SUBWATERSHED STORMWATER PLAN REPORT

MOHAWK LAKE AND MOHAWK CANAL CLEANUP AND REHABILITATION PROJECT

DECEMBER 2019

UPDATED IN JUNE 2020

-FINAL-

Subwatershed Stormwater Plan

Mohawk Lake and Mohawk Canal Functional Master Drainage and Restoration Study
Brantford, Ontario
Project # TPB188172

Prepared for:

City of Brantford
100 Wellington Square, Brantford, Ontario N3T 5R7

12/20/2019
Updated in June 2020

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June 17, 2020
Our File: TPB188172

Mr. Nahed Ghbn, P.Eng.
Senior Project Manager – Water Resources
City of Brantford
100 Wellington Square
Brantford, ON N3T 2M2

Dear Sir:

Re: Subwatershed Stormwater Plan - Mohawk Lake and Mohawk Canal Functional Master Drainage and Restoration Study - City of Brantford

We are pleased to provide you with the Subwatershed Stormwater Plan that was developed for the Mohawk Lake and Mohawk Canal Functional Master Drainage and Restoration Study.

Sincerely,

Wood Environment & Infrastructure Solutions
a Division of Wood Canada Limited

Per: Matt Senior, M.A.Sc., P.Eng.
Senior Engineer - Water Resources

Reviewed by:

Per: Ron Scheckenberger, M.Eng., P.Eng.
Principal Consultant

MJS/AP/RBS

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1.0 Introduction

1.1 Background and History

The Mohawk Lake and Mohawk Canal and the surrounding parklands are located in the southeast sector of City of Brantford, proximate to the City's downtown; the subject lands drain to the Grand River (ref. Drawing 1[1]). Mohawk Lake was constructed in the 1800s as part of the canal system to provide access for barges traveling through Brantford and to enable the barges to turn around. In the early 1900s, the lake and the surrounding parkland provided the community with recreational opportunities to residents city-wide and continues to offer valuable natural heritage for the City.

In the 1980s, the inflow from the Grand River, diverting flow to the canal, was disconnected with the removal of a dam. Years of municipal stormwater drainage and a legacy of industrial discharges have resulted in the deterioration of the lake. Industrial discharges have been largely discontinued for a number of years and recently upstream brownfield remediation has largely eliminated the potential for migration of contaminants from former industrial lands adjacent to the lake and canal.

The lake surface area is about 13 hectares; the water depths range from 1 to 3 meters. The Mohawk Lake subwatershed area (directly to Mohawk Lake and Canal; not including downstream areas) is approximately 873 hectares. The lake is primarily replenished by stormwater coming from municipal storm sewers that service the drainage of roadways, parking areas, and individual properties via catch basins, connected directly to the area's storm sewers. The lake water quality is largely determined by the quality of the incoming urban runoff. The land use within the subwatershed is primarily low to medium density residential, commercial and some industrial properties.

1.2 Study Purpose and Approach

In 2017, the City, with financial support from the Federal Government, approved a plan to initiate the Mohawk Lake and Mohawk Canal Cleanup and Rehabilitation Project (the Project) to improve the environmental quality of Mohawk Lake and Mohawk Canal and provide enhanced recreational, fish and wildlife conditions through improved water quality. This rehabilitation project consists of four (4) phases (Figure 1.1):

- Characterization Study (largely Completed Oct, 2019) – Phase 1;
- Subwatershed Stormwater Plan – Phase 2 (this project);
- Environmental Assessment and Master Plan - Phase 2 (this project); and
- Design & Construction of the Cleanup and Remedial Work (future phase).

The Characterization Study which began early 2018 and largely completed Oct 2019, has focused on determining the current environmental conditions of the lake and canal with the intent to define baseline conditions to support future rehabilitation measures. This study has been essential in supporting the future study phases, including developing subwatershed stormwater management guidelines, environmental

[1] Drawings are provided at the end of the report.

assessment needs and ultimately the direction to facilitate the cleanup of the lake and canal.

Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood) was retained by the City to complete Subwatershed Stormwater Plan, Environmental Assessment and Master Plan components of the Project.

The Subwatershed Stormwater Plan is intended to develop and assess alternative approaches to maintain, and ideally restore and enhance the health of the overall Mohawk Lake subwatershed. The primary focus is expected to be upon the amount, and particularly the quality, of the stormwater runoff discharging to Mohawk Lake and Mohawk Canal. The scope of work therefore includes an assessment of quantity considerations hydrology and hydraulics (including quantity and erosion control and water budget), as well as quality considerations. Related overall constraints are also considered, including archaeology and cultural heritage, groundwater and hydrogeology, natural heritage (ecology), to support the development of an overall stormwater management (SWM) strategy. The SWM strategy will consider both existing conditions and future conditions associated with future growth and capital works. A long-term implementation and monitoring plan is also to be developed, in order to ensure a strategy is in place to complete the required works, as well as a system to monitor its technical effectiveness.

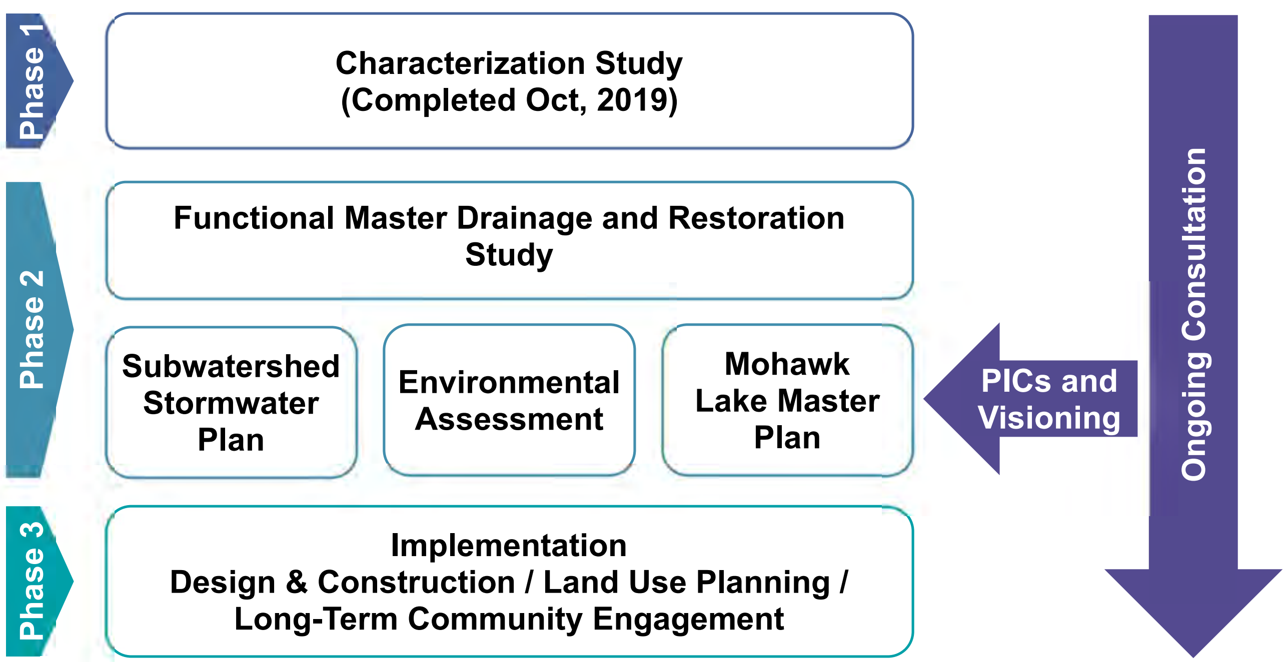


Figure 1.1: Mohawk Lake and Mohawk Canal Project Phasing

2.0 Background Review

Prior to undertaking the technical analyses in support of the Subwatershed Stormwater Plan, a background review of previously completed work is considered warranted to ensure the context of the subwatershed is understood, including any potential opportunities and constraints. The Characterization Study (Aquafor Beech Limited, October 2019) is considered the primary resource for this effort. The background review has been organized into relevant sub-disciplines to summarize the associated considerations, as follows:

- Cultural Heritage and Archaeology
- Geology, Hydrogeology and Groundwater
- Hydrology and Stormwater Management
- Hydraulics
- Fluvial Geomorphology
- Water Quality
- Sediment Quantity and Quality
- Natural Heritage and Ecology
- Potential Sources of Contamination

2.1 Cultural Heritage and Archaeology

2.1.1 Scope/Background

2.1.1.1 Cultural Heritage

A Cultural Heritage Landscape (CHL) Feasibility Study was conducted for Mohawk Canal and Alfred Watts Hydro Generation Station Ruins by ASI in 2016, which included a review of relevant mapping, review of municipal heritage inventories, contact with relevant agencies and authorities, and fieldwork in the form of a walking survey.

The CHL Feasibility Study area focused on the Mohawk Lake and Mohawk Canal between the Grand River and Shallow Creek, and either side of the canal banks. A large portion of the Mohawk Lake study area upstream of the lake and canals was not included.

2.1.1.2 Archaeology

An Archaeological Master Plan was developed in 1997 by ASI for the City of Brantford, which included a compilation of archaeological sites within Brantford, development of an archaeological site potential model, and review of relevant policies and guidelines. The Archaeological Master Plan and associated archaeological potential mapping was updated in 2006 and again in 2014 as part of the City's Official Plan Review.

A Stage 1 Archaeological Assessment Report was completed by Wood in support of the Project (Wood, 2019). The study area examined encompasses the entire subwatershed area for the Mohawk Lake and Canal. Within the overall subwatershed area, only certain portions of the study area have been determined to exhibit archaeological potential, and the study area for the purposes of this report is limited to the areas within the subwatershed identified by the City of Brantford Planning Department's Archaeological Potential Mapping as having archaeological potential. In addition to these areas of potential, the Mohawk Lake District Study Area has been included as part of the study area. The combined study area for the Stage 1 Archaeological Assessment Report (Wood, 2019), as determined by the above, measures 232.45 ha.

The study area was historically described as Part of Lots 1, 2, 5, 19, 25, 26, and Lovejoy Lot, Mohawk Parsonage Lot, School Lot, Grand River Navigation Co. Lot, Eagles Nest Tract, Smith Tract, Lots A and B, Concession 4, and the Town of Brantford, in the Geographic Township of Brantford, County of Brant.

The Stage 1 archaeological assessment was carried out in accordance with the Ontario Ministry of Tourism, Culture and Sport's ("MTCS") Standards and Guidelines for Consultant Archaeologists (2011), under an Ontario Professional License to Conduct Archaeological Fieldwork (P348) held by Barbara Slim, Senior Archaeologist at Wood. The project information was acknowledged by the MTCS on 03 September 2019 with the approval of PIF number P348-0068-2019 (Stage 1).

