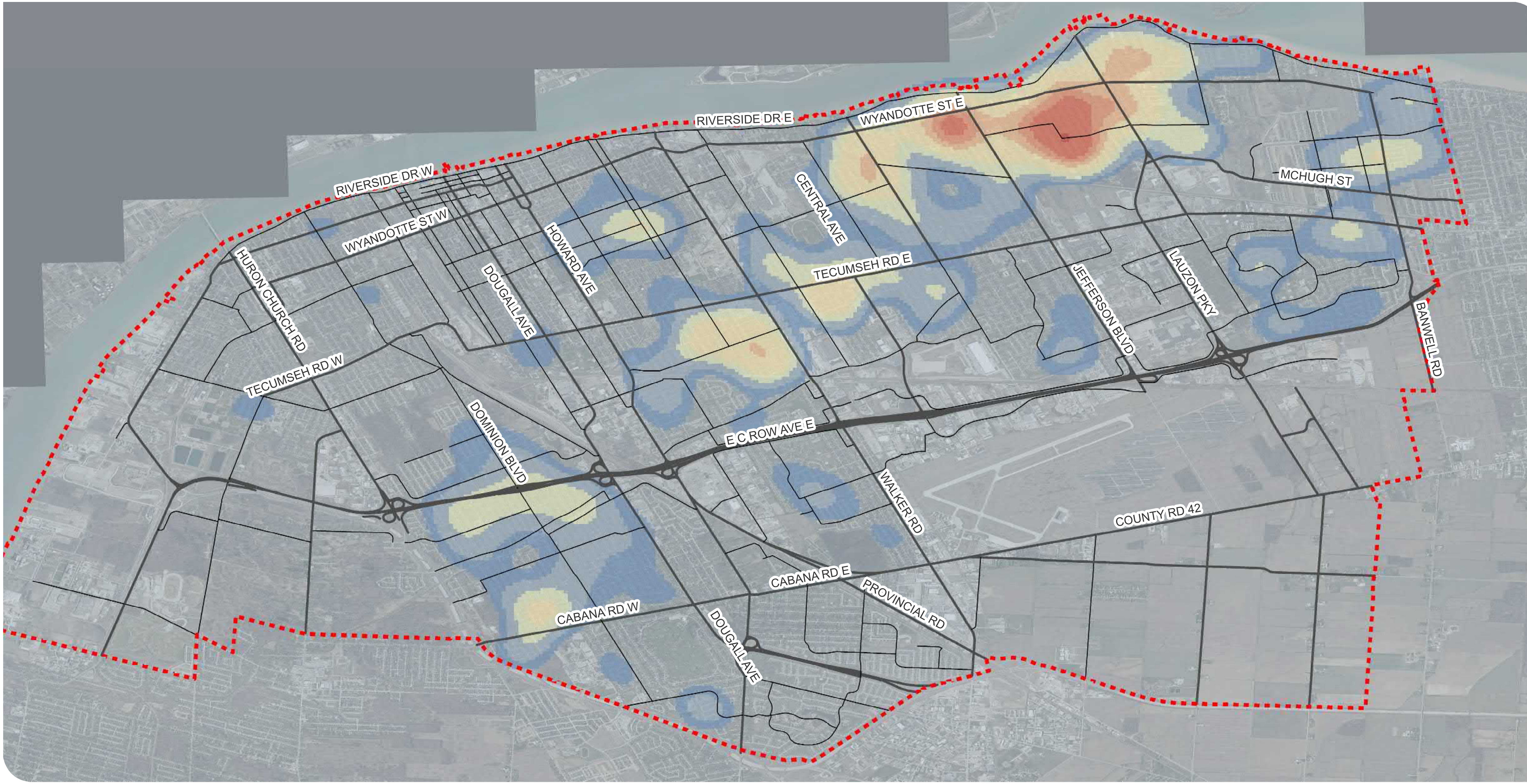

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

BASEMENT FLOODING CALLS - HEAT MAP - SEPT 28, 2016 AUG 28, 2017

FIGURE F.2.1

THE CITY OF WINDSOR

SCENIC PARKWAY OR COLLECTOR ROAD

EXPRESSWAY OR ARTERIAL ROAD

STUDY AREA

REPORTED FLOODING (CALLS/HA)

HIGH (9.2 CALLS/HA)

LOW (2.2 CALLS/HA)

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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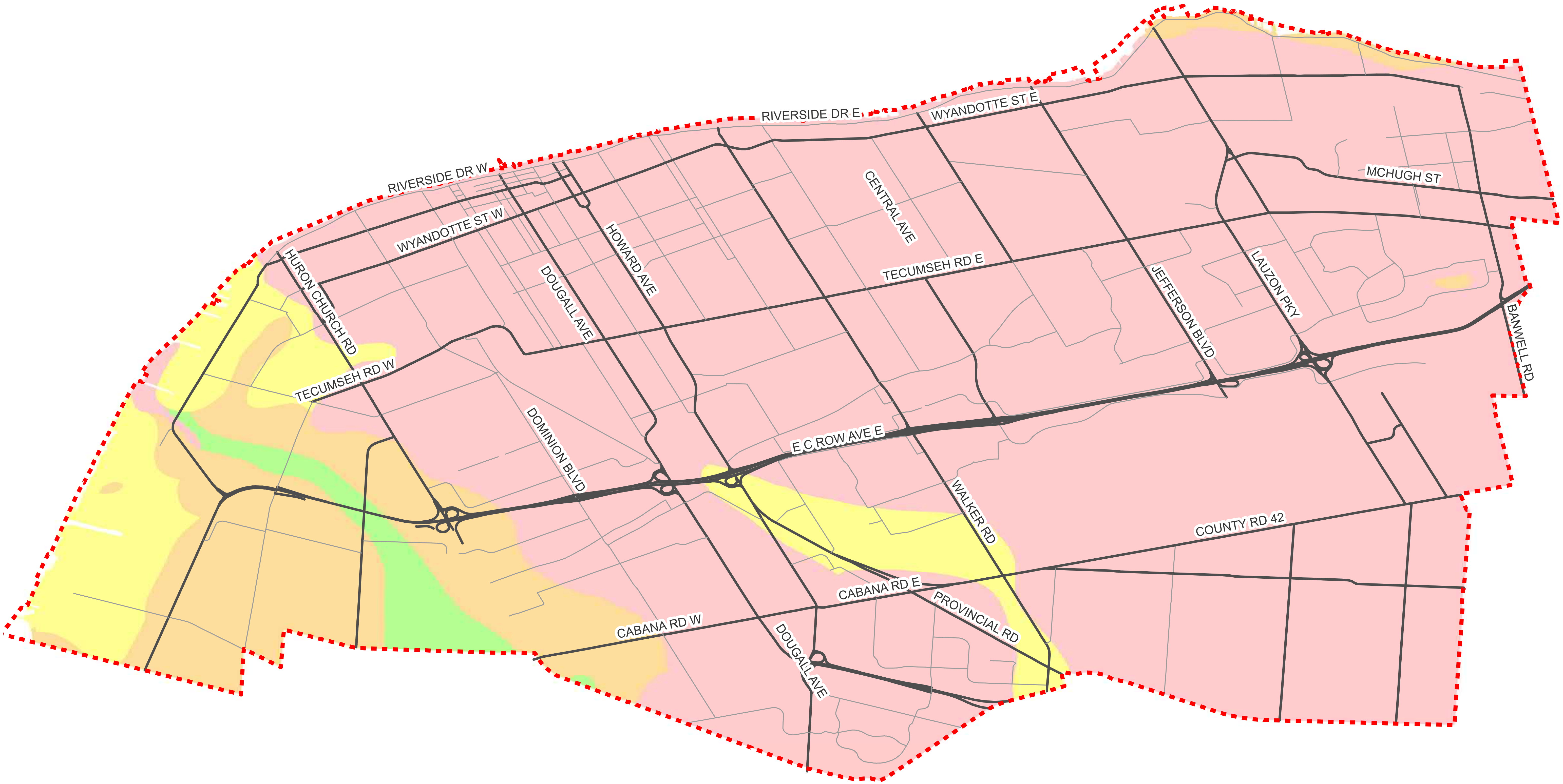

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

SOILS MAP

FIGURE F.4.1

HIGH INFILTRATION RATE SOILS

MODERATE INFILTRATION RATE SOILS

SLOW INFILTRATION RATE SOILS

VERY SLOW INFILTRATION RATE SOILS

SCENIC PARKWAY OR COLLECTOR ROAD

EXPRESSWAY OR ARTERIAL ROAD

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

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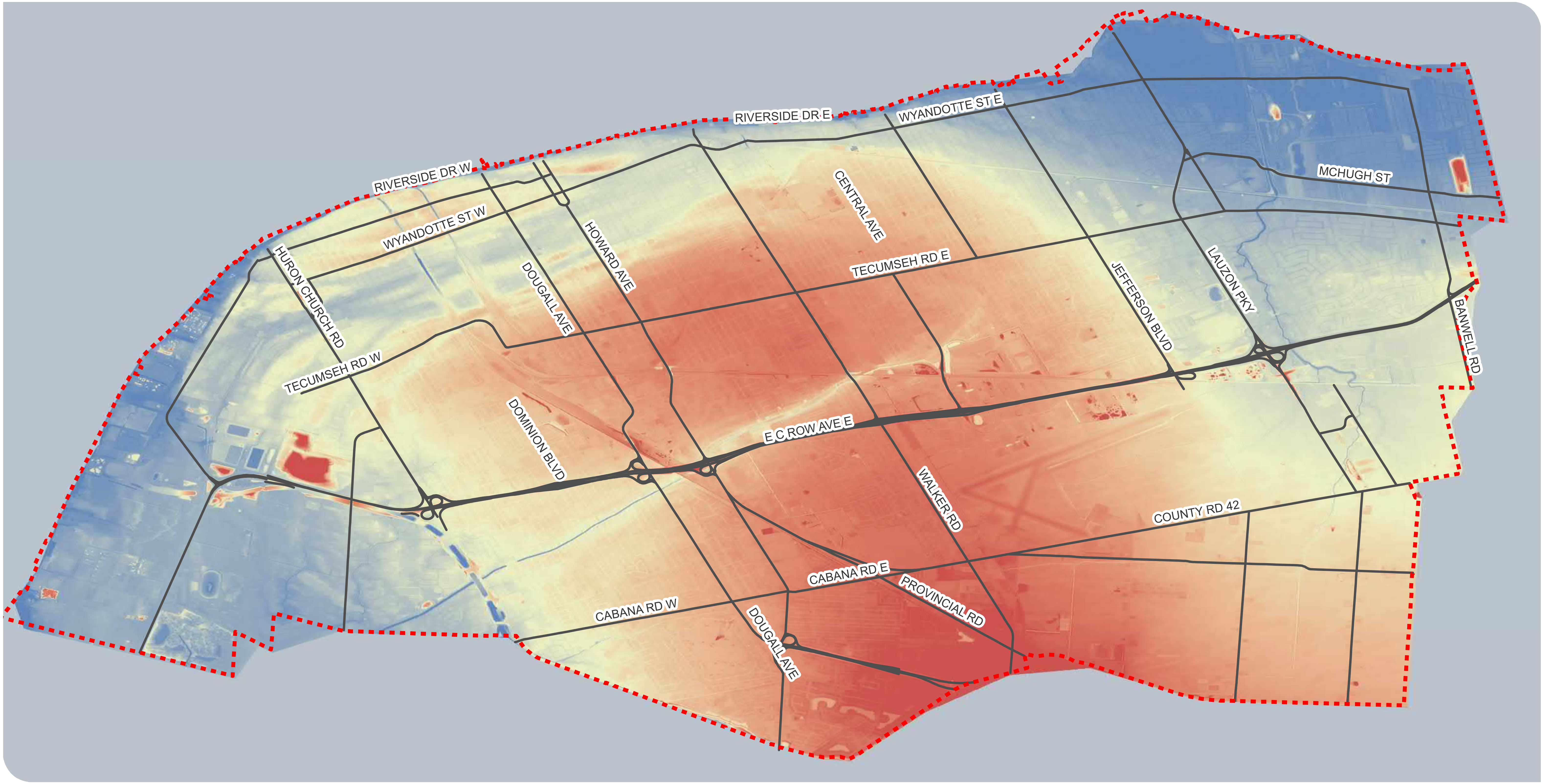

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

TOPOGRAPHIC HEAT MAP

FIGURE F.4.2

THE CITY OF WINDSOR

TOPOGRAPHIC HEAT MAP (ELEVATION m)

195 m OR HIGHER

174 m OR LOWER

EXPRESSWAY OR ARTERIAL ROAD

STUDY AREA

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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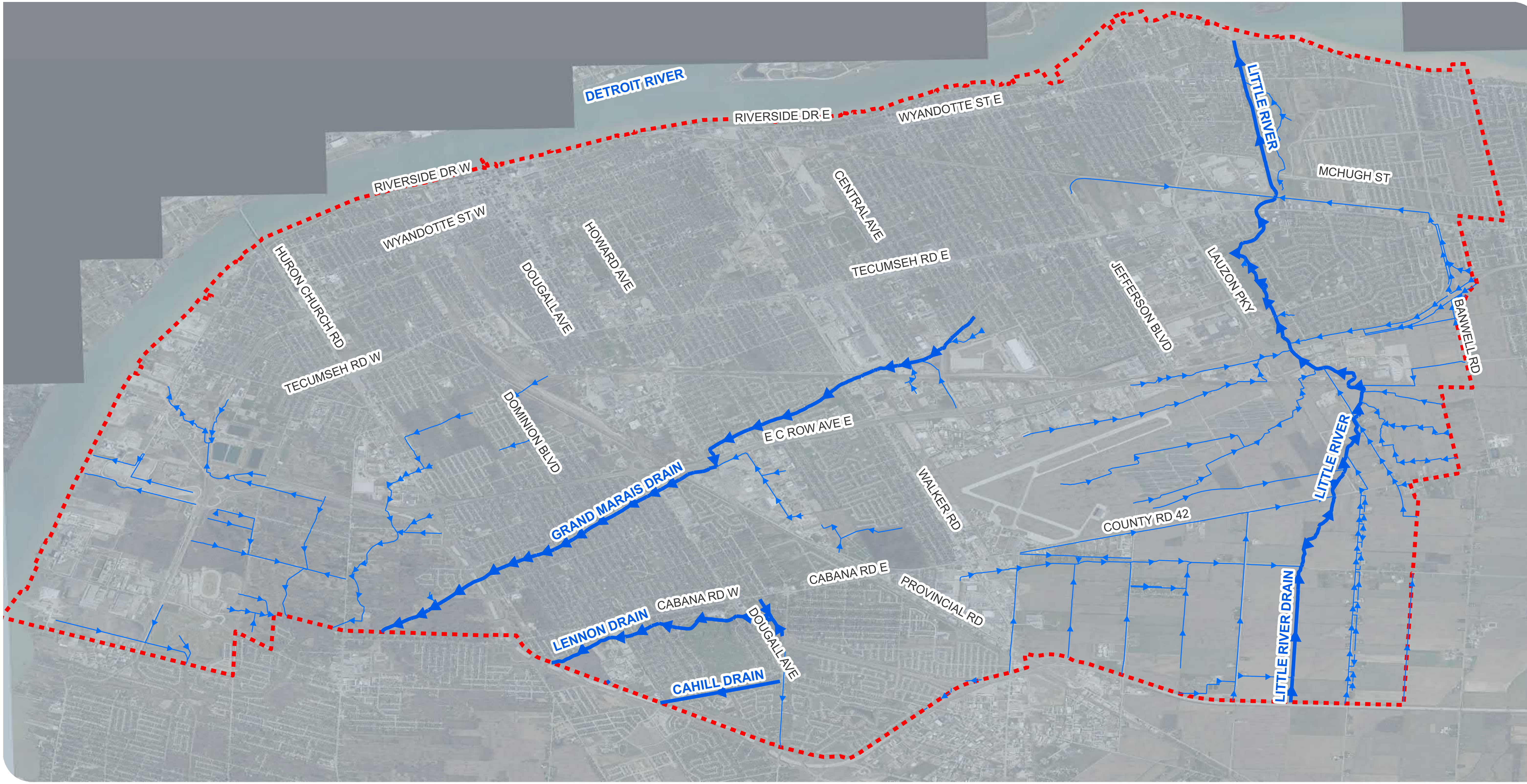


CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

RECEIVING WATERCOURSES

FIGURE F.4.3

OTHER WATERCOURSES AND DRAINS

MAJOR WATERCOURSE OR DRAIN

STUDY AREA

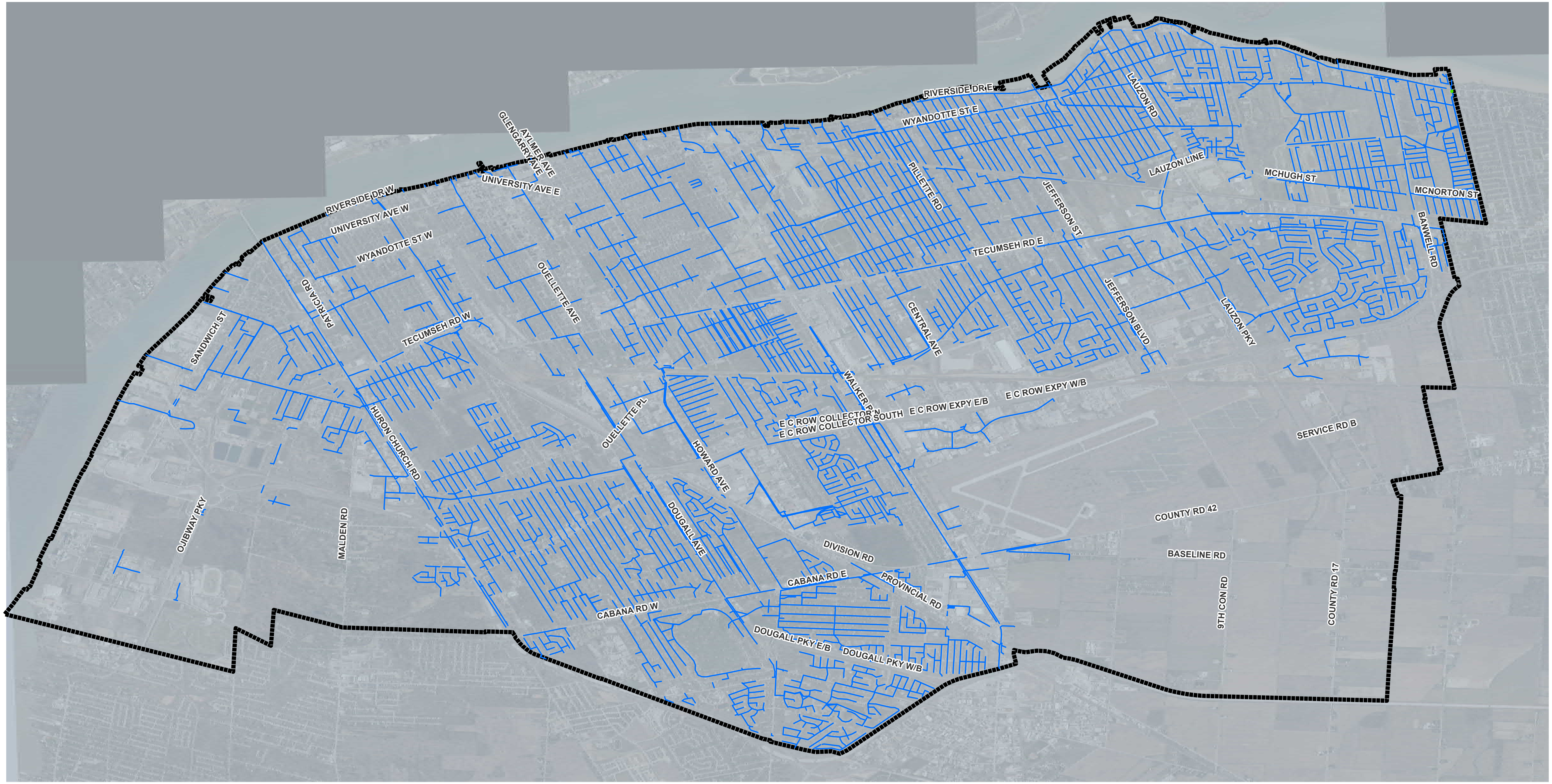
MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20



CITY OF WINDSOR
SEWER AND COASTAL FLOOD
PROTECTION MASTER PLAN

MODEL STORM SEWER CONDUITS
FIGURE 4.4.1

THE CITY OF WINDSOR

STUDY AREA
STORM SEWER

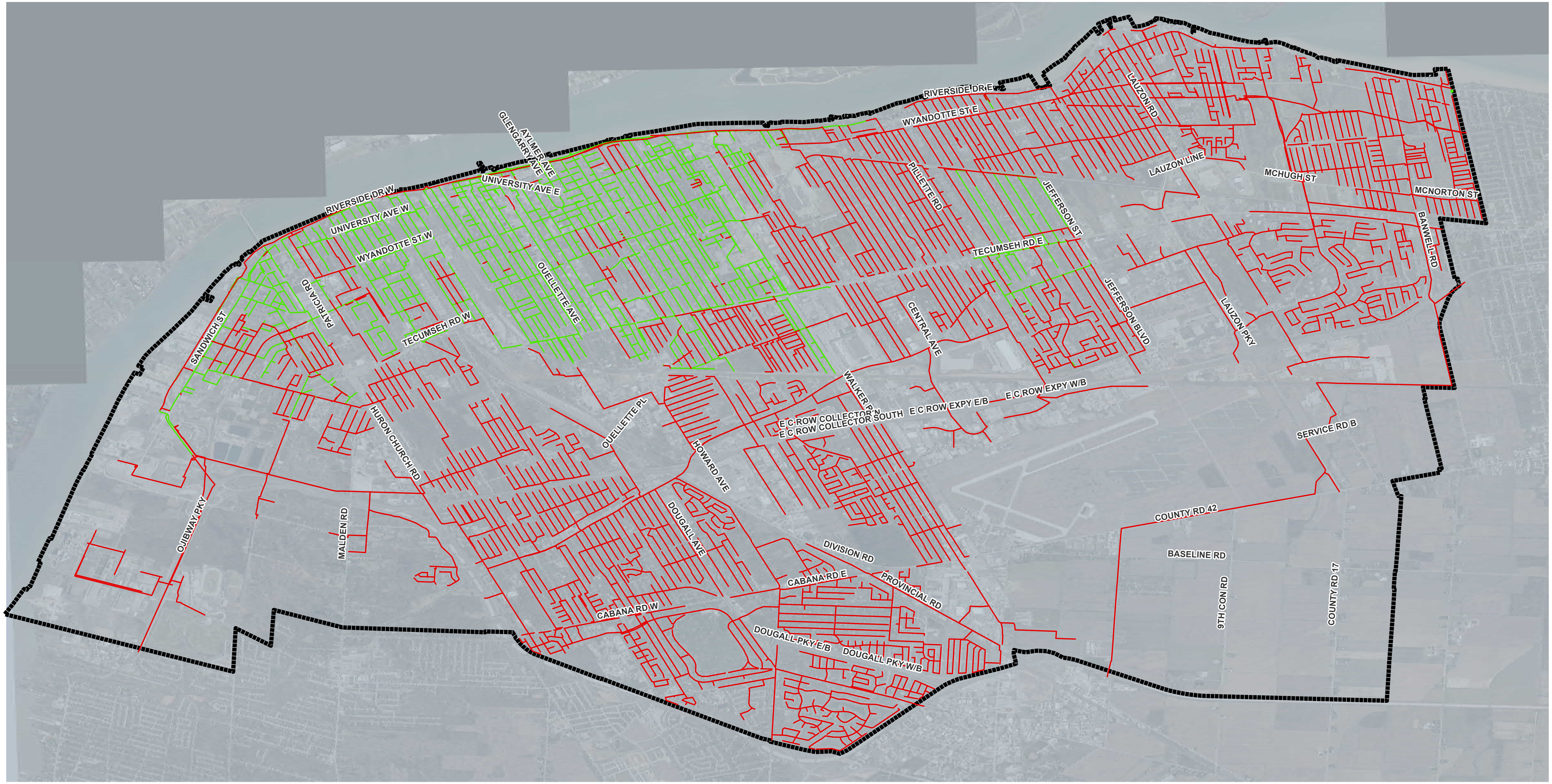
DILLON CONSULTING
Aquafor Beech Limited

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

N W E S

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20



CITY OF WINDSOR
SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

MODEL SANITARY AND COMBINED SEWER CONDUITS

FIGURE 4.4.2

STUDY AREA
COMBINED SEWER
SANITARY SEWER

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

SCALE 1:60,000

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

DOWNSPOUT DISCONNECTION

FIGURE F.4.5

- 100-90% DISCONNECTED
- 90-80% DISCONNECTED
- 80-70% DISCONNECTED
- 70-60% DISCONNECTED
- 60-50% DISCONNECTED
- 50-40% DISCONNECTED
- 40-30% DISCONNECTED
- 30-20% DISCONNECTED
- 20-10% DISCONNECTED
- FLOW MONITORING AND HYDRAULIC MODELING OF THE SEWER SYSTEM (2016)

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\DILLON.CA\DILLON_DFS\LONDON\LONDON CAD\GIS\VISUAL COMMUNICATIONS DI\MXD TEMPLATES\BLUE - 11X17 LANDSCAPE - LEGEND BOTTOM.MXD