2.1.2 Constraints

2.1.2.1 Cultural Heritage

The CHL Feasibility Study identified forty-seven (47) resources as having cultural heritage value, of which twenty-four (24) were identified as being strong candidates for conservation, nineteen (19) as being candidates for conservation, and four (4) as being weak candidates for conservation. Of these resources, twenty-seven (27) cultural heritage landscapes were identified, and twenty (20) built heritage resources were identified.

The Mohawk Canal and Alfred Watts Hydro Generating Stations Ruins were previously identified as meeting the criteria for designation under the Ontario Heritage Act (OHA Regulation 9/06). The CHL Feasibility Study confirmed this finding and recommended that the Mohawk Canal and Alfred Watts Hydro Generation Station Ruins area be recognized as a CHL through an Official Plan Amendment (OPA), accounting for approximately the entirety of Mohawk Lake and Mohawk Canal.

The Cockshutt Timekeeper's Building is designated under the Ontario Heritage Act, and Shallow Creek Park and a cottage along the West Canal are listed on the City's Heritage Inventory. In addition, the following heritage structures and landscapes have the potential to be recommended for designation as part of the ongoing Cultural Heritage Study: the Canadian Military Heritage Museum, the Kanata Village, Mohawk Park, Mohawk Chapel and the Woodland Cultural Centre.

The recommended implementation process of the CHL includes the preparation of a CHL Technical Study and Conservation Plan, an OPA for the designation of the CHL, public consultation and stakeholder engagement, and an update of the City of Brantford Archaeological Master Plan and mapping of areas of archaeological potential. A CHL designation is intended to conserve a property and promote further understanding of the cultural heritage value of the area, in order to create a framework for its conservation and management in the future. The CHL designation may impose constraints on future development options, as well as potential remediation options by restricting site modifications. The designation is not intended to stop or prevent change, nor is it intended to stop or prevent legitimate traditional uses.

The CHL Feasibility Study recommended a CHL designation be assigned for the entire area; the recommendation did not provide specific recommendations or differentiate between resources that were identified as being *strong* candidates for conservation versus *weak* candidates, or built resources versus cultural heritage landscapes. Some of the cultural heritage resources include bridges and the abandoned locks, which may be assigned greater restrictions, in order to ensure their conservation.

2.1.2.2 Archaeology

The Areas of Archaeological Potential mapping provided by the City of Brantford Planning Department identified six (6) areas of interest to the Mohawk Lake Characterization study. Of these areas, four (4) hold potential relevance to the Cleanup and Rehabilitation Project: 1) Greenwich Street along the south side of Mohawk Lake; 2) Shallow Creek Park; 3) the Alfred Watts Generating Ruins; and, 4) the southern part of the Study area around Mohawk Street. A Stage 1-3 Archaeological Assessment was completed by ARA (A Stage 1-3 Archaeological Investigation was completed by ARA (Stage 1-3 Archaeological Assessment Proposed Greenwich Street Trunk Sanitary Sewer Replacement, Brantford, Ontario; PIF P007-096-2006 and P007-101-2006); however, this report was not available for review and as such, the details are unknown.

As part of the background review, the following sites of archaeological significance have been identified (ref. Drawing 2):

- Middle Archaic and historic First National (FN) artifacts associated with the residential school, located on the property of the Mohawk Institute (AgHb-608). A Stage 3 AA is ongoing for the area southeast of the driveway and residential school. A Stage 4 AA will be required.
- Middle to Late Woodland Transitional site located south of Greenwich Street, North of Mohawk Street (AgHb-371). A total of 324 artifacts were recovered. Given the wide area from which artifacts were recovered, it seems plausible that the site represents the remains of a village or hamlet. Stage 3 AA has been completed and Stage 4 AA will be required.
- Findspot located within Mohawk Street Landfill (AgHb-217). No further assessment required.
- Pre-contact site located south of Glenwood Drive and east of Locks Road (AgHb-614). No further assessment required.

As part of Municipal Class Environmental Assessment (EA) requirements, sites of archaeological significance must be assessed at a minimum to a Stage 3 AA, in order to provide sufficient information to evaluate the preferred alternatives. Two (2) of the sites of archaeological significance were cleared of further assessment. The remaining two (2) sites were recommended for Stage 4 AA, which will need to be undertaken in future phases of the Mohawk Lake and Canal Cleanup and Rehabilitation Project. Precautionary measures in the form of buffers will be required to protect these sites from disturbance until further archaeological assessment has been completed. The following buffers are recommended for the three (3) sites requiring Stage 4 AA:

- A 20 metre (m) no-go buffer for machinery.

- A 50m no-go buffer for invasive activities, which should be monitored by a licensed archaeologist.

The study area is situated within a designated Cultural Heritage Landscape and along Mohawk Lake and Mohawk Canal. Portions of the study area have already been subject to archaeological assessments which have resulted in the documentation of numerous sites. The Stage 1 background study and property inspection indicated that undisturbed portions of the study area have archaeological potential and warrant Stage 2 property assessment based on: 1) the presence of a natural water source, Mohawk Canal, within the study area; 2) the known presence of 317 registered archaeological sites within a 1-km radius, providing direct evidence that this general area had been exploited by both pre-contact Aboriginal and historic Euro-Canadian peoples; 3) the proximity of historical transportation routes, including the Mohawk Canal, Greenwich Street and Mohawk Street; and 4) the previous identification of archaeological potential in the western portion, eastern portion, as well as in areas south of Mohawk Lake according to the City of Brantford Archaeological Potential Map.

On the basis of the Stage 1 property inspection and a review of recent land use history, Wood identified that: 1) 35% (81.65 hectares) of the study area consists of structures, railroad tracks, concrete lots, brownfield area, and reclaimed land (Shallow Creek Park) where it is assumed that archaeological potential has been removed; 2) 6% (14.75 hectares) is permanently wet, or now part of Mohawk Lake and Canal, and therefore has low archaeological potential; and 3) 59% (136.06 hectares) has archaeological potential and warrants Stage 2 assessment.

Of the 136.06 hectares that retain archaeological potential, 128.91 hectares are unploughable lands that should be assessed by means of test-pit survey, and 7.15 hectares are ploughable lands that should be assessed by means of pedestrian survey.

In light of the results presented above, the following recommendations are made, subject to the conditions outlined below and the advice on compliance with legislation provided in section 4.0 of the Stage 1 Archaeological Assessment Report (Wood, 2019):

1. Stage 2 archaeological assessment in the form of a test-pit survey should be conducted within landscaped areas/woodlots (128.91 hectares) that retain archaeological potential. The test pits should be excavated by hand at regular 5 m intervals in a grid-pattern and to a depth of 5 cm into the subsoil. The stratigraphy of soils excavated during test pitting should be examined in order to detect cultural soil horizons and excavated soils are to be screened through 6-mm mesh to facilitate the recovery of artifacts.

   The pattern and intensity of test pit placement may be altered due to changes in archaeological potential in different parts of a study area and/or the presence of disturbed soils indicating impacts to, or removal of, archaeological potential. Any such areas of disturbance should be evaluated and photo-documented.

   If archaeological resources are found, their exact distribution should be documented, and any diagnostic artifacts recovered and inventoried. Upon the discovery of cultural materials, the survey grid should be continued to determine whether there are enough archaeological resources to meet the criteria for making a recommendation to carry out Stage 3 assessment. In the event that insufficient archaeological resources are recovered, eight additional test pits are to be dug in a 2–2.5-m radius around the isolated positive test pit, followed by the hand excavation of a 1-m by 1-m test unit over the positive test pit. As with the test pits, soil fills within the test unit should be screened for artifacts through 6-mm mesh. These artifacts are to be recovered and recorded by provenience.

2. Stage 2 archaeological assessment in the form of a pedestrian survey at 5-m intervals should be conducted on open agricultural lands that retain archaeological potential (7.15 ha). These fields must first be freshly ploughed by means of mouldboard ploughing (and may require disk harrowing in heavy clay) to provide for at least 80% ground surface visibility. Prior to the pedestrian survey, the newly ploughed fields should also be allowed to weather through one heavy rainfall or several light rainfalls.

   If archaeological resources are encountered, the 5 m transects should be decreased to 1 m over a minimum radius of 20 m around the archaeological find(s) until the full extent of the scatter has been identified or the find is determined to be isolated. In the case of a discrete scatter of artifacts, all formal artifact types and diagnostic categories are to be collected, but enough undiagnostic artifacts should be left in-situ to allow them to be relocated in the event that further assessment is required. The exact location of archaeological resources should be documented using one or more of a combination of: the Global Positioning System, topographic survey or other precision measurements. As with test-pit finds, surface finds should be recovered and recorded by provenience.

3. Stage 4 mitigation is warranted for Site AgHb-371, located within the study area. The following was recommended as the result of ARA's Stage 3 investigations (ARA 2014: 17):

   The Stage 3 archaeological assessment of the proposed corridor at Findspot 1 yielded data which was clearly sufficient to trigger further Stage 4 work. Given that the existing sewer is in need of replacement, site impacts may be unavoidable. A Ministry of Culture-sanctioned strategy involving a mixture of both targeted Stage 4 excavations, within the corridor, and site avoidance and protection, for the remainder of Findspot 1, is strongly recommended. In the future, should any portion of these lands be threatened by construction activities a full Stage 4 excavation should be undertaken. (ARA 2014: 17).

4. Stage 4 mitigation is also warranted for Site AgHa-181, located within the study area. As a result of ARA's Stage 3 investigations, Findspots 1a, 1b, 1c, 1d, 1f, 1g, 2, 3, 4a, 5, 7, 9, 11 and 15 were recommended for Stage 4 mitigation of development impacts as follows: Block excavation, undisturbed midden documentation and mechanical topsoil removal for Findspots 1a, 1b, 1c, 1d, 1f and 1g; Block excavation and mechanical topsoil removal for Findspot 2; Feature excavation and mechanical topsoil removal for Findspots 3, 4a, 5, 11 and 15; and Block/feature excavation and mechanical topsoil removal for Findspot 9.

5. No further assessment is required at Site AgHb-217, located within the study area (MTCS 2019).
6. The remainder of the study area does not require further archaeological assessment as these lands have either been fully assessed or exhibit low archaeological potential due to permanently wet conditions or the prior removal of archaeological potential.

2.1.3 Linkages (Features and Function)

2.1.3.1 Cultural Heritage Linkages

The CHL Feasibility Study conducted by ASI recommended the Mohawk Canal and Alfred Watts Hydro Generation Station Ruins be designated a CHL, which includes the majority of Mohawk Lake and Mohawk Canal and the entirety of Mohawk Park. The subject CHL for this area consists of an evolved cultural heritage landscape, where the evolutionary process is still in progress. A CHL designation does not mean the landscape cannot be changed or altered, but it must consider the cultural heritage value of the site and provide justification for alterations. Restoration and development recommendations intended to remove contamination from the canal-lake system, that result in modifications to the landscape, may be justifiable, as safety takes precedence over cultural heritage considerations. An accepted approach to preserving CHLs, while permitting alterations, is the memorialization of the landscape through interpretive signage and photographs. Strategic sediment removal is not anticipated to be restricted as it occurs beyond the sight line and therefore would not affect the cultural heritage value.

2.1.3.2 Archaeological Linkages

Recommendations for restoration and development alternatives must account for the recommendations of the Stage 1 Archaeological Assessment Report (Wood 2019), including carrying out Stage 2 Archaeological Assessment on areas that retain archaeological potential and Stage 4 mitigation for Site AgHb 371 and Site AgHa-181.

2.2 Geology, Hydrogeology and Groundwater

2.2.1 Scope

The Characterization Study (October 2019) provides a general description and characterization of the soils, overburden, hydrogeology and groundwater for the Mohawk Lake and Mohawk Canal Cleanup and Rehabilitation Project.

The Characterization Study has documented the geology of the study area based on previous investigations and ten (10) boreholes advanced at Mohawk Lake, including wells (seven (7) sites; three (3) nested).

Single well response tests were conducted on six (6) of the wells, with the resulting estimates ranging from 4.4×10^{-8} m/s to 4.1×10^{-5} m/s. The tests were all falling head tests with pre-test water levels below the top of well screen and analysis based mainly on early time response data. Consequently, the results could be affected by infiltration of water to the well annulus sand filter pack. Based on the data and information provided in Appendix A-1 of the Characterization Study, comments are provided below for each test:

- MW#1D – The pre-test water level is only ~0.5 m below the top of well screen. There appears to be no notable early time effects; 4.4×10^{-8} m/s is considered reliable for the screened silt, silty sand/silty clay;
- MW#2 – The pre-test water level is within silty clay below the base of the sand. Almost complete head loss (H/H0 =0.1) occurs within 50 s; 1.5×10^{-5} m/s is likely to represent infiltration to the sand filter pack and upper sand;
- MW#4D - The pre-test water level is within silty clay at the top of the well screen just below the base of the fill. All head loss (H/H0 =0.45) occurs within 50 s after which the water level does not decline; 5.4×10^{-6} m/s is likely to represent infiltration to the sand filter pack and potentially Fill (silty sand) just above the top of the well screen;
- MW#5/5R - The pre-test water level is within silty clay above the sandy gravel at the base of the well. Head loss is uniform and gradual (H/H0 =0.65 after 550 s); 2.5×10^{-7} m/s is too low for gravel, which would be expected to dominate the hydraulic conductivity of this well;
- MW#6 - The pre-test water level is within silty clay above silty sand. Most head loss (H/H0 =0.3) occurs within 60 s after which the water level does not decline much; 4.1×10^{-5} m/s is likely too high for silty clay and silty sand. It is more likely to represent flow through the sand filter pack to the Fill (sand) immediately above the well screen;
- MW#7D - The pre-test water level is within fill (sand). Head loss occurs within 20 s and is very limited (H/H0 =0.8) after which the water level does not decline; this type of response suggests there is potentially a well construction issue and 1.4×10^{-6} m/s should not be considered representative of the soils indicated in the well log.

The Hazen method was used to estimate hydraulic conductivity from the soils sampled from MW#5/5R (sandy gravel) and MW#6 (silty sand), which gave results of 1.6×10^{-5} m/s and 1.0×10^{-5} m/s respectively.

Overall, the well logs and hydraulic data indicate the following hydro stratigraphy:

- a shallow aquifer usually within 2 – 5 mbgs comprising fill (mainly sand or silty sand, with some silty clay, gravel and organics) and sand with a hydraulic conductivity of around 1×10^{-5} m/s +/- half an order of magnitude. Cross-sections on drawings 7-2A and 7-2B of Appendix-A1 of the Characterization Study show this unit to be largely unsaturated;
- a deeper aquitard comprising mainly silt and silty clay, with subsidiary silty sand with a hydraulic conductivity lower than 1×10^{-7} m/s. Cross-sections on drawings of 7-2A and 7-2B of Appendix-A1 of the Characterization Study show the water table just above or within this unit.

The groundwater levels and flow directions were characterized based on twelve (12) months of groundwater level data collection, beginning in September 2018, comprising a total of ten (ten) records collected at the seven (7) new well sites. The record of MW#5 starts in February 2019 as the headworks of this well was destroyed during a vehicular incident and re-established in February 2019.

One (1) sampling round has been completed with analyses reported for conductivity, pH, turbidity, chloride, cyanide, dissolved metals, hexavalent chromium, volatile organic compounds (VOCs), hydrocarbons and polycyclic aromatic hydrocarbons (PAHs).

The results of the groundwater level monitoring program are presented in a series of hydrographs in the Characterization Study together with temperature plots. It should be noted that the format of the groundwater hydrographs is not conducive to thorough review as:

- Changes in the groundwater level are not clear as the vertical scale of the hydrographs (25 m) is far greater than the seasonal variation (mostly less than 2 m); and
- In MW3 the groundwater level is below the bottom of the well for most of the record; and

Overall the data indicate that groundwater levels have stayed relatively consistent across the year with peak groundwater levels coinciding with the freshet.

The Characterization Study has one (1) groundwater level contour map interpreted from the measured groundwater levels in the ten monitoring wells. It does not include data from other sources, so the interpretations regarding groundwater flow directions are restricted to the immediate vicinity of Mohawk Lake. This contour map indicates southwards groundwater flow from the high-ground in the north towards the Grand River.

The Characterization Study indicates that the area north of Mohawk Lake is a recharge area and south is a discharge area based on the vertical gradients and groundwater temperatures. Wood considers that the Characterization Study data are more consistent with Mohawk Lake acting as a groundwater flow through feature associated with predominantly horizontal groundwater flow draining along the base of the shallow aquifer (sandy fill and sand) above the aquitard (mainly silts and silty clays). In addition to the hydro stratigraphy described above, this is supported by the following information:

- As indicated in Section 4.3.3, the elevation of the Mohawk Lake outlet control structure is 198.1 masl, which controls the water level of Mohawk Lake. To the north of Mohawk Lake, the groundwater levels are above 207 masl, with exception of MW4S and 4D, which are 198.5 at masl. To the south of Mohawk Lake, the groundwater levels are around 195 to 196 masl. In combination, these data indicate groundwater discharge to Mohawk Lake along the north bank and surface water exfiltration from Mohawk Lake to groundwater along the south bank.

- Based on the manual groundwater level data (Appendix-A1 of the Characterization Study), the vertical hydraulic gradients appear to be relatively subdued. On the north bank, the shallow groundwater levels at MW#1S are on average approximately 0.2 m higher than the deeper groundwater levels at MW#1D, indicating a downward vertical hydraulic gradient. The groundwater level difference at the other two nested sites are very limited; measured differences are on average approximately 0.02 m at MW#7S/MW#7D (south bank) and 0.03 m at MW#4S/MW#4D (north bank), in both cases indicating upward vertical gradients. The magnitude of these groundwater level differences is not sufficient to indicate a discharge area to the south of Mohawk Lake. They are more consistent with predominantly horizontal flow.
- The temperature data are variable. Lower temperatures tend to occur north of Mohawk Lake with warmer temperatures south of the lake as indicated in the Characterization Report. All the monitoring wells are shallow, which may cause a relatively large seasonal variation in groundwater temperatures; depth to water table could also influence this variation. The more variable temperatures along the south bank of Mohawk Lake may also be due to surface water exfiltration to groundwater.

It is uncertain if groundwater discharge to Mohawk Lake on the north bank exceeds surface water exfiltration to groundwater on the south bank based on the data presented in the Characterization Report (October 2019). However, it would appear that horizontal hydraulic gradients are greater on the northern side of the lake, potentially indicating higher groundwater discharges, consistent with the results of the Characterization Study water balance (October 2019) and that presented in Gore & Storrie (1995).

2.2.2 Constraints

Generally, the soils from the ten (10) boreholes comprise a predominantly sandy fill overlying silty clay. The fill is generally 2 – 3 m thick, but at one (1) location exceeded 6.5 m thick. These boreholes are mapped by the Ontario Geological Survey (OGS) in alluvium (south of Mohawk Lake) or laminated glaciolacustrine deposits (north of Mohawk Lake). Except for two (2) boreholes (MW#7 nested well site), none of the new boreholes are located within the potential development areas of the study area.

The potential development areas are mapped by the OGS to lie in the following overburden units:

- Modern alluvial deposits of the Grand River comprising unsubdivided muck, clay, silt, sand and gravel;
- Older alluvial deposits comprising sand and gravel; and
- Coarse-textured glaciolacustrine deposits.

Based on previous reports, Aquafor Beech (2019) estimated the overburden to be about 20 m thick resting on the Silurian bedrock of the Salina Formation.

Exceedances of the O. Reg. 153/04 Table 1 groundwater standards have been recorded for some of the following parameters: pH, chloride, cyanide, dissolved metals, hexavalent chromium, VOCs, hydrocarbons and PAHs. The interim Characterization Study reviewed previous studies on groundwater contamination in the study area and mapped the potential sources for groundwater contamination based on existing information.

The following constraints have been identified associated with the geology and groundwater for the potential development lands within the study area:

- There is historical groundwater contamination around Mohawk Lake. Specifically, the area of Shallow Creek Park to the west of Mohawk Lake was investigated in 1995 by Gore and Storrie and found the area to be affected by coal tar wastes with associated PAH contamination of groundwater. For this area Gore and Storrie (1995) interpreted the contaminants to be relatively immobile. Although mostly outside the potential development lands (ref. Drawing 7), the groundwater quality samples from the Aquafor Beech wells showed elevated PAH, hydrocarbon (F2 and F3), barium, zinc and chloride concentrations exceeding O. Reg. 153/04 Table 1 groundwater standards.
- Any redevelopment is therefore likely to require a site condition assessment for soil and groundwater contamination, to determine the risk of contaminant mobilization in groundwater.
- Information provided by Aquafor Beech (2018) indicates that Mohawk Lake is a groundwater discharge feature. Mohawk Lake and Mohawk Canal lie mostly within an Intake Protection Zone (IPZ 3), with the downstream end within an IPZ 2. An expected constraint of any new development will be that the groundwater discharge to Mohawk Lake and associated surface water features, would not be reduced either in quality or quantity.
- The elevation of the outlet control structure of Mohawk Lake may influence groundwater-surface water interaction at the lake.
- Development infiltration may not be less than pre-development infiltration.
- Soil erosion would have to be controlled to prevent discharge of water with excessive suspended and/ or contaminated sediment load to Mohawk Lake and Canal.