PROJECT: 17-6638 STATUS: FINAL DATE: 09/28/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD
PROTECTION MASTER PLAN

Developement: Prior & Post 1980

FIGURE 4.6

Residential Developement Built Pre 1980

Parcels

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

N W E S

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

PRIORITY UPGRADE

FIGURE F.4.7

THE CITY OF WINDSOR

Priority Upgrade Sanitary or Combined Sewers rated "Poor" or "Very Poor"

Remaining Conduits

Study Area

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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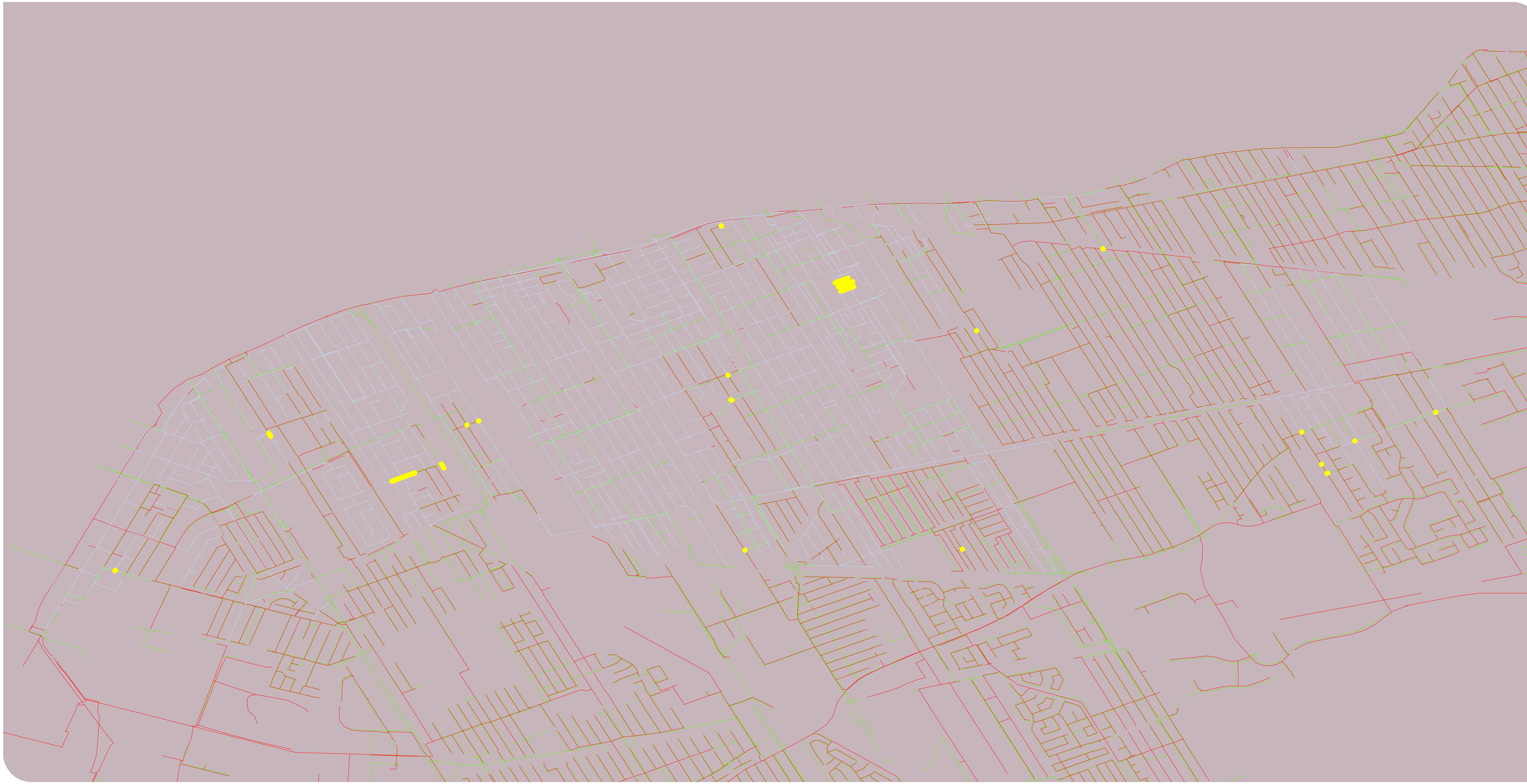

CITY OF WINDSOR

SEWER AND COASTAL FLOOD
PROTECTION MASTER PLAN

Existing Backflow Prevention Device Locations

FIGURE 4.8

Sewers where Backflow Prevention Device are located

Combined Sewers

Sanitary Sewers

Storm Sewers

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:40,000

N W E S

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD
PROTECTION MASTER PLAN

Interceptor & Overflow Locations

FIGURE 4.9

Existing Sluice Gate Location
Existing Weir Location
Combined Sewers
Sanitary Sewers
Storm Sewers

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:40,000

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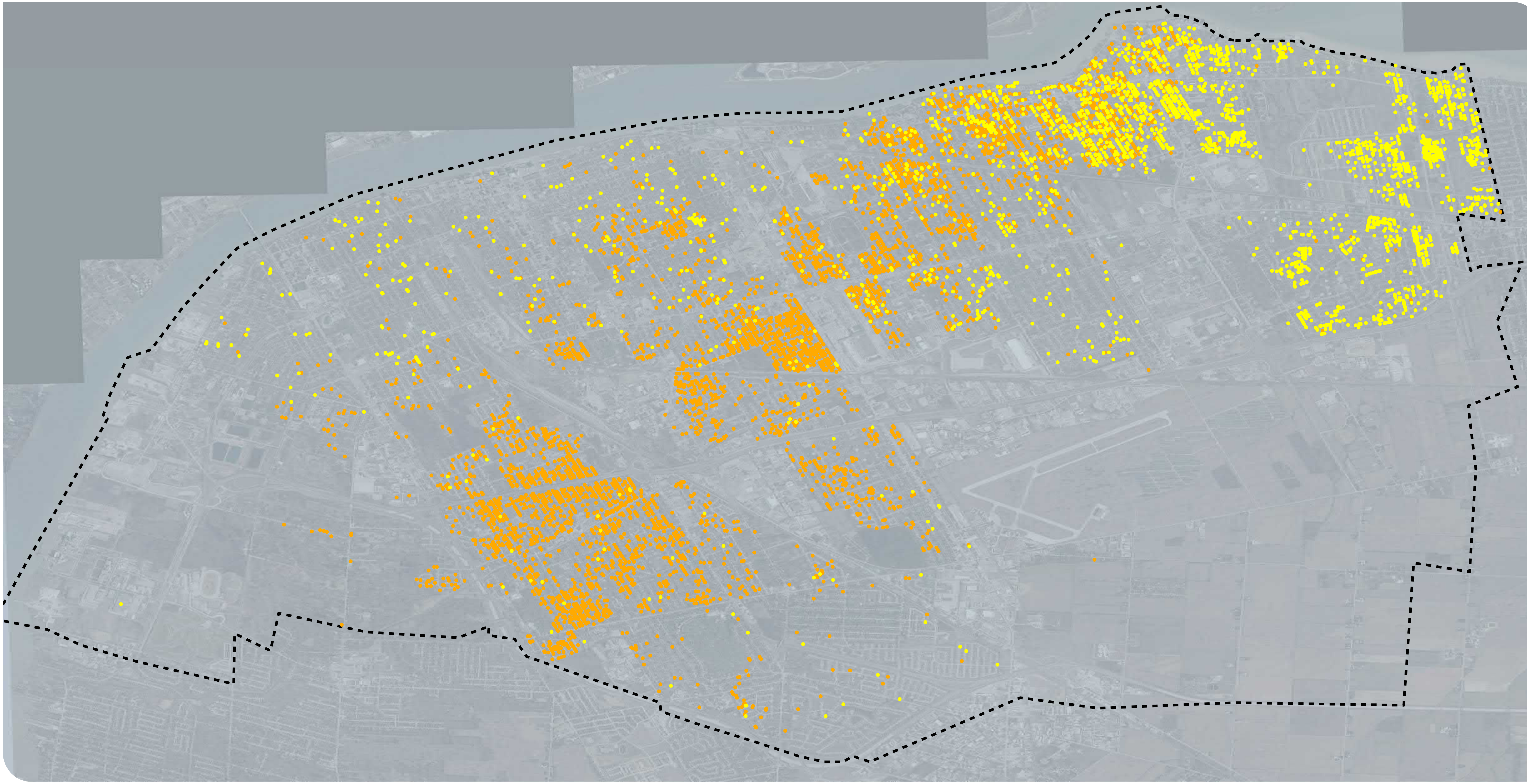
W E
S

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD
PROTECTION MASTER PLAN

Flooding Calls: 2016 - 2017

FIGURE 4.10

Flooding Calls 2016
Flooding Calls 2017
Study Area

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

N W E S

PROJECT: 17-6638 STATUS: FINAL DATE: 10/22/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

RAIN GAUGE LOCATIONS

FIGURE F.6.1

CITY RAIN GAUGE

AMG RAIN GAUGE

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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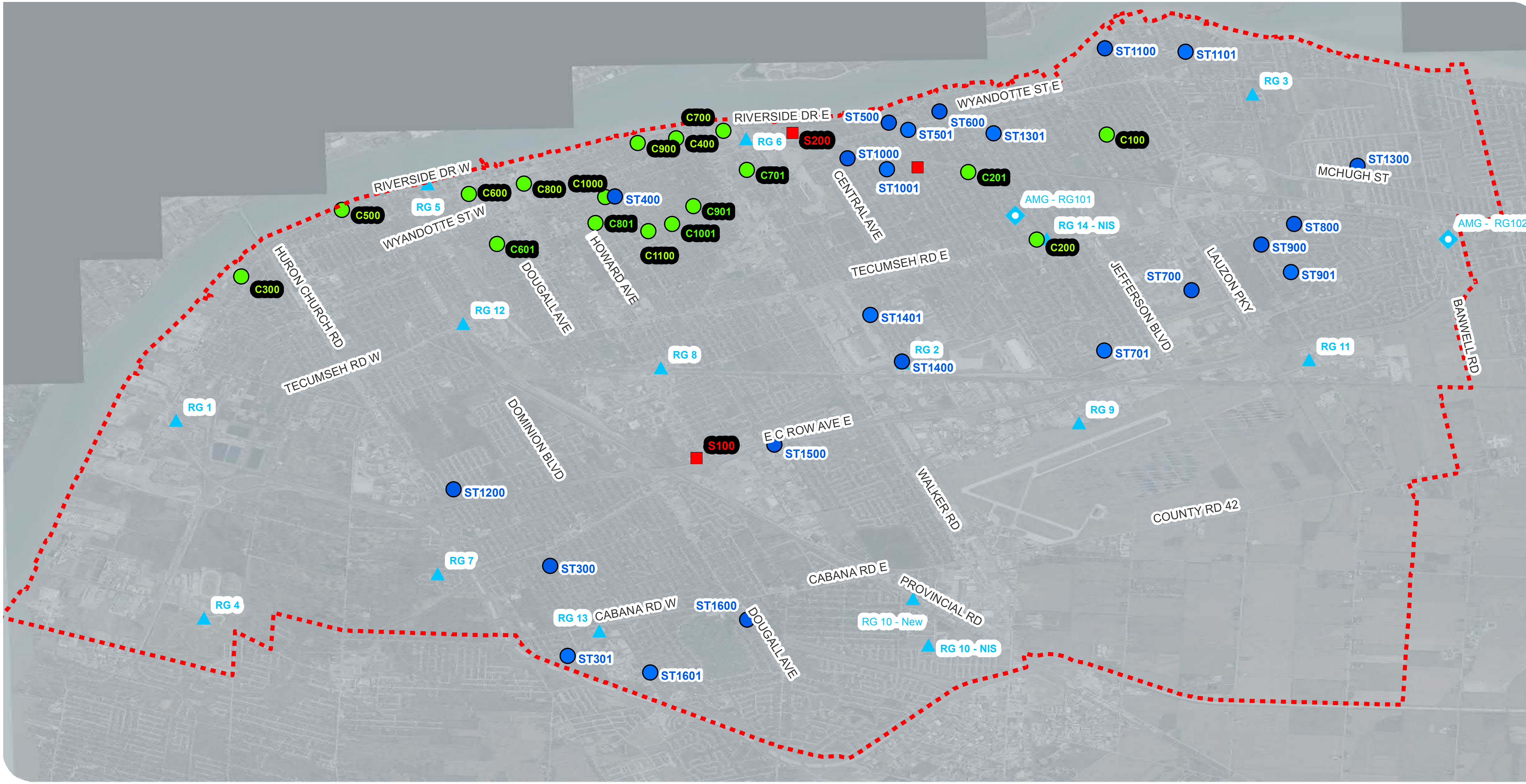


CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

2013 & 2014 TEMPORARY FLOW MONITOR LOCATIONS

FIGURE F.6.2

2013 & 2014 SANITARY SEWER FLOW MONITOR	CITY RAIN GAUGE
2013 & 2014 STORM SEWER FLOW MONITOR	AMG RAIN GAUGE
2013 & 2014 COMBINED SEWER FLOW MONITOR	STUDY AREA

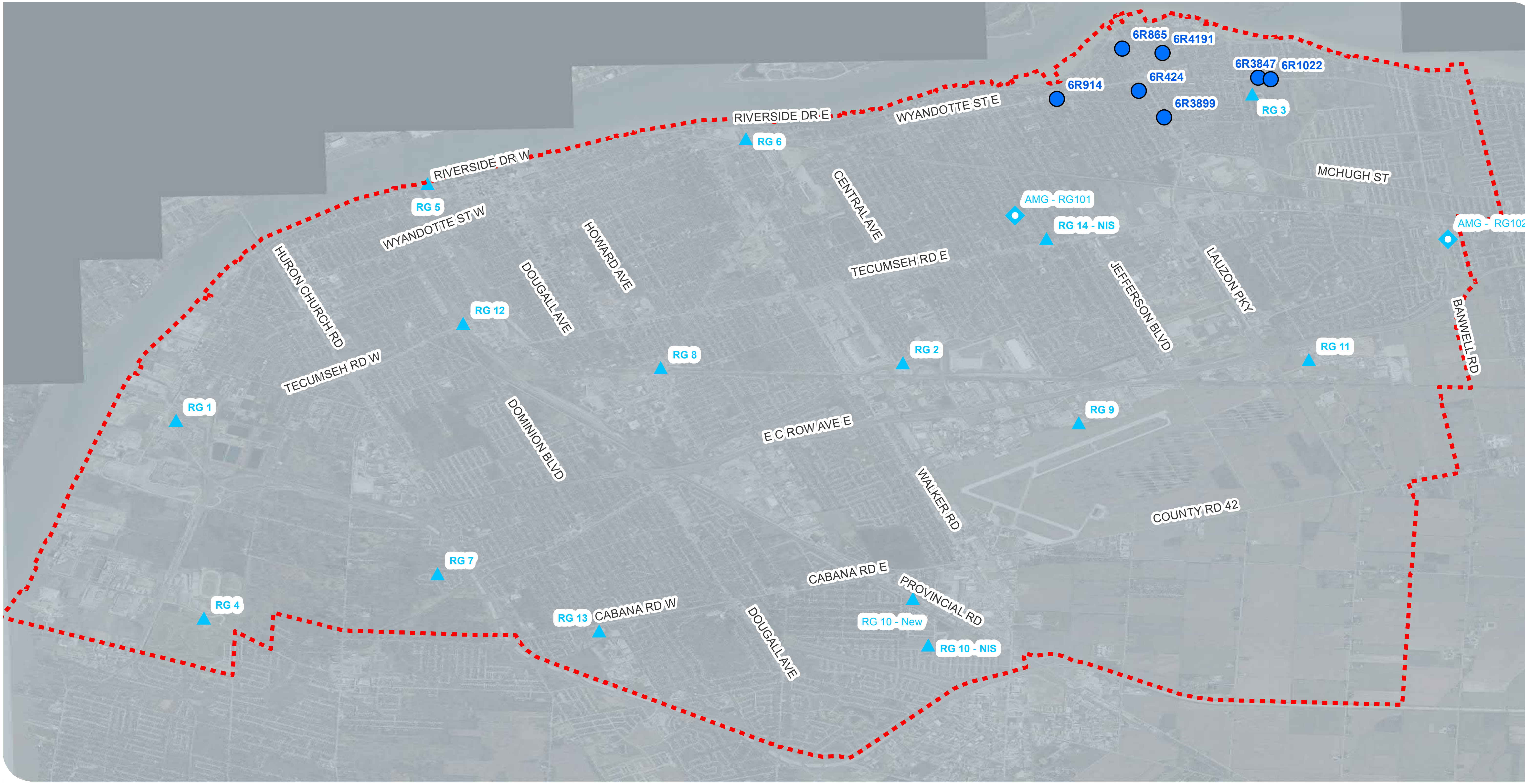
MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\ 17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 09/30/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

2017 TEMPORARY FLOW MONITOR LOCATIONS

FIGURE F.6.3

2017 STORM SEWER FLOW MONITOR

CITY RAIN GAUGE

AMG RAIN GAUGE

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

ON-GOING SANITARY SEWER FLOW MONITOR LOCATIONS

FIGURE F.6.4

CITY RAIN GAUGE

SANITARY SEWER FLOW MONITOR (2013-2018)

AMG RAIN GAUGE

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR
SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

2018 FM PROGRAM STORM AND SANITARY FLOW MONITOR LOCATIONS
FIGURE F.6.5

STORM AND SANITARY SEWER FLOW MONITOR
STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

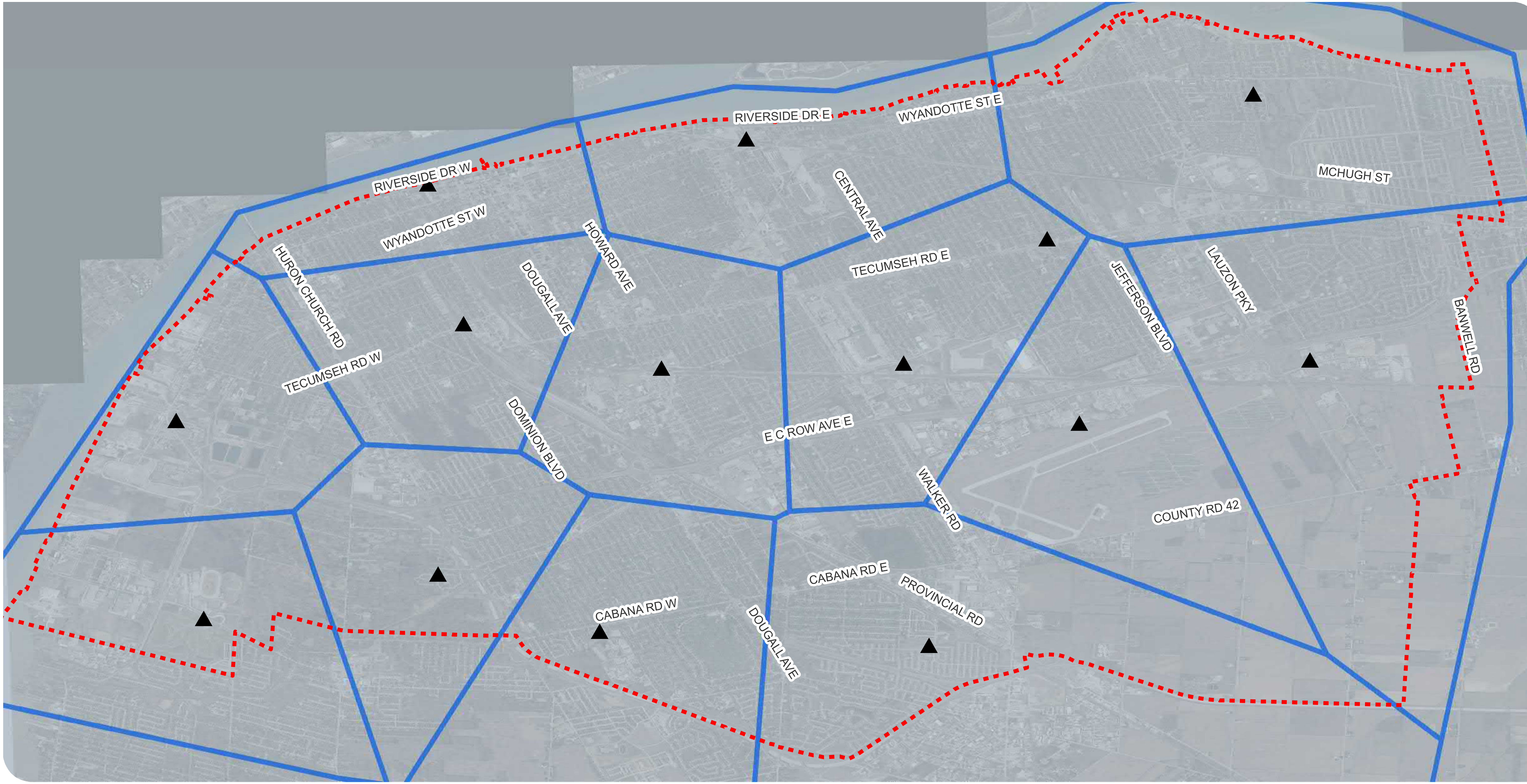
MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

THIESSEN POLYGONS FOR AUG 28, 2017

FIGURE F.7.1

THIESSEN POLYGONS REPRESENTING RAINFALL DISTRIBUTION FOR AUGUST 28, 2017

RAIN GAUGE

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\G:\CAD\GIS\17-6638 SEWER AND OVERLAND DRAINAGE MP \GIS\TECHNICAL VOLUME I REPORT

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

RECORDED SURFACE FLOODING

FIGURE F.7.2

RECORDED SURFACE FLOODING FROM PHOTOS DURING AUGUST 28/29, 2017 AND SEPTEMBER 28, 2016 STORM EVENTS

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

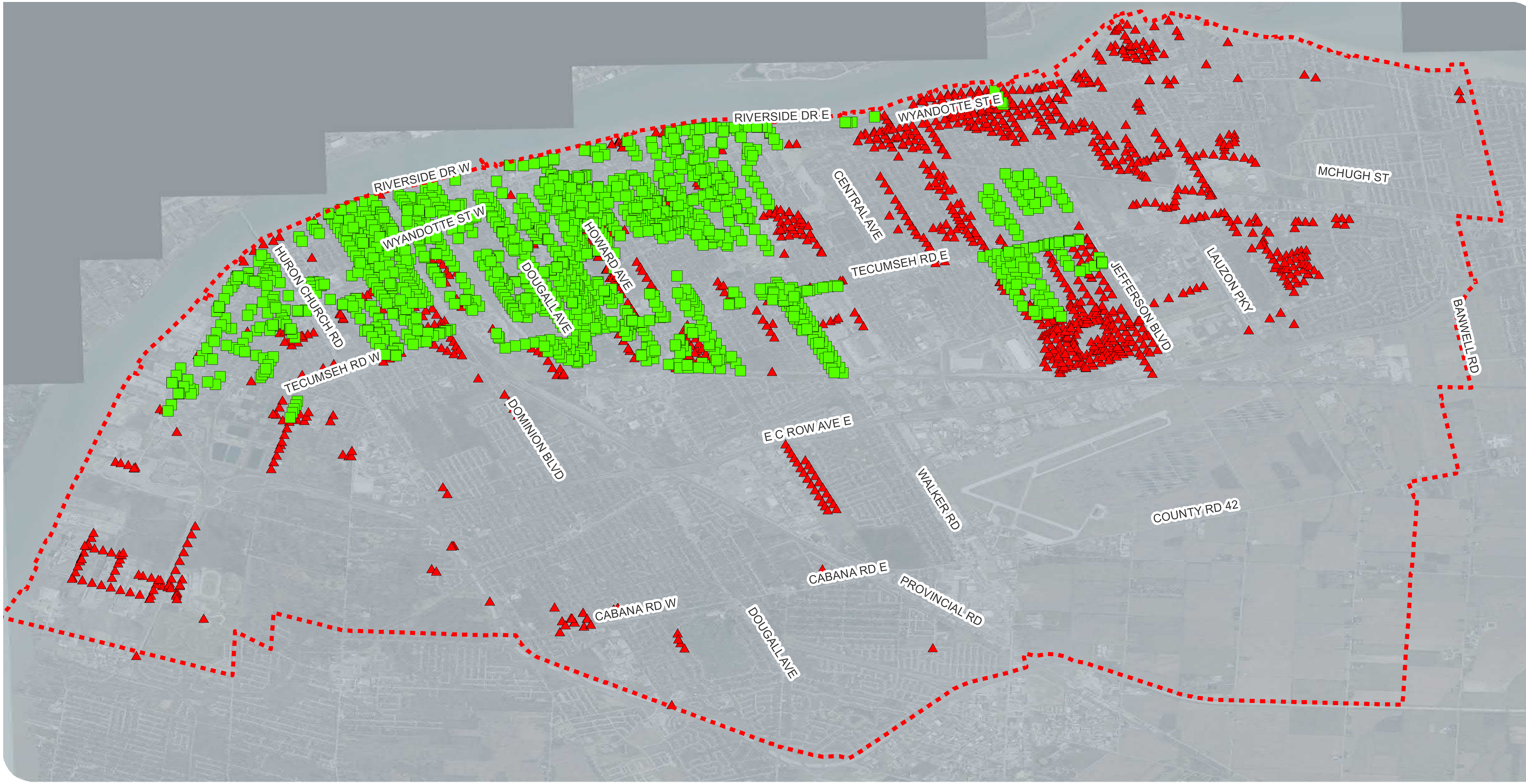
MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\G:\CAD\GIS\17-6638 SEWER AND OVERLAND DRAINAGE MP \GIS\TECHNICAL VOLUME I REPORT