Data Constraints

The following data and information constraints have been identified:

1. Data on surficial geology (borehole data collected from previous studies, MECP well records and published OGS geological map) in the project area have not been compiled into a single map showing required detail of the surface geology of the potential development lands and Mohawk Lake and Mohawk Canal. Such a map will be required to provide a qualitative or semi-quantitative assessment of potential impacts on infiltration that any development may have.

2. Information available on groundwater levels (understanding from previous reports, groundwater levels in the investigation report, MECP water well records etc.) have not been processed into a groundwater level contour map depicting groundwater flow directions for the development lands at Mohawk Lake and relevant up-gradient and downgradient areas.
3. The Characterization Report did not consider the water level of Mohawk Lake for the interpretation of groundwater level data. Wood has considered this information and suggests a revised conceptual understanding of groundwater flow in the immediate vicinity of Mohawk Lake. Mohawk Lake is considered a groundwater through-flow feature, likely with some net discharge to surface water. Groundwater flow is primarily along the base of a surficial aquifer comprising sand fill and sand.

2.2.3 Linkages (Features and Function)

Potential development within the study area has the potential to impact the groundwater system in the following ways:

- In the short term, construction activities such as dewatering may cause temporary changes to the groundwater flow system.
- In the long term, additional development may cause a change in infiltration and overall water balance.

The effects may include changes to the discharge rates to Mohawk Lake and Mohawk Canal, and the potential to mobilize groundwater contaminants.

The groundwater linkages associated with the potential development land within the study area are as follows:

- Temporary changes during construction such as dewatering, diversion of surface waters or storm water management measures, may cause temporary changes to the groundwater flow system;
- Permanent changes to the surface of the potential development lands may cause a change to infiltration, either a reduction due to the introduction of impervious surfaces, or an increase if engineered infiltration features are introduced [e.g. Low Impact Development Best Management Practices (LID BMPs)], flow through utility trenches) and existing impervious surfaces are removed. A change in vegetation could result in either decreases or increases in infiltration depending on form and function.

The main effects, either temporary or permanent, that may result from these changes to the groundwater system are:

- Changes to groundwater discharge rates to Mohawk Lake and Mohawk Canal; and
- Mobilization of existing groundwater contamination or introduction of new groundwater contamination (e.g. infiltration of deicers from infiltration of storm runoff) causing discharge of poorer-quality water to Mohawk Lake and Mohawk Canal.

2.3 Hydrology and Stormwater Management

2.3.1 Scope

The Characterization Study (October 2019 Final Report) provides a general overview of the drainage systems and drainage area characteristics of the Mohawk Lake and Mohawk Canal subwatershed. Reference is made to the previously completed Mohawk Lake Rehabilitation Project Reporting Series, specifically the Stormwater Management Study Report (Gore & Storrie Ltd, 1995). Reference is also made to the hydrologic/hydraulic analysis work completed as part of the Master Servicing Plan (Volume V – Stormwater Master Plan, BluePlan, 2014).

The Mohawk Lake subwatershed is presented generally in Drawing 3 (more updated subcatchments are presented in Drawing 8, which are discussed in greater detail in Section 4 of the report). As per the Characterization Study, a total drainage area of 839 ha is indicated, which differs from the previous Stormwater Management Study Report, which indicated a total of 754.7 ha (the majority of which (702.7 ha) drains to the West Canal upstream of Mohawk Lake). The drainage area consists of a mixture of land use types, including residential, commercial, industrial, and open space/parklands. The subwatershed does not contain any stormwater management facilities, nor any oil/grit separator units. As noted in the Characterization Study, Mohawk Lake generally serves as an “informal” stormwater management facility for the subwatershed, given the untreated nature of the contributing drainage areas and the permanent pool within the lake.

Beyond Mohawk Lake and Mohawk Canal, there are generally no open channel drainage systems, given the history of development and watercourse enclosures. Two (2) tributaries are noted at the downstream limits of the watershed, however only one (Tributary 1) drains into the Mohawk Canal system; The other (Tributary 2) outlets directly to the Grand River in close proximity to the Mohawk Canal outlet. The balance of the watershed is drained by urban drainage systems, comprised of storm sewers and overland flow (although overland flow paths do not appear to have been specifically designed or assessed in the previous studies).

The Stormwater Management Study Report (Gore & Storrie Ltd., 1995) included the development of an INTERHYMO/OTTHYMO hydrologic model for the watershed, which is a dated modelling platform (typically such models may be executed in the SWMHYMO modelling platform with some minor modifications or must be migrated to the newer Visual OTTHYMO platform). Simulated peak flow results, as well as the water budget results from that study were reproduced in the Characterization Study Report (October 2019). The results of the water budget (which did not consider lake bed seepage) determined that 82% of the annual inflow to Mohawk Lake is sourced from surface runoff, with the balance (18%) from groundwater seepage/baseflow.

As part of the Master Servicing Plan (Volume V – Stormwater Master Plan, BluePlan, 2014), an “all pipes” hydrologic/hydraulic model was developed for the entire City in the InfoSWMM platform. Significant ditches and culverts were also included; open channel transects representing Mohawk Canal and Mohawk Lake are also included in the modelling. The modelling was validated to address any obvious errors or issues, including a comparison to anecdotal information, where available.

The base modelling developed as part of the 2014 study was further refined through the subsequent “Stormwater Flow Monitoring and System Model Calibration Study” (Aquafor Beech Ltd, and Thompson Flow Investigations Inc, January 2018). That study involved flow monitoring at fifteen (15) different locations across the storm sewer system (City-wide) for a 1-year period to provide calibration data. Three (3) of the flow monitors (FM1, FM2, and FM10) were located within the Mohawk Lake watershed, in close proximity to Mohawk Lake and Mohawk Canal (i.e. near storm sewer outfalls). The modelling was subsequently calibrated and validated based on the available monitoring data. Calibration to the sites within the Mohawk Creek subwatershed was noted as “average” (FM2) or “good” (FM1 and FM10).

As part of the Characterization Study, additional flow and precipitation monitoring was completed, beginning in May/June 2018. Three (3) additional flow monitors were installed in proximity to the Mohawk Lake/Mohawk Canal area; two (2) gauges upstream of Mohawk Lake, and one (1) gauge downstream. The monitoring program encountered issues with vandalism/theft, as well as rating curve stability, thus only a limited amount of surface water monitoring data were available/summarized as part of the Characterization Study (October 2019). As part of the additional 8-months of environmental monitoring, Aquafor Beech prepared an Interim Monitoring Memorandum in February 2019 to provide an update on the ongoing monitoring programs. The stream flow monitoring program included the installation of HOBO loggers at the three flow monitoring stations and collected data at 15-minute intervals between November 1st and December 4th, 2018, after which it was suspended due to frozen conditions. Flow monitoring data was re-commenced in 2019, up until June 18th, 2019.

Rating curve development was initiated, however complications due to low-gradient of the lake and canal, and frozen conditions, have not supported the additional spot-flow measurements required to complete the rating curve development. As per the I Characterization Report (Oct 2019), rating curves were only generated for gauge FM1. The rating curve for this location was developed based on a power equation trendline, it is not clear if hydraulic modelling verification was used to confirm reasonableness of the rating curve, particularly at higher elevations. Based on the preceding, the water level monitoring data from the Characterization Study cannot be directly applied for flow calibration, however could be useful for a general verification/validation.

Notwithstanding the preceding, a high-level water balance/water budget was also completed as part of the Characterization Study (October 2019) using the available flow monitoring data. The report concluded that more water leaves (29%) the Mohawk Lake system through the outlet control structure than enters it from the storm sewer network, suggesting a groundwater flow input. This was noted to be consistent with previous studies (Gore and Storrie, 1995), which concluded that approximately 18% of input flows are sourced from groundwater.

The rainfall monitoring program included the installation of a tipping bucket rain gauge in June 2018 on the roof top of the Pollution Control Centre located at 180 Greenwich Street, located to the south of Mohawk Lake. Continuous data was collected at 15-minute intervals and summarized into daily precipitation totals between November 1st and December 4th, 2018. For 2019, data were collected from May 1st, 2019 to June 18th, 2019.

As part of the Characterization Study, the previously noted InfoSWMM modelling was converted to InfoWorks ICM. The Draft Characterization Study Report (October 2018) notes that the InfoWorks ICM modelling indicated some “inconsistencies” as compared to the InfoSWMM modelling, thus the results presented in that report are based on the InfoSWMM modelling platform. As part of the final report (October 2019), the issues with the InfoWorks ICM modelling were presumably addressed, as presented results are based on that version of the modelling. The InfoWorks ICM model was applied to assess performance under design storm (2 through 100 Year, 24-Hour Chicago Storms), Regional Storm.

An additional model calibration effort was completed as part of the Characterization Study, focusing on different hydrologic parameters than those applied in the previous “Stormwater Flow Monitoring and System Model Calibration Study” (Aquafor Beech Ltd., 2018). From the discussion in the Characterization Study Interim Report, it is unclear whether these additional parameter adjustments are reflected in the presented design storm and Regional Storm results, although it is assumed that they would have been incorporated. The resulting flows from this updated modelling were used as input to the subsequent hydraulic modelling of the Mohawk Canal and Mohawk Lake system (discussed further in Section 2.4). The modelling was also used to assess the performance of the storm sewer system (to identify the potential for surcharging) for the 2-, 5- and 10-year storm events.

2.3.2 Constraints

Constraints related to hydrology and stormwater management for the current study can be separated into two (2) broad categories: those related to overall existing deficiencies in the stormwater management (SWM) systems, and those related to the existing modelling tools available to assess those systems.

With respect to the former, there are currently no SWM systems in place for the upstream drainage areas, either with respect to quantity control (focus of the current section) or quality control (as discussed in subsequent sections). In addition, with the exception of the Mohawk Canal and two (2) minor open channel tributaries, the entirety of the watershed is serviced by urban drainage systems (enclosed storm sewers with catchbasins and overland flow systems). The combination of these two factors greatly affects the hydrologic cycle and water balance within the subwatershed, and ultimately the downstream receiver, Mohawk Lake. Given the lack of infiltration (and associated baseflow/interflow), and absence of runoff management from impervious surfaces, runoff contributions to Mohawk Lake are high, and would also tend to be more peaked and rapid, which would tend to also impact the potential for erosion and modified baseflow contributions and longer-term circulation within the receiver.

Future re-development/intensification within the subwatershed would provide the opportunity to retroactively provide SWM controls, including quantity and erosion control. Notwithstanding, consideration would need to be given to the overall need and benefit to upstream SWM, and the potential impacts to the overall Mohawk Lake System. This would include the potential benefits of runoff quantities and hydro-period to flow circulation.

Based on a review of the available modelling at the outset of this study (i.e. the InfoSWMM modelling prepared for the October 2018 Draft Characterization Study rather than the InfoWorks ICM modelling applied for the final October 2019 reporting), the following constraints have been noted:

- The subcatchments (approximately 2,600 draining to the Mohawk Lake outfall) within the modelling are irregular (refer to Figure 2.3.2), with inconsistent boundary shapes and areas (many less than 0.01 ha) which do not typically correlate with roadways and other features. It was noted in the Master Servicing Plan (MSP) that the subcatchments were "delineated and assigned through an automated process"; it is unclear whether or not the boundaries were verified/validated following the application of the automated delineation tool.
- The connection between land use and subcatchment parameterization within the MSP is not clearly explained. The subsequent Stormwater Flow Monitoring and System Model Calibration study refers to using land use classification data (zoning by-law) to determine which parameters would require adjustment but does not suggest that the base parameters from the MSP were altered consistently using this information. In order to reasonably assess different subwatershed-based land use changes and SWM strategies, the basis for the initial model parameterization should be clearly understood, as well as subsequent calibration adjustments.
- Some hydrologic modelling parameters are beyond typically accepted standard values, including:
    - Subcatchment lengths at a ratio of 12:1 length : width (based on Wood's previous experience, typically the maximum accepted value is 5:1)
    - High values for Manning's Roughness for overland flow (0.25 and 0.50 for impervious and pervious land segments); the impervious value in particular is approximately an order of magnitude higher than typical values (0.02 or less). Both values also differ from the Characterization Study report (page 111 in the Characterization Study Report (October 2019)) which suggests values adjusted to between 0.1 and 0.45.
    - Horton's Drying Time set at a default of 0.001 days, which is not considered to be a realistic result, and would impact any continuous simulation results
- The peak flows generated by the InfoSWMM modelling presented in the Characterization Study (interim) are approximately half those from the previous Stormwater Management Study (Gore & Storrie Ltd, 1995). It should be noted that the InfoSWMM modelling also does not include any representation of the storage/attenuation function of Mohawk Lake (open channel sections only).
- Based on an initial re-run of the supplied InfoSWMM modelling, simulated peak flow results for the 2-year storm event do not match the values reported in the Characterization Study (interim report). Although attempts were made to reconcile these differences with the previous consultant (due to potential

differences in model setup, etcetera), ultimately the reasons for these differences were not resolved.

- As noted in the Characterization Study (October 2019), there is no major system represented within the modelling (overland flow) or associated assessment of inlet capacity connection between minor/major systems (i.e. catchbasins). There also does not appear to be any surcharge depth or other method applied to minor (storm sewer) nodes to contain flow. As such, the ability of the current modelling to reasonably assess more formative storm events (which would exceed the capacity of the storm sewer system and result in overland flow) is questionable and needs to be addressed.

Figure 2.1: Typical Subcatchment Boundaries within Previous InfoSWMM Modelling

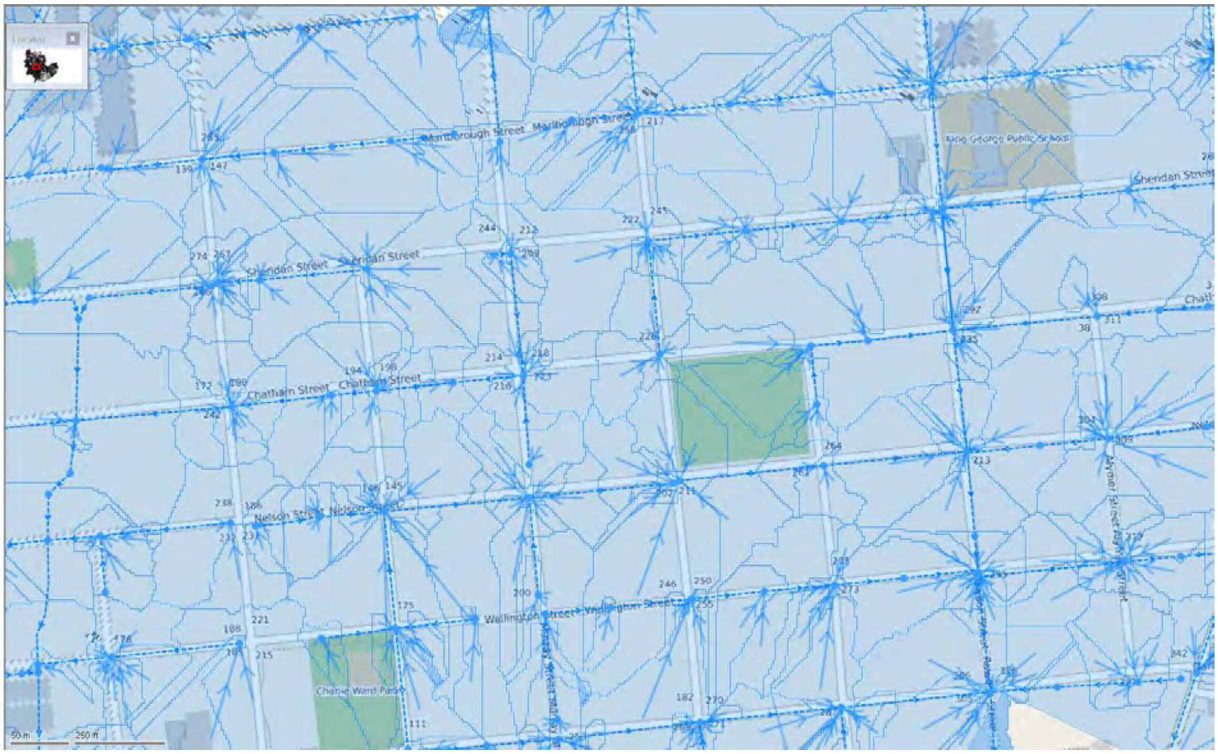


Figure 2.2: Typical Subcatchment Boundaries within Previous InfoWorks ICM Modelling

Data Constraints

As noted previously, a number of issues have been identified with respect to the hydrologic modelling to be applied for the current study. Given the preceding issues, Wood recommended a supplemental work plan scope to the City of Brantford (May 17, 2019) to generate a new/updated hydrologic/hydraulic model for the Mohawk Lake Subwatershed using the InfoSWMM platform. This scope was subsequently approved by the City. Further model development details are provided within Section 4.0 of this report.

2.3.3 Linkages (Features and Function)

The lack of upstream stormwater management (SWM) controls would have the potential for several impacts on the Mohawk Lake and Mohawk Canal systems. As noted previously, the urbanization of the subwatershed in the absence of controls has altered the hydrologic cycle (decreased infiltration, recharge and baseflow, increased runoff). The increased runoff results in larger, more peaked discharges to the receiving system, which also would have negative impacts to erosion and channel stability (as per subsequent discussions with respect to fluvial geomorphology).

The approach to implementing SWM measures for future re-development/intensification will require careful consideration. From a quantity control perspective, current SWM measures include consideration for water balance, as well as peak flow and erosion control, which typically involves infiltration measures (Low Impact Development Best Management Practices, or LID BMPs). These measures would potentially need to consider groundwater impacts (as noted in previous sections), as well as the ultimate benefit/consequence to the receiving system. Impacts on water conservation should also be considered, such as LID BMPs and water efficient landscaping within Mohawk Park, which have the potential to reduce water use related to operations and maintenance. Given the potential desire for circulation and movement of water in Mohawk Lake, in some cases engineered infiltration of upstream water may have unintended negative consequences. This has been considered further as part of subsequent analyses and development of preferred alternatives.

2.4 Hydraulics

2.4.1 Scope

A new georeferenced hydraulic model (HEC-RAS) was prepared as part of the Mohawk Lake Characterization Study (October 2019) for the Mohawk canal and lake systems. The model does not include Shallow Creek, an upper section of watercourse between East Avenue and the start of the Mohawk Canal.

It is noted that Mohawk Lake and a portion of the Mohawk Canal are also within the Regulatory floodplain for the Grand River (ref. Drawing 4). Notwithstanding, the Mohawk Lake area is designated as a Special Policy Area (SPA) by the Grand River Conservation Authority (GRCA). This designation permits development (with restrictions), despite the fact that the area is located within the Regulatory floodplain. There is also a dyke system in place to the south of Mohawk Lake, which connects to the south bank of the East Canal in proximity to the Grand River.

Topographic survey and pond bathymetry were completed as part of the Characterization Study. These data were used to create updated topography and are the basis for developing hydraulic cross-sections of the Lake and Canal. Hydraulic structures (culverts) were also incorporated based on the completed field survey. Obstructions were included in the modelling to account for the blockage associated with structures within the floodplain. Flows from the InfoWorks ICM modelling were applied, with a normal depth boundary condition at the downstream limits, in combination with a rating curve defined within the geometry data for the most downstream cross-section (XS 1240), based on the stage-discharge relationship for Mohawk Lake from the 1995 Stormwater Management Study (Gore & Storrie, 1995).

The resulting floodplain extents for the 2-100-year storm events and the Regulatory event (Hurricane Hazel) were prepared and presented accordingly. The results indicate that the primary floodplain extends beyond Mohawk Lake would be to the south, towards Mohawk Street and the Water Pollution Control Plan (WPCP). The presented floodplain extents indicate the limits of Mohawk Lake would be exceeded for the 50-year storm event and greater. A comparison to the Stormwater Management Study Report (Gore & Storrie Ltd., 1995) indicates that Regional Storm flood levels from the Characterization Study (2019) is approximately 1.71 m lower than those from the 1995 study (199.36 m from October 2019 as compared to 201.07 m in the 1995 study). This difference may be partially attributable to the notable difference in simulated peak flows prepared as part of the Characterization Study (2019), as compared to those of the Stormwater Management Study (1995).

2.4.2 Constraints

Constraints related to hydraulics for the current study can be categorized into two (2) broad types: those related to floodplain extents (i.e. lands which would be impacted by flooding), and those related to the existing modelling tools available to assess those systems.

With respect to the former (floodplain extents), the results presented in the Characterization Study indicate that lands to the south of Mohawk Lake would experience flooding for the 50-year storm event and greater, thus would have greater restrictions with respect to potential for re-development and alteration as part of restoration efforts. As noted previously, the area in question is deemed a Special Policy Area by the GRCA, thus development is permitted with conditions, typically involving flood-proofing and allowable types of development.

The floodplain extents within Shallow Creek (upstream of Mohawk Canal) are unknown. As noted previously, the completed hydraulic modelling completed for the Characterization Study (October 2019) does not include this uppermost component of the open channel conveyance system.

With respect to modelling tools, a key consideration is the potential impact of updated flows (i.e. hydrology) from the proposed updated of the hydrologic modelling (described further in Section 4.0). The potential impacts of revised flows will necessarily be assessed further as part of the modelling updates discussed further in subsequent sections of this report.