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:5 YEAR DESIGN STORM EVENT EXISTING CONDITION SANITARY & COMBINED SEWER HGL

FIGURE F.8.1

- SANITARY SEWER HGL LESS THAN 1.80m BELOW GROUND
- COMBINED SEWER HGL LESS THAN 1.80m BELOW GROUND
- STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

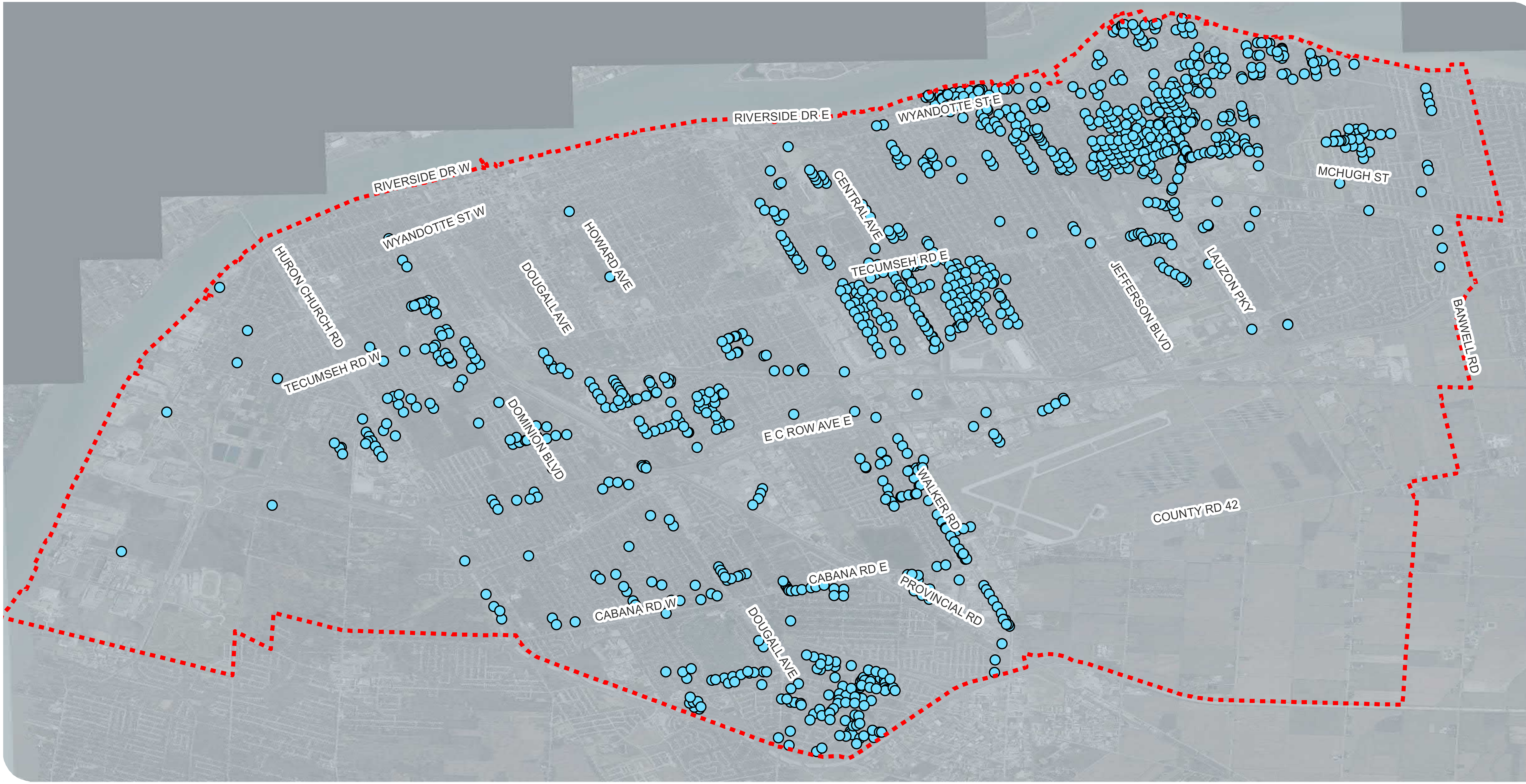
MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:5 YEAR DESIGN STORM EVENT EXISTING CONDITION STORM SEWER HGL

FIGURE F.8.2

THE CITY OF WINDSOR

STORM SEWER HGL ABOVE GROUND

STUDY AREA

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:25 YEAR DESIGN STORM EVENT EXISTING CONDITION SANITARY & COMBINED SEWER HGL

FIGURE F.8.3

SANITARY SEWER HGL LESS THAN 1.80m BELOW GROUND

COMBINED SEWER HGL LESS THAN 1.80m BELOW GROUND

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

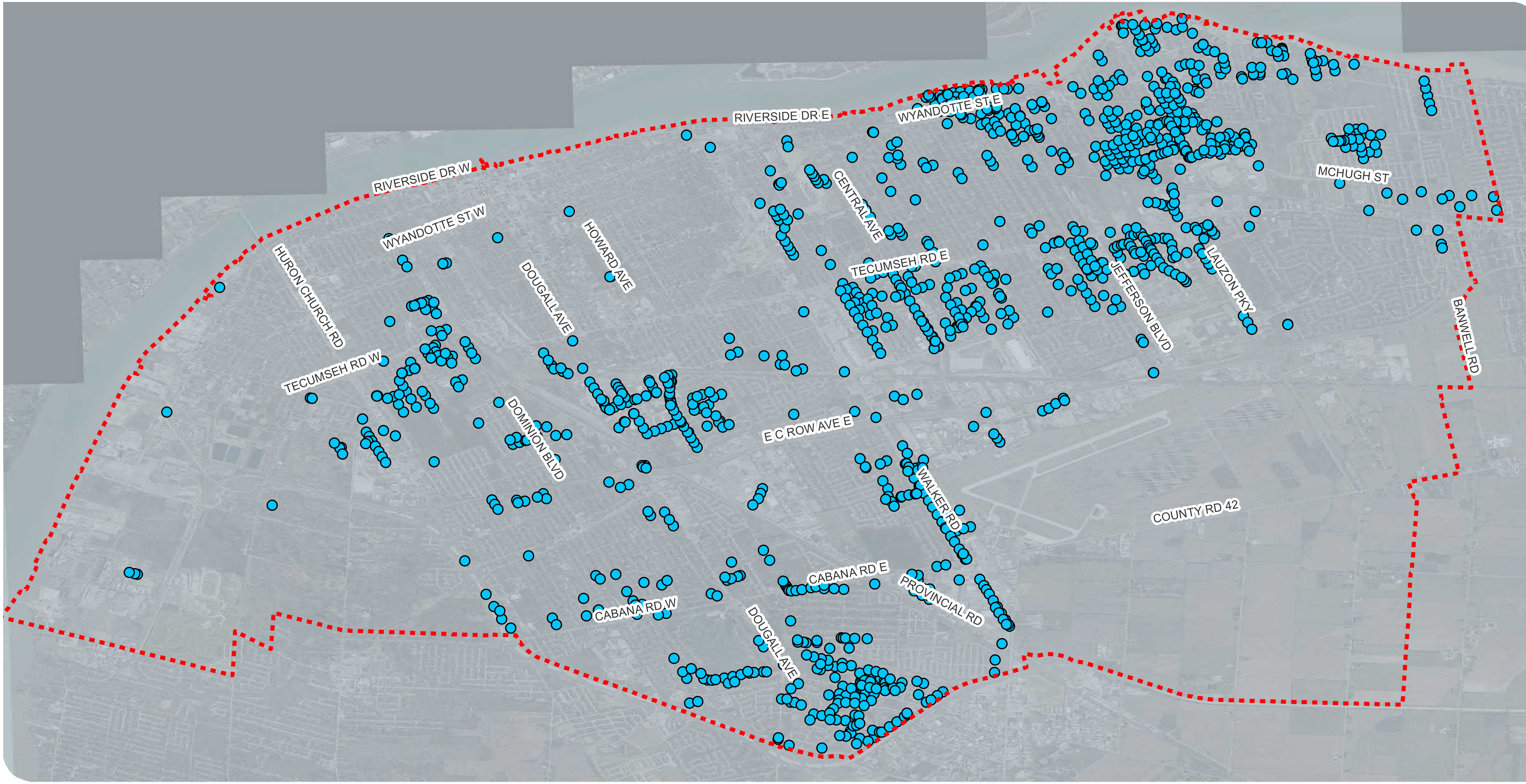
MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\ 17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:25 YEAR DESIGN STORM EVENT EXISTING CONDITION STORM SEWER HGL

FIGURE F.8.4

STORM SEWER HGL MORE THAN 0.15m ABOVE GROUND

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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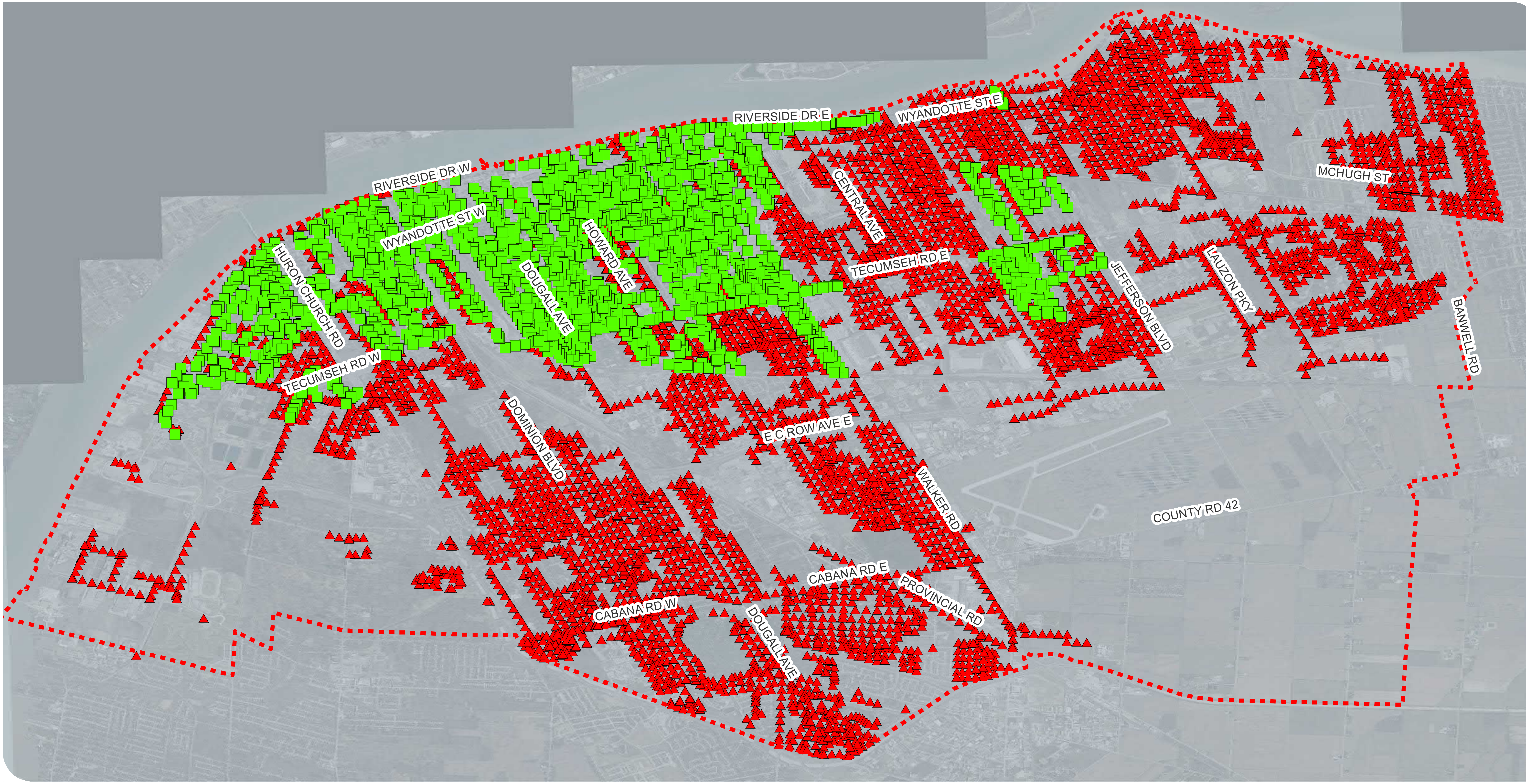
FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:100 YEAR DESIGN STORM EVENT EXISTING CONDITION SANITARY & COMBINED SEWER HGL

FIGURE F.8.5

SANITARY SEWER HGL LESS THAN 1.80m BELOW GROUND

COMBINED SEWER HGL LESS THAN 1.80m BELOW GROUND

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

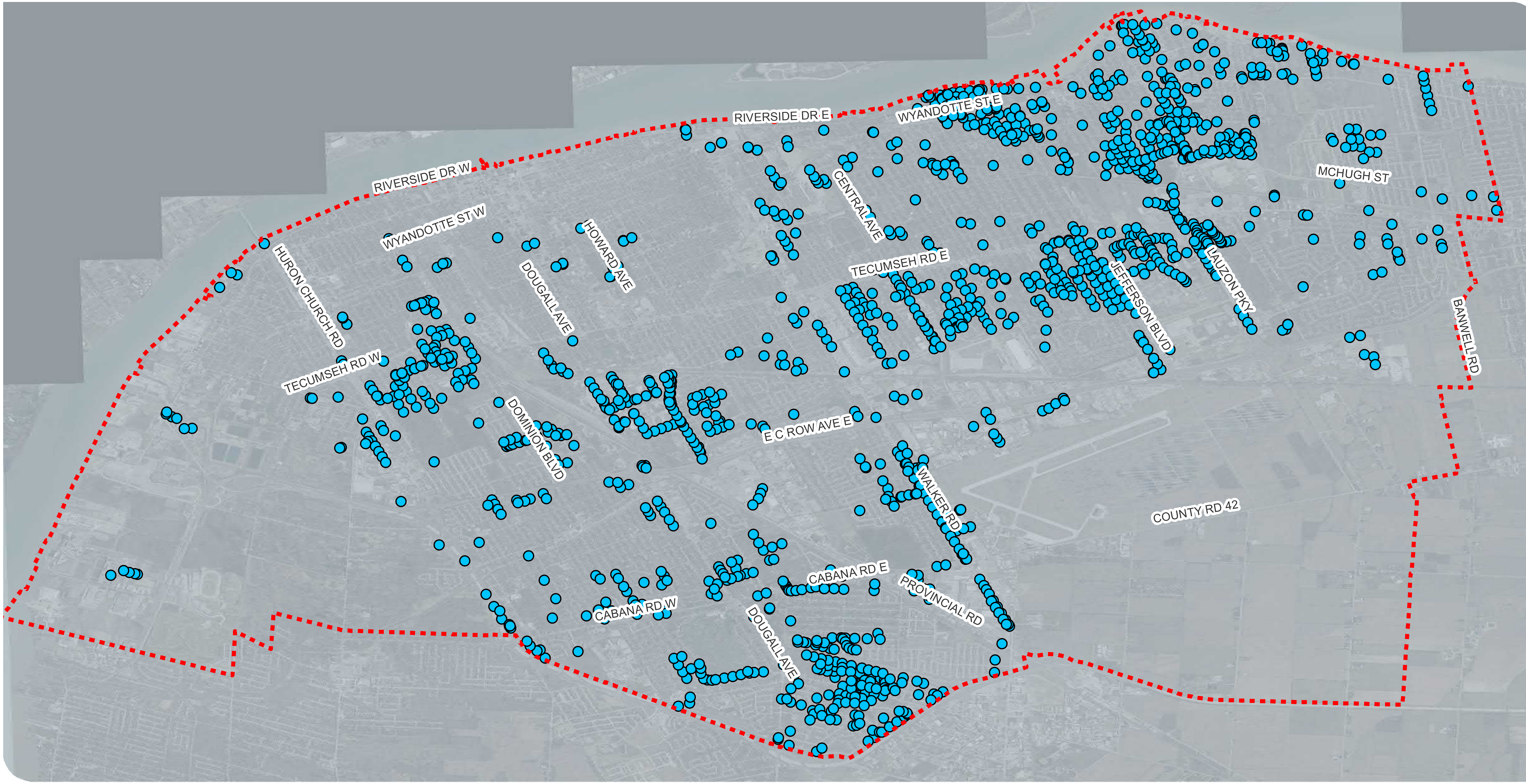
0 0.5 1 2 km

SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:100 YEAR DESIGN STORM EVENT EXISTING CONDITION STORM SEWER HGL

FIGURE F.8.6

STORM SEWER HGL MORE THAN 0.30m ABOVE GROUND

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

1:100 YEAR DESIGN STORM EVENT EXISTING CONDITION MODELLED SURFACE FLOODING

FIGURE F.8.7

SURFACE FLOODING LESS THAN 0.30m

SURFACE FLOODING MORE THAN 0.30m

STUDY AREA

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\
17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

CITY OF WINDSOR
SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

URBAN STRESS TEST DESIGN STORM EXISTING CONDITION SANITARY & COMBINED SEWER HGL
FIGURE F.8.8

THE CITY OF WINDSOR

SANITARY SEWER HGL LESS THAN 1.80m BELOW GROUND
COMBINED SEWER HGL LESS THAN 1.80m BELOW GROUND
STUDY AREA

DILLON CONSULTING
Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

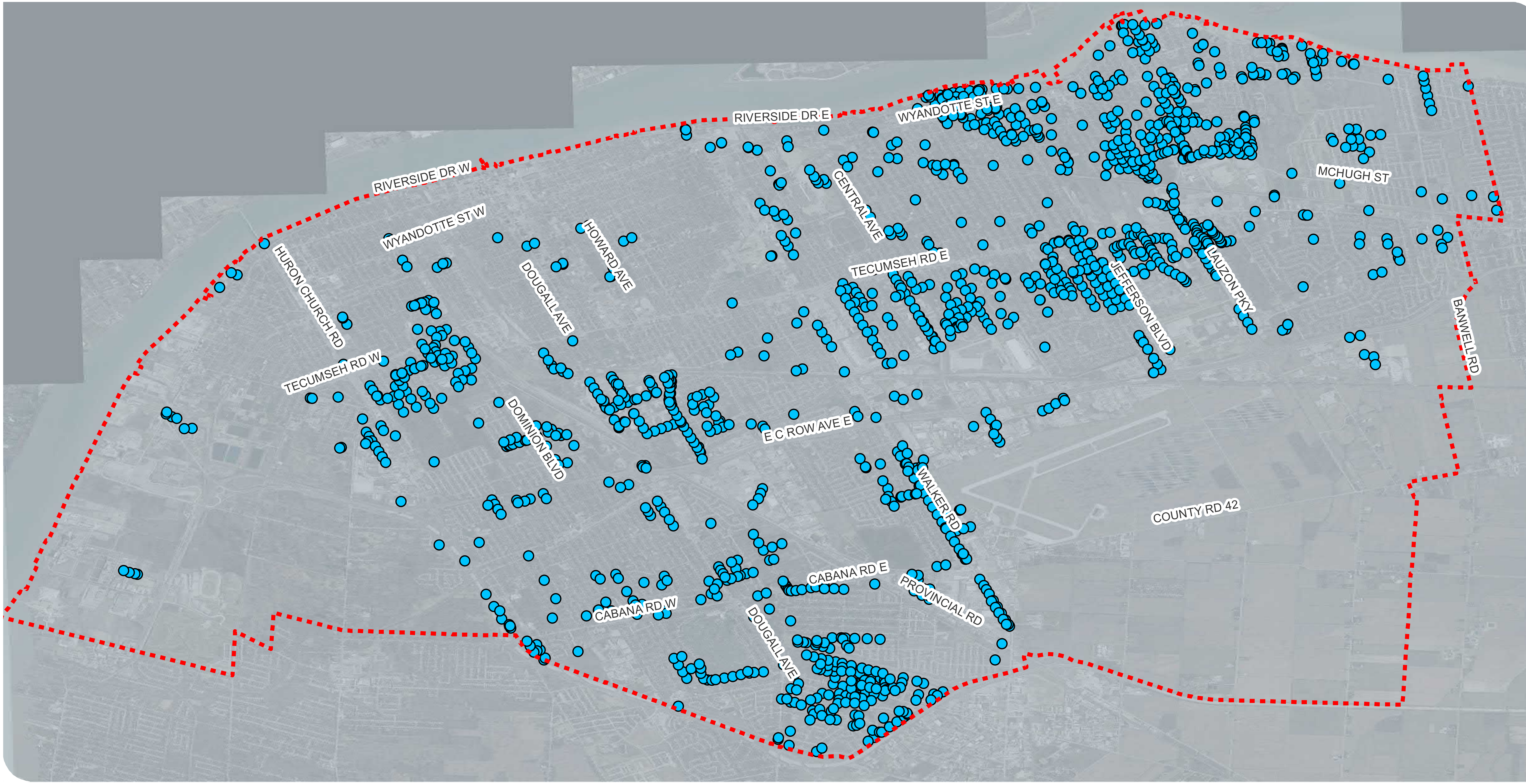
MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR
SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

URBAN STESS TEST DESIGN STORM EXISTING CONDITION STORM SEWER HGL
FIGURE F.8.9

STORM SEWER HGL MORE THAN 0.30m ABOVE GROUND
STUDY AREA

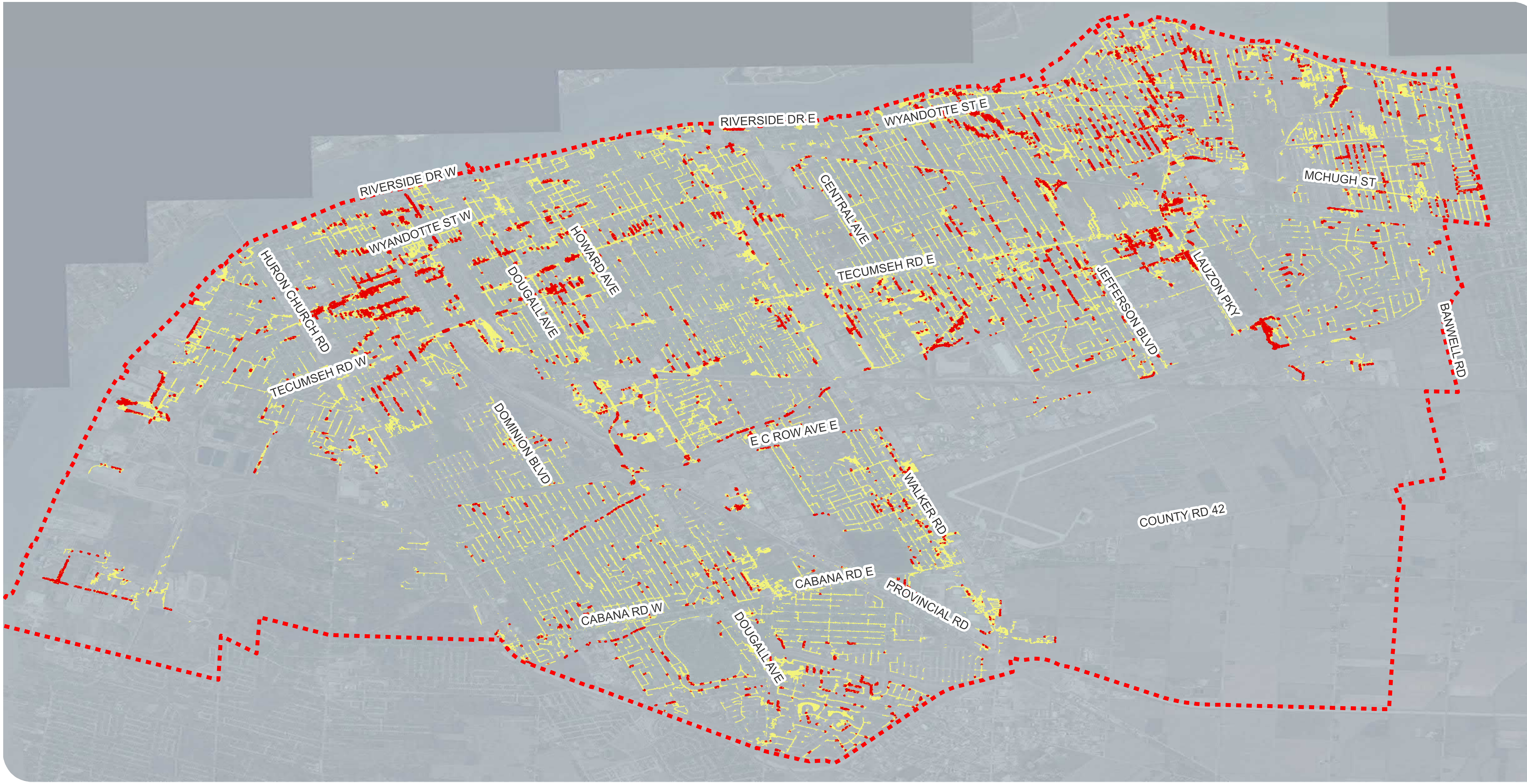
MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

URBAN STRESS TEST DESIGN STORM
EXISTING CONDITION
MODELLED SURFACE FLOODING

FIGURE F.8.10

THE CITY OF WINDSOR

- SURFACE FLOODING LESS THAN 0.30m
- SURFACE FLOODING MORE THAN 0.30m
- STUDY AREA

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

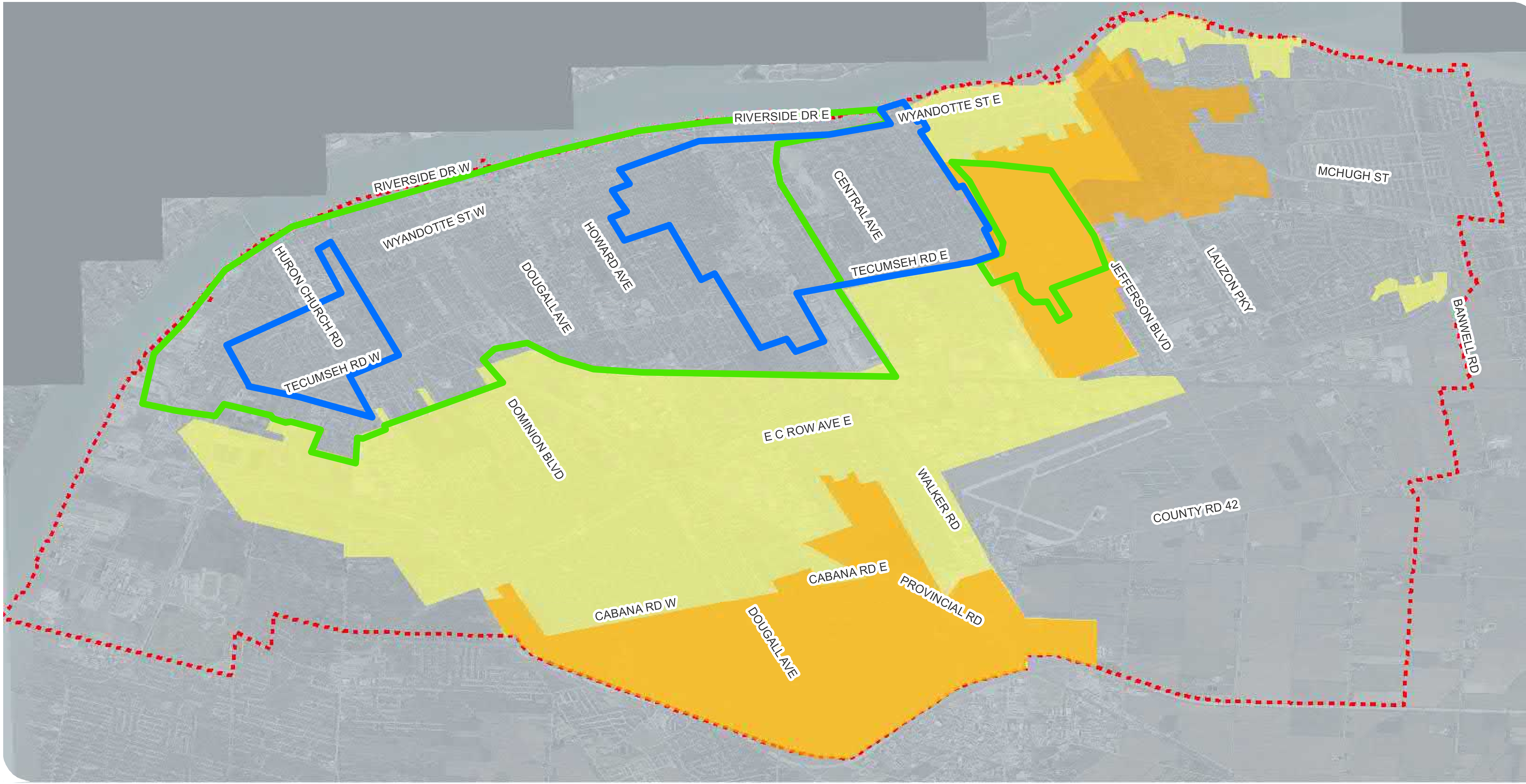
0 0.5 1 2 km

SCALE 1:60,000

N W E S

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

SEPARATED SANITARY SEWER INFLOW & INFILTRATION POTENTIAL VOLUME BASED ON OBSERVED DATA

FIGURE F.8.11

DUAL MAINTENANCE HOLE AREA
COMBINED AREA
HIGH RDII POTENTIAL BASED ON TOTAL VOLUME
MODERATE RDII POTENTIAL BASED ON TOTAL VOLUME
STUDY AREA

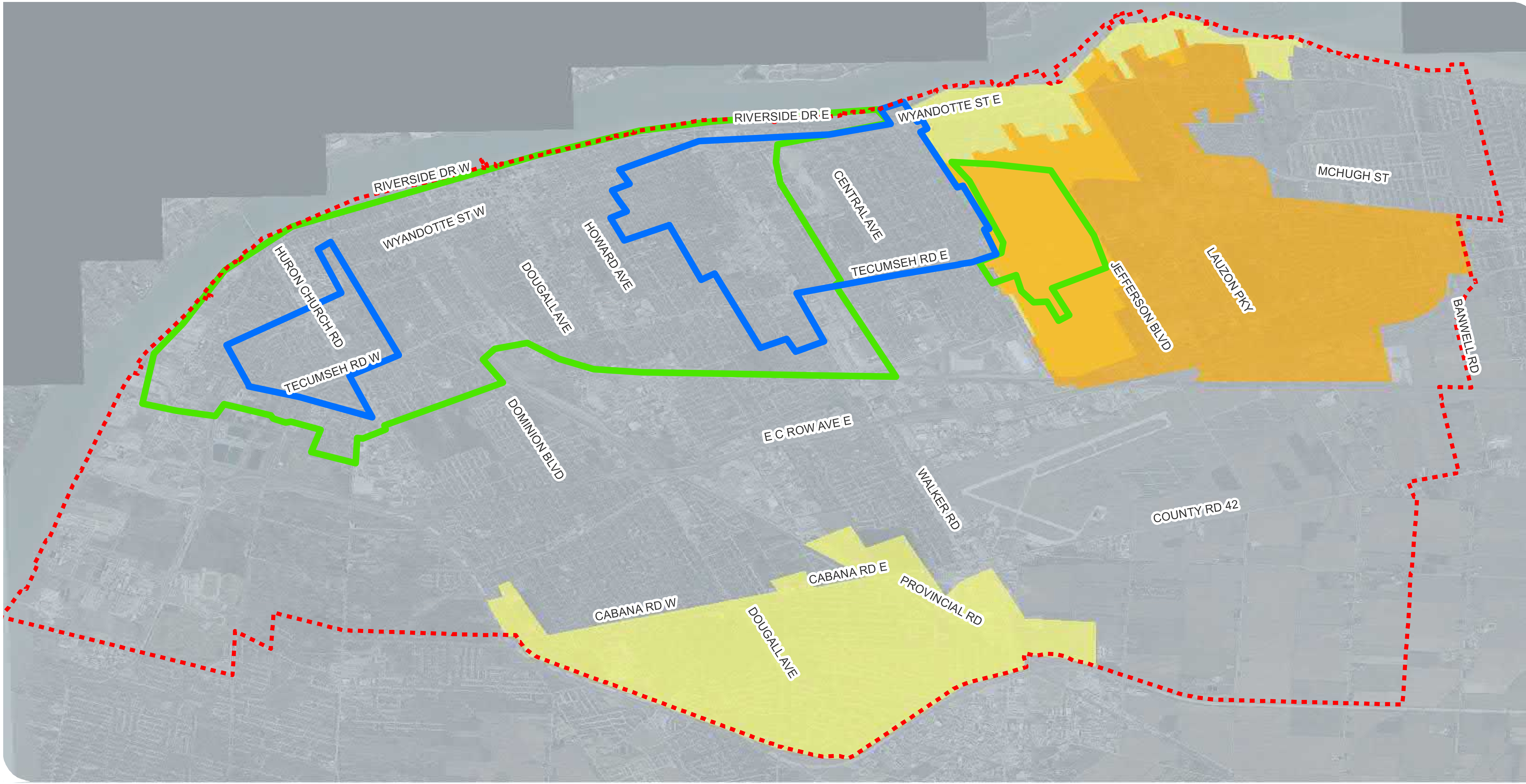
MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km
SCALE 1:60,000

FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20



CITY OF WINDSOR

SEWER AND COASTAL FLOOD PROTECTION MASTER PLAN

SEPARATED SANITARY SEWER INFLOW & INFILTRATION BASED ON OBSERVED DATA PEAK FLOW FACTOR

FIGURE F.8.12

THE CITY OF WINDSOR

DUAL MAINTENANCE HOLE AREA

COMBINED AREA

HIGH RDII POTENTIAL BASED ON RATIO OF PEAK WWF AND AVERAGE DWF

MODERATE RDII POTENTIAL BASED ON RATIO OF PEAK WWF AND AVERAGE DWF

STUDY AREA

DILLON CONSULTING

Aquafor Beech Limited

MAP DRAWING INFORMATION:
DATA PROVIDED BY CITY OF WINDSOR

MAP CREATED BY: IDW
MAP CHECKED BY: LMH
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.5 1 2 km

SCALE 1:60,000

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FILE LOCATION: \\dillon.ca\DILLON_DFS\Windsor\Windsor CAD\CAD\GIS\17-6638 Sewer and Overland Drainage MP\GIS\Technical Volume I Report\Figures

PROJECT: 17-6638 STATUS: FINAL DATE: 10/01/20

Appendix D-1

Supporting Technical Memos

DILLON CONSULTING

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MEMO

TO: File
FROM: Ian Wilson, P.Eng.
DATE: April 28, 2018
SUBJECT: City of Windsor Sewer Master Plan – Field Conditions Survey and Desktop Analysis
OUR FILE: 17-6638

Dillon Consulting Limited (Dillon) and Aquafor Beech Limited (ABL) have been retained by the City of Windsor to complete the Master Plan for the City's sanitary, storm, combined and overland drainage systems. Project team members have started model development for the City of Windsor (City) Sewer Master Plan (MP) project. The following memo outlines the work completed by Dillon staff for the collection of existing conditions across Windsor. Work included analysis of catch basin inventory databases and GIS information, field investigation of downspouts, property grading, and curb/catch basin information.

1.0 Study Objectives

1.1 Field Survey Data Collection

Data was collected to define and characterize connections to the City's storm, sanitary and combined sewer systems. Following the September 2016 and August 2017 flooding events, it became necessary to investigate flood sources and existing conditions in areas exposed to heavy flooding. This data will be then used to determine remedial measures to mitigate basement and surface flooding.

1.2 Flow Monitoring and Hydraulic Modeling of the Sewer System (2016)

The City of Windsor experienced significant basement flooding during a rainfall event in June 2010. The purpose of the study was to collect sewer flow data over a period of 2 – 3 years and to develop a baseline calibrated model for each sewer system throughout the City. The calibrated model is to be used as a tool in assessing existing sewer systems for the Sewer Master Plan.

A field reconnaissance of the study area was conducted in the Summer/Fall of 2015 by the project team. The objective of the field study was to visually inspect a number of representative properties located throughout the City to determine the percentage of downspouts that discharge to the ground verses those that are directly connected to the sewer.

2.0 Desktop Data Analysis

2.1 Catch Basin Inventory

The City of Windsor provided two files defining the existing catchbasin inventory, including a shapefile with a georeferenced location, and an excel sheet with catchbasin meta data. Each catchbasin in the City has a unique Unit ID which is identified in both the shapefile attribute table and the excel table. The catchbasin shapefile had incomplete assessment of its identification of unit type. A properly identified list was developed within the shapefile data to better characterize existing conditions in the study areas. With the updated data source, the points from the shapefile could properly be separated by the type of catchbasin for future use.

2.2 Downspout Connection Data

Downspouts which discharge to the ground reduce inflow to sewer system. Several representative streets across the City of Windsor were selected to collect information on downspout connection. Data was collected on those selected streets by inspection on Google street view for the number of homes on the street, number of connected downspouts, number of disconnected downspouts, and number of downspouts which were not visible. The data collected for each representative area in this desktop study is shown in Appendix A.

3.0 Field Investigation

Following the collection and analysis of available digitized data, a field investigation was deemed necessary for collection of data that could potentially be inaccurate without visual inspection. A similar approach was taken in this field study to that done in the Flow Monitoring Study to expand on the area covered across the City. The areas selected for investigation were identified by high concentrations of flooding reports and by location of flow monitors/depth sensors. A map was created to ensure no overlap between areas previously investigated in Phase I and the areas investigated in Phase II. Roughly 55% of the City of Windsor's residential area has now been investigated within the current and previous studies.

The field work entailed the following: a count of the number of homes with downspouts disconnected, count of homes with driveway and lot grading towards house, identification of catchbasin type, grade of road and identification of significant local low point in road, and confirmation of shapefile identification of catchbasins in the area. The counts and observations from the field reconnaissance are summarized in Appendix B. During the investigation, photos were taken to illustrate the condition in each area primarily showing the street condition, curb condition, local catchbasins, lot/driveway grading, and roof leader connection. In Appendix C, three photos are displayed for each area investigated in the field including one of a disconnected downspout where runoff is shown discharging to grass areas or to the driveways, one of a connected downspout where runoff directly discharges to the sewer, and one of a representative catchbasin with curb conditions shown.

City of Windsor
17-6638

Downspout Connection Extent

THE CITY OF WINDSOR

100-90% DISCONNECTED	70-60% DISCONNECTED	40%-30% DISCONNECTED
90-80% DISCONNECTED	60-50% DISCONNECTED	30-20% DISCONNECTED
80-70% DISCONNECTED	50-40% DISCONNECTED	20-0% DISCONNECTED

FLOW MONITORING AND HYDRAULIC MODELING OF THE SEWER SYSTEM (2016)

DILLON CONSULTING

MAP CREATED BY: MRM
MAP CHECKED BY: IW
MAP PROJECTION: NAD 1983 UTM Zone 17N

0 0.375 0.75 1.5 2.25 3 km
SCALE 1:60000

FILE LOCATION: \\DILLON.CA\DILLON_DFS\LONDON\LONDON CAD\GIS\VISUAL COMMUNICATIONS DI\MXD TEMPLATES\BLUE - 11X17 LANDSCAPE - LEGEND BOTTOM.MXD

PROJECT: 17-6638

DATE: 03/14/18

Appendix A: Google Street View Investigation Data

Street Name	# of Homes	# Connected	# Disconnected	# Not Visible
Betts Avenue	36	5	21	10
Askin Avenue	48	28	6	14
Randolph Avenue	42	20	8	13
California Avenue	28	26	0	2
St. Clair Avenue	70	24	40	6
St. Patrick's Drive	68	29	36	3
Alexandra Avenue	44	5	21	18
Dandurand Blvd.	46	11	20	11
Virginia Park Avenue	39	11	19	9
Radison Avenue	29	12	15	2
Ducharme Street	103	45	35	23
Lynn Street	46	17	19	10
Lillian Avenue	53	28	17	8
Elsmere Avenue	161	46	85	31
Buckingham Drive	164	37	100	27
Westminister Blvd.	82	19	49	14
Jos St. Louis Avenue	110	41	45	24
Fairview Blvd.	145	22	110	13
Ridge Road	79	42	20	17
Eastcourt Drive	75	35	20	20
Venetian Avenue	105	30	75	0

Appendix B: Field Investigation Data

Street Name (Area)	# of Homes	# Connected	# Disconnected	# Not Visible
Caledon Court (1)	40	16	18	6
Proper grading of driveways and lots. One set of double grate catchbasins.				
Lambeth Road (1)	38	24	12	2
Clear positive lot/driveway grade.				
Rushton Drive (1)	71	41	27	3
Proper grading of driveways and lots.				
Halpin Road (2)	55	44	7	4
Proper grading of driveways and lots.				
Rosebriar Road (2)	25	19	6	0
Road redone recently. Low-positive driveway/lot grade.				
Pineview Crescent (2)	55	31	21	3
Proper grading of driveways and lots. One set of double grate catchbasins.				
Whistler Court (3)	50	21	29	0
Good grade. Most homes with one connected and one disconnected downspout.				
Treverton Crescent (3)	67	26	41	0
Good grade. Most homes with one connected and one disconnected downspout.				
Belleperche Place (4)	67	6	60	1
Overall positive lot/driveway grading.				
Belle Isle Blvd. (4)	64	6	52	1
Good slope to road from driveways. Curb inlet catchbasins identified on road.				
Matthew Brady Blvd. (4)	59	5	51	3
Positive lot/driveway grade. Low curb, curb inlet catchbasins at Tranby. Primarily disconnected to yard.				
Betty Drive (5)	39	14	25	0
Low positive grade of driveways/lots.				
Isack Drive (5)	31	10	20	1
Primarily flat driveways/lots. Few properties with lots appearing to go back to house.				
Genevieve Avenue (5)	44	14	28	2
Low to flat lots typically.				
Watson Avenue (6)	33	3	29	1
Positive lot/driveway grade. Primarily disconnected to yard. Curb inlet catchbasins.				
Laporte Avenue (6)	34	5	27	2
Low to no slope on lots.				

Street Name (Area)	# of Homes	# Connected	# Disconnected	# Not Visible
Frank Avenue (6)	31	21	8	2
Generally flat area with no grade. Few properties with clear negative grade.				
Arthur Road (7)	79	7	67	5
Mostly flat lots and driveways.				
Francois Road (7)	92	3	87	7
Overall good grade, only a few homes with flat lots/driveways.				
Labadie Road (8)	77	2	70	5
Proper grading. Good road/curb conditions.				
Malta Road (8)	44	2	42	0
Proper grading. Good road/curb conditions.				
Hickory Road (9)	122	38	79	5
Low/no curb. Good grade towards road.				
Cadillac Street (9)	123	20	100	3
Standard curb. Primarily disconnected downspouts to driveways with good grade.				
Hildegarde Street (10)	60	26	30	4
Low/no curb. Very low-no grade on driveways and lots. Some lots appear to slope to house. Lots of ponding seen on road and lots after a day of light rain.				
Charlotte Street (10)	48	15	30	3
Low/no curb. Very low-no grade on driveways and lots. Some lots appear to slope to house.				
Alexandrine Street (10)	32	20	8	4
No curb. Low-flat sloped driveways and lots.				
Vanier Street (10)	33	20	11	2
No curb. Poor lot and driveway grading. Some ponding on side of road.				
Dandurand Avenue (11)	46	10	34	2
Low grade and low curb.				
Rockwell Blvd. (11)	41	14	26	1
Curb Inlet catchbasin. Poor lot grading. Clear driveway slope to road.				
Radisson Avenue (11)	38	9	29	0
Positive drainage towards road is clear. Curb inlet and standard grate catchbasins.				
Everts Avenue (12)	29	8	28	1
Flat-positive driveway/lot grading.				
Curry Avenue (12)	31	12	19	
Suitable grading overall, a few poorly graded lots. Low curb with roll-lip grate catchbasins.				
Alexandra Avenue (13)	32	9	20	3
Poor driveway/lot grading, with noticeable slope to homes in several locations.				

Street Name (Area)	# of Homes	# Connected	# Disconnected	# Not Visible
Academy Drive (13)	62	18	42	2
Poor grading.				
California Avenue (14)	48	21	24	3
Flat-positive driveway/lot grading. Some homes have a disconnected and connected downspout.				
Askin Avenue (14)	46	34	4	8
Flat-positive driveway/lot grading.				
Azalia Crescent (15)	60	47	12	1
Good grade on driveways, low grade on lots.				
Candlewood Crescent (15)	51	3	46	2
Driveways sloped towards road with majority of downspouts disconnected to. Several homes have downspout lead to side of home with land appearing to slope towards back of home.				
Jessop Street (15)	36	7	28	1
Poor lot grading. Majority of homes have one downspout disconnected on side of the house and one connected in front of house.				
Rankin Avenue (16)	24	15	9	0
Low points of road clear at ends of street. Flat/no grade on driveways.				
Charlevoix Avenue (16)	47	13	34	0
Excellent grade, clear slope towards road.				
Radisson Avenue (17)	51	11	39	1
No/low curb. Poor lot grading.				
Church Street (17)	98	18	78	2
No curb, positive grade. One home with driveway slope towards home.				
Maisonneuve Avenue (17)	65	15	48	2
Positive grade to road.				

Appendix C: Field Photos

Area 1

Photo 1: Connected Downspout

Photo 2: Typical Lot/Driveway Grade

Photo 3: Disconnected Downspout

Area 2

Photo 4: Connected Downspout

Photo 5: Catchbasin/Typical Grade

Photo 6: Disconnected Downspout

Area 3

Photo 7: Disconnected Downspout

Photo 8: Connected Downspout

Photo 9: Curb and Catchbasin

Area 4


Photo 10: Disconnected Downspout


Photo 11: Curb and Catchbasin


Photo 12: Connected Downspout

Area 5

Photo 13: Disconnected Downspout

Photo 14: Curb and Catchbasin

Photo 15: Connected Downspout

Area 6

Photo 16: Connected Downspout

Photo 17: Curb and Catchbasin

Photo 18: Disconnected Downspout

Area 7

Photo 19: Connected Downspout

Photo 20: Curb and Catchbasin

Photo 21: Disconnected Downspout

Area 8


Photo 22: Disconnected Downspout


Photo 23: Curb and Catchbasin

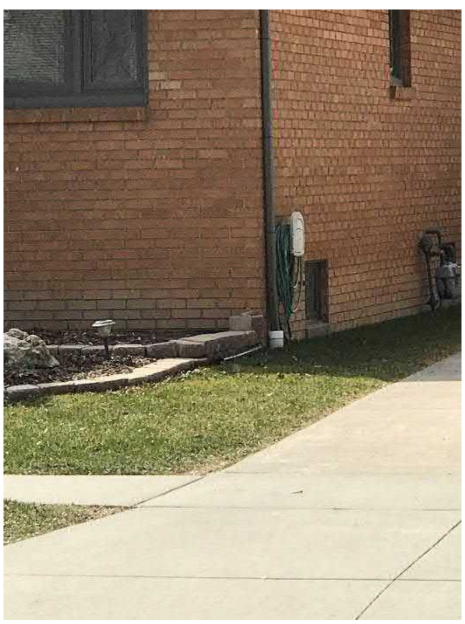


Photo 24: Connected Downspout

Area 9

Photo 25: Connected Downspout

Photo 26: Curb and Catchbasin

Photo 27: Disconnected Downspout

Area 10

Photo 28: Connected Downspout

Photo 29: Curb and Catchbasin

Photo 30: Disconnected Downspout

Area 11

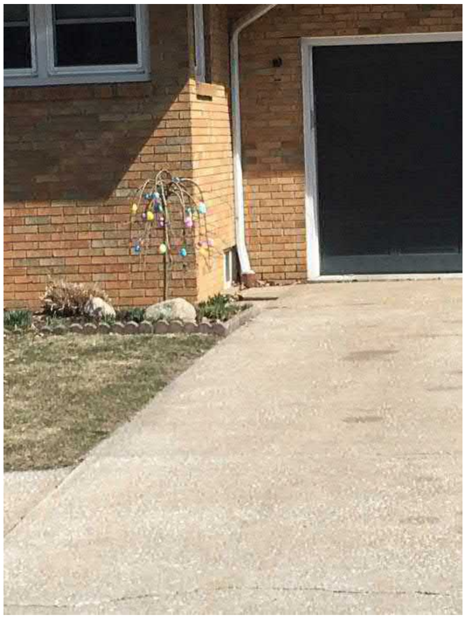


Photo 31: Connected Downspout

Photo 32: Curb and Catchbasin

Photo 33: Disconnected Downspout

Area 12

Photo 34: Connected Downspout

Photo 35: Curb and Catchbasin

Photo 36: Disconnected Downspout

Area 13

Photo 37: Connected Downspout

Photo 38: Curb and Catchbasin

Photo 39: Disconnected Downspout

Area 14

Photo 40: Connected Downspout

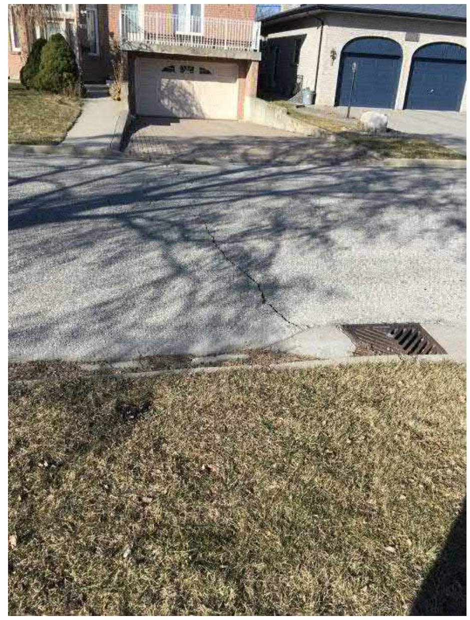


Photo 41: Curb, Catchbasin and Driveway Sloped to Home

Photo 42: Disconnected Downspout

Area 15

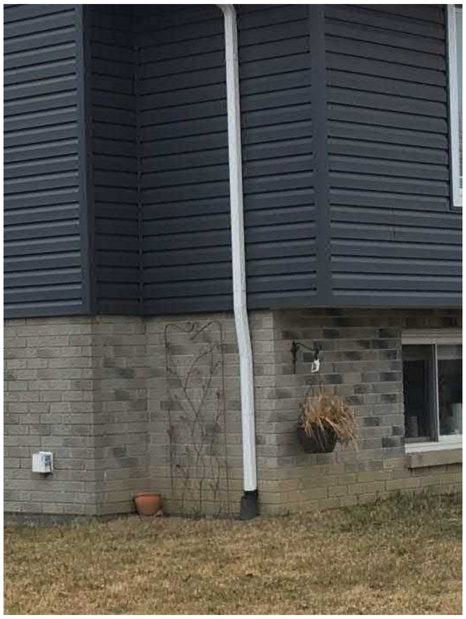


Photo 43: Connected Downspout

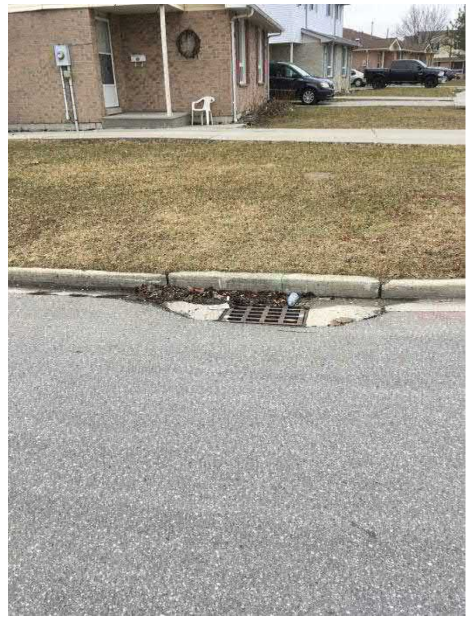


Photo 44: Curb and Catchbasin

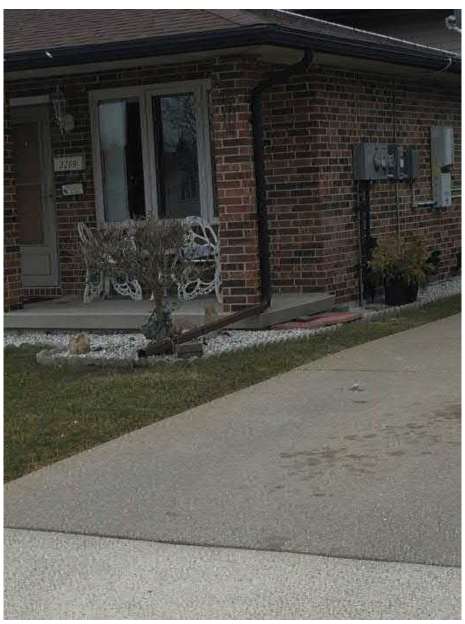


Photo 45: Disconnected Downspout

Area 16

Photo 46: Connected Downspout

Photo 47: Curb and Catchbasin

Photo 48: Disconnected Downspout

Area 17

Photo 49: Connected Downspout

Photo 50: Curb and Catchbasin

Photo 51: Disconnected Downspout

MEMO

DILLON CONSULTING

TO: File

FROM: Ian Wilson, P. Eng., M.A.Sc.