A secondary consideration with respect to the hydraulic modelling tools relates to the approach to modelling and assessment of the impact of the outlet control structure for Mohawk Lake and Canal. The hydraulic modelling (HEC-RAS) completed as part of the Characterization Study (October 2019, Aquafor Beech) terminates approximately 100 m downstream of Locks Road and employs a “normal depth” boundary condition (slope of 0.000485, or 0.0485%). Separately however as noted previously, a rating curve is incorporated as part of the most downstream cross-section (XS 1240), based on the stage-discharge relationship for Mohawk Lake from the 1995 Stormwater Management Study (Gore & Storrie, 1995). This approach is atypical; the potential impacts are reviewed further as part of the proposed hydrologic and hydraulic modelling updates, as noted in subsequent sections.

A final potential constraint relates to the potential impacts of backwater from the ultimate receiver, namely the Grand River. The hydraulic modelling completed for the Characterization Study does not incorporate such tailwater conditions, although the report does present a general comparison of Regulatory Floodplain Mapping from the GRCA with the results of the Characterization Study. In general, it is considered unlikely that peak water levels within the Grand River would occur simultaneously with peak levels in the Mohawk Lake system, given the large disparity in drainage areas and associated spatial distribution of rainfall. Notwithstanding, it is suggested that the currently available hydraulic model (HEC-RAS) for the Grand River in the vicinity of Mohawk Lake and Canal should be obtained from the GRCA, and reviewed, with the results considered as part of the hydraulic modelling assessment. This is reviewed further in subsequent sections of the report.

Data Constraints

Generally, no critical data constraints are evident with the hydraulic modelling and assessment work completed as part of the Characterization Study. The lack of defined floodplain information for Shallow Creek is notable, however not critical for the purposes of the current study. As noted, the modelling is reviewed further in conjunction with the hydrologic modelling update, as described further in subsequent sections.

2.4.3 Linkages (Features and Function)

The frequency of flooding inundation within the Mohawk Lake and Mohawk Canal area would potentially impact other disciplines, including ecological considerations associated with natural hydro-periods (i.e. riparian flora and fauna). No direct linkages to other sub-disciplines are evident. Flooding impacts would potentially impact re-development and land usage, as well as related restoration opportunities; this is discussed in greater detail in subsequent sections.

2.5 Fluvial Geomorphology

2.5.1 Scope

The Characterization Study (2019) included a review of background reports, data and base mapping to document study area conditions, including a historical assessment of aerial photography to support interpretations of historic inputs of sediment to the lake and canal system.

Reach delineation and classification was completed for the lake, canals and tributaries, and was verified through field walks; industry standards were applied.

The geomorphological field assessment specifically included the following:

- Rapid Geomorphic Assessments (RGA) of the tributary (and canal outflow) channels;
- Photographic inventories of the tributary (and canal outflow) channels;
- Mapping of existing erosion control and channel engineering structures; and
- Erosion site observations to inform the erosion risk assessment.

Lead-210 dating was conducted by Flett Research Limited and the results were summarized by Aquafor Beech in a technical memorandum (Re: City of Brantford, Mohawk Lake- Lead-210 Dating Sediment Core) in May 2019. Two sediment core samples of approximately 2 meters were collected, with recovery lengths of 1.2 metres (i.e. 40% compaction) and sectioned into a total of 100 samples. Lead-210 dating was confirmed using Cesium-127 (Cs-137) and Radiocarbon ^{14}C validation.

2.5.2 Constraints

2.5.2.1 Background Reports

The available background reports did not identify erosion concerns within the canal or lake, however much of the Mohawk Lake and Mohawk Canal surrounding area has been classified as Riverine Erosion Hazard lands by the Grand River Conservation Authority (GRCA) due to over-steepened banks (ref. Drawing 4). This designation generally prohibits development and will affect the future land use and development options for the area. This will require further investigation to determine potential constraints to future development and the Master Plan.

2.5.2.2 Reach Characterization

The Mohawk Lake system is within the Grand River watershed with surficial sediments locally dominated by till deposits of sand and silt which are currently affecting fluvial processes. Mohawk Lake is a remnant oxbow of the Grand River and historically (prior to dredging and canal construction) would have been an alluvial floodplain, with marsh/wetland characteristics. Shallow Creek forms the upstream reaches of the canal and is an alluvial channel in fair to poor condition. Shallow Creek is in a transitional state with ongoing widening evident. The tributary downstream of Mohawk Lake is an engineered channel with only the most upstream reach in a natural state. Upstream reaches of the tributary are in a stable state, while downstream reaches are unstable and degraded. The downstream reach was recommended in the Characterization Study for immediate restoration. The outflow channel of Mohawk Lake to the Grand River is an alluvial channel with grade control structures and a historic weir. The channel is in a transitional state with evidence of degradation observed. The north shore of Mohawk Lake is predominantly natural, while the south shore is artificially constructed.

2.5.2.3 Erosion Assessment and Sedimentation

The erosion assessment identified and prioritized three (3) erosion sites for environmental restoration: Shallow Creek Park (Erosion Site #1), Tributary 1 at Glenwood Drive (Erosion Site #2) and Outflow Channel (Erosion Site #3). Due to the location and scale of these sites in relation to Mohawk Lake, reducing sediment supply from within the tributary reaches would have a marginal benefit on the canal-lake system.

The Mohawk Lake and Mohawk Canal embankments were determined to be generally geomorphologically stable based on a visual assessment; detailed geotechnical assessments were recommended to confirm.

The Characterization Study investigations indicated that the storm sewer network upstream of the outfall in Shallow Creek Park may be a potential source of sand supply, as sand was found within the culvert pipes. A mobile sand bed was identified in the channel, however minimal bank sources of sand exist within the reach.

It was noted that stormwater management controls would not likely be effective in reducing sand and finer sediments transported in open-channel flow and fluvial processes and would not be effective in reducing sediment loading without implementing stream restoration and identifying the primary sediment source(s). Significant physical modifications would be required to reduce the sediment attenuation, storage and flushing within the canal-lake system. As the primary source of sediment has not been identified, the degree of physical modifications required to mitigate the sediment source remains unknown.

The Pb-210 dating analysis was completed for the core sample from a single location (Location 14). The results provided the following key conclusions regarding sedimentation:

- The top 30 centimetres of sediment was deposited in the last 55 years;
- The top 40-50 centimetres of sediment was deposited in the last 90 years;
- Pb-210 sedimentation rate is between 0.3-0.5 cm/year
- Radiocarbon ^{14}C sedimentation is approximately 0.65 cm/year for the previous 300 years; and
- Recommend average sedimentation rate is approximately 0.5 ±0.1 cm/year

2.5.2.4 Data Constraints

The Characterization Report (2019) recommended several additional studies be undertaken in order to gain a better understanding of the geomorphological context of Mohawk Lake, including:

- Identification of sediment sources from the urban drainage network (potentially the primary source);
- Investigation of existing sediment sources within local drainage area (i.e. lake, adjacent roads, gullies);
- A suspended sediment monitoring program;
- Several detailed geotechnical investigations to support:
  - Detailed engineering design at Erosion Site #2;
  - Risk assessment of local geotechnical hillslope hazards in Tributary 1; and
  - Stability of embankments along the canal.

The Pb-210 dating analysis included some significant limitations and uncertainties, potentially due to irregularities in the sedimentation rate and/or lake dredging that have not been accounted for. The Cs-137 and radiocarbon ^{14}C validation methods however support the Pb-210 CRS age model results. The Lead-210 Dating of Sediment Core technical memorandum prepared by Aquafor Beech indicated that the reliability of the Pb-210 results at Location 14 may be sufficient for the purposes of the overall study. However, analysis of the second core (Location 8) would provide further clarification regarding the variability of the sedimentation rates.

2.5.3 Linkages (Features and Functions)

Areas identified as Riverine Erosion Hazard lands generally prohibit development; recommendations for development options will thus be restricted accordingly. Where development is permitted, future development has the potential to exacerbate erosion conditions of the canal-lake system. The north shore of Mohawk Lake and Mohawk Canal is predominately natural and is designated as a Core Natural Area in the Draft Official Plan 2016, therefore is less likely to allow significant development and restoration options may be viable. The south shore of Mohawk Lake and Mohawk Canal conversely is predominately artificial and abuts areas identified for future development. Development and restoration alternatives in this area will need to consider stormwater management controls to mitigate potential impacts of development, such as increased sedimentation and reduction in natural bank characteristics. Restoration alternatives should consider locations where improvements to erosion hazards will also benefit other systems, such as aquatic habitat improvements and targeting areas of contaminated sediment.

Potential strategic sediment management to address sediment quantity and quality constraints related to contamination provide an opportunity to reconfigure the channels and restore the canal-lake system to a more natural state. The recommended CHL designation for the canal-lake system however represents a potential constraint to naturalizing the channel, as the meander belt width variations will be limited.

2.6 Water Quality

2.6.1 Scope

2.6.1.1 Mohawk Lake and Mohawk Canal

The Characterization Study included a background review of previous water quality condition reports of Mohawk Lake, complemented by a water quality testing program. Water quality testing consisted of four (4) water quality monitoring stations located throughout the study area (ref. Drawing 5). The four (4) monitoring stations, listed from east to west, included: the outflow of Mohawk Lake and contributing outfalls (WQ1), Mohawk Lake (WQ2), the inflow to Mohawk Lake and contributing outfalls (WQ3), and the West Canal (WQ4). The sampling program covered two (2) dry weather base flow events and four (4) wet-weather high flow events, distributed throughout a 6-month period between May and October 2018. The same sampling regime was implemented for six additional grab sample events between spring and summer 2019 for a total of twelve monitoring events.

2.6.1.2 Upstream Subwatershed

An adaptive monitoring program was developed to identify potential point and non-point pollution sources within the upstream watershed, which involved a background review and water quality sampling for a series of dry and wet weather events at ten (10) locations throughout the Mohawk Lake subwatershed. The water quality monitoring locations were selected based on a five (5) step approach: desktop assessment of contributing drainage areas and land uses, risk assessment of land uses, preliminary ranking of sewershed risk to water quality within Mohawk Lake and Mohawk Canal, and preliminary (followed by refined) water quality sampling. Preliminary sampling occurred for three (3) dry weather base flow events and three (3) wet weather high flow events over a 6-month period. Refined sampling was divided into three (3) rounds, each consisting of one (1) dry event and one (1) wet event at ten (10) strategically chosen sampling sites. Following each round, sampling locations were refined to upstream sites exhibiting high contamination to isolate potential pollution sources. Sewersheds were ranked as *good*, *fair* or *poor* based on their pollution scores.