DATE: November 26, 2018

SUBJECT: City of Windsor Sewer Master Plan Phase II - Assessment of Historical Flood Vulnerability

OUR FILE: 17-6638

Project team members from both Dillon Consulting Limited (Dillon) and Aquafor Beech Limited (Aquafor Beech) met at the Dillon Windsor office on December 12th, 2017. The purpose of the meeting was to discuss next steps for the City of Windsor Sewer Master Plan Phase II project. Through these discussions, it was decided that Dillon would undertake an assessment of historical flood vulnerability within the study area. The purpose of this assessment is to identify and "pre-screen" for areas of particular concern where basement and surface flooding has been the most concentrated. This exercise will assist in focusing future modelling efforts and expansion of the existing Phase I model sewer network.

HISTORICAL RAINFALL ANALYSIS

Historical rainfall data was collected from the City of Windsor (City). A total of 14 monitoring stations were reviewed for this assessment and were found to contain rainfall observations from October 2012 to September 2017. Incremental rainfall depths were collected at 15 minute intervals at each station. The general locations of the monitoring stations are presented in Figures 1 and 2.

Peak annual rainfall events for the period of record (2012 – 2017) were examined. Table 1 below summarizes peak annual short-duration rainfall intensities for the period of record. This evaluation excludes 2012 which had only a few months of data and no significant rainfall events.

Table 1: Summary of Historical Intense Rainfall Events for Observation Period (2012 – 2017)

Event Date	Total Rainfall Accumulation (mm)	Approximate Storm Duration (hrs)
June 5th/6th, 2010*	116	24
April 11th, 2013	48	28
August 11th, 2014	93	13
June 27th, 2015	70	29
September 29th, 2016	100	37
August 27th, 2017	212	29

*Alternative data source used

The focus of this flood vulnerability assessment will be on the peak annual short-duration rainfall events for the years 2016 and 2017. These two events resulted in the highest rainfall accumulation for which a summary of homeowner basement flooding reports were provided by the City.

As shown in Table 1, the 2010 storm lasted approximately 24 hours and had a maximum measured rainfall amount of 116 mm at the Riverside Drive at Jeffereson Station. The most intense rainfall was between the hours of 11:00 p.m. on June 5 and 3:00 a.m. on June 6th. The intense rainfall was also accompanied by strong winds which caused tornados to the southeast of Windsor in the Leamington area.

The 2016 storm lasted over 24 hours and had a maximum measured rainfall amount of 100 mm at the Pontiac Pump Station. An estimated 66% of the rainfall at this location occurred within a three and a half hour time frame. An image representing the location of flooding calls with the location and amount of rain at the rain gauge stations can be found in Figure 1.

The 2017 storm lasted approximately 29 hours and had a maximum measured rainfall amount of 212 mm at the Huron Estates Pump Station. An estimated 60% of the rainfall at this location occurred within a three and a half hour time frame. An image representing the location of flooding calls with the location and amount of rain at the rain gauges can be found in Figure 2.

HISTORICAL FLOOD VULNERABILITY

Pre-screening of historically flood vulnerable areas has been completed to identify areas of concern for surface and basement flooding within the study area. This exercise focused on identifying priority areas for model development and expansion. This assessment considered the following data:

- Review of basement flooding records from 2016 and 2017 storm events;
- Review of surface flooding records from 2017 storm event;
- A high level review of older flood reports (2000 – 2011) was also completed despite the lack of high resolution rainfall records for these years; and
- Review of topographic data including low lying areas.

It is noteworthy flood data from 2000 to 2011 does not specify whether reports are of basement or surface flooding. Historical flood vulnerability was divided into three categories: low, medium and high. The extents of these areas are presented in Figure 3 for basement flooding. A comparison of basement and surface flooding for the 2017 rainfall event is shown in Figure 4.

Areas estimated to have a “high” degree of vulnerability contained dense clusters of basement flood reports during the 2016 and 2017 storm events. After delineating the highest concentrations of basement flood reports, it was found that the high risk areas corresponded to roughly 2 flood reports per hectare. However, some of the worst areas had densities as high as 50 – 60 reports per hectare. The areas delineated as high risk were found to contain roughly 93% of all basement flood reports (2016 and 2017) within approximately 31% of the total study area.

“Medium” risk areas were found to have significant basement flooding reports, but at a much lower density. The medium risk areas were found to have approximately 5% of total reports in roughly 18% of the study area. “Low” risk areas were found to contain only 2% of the basement flood reports in just over half (51%) of the study area.

It is important to note that the historical basement flood vulnerability assessment described above is specific to the 2016 and 2017 events. A high level review of pre-2011 reports was undertaken and found to be roughly consistent with the two most recent storms. The vast majority of these earlier reports were found to lie within the high and medium risk areas presented in Figure 3.

As shown in Figure 4, areas with a high density of basement flooding calls overlap with areas of reported surface flooding. This indicates some commonality in basement flood risk to surface flooding, most likely coinciding with predominately low-lying residential/commercial areas.

RECOMMENDATIONS

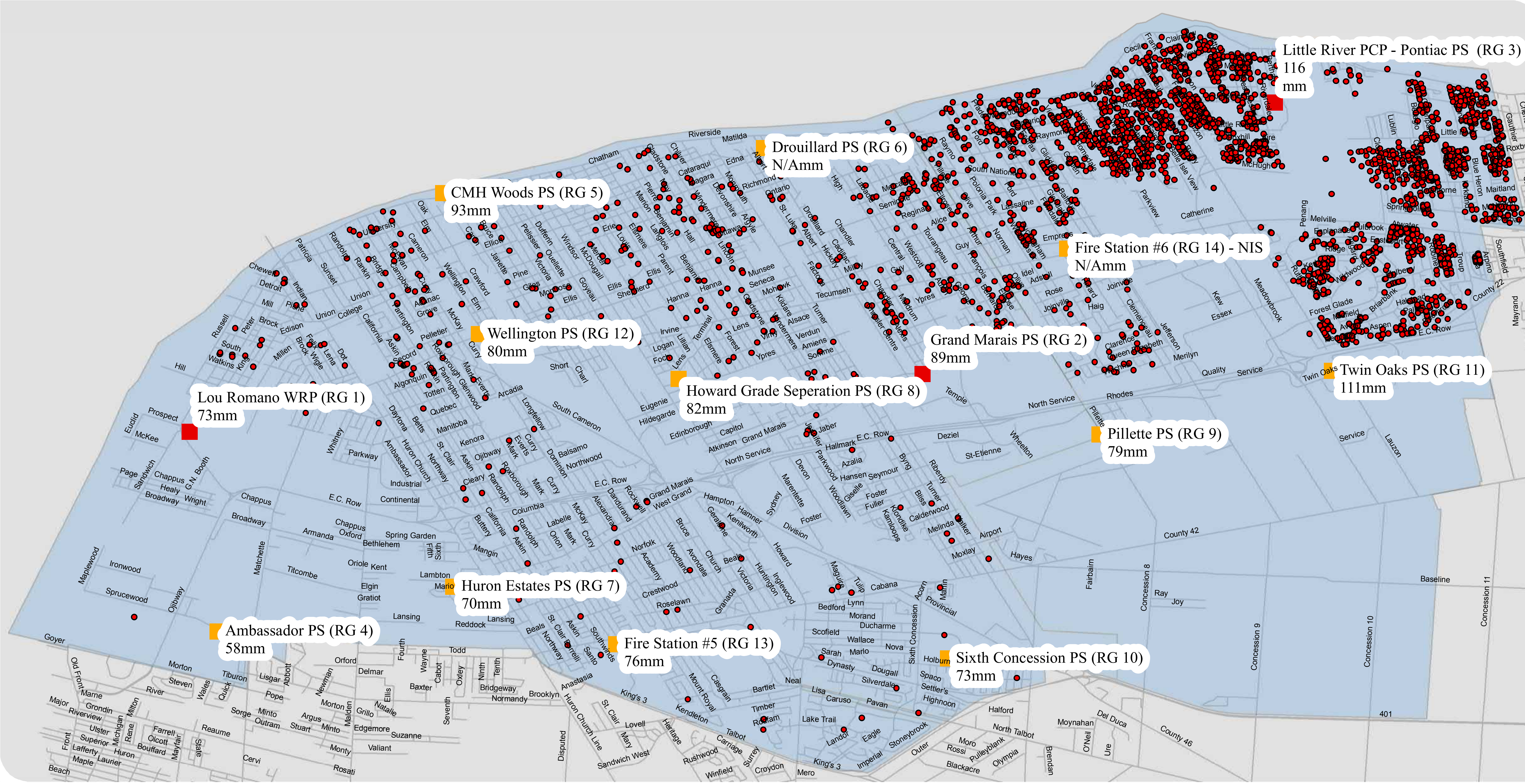
The assessment of historical basement and surface flood vulnerability described above is expected to be somewhat biased to flooding which occurred during the 2016 and 2017 events. It is possible that storms having different spatial/temporal rainfall distributions may impact flood vulnerability within the watershed.

To advance the assessment of flood vulnerability the following next steps are recommended:

- Flood reports for previous rainfall events would help to refine this assessment, particularly during the August 2014 event which was among the most intense during the observation period (92 mm in 13 hours).

- Historically vulnerable areas should be reviewed using the recently collected 2017 City LiDAR. This assessment should include the identification of existing overland conveyance routes, flow barriers and low-lying areas. Including these data in the flood vulnerability assessment will allow for a topographical assessment of flood vulnerability, independent of the temporal and spatial distribution of historical rainfall events.

- Further refinement of flood vulnerable areas based on watershed and conveyance boundaries is also recommended. Updated mapping of the sewer-shed, identifying high points and flow direction should be used to support this assessment.



CITY OF WINDSOR
MASTER SEWER PLAN

2016 FLOOD REPORT AND RAIN GAUGE MAP
FIGURE 1

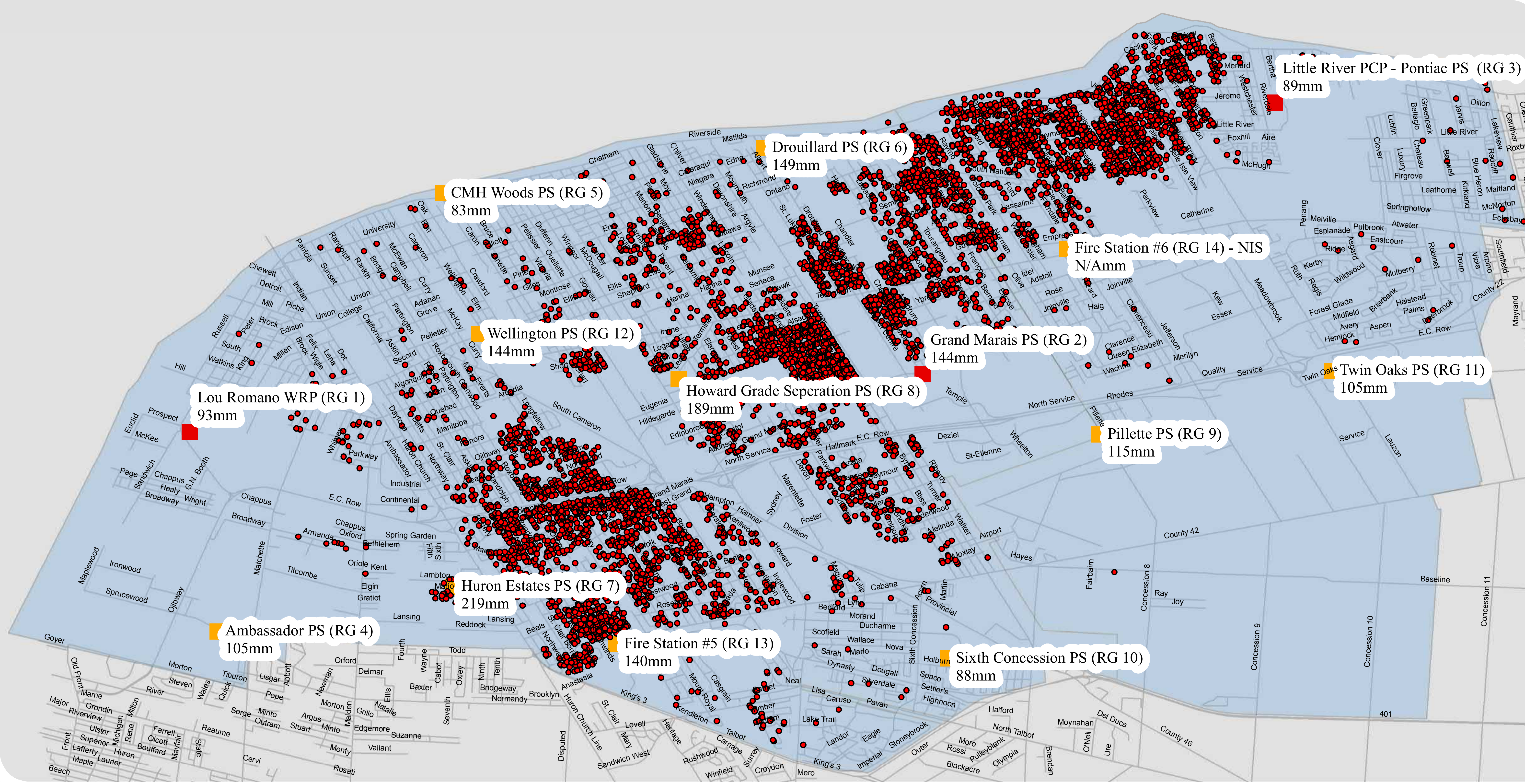
THE CITY OF WINDSOR

PRIMARY RAIN GAUGES
SECONDARY RAIN GAUGES
FLOODING CALLS SEPTEMBER 28/29 2016

DILLON CONSULTING

MAP PROJECTION: NAD 1983 UTM Zone 17N

PROJECT: 17-6638 STATUS: DRAFT DATE: DEC/17



PRIMARY RAIN GAUGES

SECONDARY RAIN GAUGES

FLOODING CALLS AUGUST 28/29 2017

CITY OF WINDSOR

MASTER SEWER PLAN

2017 FLOOD REPORT AND RAIN GAUGE MAP

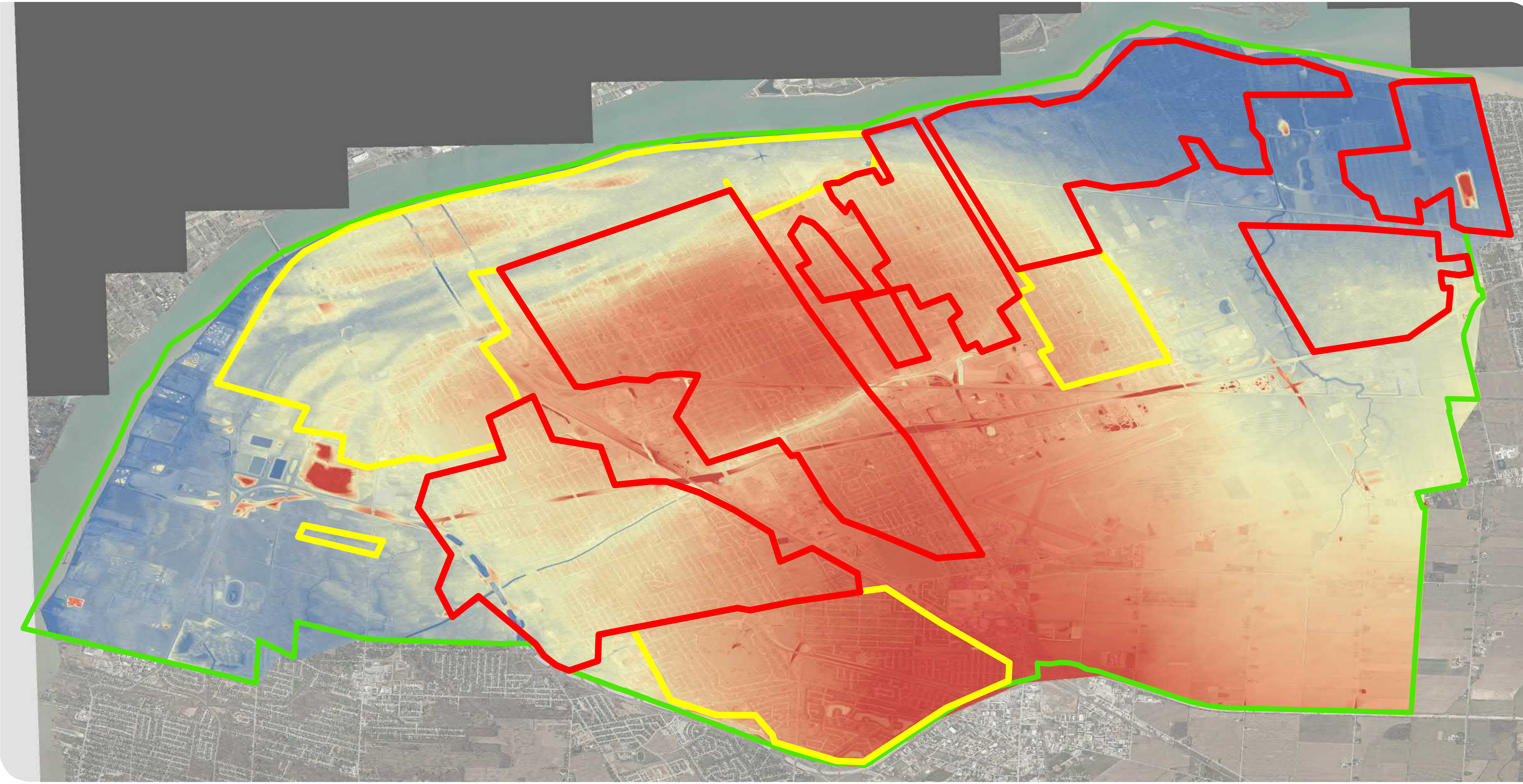
FIGURE 2

THE CITY OF WINDSOR

DILLON CONSULTING

MAP PROJECTION: NAD 1983 UTM Zone 17N

PROJECT: 17-6638 STATUS: DRAFT DATE: DEC/17



CITY OF WINDSOR
MASTER SEWER PLAN

TOPOGRAPHIC FLOOD VULNERABILITY MAP

FIGURE 3

Low-Lying Bounded Areas

High : 213 m

Low: 171 m

High Flood Vulnerability

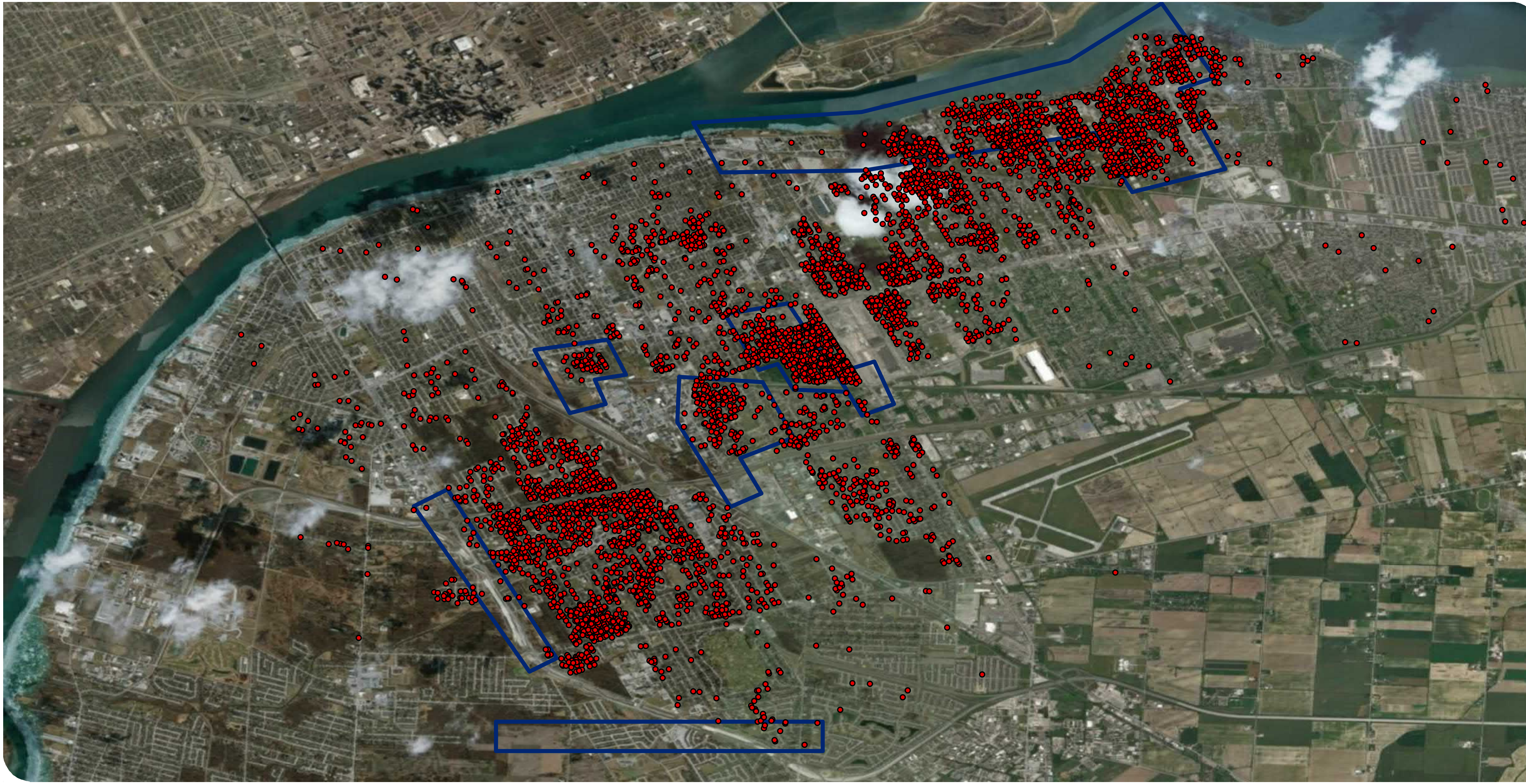
Medium Flood Vulnerability

Low Flood Vulnerability

DILLON CONSULTING

MAP PROJECTION: NAD 1983 UTM Zone 17N

PROJECT: 17-6638 STATUS: DRAFT DATE: DEC/17



CITY OF WINDSOR
MASTER SEWER PLAN

2017 BASEMENT AND SURFACE FLOODING

FIGURE 4

Surface Flooding 2017

Basement Flooding 2017

DILLON CONSULTING

MAP PROJECTION: NAD 1983 UTM Zone 17N

N W E S

0 0.5 1 2 3 Kilometers

PROJECT: 17-6638 STATUS: DRAFT DATE: MARCH 2018

MEMO

TO: File

FROM: Ian Wilson, P.Eng.

DATE: January 24, 2018

SUBJECT: City of Windsor Sewer Master Plan Phase II - Storm Sewer System Model Development

OUR FILE: 17-6638

Project team members from both Dillon Consulting Limited (Dillon) and Aquafor Beech Limited (ABL) have started model development for the City of Windsor (the City) Sewer Master Plan (MP) Phase II project. Dillon and ABL have divided the study area for model development. The following memo outlines the work completed by Dillon staff for the storm conveyance system.

Conduits and Manholes

The existing model consists of conduits that are 600 mm in diameter and larger. A small portion of conduits smaller than the specified size were previously added based on location and necessity in the model. The new Phase II InfoWorks model will consider conduits that are 375 mm in diameter and larger, with the addition of smaller conduits based on location and necessity in the model.

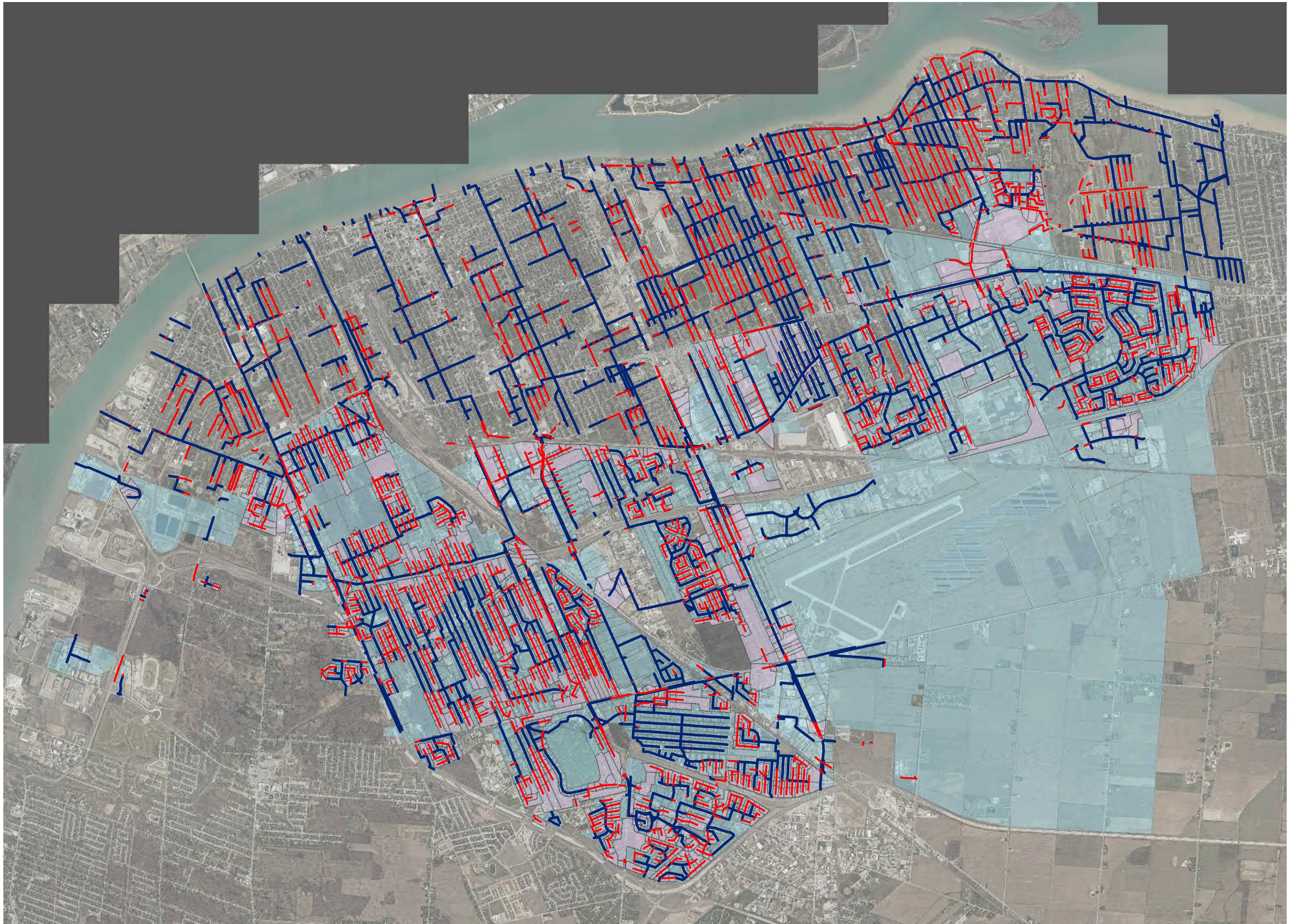
The first step in model development was to export the conduits and manholes from the existing Phase I model. These InfoWorks shapefiles were then brought into ArcMap for model development. To prepare the shapefiles, shapefiles from the City were overlapped with InfoWork shapefiles. All repeated conduits and manholes (i.e. conduits/manholes that have already been input into InfoWorks) were deleted. New pipes that were smaller than 375 mm were also deleted. However, in areas outlined as high to medium flood vulnerability, some pipes smaller than 375 mm were left.

Subcatchments

Similar to conduit and manhole development, subcatchment shapefiles were brought into ArcMap from InfoWorks. Absolute area was converted into percentage area prior to cutting the subcatchments. The subcatchments were then cut on a manhole to manhole level to include the addition of the new conduits from 375-600 mm. For consistency, ABL and Dillon have decided to name the new subcatchments as ‘Name_#’. For example, if a subcatchment was previously named ‘831641’ and was split into two new catchments, they would be named “831641_1’ and ‘831641_2’.

It is noteworthy that a boundary was created by Dillon that outlined the full extent of land that has been developed. This boundary has been sent to ABL to ensure that no area is missed when connecting the two developed areas back into one InfoWorks model.

The next step will be to complete similar steps as above for both the combined and the sanitary systems. Once all systems have been developed, shapefiles will be brought back into InfoWorks.



The City of Windsor
Master Plan

Storm System Development Update
Figure 1

- New Storm Conduits
- Existing Storm Conduits
- New Storm Subcatchments
- Existing Storm Subcatchments

0 0.5 1 2 km

N W E S

MAP DRAWING INFORMATION:
DATA PROVIDED BY COW

MAP CREATED BY: JB
MAP CHECKED BY: IW
MAP PROJECTION: NAD 1983 UTM Zone 17N

DILLON CONSULTING

PROJECT: 17-6638
STATUS: DRAFT
DATE: 08/24/11

MEMO

TO: File
FROM: Ian Wilson, P.Eng.
DATE: February 22, 2018
SUBJECT: City of Windsor Sewer Master Plan Phase II - Sanitary Sewer System Model Development
OUR FILE: 17-6638

Project team members from both Dillon Consulting Limited (Dillon) and Aquafor Beech Limited (ABL) have started model development for the City of Windsor (the City) Sewer Master Plan (MP) Phase II project. Dillon and ABL have divided the study area for model development. The following memo outlines the work completed by Dillon staff for the sanitary conveyance system.

Conduits and Manholes

The existing model consists of conduits that are 375 mm in diameter and larger. A small portion of conduits smaller than the specified size were previously added based on location and necessity in the model. The new Phase II InfoWorks model will consider existing conduits plus all conduits that are 300 mm in diameter and a number of 250 mm conduits, with the addition of smaller conduits based on location and necessity in the model. 250 mm conduits were chosen based on areas of high flood vulnerability. See vulnerability memo for more information.

The first step in model development was to export the conduits and manholes from the existing Phase I model. These InfoWorks shapefiles were then brought into ArcMap for model development. To prepare the shapefiles, shapefiles from the City were overlapped with InfoWorks shapefiles. All repeated conduits and manholes (i.e. conduits/manholes that have already been input into InfoWorks) were deleted. New pipes that were smaller than 300 mm were also deleted. However, in areas outlined as high to medium flood vulnerability, some pipes smaller than 300 mm were included.

Subcatchments

Multiple layers of sanitary subcatchments are used for this model. The three layers are dry weather flow (DWF), foundation drains (FD) and connected roofs (CR). All layers have the same shape and area but different attributes. Subcatchment naming conventions are FD_##, DWF_##, and CR_## where the number is the same for overlapping areas.

Similar to conduit and manhole development, subcatchment shapefiles were brought into ArcMap from InfoWorks. Absolute area was converted to percent area prior to cutting of subcatchments. The subcatchments were then cut on a manhole to manhole level to include the addition of the new conduits. For consistency, ABL and Dillon have decided to name the new subcatchments as ‘Name_#’. For example, if a subcatchment was previously named ‘831641’ and was split into two new catchments, they would be named ‘831641_1’ and ‘831641_2’.

DWF catchments include a population. To calculate the population for the subdivided subcatchments, prorated values were taken based on the new area. Special attention was given to land development of the new subcatchment areas. For example, if an existing subcatchment was half vegetation and half developed and was divided into two new subcatchments where one was all developed and one was all vegetation, the population would not be prorated. A population of 0 would be given to the vegetated area and the full amount would be given to the developed area. A new area was calculated for DWF, FD and CR subcatchments. Total existing and future model areas and populations were compared. It is noteworthy, a 0.1% decrease in area was found for FD and CR, while a negligible change was found in population and DWF areas.

It is important that subcatchments drain to the correct node. To update this attribute to include new subcatchments and nodes, the shapefiles were brought into Computational Hydraulic International (CHI) (PCSWMM) modelling software which automatically selects the closest node to the centroid of the subcatchment. A QA/QC was then complete to verify the program chose the correct node. The node Id was then copied into the InfoWorks model.

It is noteworthy, that a boundary was created by Dillon that outlined the full extent of land that has been developed. This boundary has been sent to ABL to ensure that no area is missed when connecting the two developed areas back into one InfoWorks model.

The next step will be to complete similar steps as above for the combined system. Once all systems have been developed, shapefiles will be brought back into InfoWorks.

MEMO

TO: File

FROM: Ian Wilson, P.Eng.

DATE: February 26, 2018

SUBJECT: City of Windsor Sewer Master Plan Phase II - Combined Sewer System Model Development

OUR FILE: 17-6638

Project team members from both Dillon Consulting Limited (Dillon) and Aquafor Beech Limited (ABL) have started model development for the City of Windsor (the City) Sewer Master Plan (MP) Phase II project. Dillon and ABL have divided the study area for model development. The following memo outlines the work complete by Dillon staff for the combined conveyance system.

Conduits and Manholes

The existing model consists of conduits that are 375 mm in diameter and larger. A small portion of conduits smaller than the specified size were previously added based on location and necessity in the model. The new Phase II InfoWorks model will consider existing conduits plus all conduits that are 300 mm in diameter.

The first step in model development was to export the conduits and manholes from the existing Phase I model. These InfoWorks shapefiles were then brought into ArcMap for model development. To prepare the shapefiles, shapefiles from the City were overlapped with InfoWorks shapefiles. All repeated conduits and manholes (i.e. conduits/manholes that have already been input into InfoWorks) were deleted. New pipes that were smaller than 300 mm were also deleted.

Subcatchments

Multiple layers of combined subcatchments are used for this model. The four layers are wet weather flow (WWF), dry weather flow (DWF), foundation drains (FD) and connected roofs (CR). All layers have the same shape and area but different attributes. Subcatchment naming conventions are WWF_##, DWF_##, FD_##, and CR_## where the number is the same for overlapping areas.

Similar to conduit and manhole development, subcatchment shapefiles were brought into ArcMap from InfoWorks. Absolute area was converted to percent area prior to cutting of subcatchments. The subcatchments were then cut on a manhole to manhole level to include the addition of the new conduits. For consistency, ABL and Dillon have decided to name the new subcatchments as ‘Name_#’. For example, if a subcatchment was previously named ‘831641’ and was split into two new catchments, they would be named ‘831641_1’ and ‘831641_2’.

WWF catchments included a dimension attribute. This attribute represents the flow length. This was calculated based on pipe length and land cover type. The following equation was used to calculate the flow length:

$$\text{Flow path length} = (2/3)l + L$$

Where: L = storm sewer segment length
l = length of building lot

Where: Residential l = 40 m
Institutional l = 200 m
Office l = 100 m
Commercial l = 60 m
Warehouse l = 150 m
Industrial l = 150 m
Open Space = 200 m

DWF catchments include a population. To calculate the population for the subdivided subcatchments, pro-rated values were taken based on the new area. Special attention was given to land development of the new subcatchment areas. For example, if an existing subcatchment was half vegetation and half developed and was divided into two new subcatchments where one was all developed and one was all vegetation, the population would not be prorated. A population of 0 would be given to the vegetated area and the full amount would be given to the developed area. A new area was calculated for DWF, FD and CR subcatchments. Total existing and future model areas and populations were compared. It is noteworthy, a 0.1% decrease in area was found for FD and CR, while a negligible change was found in population and DWF areas.

It is important that subcatchments drain to the correct node. To update this attribute to include new subcatchments and nodes, the shapefiles were brought into Computational Hydraulic International (CHI) (PCSWMM) modelling software which automatically selects the closest node to the centroid of the subcatchment. A QA/QC was then complete to verify the program chose the correct node. The node Id was then copied into the InfoWorks model.

It is noteworthy, that a boundary was created by Dillon that outlined the full extent of land that has been developed. This boundary has been sent to ABL to ensure that no area is missed when connecting the two developed areas back into one InfoWorks model.

The next step will be to complete similar steps as above for the combined system. Once all systems have been developed, shapefiles will be brought back into InfoWorks.

MEMO

DILLON CONSULTING

TO: File
FROM: Sarah Zaarour, EIT
DATE: September 21, 2018
SUBJECT: City of Windsor Sewer Master Plan – Downspout Disconnection Reports
OUR FILE: 17-6638

Dillon Consulting Limited (Dillon) was retained by the City of Windsor to complete the City's Sewer Master Plan which includes sanitary sewers, storm sewers, combined sewers and overland drainage systems. The following memo contains summaries of studies and reports reviewing the potential benefits of disconnecting downspouts. The reports within this memo have been organized by date completed.

1. Adaptation of a Storm Drainage System to Accommodate Increased Rainfall Resulting From Climate Change

Darren Waters, W. Edgar Watt and Bruce C. Anderson, November 2002

This study was completed by the department of Civil Engineering at Queens University and published in the Journal of Environmental Planning and Management in September 2003. The study reviewed the impact of a 15% increase in design rainfall intensities on a typical urban catchment to investigate adaptive measures. The study area evaluated was the Malvern Catchment in Burlington, Ontario. A calibrated model (PCSWMM 2000) was used to: (1) determine the system performance under current and climate-changed design rainfalls; and (2) calculate the magnitudes of various adaptive measures required to reduce the peak discharge to current levels.

The principal findings were as follows:

- General Circulation Model results indicate that rainfall intensity is expected to increase by 10% to 20% over Southern Ontario within the next 100 years. For the purpose of this study, an assumed increase in rainfall intensities of 15% was applied to an urban stormwater simulation model.
- Rainfall input 15% higher than the current two-year, one-hour storm was applied in conjunction with the Malvern SWMM model. Increase in rainfall resulted in a 19% increase in runoff volume, and a 13% increase in peak discharge, causing 24% of the pipes in the catchment to surcharge.
- Three retrofit options were analyzed for the Malvern urban catchment: disconnection of full/half roof area, providing peak discharge reductions of 39% and 18% respectively, increase in surface storage by 45 m^3 per impervious hectare to provide a peak discharge reduction of 14%, and reduction in the rate of stormwater inputs to the sewer system by providing 40 m^3 of surface storage per impervious hectare on the streets to reduce the peak discharge by 13%.

2. Evaluation of Low Impact Development Stormwater Technologies and Water Reuse Options for the Lake Simcoe Regions

James Li, Douglas Banting, Darko Joksimovic, and Mike Walters, 2010

This report was completed by Ryerson University in conjunction with the Lake Simcoe Region Conservation Authority (LSRCA). The project's goals were to: identify opportunities for implementing low impact development technologies (LID) and water reuse options, planning level quantification of the benefits provided in terms of reduced nutrient loadings to Lake Simcoe, and provide guidance to municipalities within the watershed.

Phase I of the project compiled all the existing data, information, and LIDs in GIS format. Phase II carried out a more detailed study of the usage of LIDs identified in Phase I as being potentially suitable, evaluated the best combinations of LID (and their placement), and quantified preliminary costs for implementation. Downspout disconnections were considered a common lot-level LID practice. Additionally, the effects of future development and climatic changes on the overall efficiency of solutions were evaluated. The study findings indicate that the implementation of the feasible LIDs such as bio-retention cell, rainwater harvesting, greenroof, and downspout disconnection could potentially reduce the nutrient loading from the uncontrolled study area by about 10% to 20%.

3. The Wingham Rain Barrel Study

Insurance Bureau of Canada (IBC) and the Township of North Huron, June 2011

This study was conducted in the Wingham, Ontario, between 2009 and 2011. Wingham is part of the Township of North Huron and is located within the Maitland watershed and is in the southwestern part of the Province on Lake Huron. The pilot was used to determine the challenges and the impact on water system infrastructure after installing a rain barrel at the majority of households in a community to manage stormwater runoff.

Rain barrels were monitored and analyzed by IBC and were distributed free of charge to residents. The Town of Wingham has a combined sewer overflow system, so when rain barrels were installed, 70% of the homeowners also had their downspouts disconnected from the sewer system. As a result, there was a 26% reduction in the ratio of rainwater to volume of water pumped at the sewer treatment plant between 2008 and 2009 and 5% reduction between 2009 and 2010. It was recommended that a mechanism be installed to the rain barrels in the future to guarantee they are drained before another rainfall event. The project was considered to be successful.

4. Hydrologic Modeling Analysis of a Passive, Residential Rainwater Harvesting Program in an Urbanized, Semi-Arid Watershed

Thomas C. Walsh, Christine A. Pomeroy, Steven J. Burian, Journal of Hydrology, November 7, 2013

This paper presents the results of a long-term, continuous hydrologic simulation analysis of a watershed-scale residential rainwater harvesting (RWH) program in the Chollas Creek watershed, San Diego, California, USA. The U.S. Environmental Protection Agency's Storm Water Management Model (SWMM) simulated rainfall-runoff responses for variations in a RWH network, including the RWH unit storage size, the number of implementing households, the amount of time before a unit is allowed to release captured runoff (i.e. drain delay), and the time it takes for the unit to drain (i.e. coefficient of discharge).

Comparison of results found reductions to increase linearly with capacity and implementation. Maximum long-term watershed volumetric reductions between 10.1% and 12.4% were observed for the period of analysis (1948–2011) with a range of RWH storage sizes (227 L barrels to 7571 L cisterns). The ratio of overflow to underdrain flow, ranging from 5.17 to 0.014 (227–7571 L), exhibits the ability of cisterns to fully capture the majority of annual and long-term events. Sensitivity analysis found regional precipitation characteristics and disconnection of rooftop runoff to impact long-term watershed reduction potential more so than available RWH capacity.

Normalization of net present value (NPV) to volumetric reductions yielded a RWH unit cost of $0.20–$1.71 per 1000 L of watershed runoff reduced on average per year. Minor variations in cost based on the extent of watershed implementation highlights the potential to incrementally institute RWH programs. For the case study location, the 227-L rain barrel provided the greatest cost-effectiveness, reducing an average 6500 L of runoff per dollar invested for the analysis period.

5. Evaluating the Performance of Disconnected Downspouts on Existing and Amended Lawns as a Stormwater Control Measure

N.B. Carmen, W.F. Hunt, and A.R. Anderson, 2014

This report was published by North Carolina State University in 2014. The study compiles data from four paired residential downspout disconnection studies in Durham, North Carolina. The data collection spans two study periods. In the initial study period (January – October 2013), each site was designed to compare the performance of disconnected downspouts releasing water over lawns for one of three varying conditions: slope of lawn, length of lawn, or contributing roof area. Analysis of data from the initial study period shows 59 – 99% total volume reduction. The second study period (January – September 2014) will analyze the impact of tilling and soil amendments on the performance of downspout disconnection (DSD).

Based on findings from the initial nine-month study period, downspout disconnection appears to be an effective stormwater control measure. Upon implementation on the watershed scale, this can have huge impacts on the health of receiving water bodies. The large volume reduction during storm events will alleviate the strain on streams to contain high velocities and allow for municipal stormwater systems to more effectively treat the design storm. Additional research is needed on the effectiveness of DSD in other climates and site conditions, but municipalities should continue efforts to incorporate DSD in stormwater master plans and encourage homeowners to utilize existing lawn areas for on-site stormwater treatment.

6. Assessment of Downspout Disconnection by Modeling Infiltration Potential in Urban Areas

Mareike Anika Becker, Norwegian University of Science and Technology, June 2016

This thesis investigates the effect of downspout disconnection as a measure for stormwater management. To identify how soil parameters affect the amount of infiltration, simulations were completed with varied soil parameter inputs.

By comparing the soil types at the sites and the ratio between the size of the roof area and the size of the infiltration area, the following is suggested. If the soil at the site is sandy and the infiltration area is one to twice as big as the roof area, it can be assumed that the infiltration capacity is good enough to infiltrate the amount of generated stormwater. Dependent on the soils ability to infiltrate water, it may be enough that the infiltration area is one to twice as big as the roof area, but this should be considered especially if the soils saturated hydraulic conductivity is a lower value. Whether this soil has a large enough infiltration capacity or not is dependent on the percentage of silt and sand fraction in the soil. The results obtained in this thesis, shows that by disconnecting the downspouts from the sewer system, the reduction of amount of stormwater can be significant, where the soil properties are adequate. Downspout disconnection is therefore evaluated as a measure that should be considered in areas where stormwater management is a challenge.

7. Residential Stormwater Management Pilot Project Downspout Redirection Project

Andee Pelan, Lake Simcoe Conservation Authority, 2017

This report examines the practicality of a downspout redirection program, which aims to redirect downspouts away from impervious surfaces towards areas where infiltration can occur. By redirecting the downspouts to nearby pervious areas, it will reduce overall stormwater volumes in residential areas at a fairly low cost. The project study area consisted of a single catchment in Barrie, Ontario. Site surveys concluded a majority of disconnected downspouts were directed onto impervious area (i.e. driveways, walkways).

Two methods were examined to entice homeowners to redirect their downspouts to a pervious area. The first approach investigated the effectiveness of using outreach methods to elicit voluntary homeowner action. The second approach involved offering landowners an incentive to redirect their downspouts at no cost to the homeowner. Cost-effectiveness was determined by comparing stormwater volume reduction per m^3 to the cost of running the program. Two types of stormwater volume reduction projects occurred: (A) direct to subsurface infiltration trenches and (B) direct to lawns/permeable surfaces where at least 70% of rooftop runoff will infiltrate when the maximum rainfall depth (25 mm) is considered. Overall, it was determined that the 24 infiltration trench projects had a depth reduction of 476 mm/year and the 6 overland downspout extensions had a depth reduction of 420 mm/year.

Summary and Conclusions

A summary of the reviewed studies and reports is presented in **Table 1**. Disconnection of downspouts, directed to pervious surface (i.e. lawns) can reduce total inflow to the receiving sewer system(s). Disconnection was found to be most effective when discharging to sandy soils with at least 1 to 2 times the area of the roof. The reduction in sewer inflow was more evident in smaller storm events. Coupling the disconnected downspout with a rain barrel (if emptied when full) or infiltration trenches could further reduce sewer inflow.

Table 1: Summary of Findings

Report Number	Date Published	Key Points

1	November 2002	• Full roof downspout disconnection showed a 39% reduction in peak discharge:
		  • 15% increase in rainfall intensity used to represent climate change in 1:2 year 1 hour model.
		  • Increase in rainfall intensity showed a 13% increase in peak discharge.

2	2010	• LIDs such as bio-retention cell, rainwater harvesting, greenroof, and downspout disconnection could potentially reduce the nutrient loading from the uncontrolled study area by about 10 to 20%.
3	June 2011	• 26% reduction in the ratio of rainwater to volume of water pumped at the sewer treatment plant between 2008 and 2009 and 5% reduction between 2009 and 2010: • 70% of downspouts were disconnected and rain barrels were added.
4	November 2013	• Maximum long-term watershed volumetric reductions between 10.1% and 12.4% were observed for the period of analysis (1948–2011) with a range of rainwater harvesting storage sizes (227 L barrels to 7571 L cisterns).
5	2014	• Overall median performance of all monitored DSD systems was 75% cumulative volume reduction over the course of nine months.
6	June 2016	• Disconnecting downspouts from the sewer system, can reduce the amount of stormwater significantly, where the soil properties are adequate.
7	2017	• 24 infiltration trenches had a depth reduction of 476 mm/year and the 6 overland downspout extensions had a depth reduction of 420 mm/year. • Maximum rainfall depth considered was 25 mm.