2.6.2 Constraints

2.6.2.1 Mohawk Lake and Mohawk Canal

Background Review Findings

A water quality study (ref. 1983 by Roff, Emerson, Dorey and Bisset) determined the water in the study area to be fairly hard and slightly alkaline, and temperature distribution to be fairly uniform. High levels of phosphorus, nitrogen, suspended solids, copper, cadmium and nickel were detected. Extremely high levels of magnesium were detected in Mohawk Canal, and aluminum in East Ward Creek.

A subsequent water quality study conducted in 1994 by Ecological Services for Planning detected high levels of phenols, copper, zinc, nitrogen, phosphorus and BOD loadings. Concentrations of phosphorus, ammonia, phenols, copper, and zinc exceeded the Provincial Water Quality Objectives (PWQO's).

Annual testing of storm outfalls conducted in 2014 by the City of Brantford, identified high bacteria levels for Mohawk Lake and Mohawk Canal, however not unusually high. It was identified that aquatic biota in the lake have likely been affected by the poor water quality, indicated by the various parameter exceedances of the PWQO's.

Characterization Study Water Quality Monitoring Program Findings

Water samples were analyzed for total suspended solids, nutrients (including nitrate and total phosphorus), and a range of metals, bacteria, and polycyclic aromatic hydrocarbons. While concentrations were variable the following parameters commonly exceeded their respective concentration guidelines at all four (4) monitoring stations:

- Total Suspended Solids
- Nitrate
- Total Phosphorus
- E. coli
- Total Coliforms
- Aluminum
- Copper
- Iron
- Zinc
- Manganese
- Anthracene Benzo(a)anthracene
- Benzo(g,h,i)perylene
- Benzo(k)fluoranthene
- Chrysene
- Dibenzo(a,h)anthracene
- Fluoranthene
- Phenanthrene

The Characterization Study indicates that water quality generally improves from the west to the east of Mohawk Lake and Mohawk Canal, with lower concentrations of the exceeded parameters occurring at WQ-1 and WQ-2 compared to WQ-3 and WQ-4. This observation may be a result of dilution as the water moves eastward into Mohawk Lake, and potentially indicates sources of contamination are entering the system in the west canal. This is further supported by the extreme PWQO guideline exceedances for PAHs at WQ-4, indicating that contamination may be a result of local runoff from nearby industrial lands. The Characterization Study identified similar parameter results as the 1994 study, with the exception of increased concentrations of phosphorus, iron, manganese and zinc.

Poor water quality was also identified from an aesthetic perspective, with substantial levels of trash and debris observed in the West canal (e.g. grocery carts, computer monitors), the deterioration of which may also be contributing to the poor water quality. Effectively reducing trash in the canal-lake system would require a multi-pronged approach, however, removing the existing trash is a recommended short-term solution. Ongoing maintenance and a shift in the actions of park users would be required to maintain the state of the system.

Due to the high concentrations of E. Coli and Total Coliforms, it was recommended to monitor for these contaminants in the future, particularly due to the potential use of Mohawk Lake for recreational purposes such as swimming. The potential link between E. Coli and Total Coliforms with phosphorus and nitrogen, was also identified.

2.6.2.2 Upstream Subwatershed

The water quality monitoring program for the upstream subwatershed identified drainage areas with the greatest parameter exceedances, which also indicate potential contaminant sources for Mohawk Lake and Mohawk Canal. The third and final round of water quality sampling was taken in October 2018. Four (4) significant pollutant "hotspots" were identified as PSM-9,2,6C and 7 (ref. Drawing 5) and are generally located to the north of Mohawk Lake and the West Canal, between Rawdon Street and Wayne Gretzky Parkway. Two (2) of the sewershed areas identified as pollutant hotspots are located in known industrial sectors, which could be the potential pollution source. One (1) identified pollutant hotspot drains into another, which could be the potential source of the pollution. The fourth pollutant hotspot consists of commercial, institutional and residential sectors, however is a high traffic area which could be the source of the pollution. Sewersheds were ranked as *poor*, *fair* and *good*, however it should be noted these classifications are relative, and all sewersheds exceeded PWQO's. The parameters which demonstrated exceedances were similar to those identified in the Mohawk Lake and Mohawk Canal.

Identifying whether the contaminant sources are due to legacy sources versus ongoing activities will need to be determined in order to mitigate the source and improve the water quality. If the pollutant source is identified to be due to on-going activities, remediation measures will not be sufficient, and action will be required on behalf of the City to regulate the source. Continued monitoring of ambient water quality and sediment conditions within the lake will assist with differentiating legacy and active pollutant loading sources and management of existing water quality restoration programs.

2.6.2.3 Data Constraints

The Characterization Report recommended the following investigations within the upstream watershed:

- Investigations to determine potential storm sewer and sanitary sewer cross connections near the intersection of Rawdon Street and Bruce Street.
- Further investigations to isolate pollution "hotspots".

Water quality data collected and evaluated in the Characterization Report were aimed at understanding how various stormwater pollutants respond after being discharged to surface water. Additional long-term seasonal evaluation of limnological response variables such as chlorophyll-a and dissolved oxygen is recommended. Water quality conditions may vary significantly at different depths depending on whether the lake is frequently stratified. Notably, without these data, it is difficult to assess the effects of stormwater pollutants on the ecological condition of the waterbody and what role internal recycling may play.

2.6.3 Linkages (Features and Function)

Mohawk Lake and Mohawk Canal is primarily sourced by stormwater runoff from the surrounding urban area and adjacent outfalls. As suggested by the significant exceedances in PAH's at WQ-4, contaminants may be entering the system through local stormwater runoff from the industrial uses adjacent to the West Canal. Identifying the contaminant sources and applying stormwater controls to treat the runoff prior to entering the system may play a significant role in improving the water quality of the lake and canal over the long term.

The form of restoration measures will be dependent on contaminant source type (non-point vs. point) and whether the activity is ongoing. An active industrial site (Sonoco Products of Canada) is on the north shores of the West Canal and has been recommended for monitoring.

Mohawk Lake and Mohawk Canal feed directly into the Grand River, which the City of Brantford and Six Nations of the Grand River use as a primary drinking water source (GRCA, 2018). The potential of the degraded water quality within the canal-lake system to affect the drinking water source, emphasizes the importance of improving the water quality of the system prior to entering the Grand River. The impacts of climate change on Canadian water resources are predicted to be more impactful for those municipalities sourcing water from local surface or groundwater supplies as opposed to Lake Ontario (Natural Resources Canada, 2016). Stormwater controls and restoration measures should consider the impacts on sustaining water quality within the lake-canal system, the Mohawk Lake and Oxbow Wetland Complex, and the overall watershed, in order to positively contribute to the conservation of water quality within the Grand River.

Sedimentation, as a result of erosion of Mohawk Lake and Mohawk Canal, as well as the contributing tributaries and outflows, has a direct effect on water quality, as the accumulated sediment has been identified to contain concentrations of various contaminants that exceed the severe effect levels for benthic organisms. While the implications for human health and the current degree of internal contaminant recycling have yet to be determined, strategic sediment removal through dredging and various sediment quantity and sediment quality restoration alternatives could provide near-term water quality improvements that may extend the benefits from prior and future pollution source control efforts. The linkages between the subwatershed contamination and lake health should be considered as part of the selection of restoration alternatives. Similarly, restoration alternatives targeted at improving the water quality of Mohawk Lake and Mohawk Canal should consider the corresponding benefits to the natural heritage system, specifically aquatic habitat, as the parameter exceedances of various Provincial Sediment Quality Guidelines (PSQGs), have been identified to negatively impact aquatic biota due to impacted water quality.

Degraded water quality will have a negative effect on the recreational activities that are safe to occur within Mohawk Lake, particularly for human contact due to the high concentrations of *E. coli* and total coliforms. Degraded water quality from an aesthetic perspective will further influence the recreational potential of the lake and surrounding area, due to the high levels of trash and debris, which will reduce the appeal of the area as a park and the ability of users to swim and boat in the lake.

Development and increased impervious area can negatively impact water quality due to surface water runoff that transports contaminants. Future development that increases the amount of impervious area can also further degrade the runoff water quality, and stormwater management controls such as Low Impact Development Best Management

Practices (LID BMPs) should be considered to partially treat or retain the water at source.

2.7 Sediment Quantity and Quality

2.7.1 Scope

A background review was conducted for sediment quantity and quality reports completed between 1972 and 1994. The sediment assessment conducted as part of the Characterization Study included both sediment quantity and quality.

2.7.1.1 Sediment Quantity

The sediment quantity assessment for the Characterization Study included a bathymetric survey and sediment profiling following the “rod and measure” approach and using GPS survey equipment. Cross-sections were completed at a minimum of 20 m along the canals, with points every 3.0 to 5.0 meters along the cross-section.

2.7.1.2 Sediment Quality

The sediment quality assessment consisted of a sampling program that included the collection of surficial sediment and sediment core samples at twenty (20) locations within the Mohawk Lake and Mohawk Canal. Two (2) different sample collection methods were used; the surficial samples were collected using Petite Ponar, whereas the deeper sediments were collected with core sampling using the Pollutech’s hammer core technique. At each location, three (3) samples were taken at varying depths, resulting in a total of sixty (60) individual samples.

2.7.2 Constraints

2.7.2.1 Sediment Quantity

The bathymetric survey results were digitized into a digital terrain model (DTM) depicting the top of sediment and unconsolidated lake bottom. The findings indicated:

- The sediment thickness is greatest toward the north half of the lake.
- The water in the lake gets progressively deeper from the west to east.
- The deepest portion of the lake forms a general band along the middle, which reaches depths of approximately 4.4 m.

Location	Approximate amount of unconsolidated sediment	Sediment thickness	Water depth
Mohawk Lake	155,000 m^3	0 – 2.4m	0 – 2.5m
Canals	30,000 m^3	0 – 1.5m	0 – 1.0m

2.7.2.2 Sediment Quality

The sampling results from eighteen (18) stations and three sampling intervals collected from Mohawk Lake and the east and west canals were compared against two (2) provincial regulatory guidelines: *Guidelines for Identifying, Assessing and Managing Contaminated Sediments in Ontario (MECP, 2008)* to assess sediment quality, and *Soil,* *Ground Water and Sediment Standards for Use Under Part XV.1 of the 'Environmental Protection Act'* to assess the acceptability of the soils related to various land disposal sites and approaches.