Appendix D-2

2018 Flow Monitor Installations

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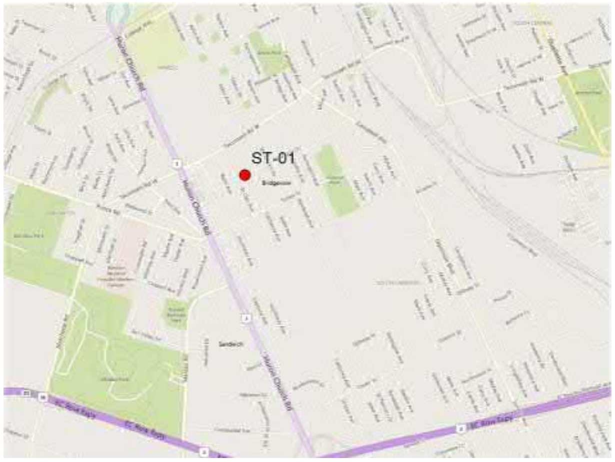
ST-01: MH 8R4234: Flow Monitor Installation



Map

Birdseye

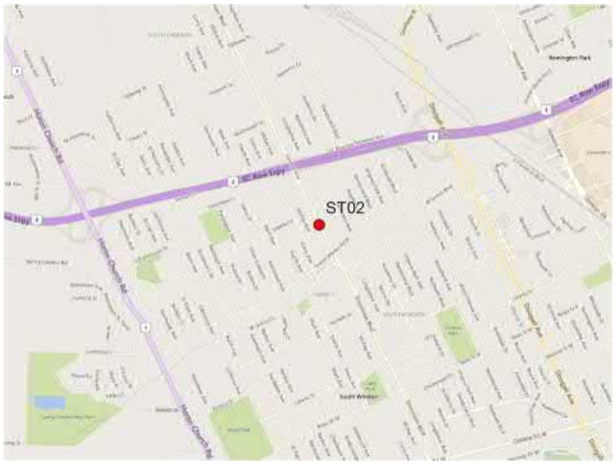
Inflow

Monitor

Outflow

Sensors

ST-02: Flow Monitor Installation



Map

Birdseye

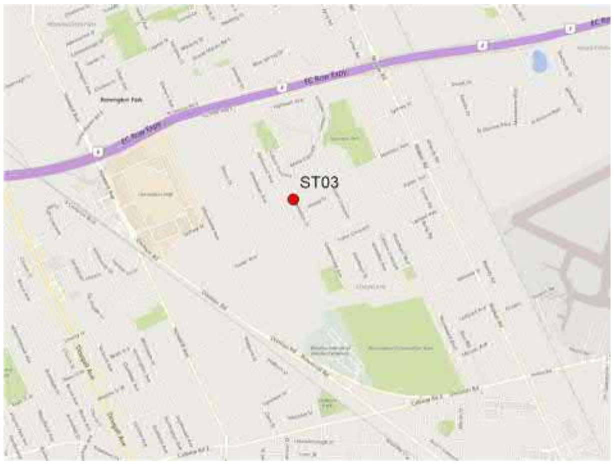
Inflow

Monitor

Outflow

Sensors

ST-03: MH : Flow Monitor Installation



Map

Birdseye

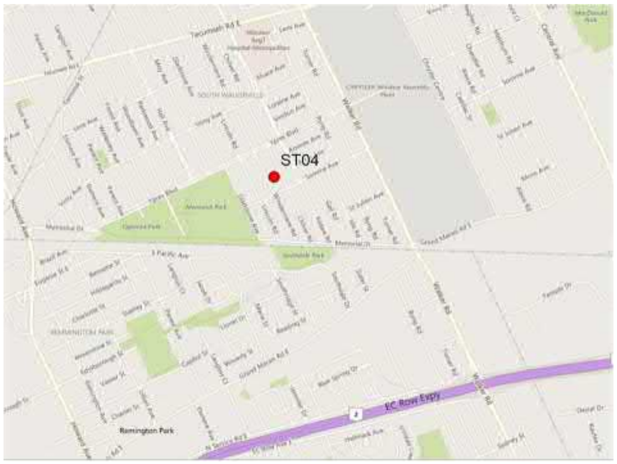
Inflow

Monitor

Outflow

Sensors

ST-04: MH : Flow Monitor Installation



Map

Birdseye

Inflow

Monitor

Outflow

Sensors

ST-05: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

ST-06: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

ST-07: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

ST-08: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

ST-09: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

ST-10: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-01: MH : Flow Monitor Installation

Map

Birdseye

Inflow

Monitor

Outflow

Sensors

SA-02: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-03: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-04: MH : Flow Monitor Installation

Map

Birdseye including Flume

Inflow

Monitor

Outflow

Sensors

SA-05: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-06: MH : Flow Monitor Installation

Map

Birdseye including Flume

Inflow

Monitor

Outflow

Sensors

SA-07: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-08: MH : Flow Monitor Installation

Map

Birdseye include Flume

Inflow

Monitor

Outflow

Sensors

SA-09: MH : Flow Monitor Installation

	
Map	Birdseye
	
Inflow	Monitor
	
Outflow	Sensors

SA-10: MH : Flow Monitor Installation

Map

Birdseye

Inflow

Monitor

Outflow

Sensors

Appendix D-3

Surface Flooding Photos

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City of Windsor Storm Flooding Photos – September 29-30, 2016

Riverside Dr. between Buckingham and St. Rose

Riverside Dr. between Buckingham and St. Rose

Aspen Lake

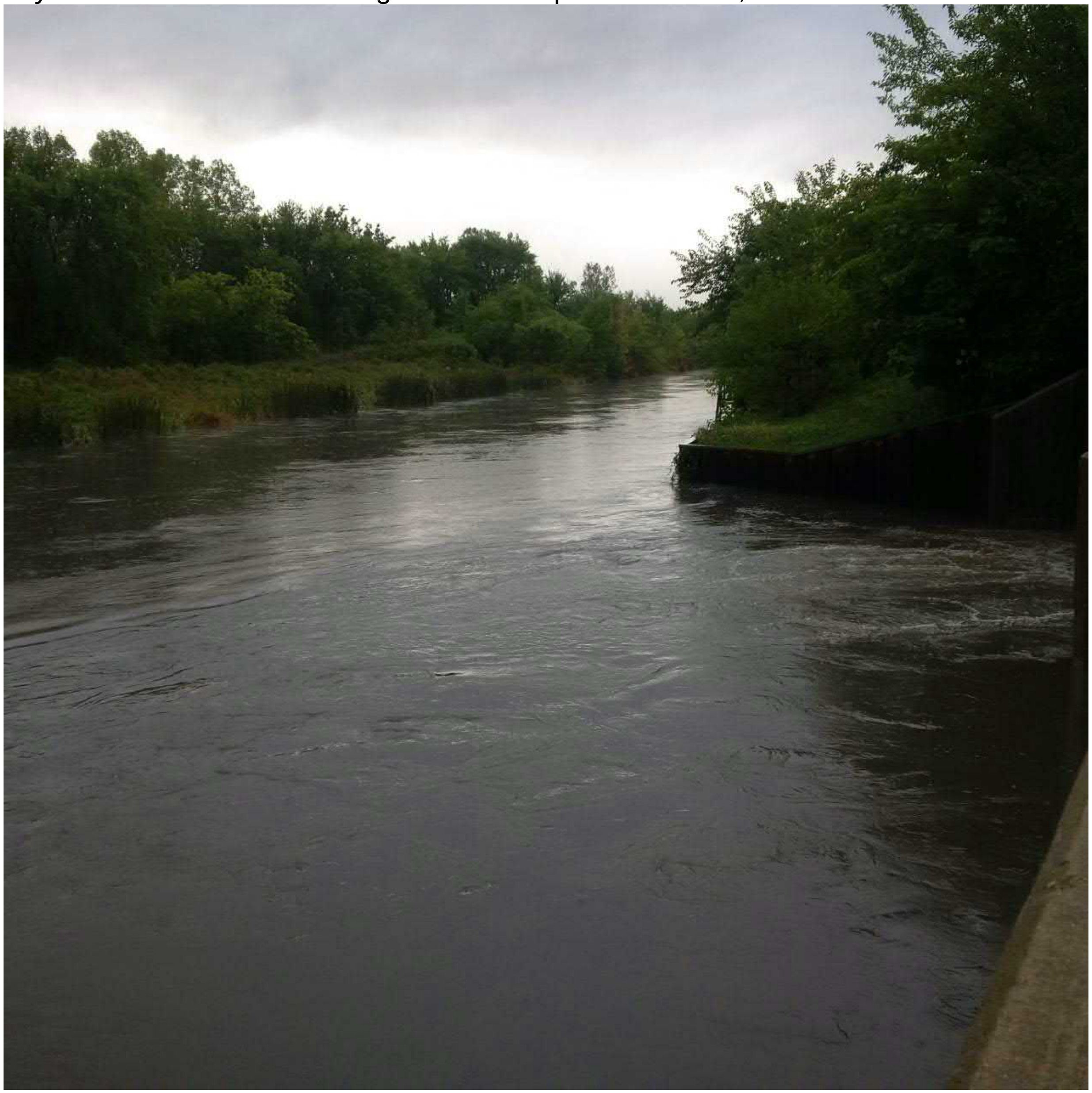
Aspen Lake

Aspen Lake

Little River – taken from McHugh St. bridge looking north

Little River – taken from McHugh St. bridge looking north

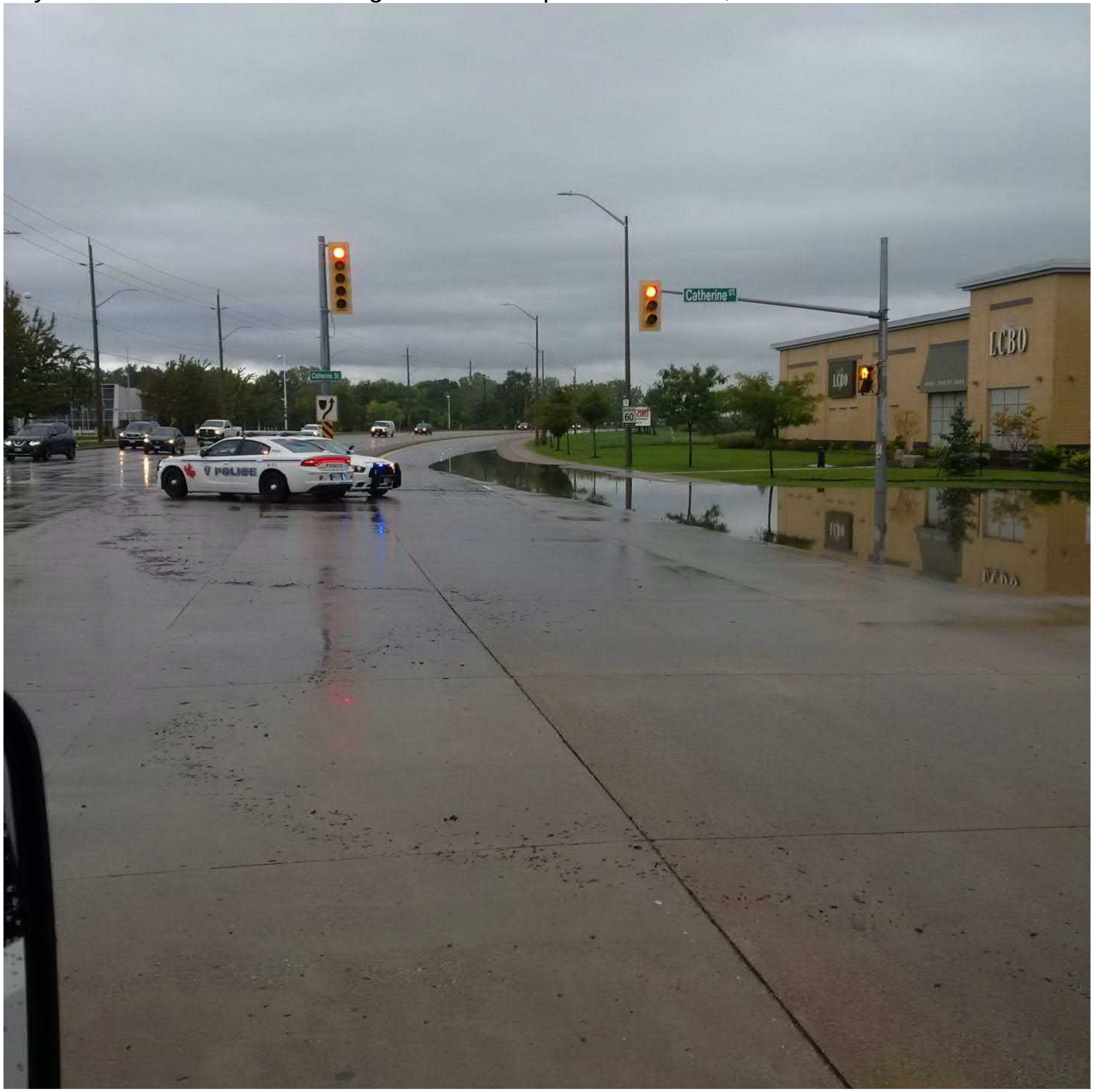
Little River at Little River Rd. Bridge



Little River at Little River Rd. facing south

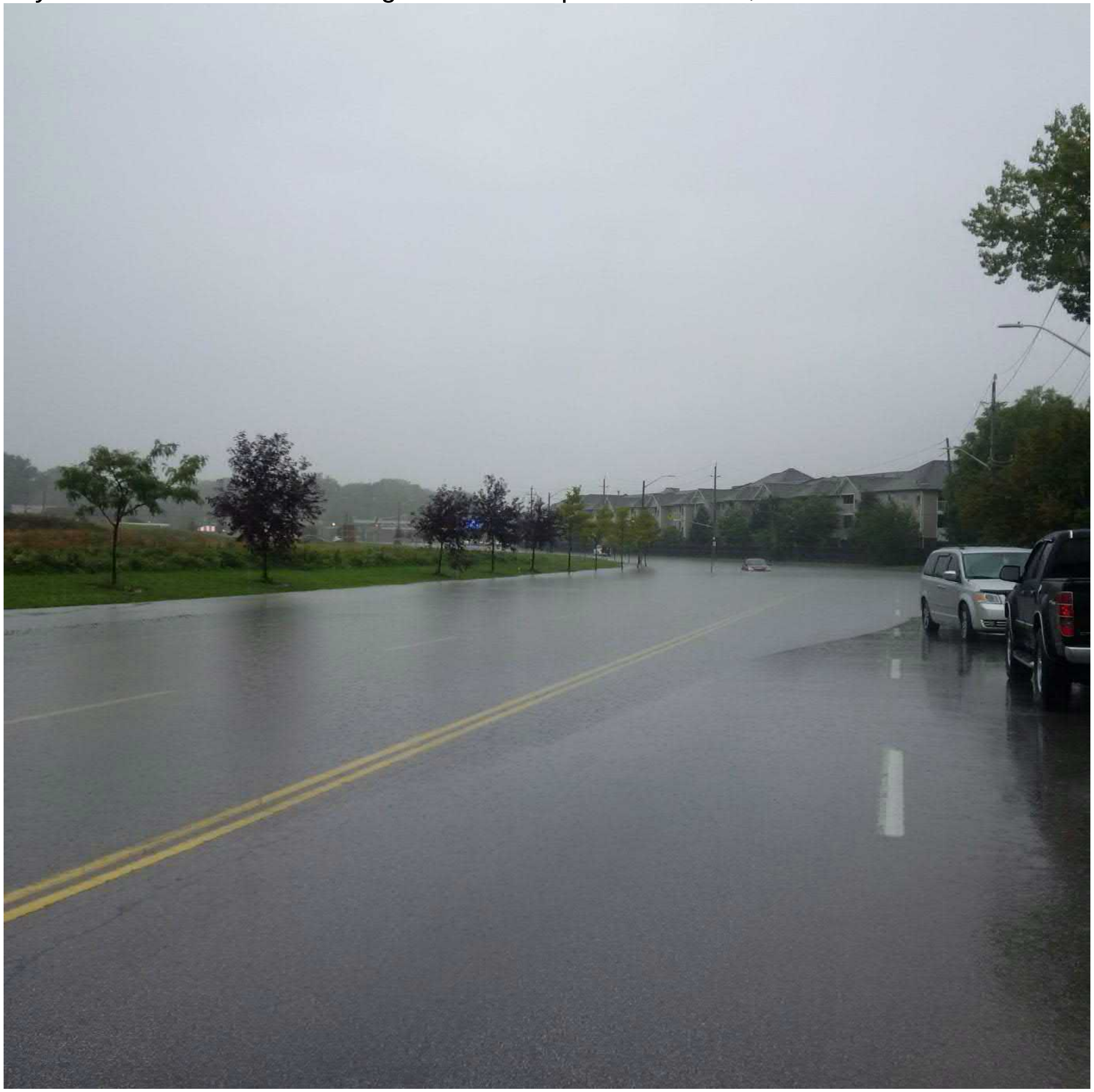
City of Windsor Storm Flooding Photos – September 29-30, 2016

Lauzon Parkway at Catherine intersection



Lauzon Parkway at Catherine intersection

Hawkins Drain at Lauzon Rd.



McHugh at Darfield facing west

McHugh at Darfield facing east

Catch basin on McHugh near Darfield

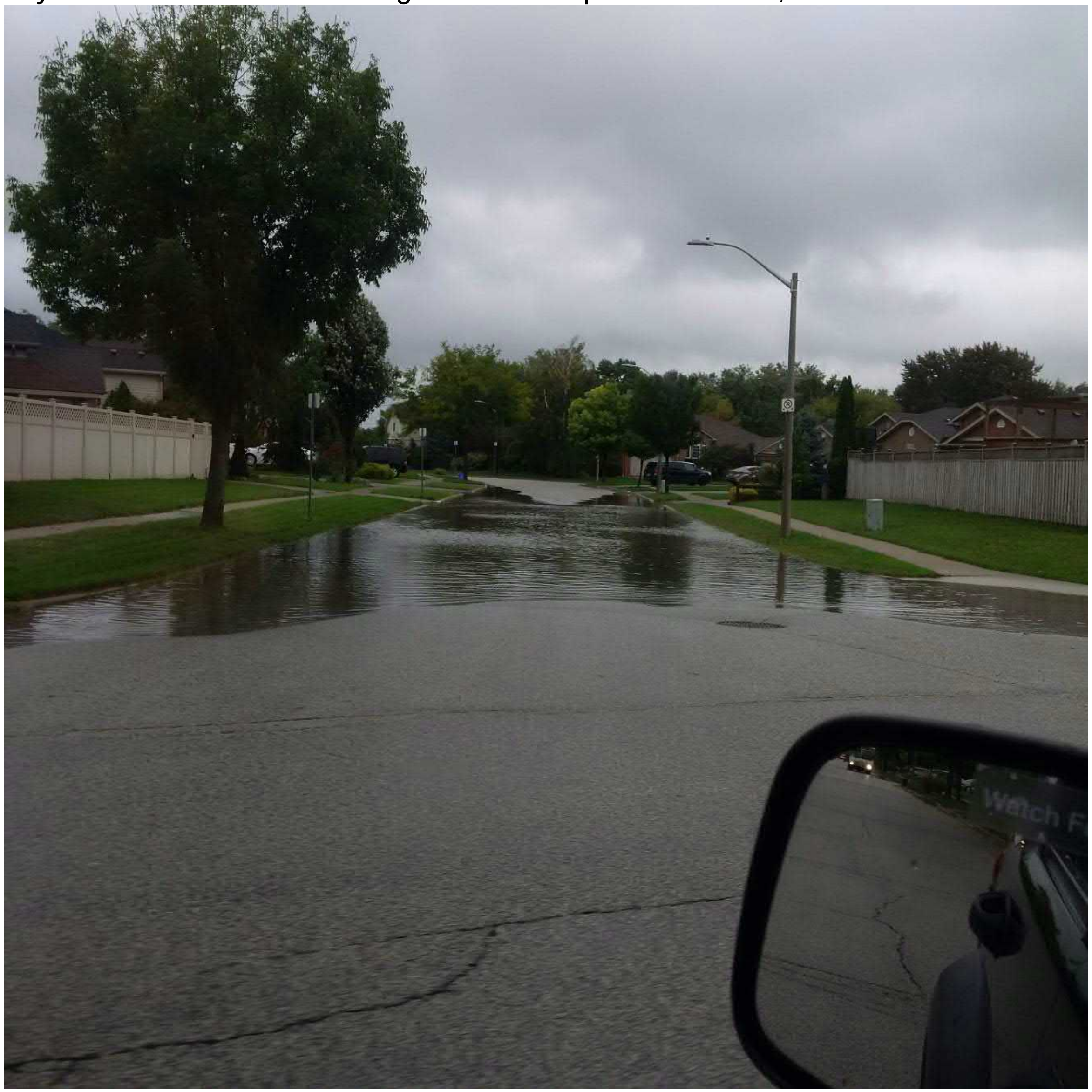
Pond in front of WFCU arena

Pond in front of WFCU arena

Blue Heron Pond

Blue Heron Pond ~ 11:30am

Blue Heron Pond ~ 6:20pm



Street adjacent to Cora Greenwood

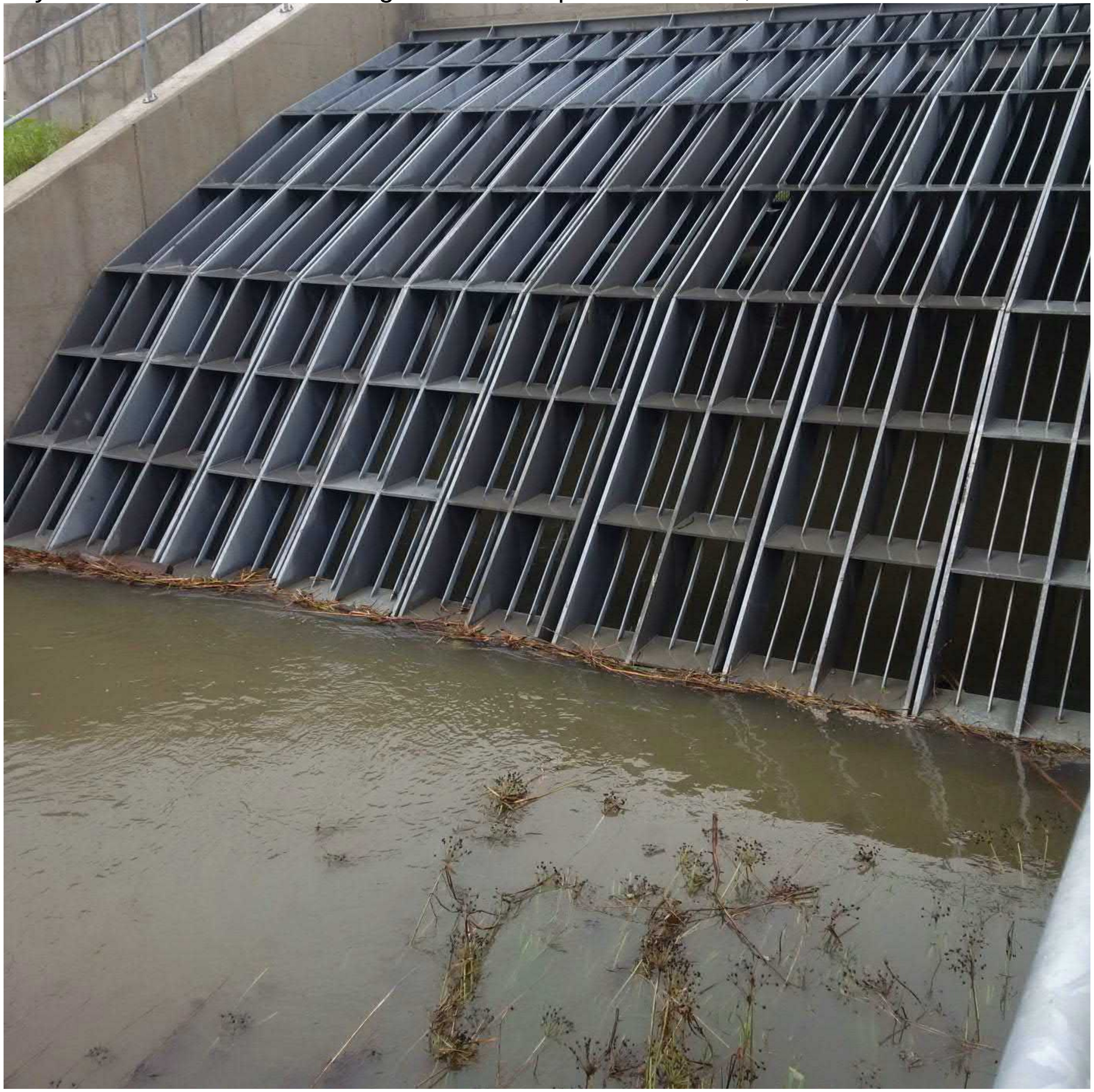
Royal Timbers Pond

Royal Timbers – Urban Lane

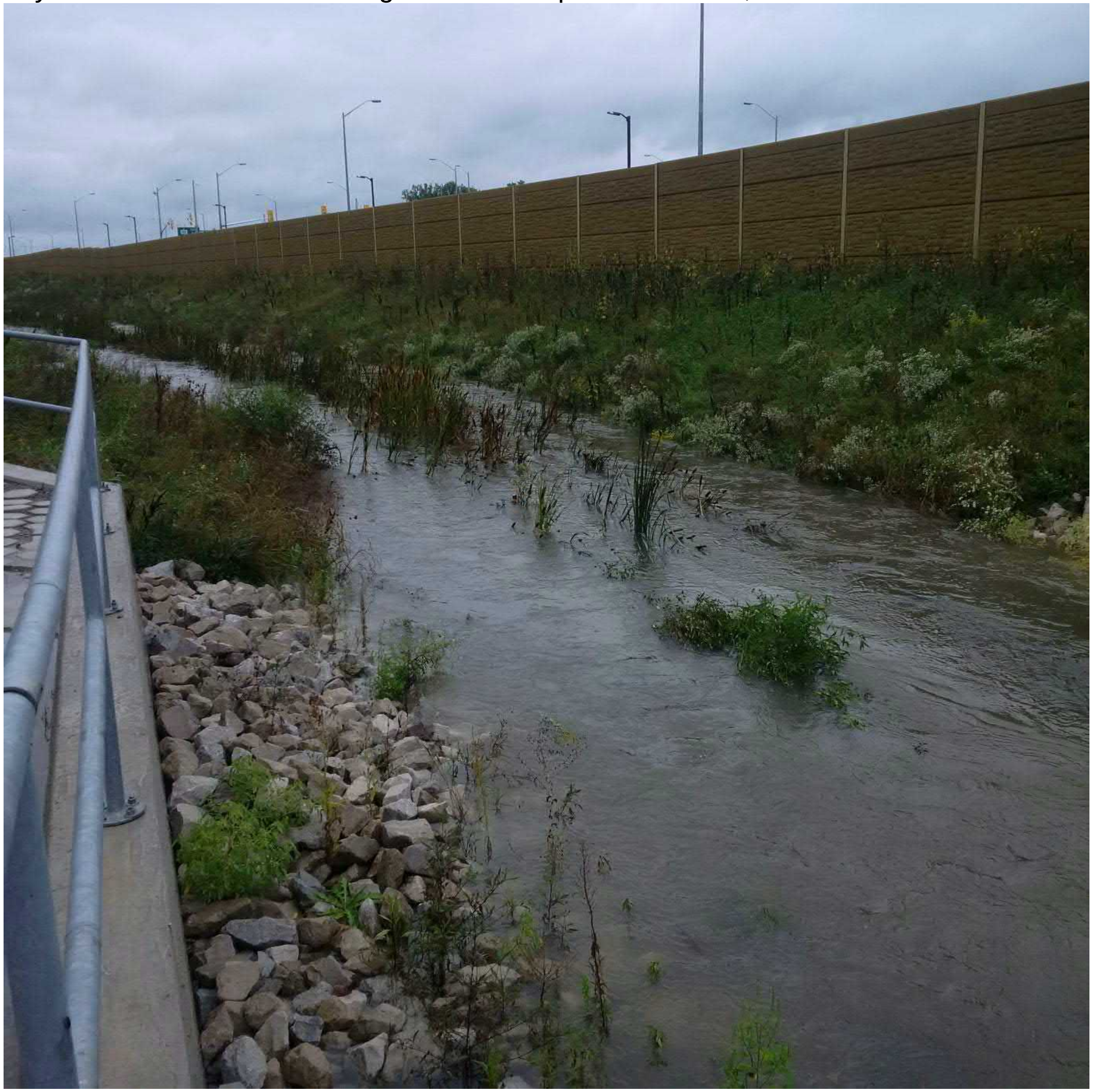
Grand Marais Drain at South Cameron

Grand Marais Drain at South Cameron

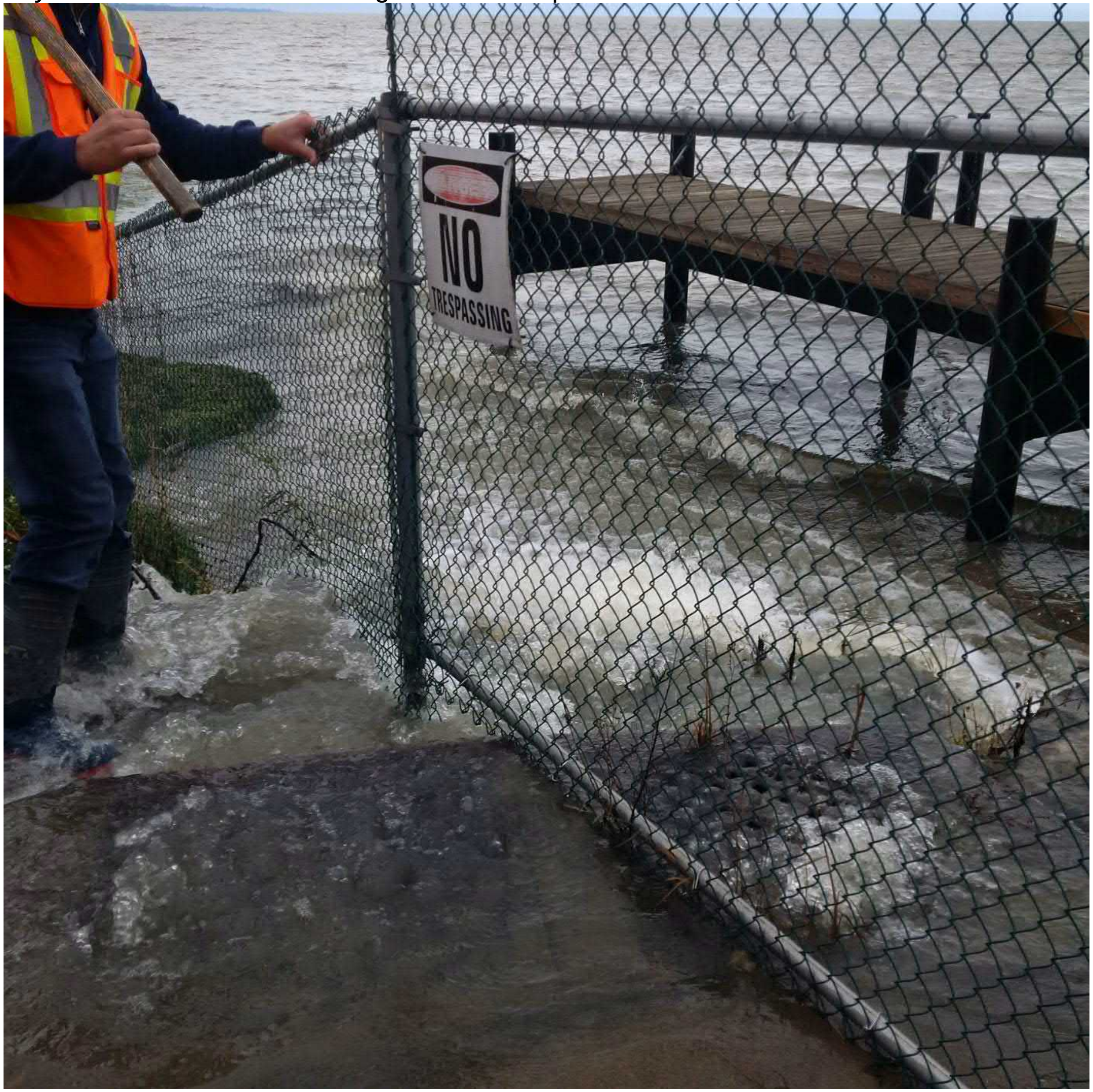
Lennon Drain at rear of South Winds condominiums



Lennon Siphon



Lennon Drain at Lennon Siphon



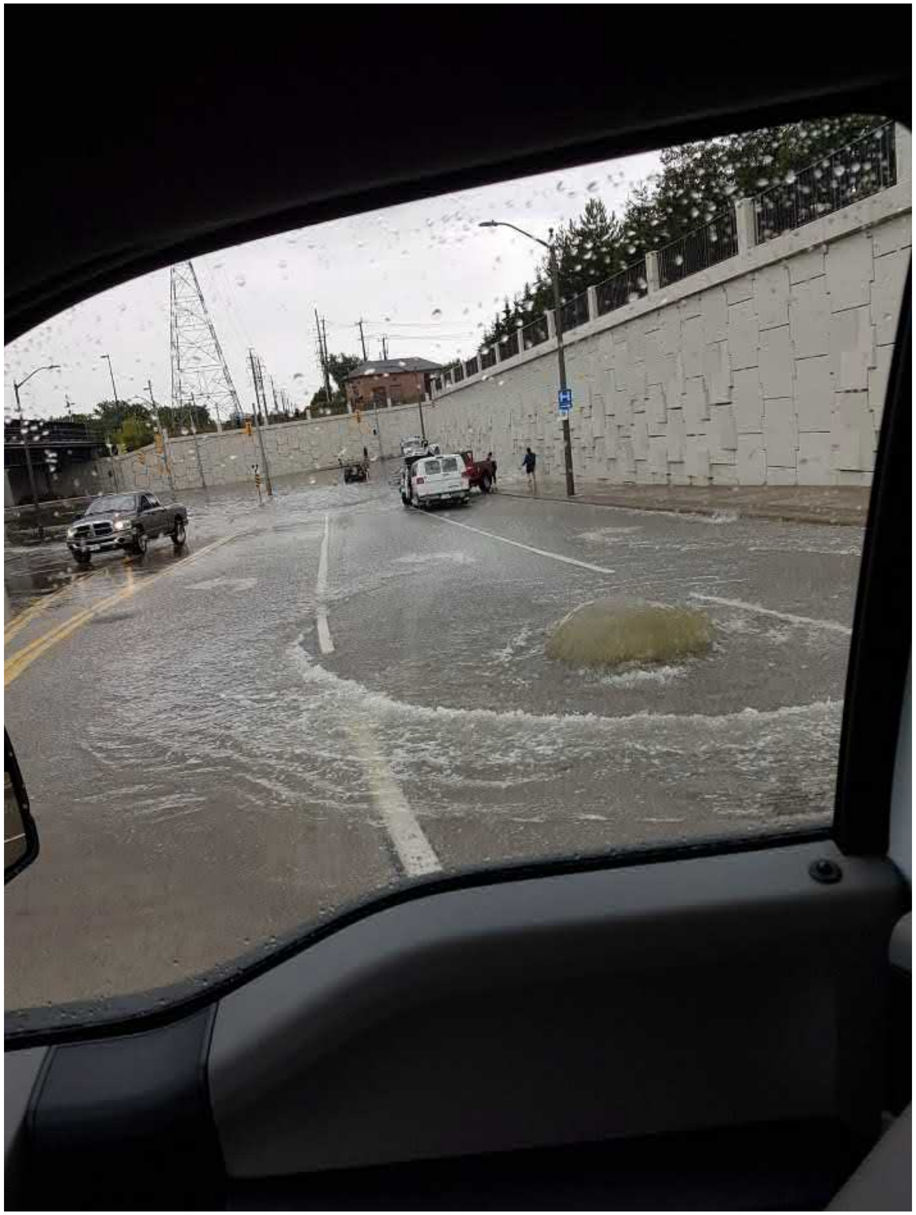
Blue Heron Outlet at Lake St. Clair

Blue Heron Outlet at Lake St. Clair

Blue Heron Outlet at Lake St. Clair

Blue Heron Pond ~ 7:00am September 30, 2016

Flood Event August 29, 2017



Grand Marais @ Walker

West Grand @ Dougall

Grand Marais Drain looking west to Balmoral tunnel

California @ Norfolk

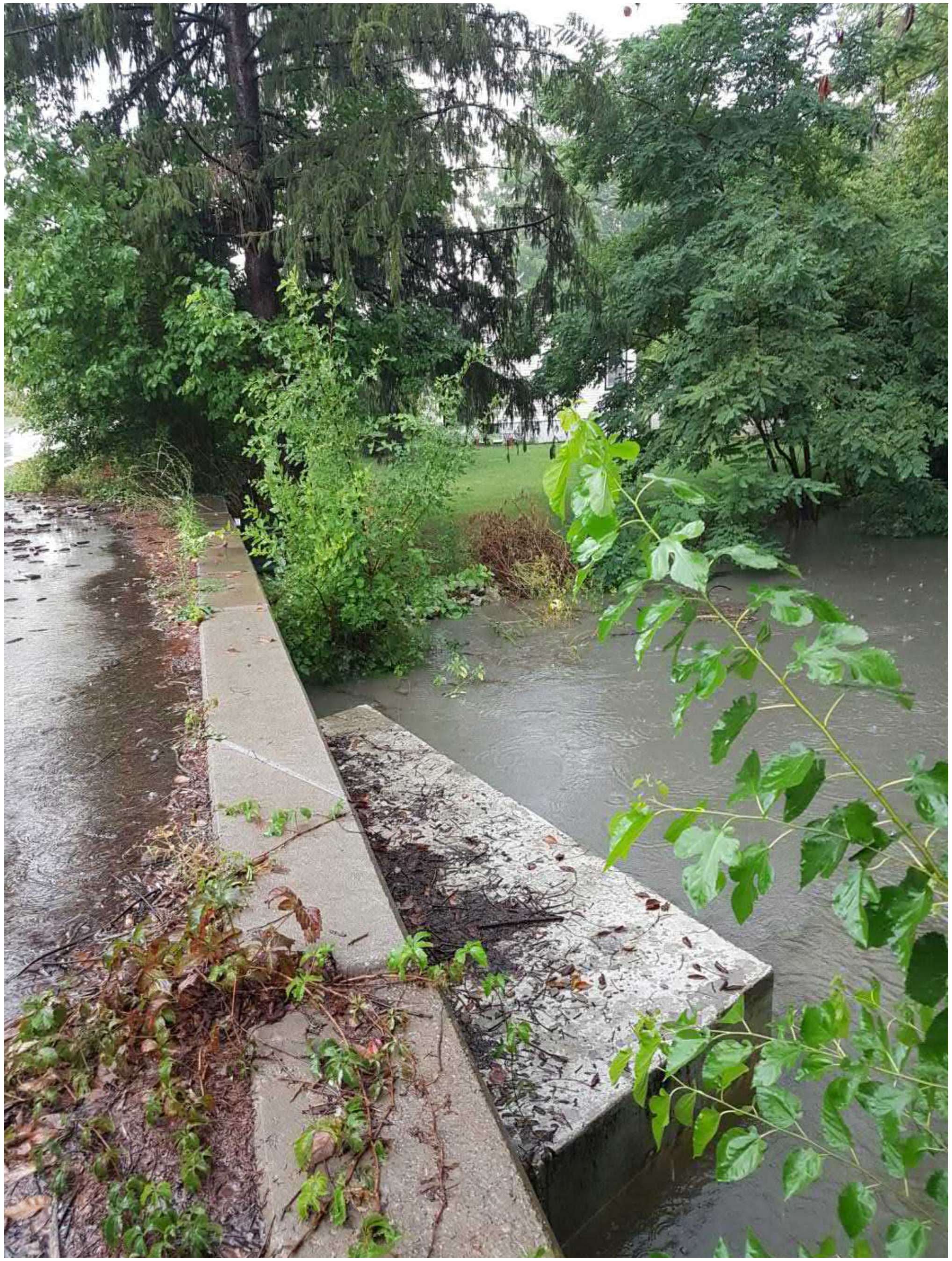
California @ Norfolk

Basin Drain @ Spring Garden

Basin Drain @ Spring Garden

Basin Drain @ Kent St.

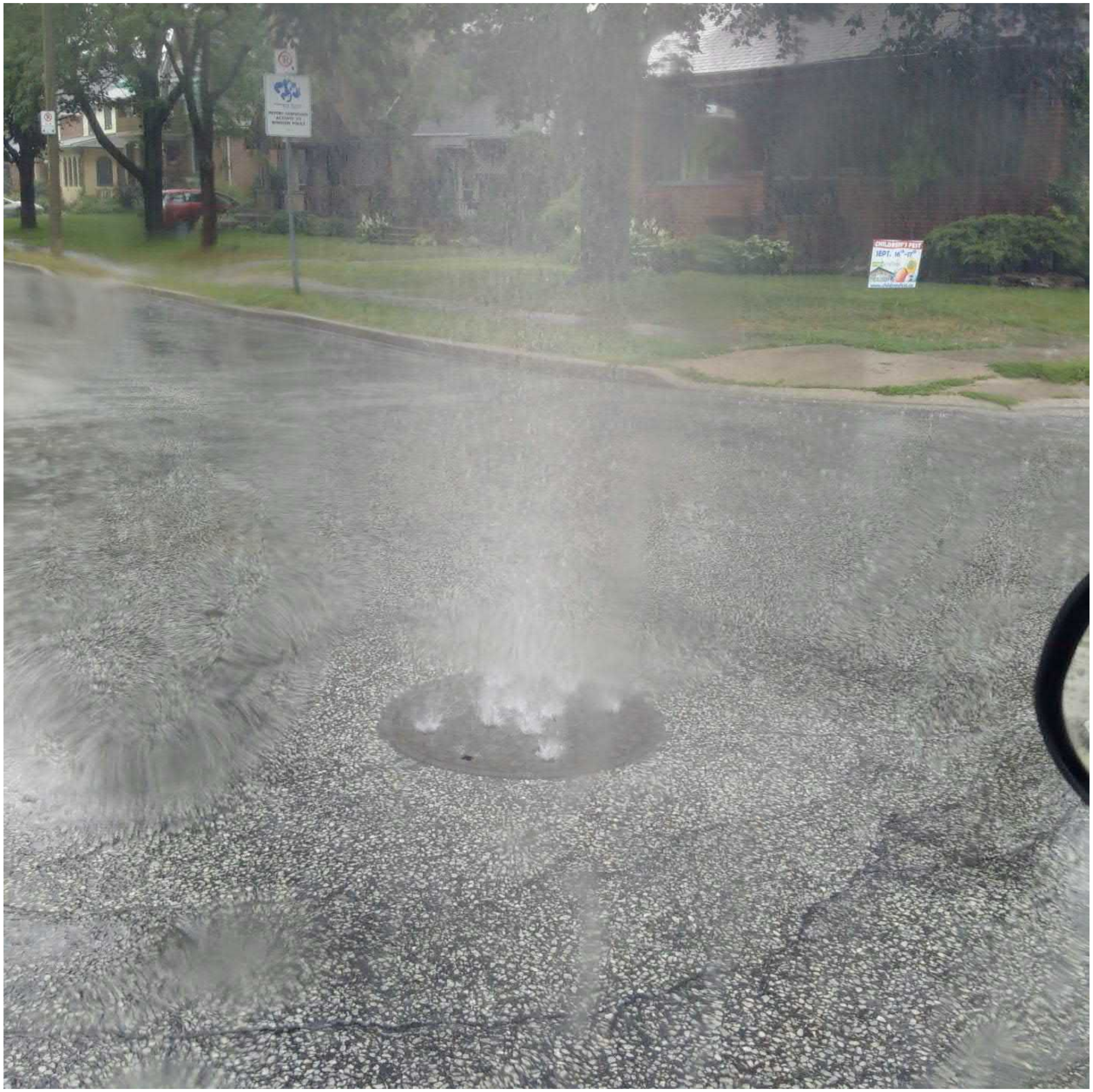
Turkey Creek @ Todd Lane



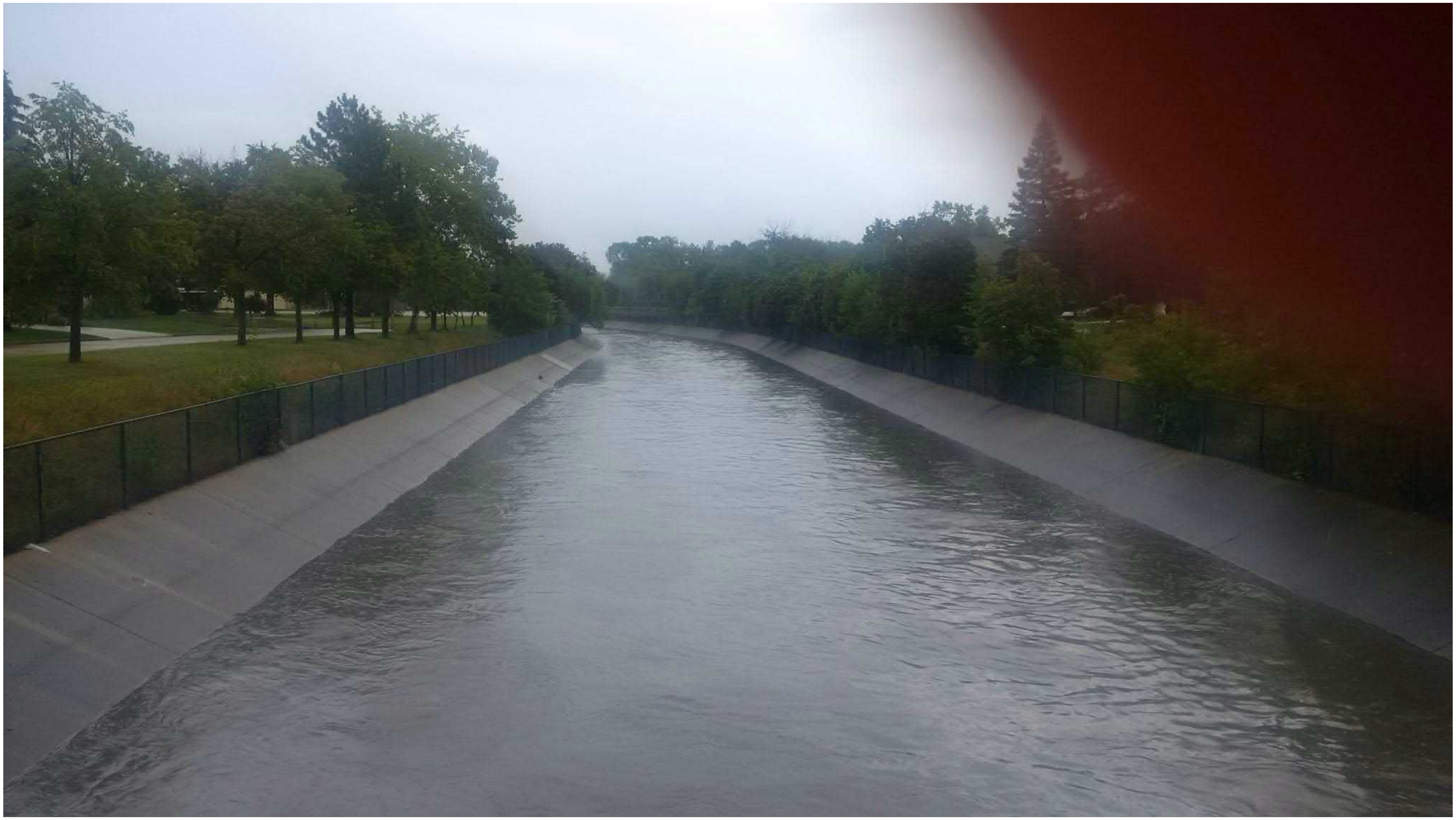
Basin Drain @ Malden Rd.

Basin Drain @ Malden Rd.

Ypres @ Wellesley



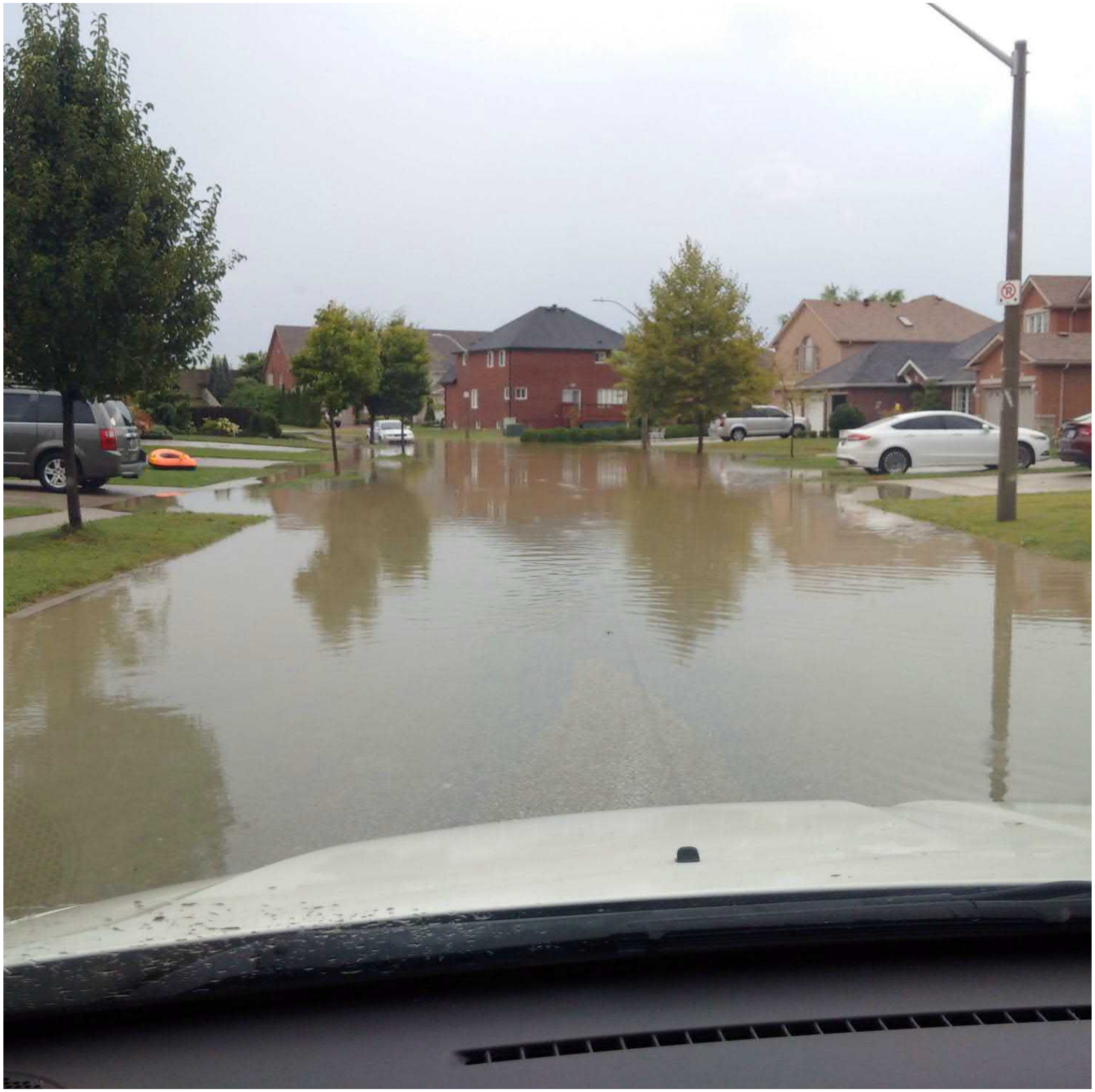
Victoria @ Shepherd



Grand Marais Drain @ Rankin (facing west)

Longfellow Ave.

Longfellow Ave.



Piazza St.

Alexandra @ Longfellow