In accordance with the PSQG's, the sediment samples were analyzed for nutrients, metals, PAHs, organochlorine pesticides and PCBs, and assigned an effect level of 'No Effect', 'Lowest Effect', or 'Severe Effect', in relation to the potential effect of the parameter exceedance to impair the aquatic environment. The majority of the parameters fell within the 'Lowest Effect' category, except for the following:

- All metals exceeded the 'Lowest Effect' at the majority of sampling locations within the lake, except for arsenic which exceeded at one (1) location;
- Copper exceeded 'Severe Effect' at four (4) locations (towards the west end of the lake);
- Lead exceeded 'Severe Effect' at eight (8) locations (towards the west and south end of the lake);
- All locations exceeded 'Lowest Effect' for one (1) or more PAHs, with the majority exceeding for eight (8) or more; no samples reached 'Severe Effect'; and
- PCBs exceeded 'Lowest Effect' at all locations, with the exception of two (within the east canal).

Sediment quality is most significantly impacted at the west end of Mohawk Lake and Mohawk Canal and improves towards the east end. Several sediment samples contained Copper and Lead concentrations that were identified to have "Severe Effects" as per the PSQG's. Additionally, sediment samples at all sampling locations exceeded 'Lowest Effect' for PCB concentrations, all metals (with the exception of arsenic), and one (1) or more PAHs.

Sediment samples from all three collection intervals were tested against O. Reg. 153/04 soil standards to determine acceptability for future disposal. The results of the sediment sample analyses found the following:

- Metals: cadmium, lead and zinc generally exceeded Table 3 standards for Industrial/ Commercial land use in the top and middle intervals; several additional metals exceeded Table 1 standards for the top and middle sampling interval;
- VOCs: Marginally exceeded Table 1 standards;
- PAHs: Seven (7) PAHs exceeded Table 3 standards for Industrial/ Commercial land use. Acenaphthylene exceeded Table 5 standards at four (4) locations (towards the west and south of the lake);
- PHCs: Approximately half of the locations exceeded Table 3 standards for Industrial/ Commercial (towards the west and south end of lake);
- Organochlorine Pesticides: Zero locations were above the detection limits; and
- PCBs: Twelve (12) locations exceeded Table 3 standards for Residential/ Parkland/ Institutional and were found primarily within the middle sampling interval.

The Characterization Report indicated that Mohawk Lake sediment is non-hazardous based on three samples and the results of the Ontario Reg. 347 Leachate Extraction Tests. Sampling results indicated that the contamination levels within a significant portion of the sediment is sufficiently elevated that disposal sites are restricted to Table 3 and Table 5 standards. Due to the significant quantity of potentially impacted sediment (185,000m^3), locating an acceptable disposal site may represent a major financial and logistical constraint. Strategic removal of sediment “hot-spots” may provide a more economical and effective means of restoration.

Data Constraints

The sediment chemistry results provided in the Characterization Report cover a wide range of pollutants which have been compared to regulatory thresholds. Regulatory thresholds, while useful to assess specific toxic affects to a narrow range of species, may not be suitable by themselves to determine the need for restoration work. Therefore, additional evaluations are recommended to assess and identify the linkages of contaminated sediment to ecological health and sustainable restoration of the system.

2.7.3 Linkages (Features and Function)

Impacted sediment and the associated long-term storage of contaminated material has undoubtedly contributed to the degradation of the water quality in Mohawk Lake and Mohawk Canal due to long-term exposure and has the potential to negatively influence surface and groundwater quality due to contamination migration. Strategic removal of material to reduce problematic sediment accumulation, along with activities to reduce erosion, may be restricted due to sediment areas that are highly contaminated. Moving the sediments may result in the mobilization of contaminants, therefore the advantages and disadvantages of restoration alternatives will need to be carefully assessed across disciplines. A further consideration related to the impact of sediment quality on water quality relates to the impact on ecological systems and recreational uses, due to concern for public safety.

Development activities upstream, and adjacent to, the canal-lake system should be monitored to determine the primary sources of sediment loading, in order to develop a long-term solution for Mohawk Lake and Mohawk Canal.

2.8 Natural Heritage and Ecology

2.8.1 Scope

The Characterization Study (2019) included a review of natural heritage planning policies, including policies from the City of Brantford Official Plan and Grand River Conservation Authority. A background review was completed of previous aquatic ecosystem studies conducted within Mohawk Lake related to the fish community, benthic macroinvertebrate community, and aquatic habitat. The terrestrial ecosystem background review included studies related to flora, vegetation communities, species-at-risk (SAR) and other species of conservation concern, and significant wildlife habitat. Historical information related to the terrestrial ecosystem was noted to be insufficient, and the assessment of Natural Heritage System (NHS) features could not be determined solely through review of background information, resulting in a requirement for a significant field survey program.

2.8.1.1 Aquatic Ecosystem

Fish community, benthic macroinvertebrate, and aquatic surveys were completed as part of the Characterization Study. Fish surveys included 4 minnow traps and a fyke net over a five (5) day period only targeting Mohawk Lake; electrofish and seine net surveys were not conducted due to local conditions. Benthic macroinvertebrate surveys were conducted following the travelling kick and sweep method with three replicates conducted. Aquatic habitat surveys were conducted using Section 4: Module 2 of Ontario Stream Assessment Protocol (OSAP) for Point-Transect Sampling for Channel Structure, Substrate and Bank Conditions; dissolved oxygen and temperature were also measured within the lake.

2.8.1.2 Terrestrial Ecosystem

Biophysical studies completed as part of the Characterization Study included breeding bird surveys, amphibian calling surveys, incidental observations of wildlife surveys (e.g. reptiles, lepidopterans, odonates, mammals) and botanical and vegetation community surveys. Vegetation communities were assessed in accordance with the *Ecological Land Classification Protocol for Southern Ontario* and complemented by aerial imagery interpretation and roadside assessments. Wetlands were assessed according to the *Ontario Wetland Evaluation System (OWES), Southern Manual*. Botanical inventory and vegetation community surveys were completed in the summer/early fall, to identify vascular plants in the study area. Breeding bird surveys were conducted in accordance with the *Ontario Breeding Bird Atlas (OBBA)* protocol in June 2018 over the course of five (5) dates; a total of 28-point count surveys were established within the study area, reflective of areas where significant species and/or habitat were considered to be present and included a review of eBird (an online database of public observations). Targeted mammal surveys were not undertaken for the Characterization Study; field surveys conducted in 2018 resulted in incidental mammal observations. Amphibian call surveys were conducted in accordance with *the Marsh Monitoring Program* standard protocol, on still nights typically immediately after rain. SAR and other species of conservation concern were identified through several primary and secondary information sources, including correspondence with the Ontario Ministry of Natural Resources and Forestry (MNRF) and other background information sources. Significant Wildlife Habitat (SWH) was identified in accordance with the *Technical Guide for Ecoregion 7E* (MNRF, 2015).

2.8.2 Constraints

2.8.2.1 Aquatic Ecosystem

Historic fish community surveys (1972 and 1993) from Mohawk Lake identified cyprinid species, generally known to be tolerant to degraded conditions. Pumpkinseed (*Lepomis gibbosus*), a species somewhat resilient to impaired conditions was also identified. No large predator or game fish were captured as part of these historic surveys. Additional fish community surveys completed in 1995 reported a diverse assemblage of top-level and mid-level predators, as well as omnivorous and planktivorous species. These surveys also identified Common Carp (*Cyprinus carpio*), an invasive species generally known to thrive in lake/lotic systems with high turbidity. It was estimated that Common

Carp comprised approximately 50% of the catch. The MNRF recently confirmed the presence of the species reported in 1995. Results from the fish community surveys completed as part of the Characterization Study confirmed previously identified species with the addition of Creek Chub (*Semotilus atromaculatus*) and Bluegill (*Lepomis macrochirus*). No sensitive species or SAR were captured.

Previous studies noted that the existing silt substrate limited the potential for fish spawning, as fish do not typically spawn over such substrates. It was also noted that the lack of emergent vegetation nearshore limited the potential for nursery habitat for juvenile fish. Current Fisheries and Oceans Canada (DFO) SAR mapping indicate critical habitat for Eastern Sand Darter (Ammocrypta pellucida) and Round Pigtoe (Pleurobema sintoxia) in the Grand River downstream of the outflow channel. DFO SAR mapping identified additional SAR fish and mussel species potentially occurring in the reaches immediately downstream of the outflow channel, including, Black Redhorse (Moxostoma duauesnei), Silver Shiner (Notropis Photogenis) and Wavy-rayed Lampmussel (Lampsilis fasciola). The Characterization Study identified the potential for three (3) aquatic SAR within the study area; Rainbow Mussel (Villosa iris), Round Pigtoe and Wavy-rayed Lampmussel. Given the current observed habitat conditions, it was determined that these species do not likely inhabit the Mohawk Lake system.

Benthic macroinvertebrate sampling in 1972 only identified species within the outflow channel. The identified species were all considered to be pollution tolerant. Benthic macroinvertebrate sampling in 1995 noted a higher diversity of species along the littoral zone compared to the profundal zone. With the exception of a few species, all were considered to be tolerant to pollution. Benthic macroinvertebrate surveys undertaken as part of the Characterization Study focused on nearshore areas around the perimeter of the lake, within the canal and the outflow channel. The results indicate that conditions are considered not to be impaired; however, conditions within the canal and outflow channel were noted to be poorer compared to the lake.
The results of the Characterization Study identified the Mohawk Lake system to have a cool-warm water thermal regime with an assemblage of species that are intermediately tolerant to adverse and impaired conditions. The highest quality of habitat identified included the littoral nearshore areas of Mohawk Lake. Habitat within the profundal zone was considered to be impaired and highly influenced by deep sediment accumulations, which has impacted the benthic macroinvertebrate community and reduced dissolved oxygen concentrations.

Recommended Habitat Enhancements

To improve aquatic habitat conditions the Characterization Study included the following recommendations:

- Create a varied bathymetric profile of the lake to provide diversity of water depth and thus habitat for fish;
- Introduce coarse substrate material into the Mohawk Canal and to an extent within the lake to increase substrate diversity and promote a variety of habitat for aquatic vegetation, invertebrates and fish;
- Introduce coarse substrate material into the Mohawk Canal to improve hydraulic conditions, expand capacity and utilization for a variety of lentic and lotic fish

species. These changes could also improve sediment transport, under the assumption that incoming bedload is controlled and not substantially impactful to the hydraulic regime provided by the additional coarse substrate; and
- Addressing identified erosion areas (GRCA – Riverine Erosion Hazard Lands) within the lake, canal and tributaries where over-steepened banks are present.

Constraints related to the implementation of aquatic natural heritage improvements included:

- The effectiveness of introducing coarse substrate material will be dependent on the identification and mitigation of the primary sediment sources. Coarse substrate materials will become buried in sediment and yield limited benefit unless the quantity of sediment entering the system is reduced.
- The ability to vary the bathymetric profile of the lake will be dependent on the assessment of sediment contamination and whether transporting the sediment will result in the mobilization of contaminants.
- Mohawk Lake and Mohawk Canal are part of a larger natural heritage system, which is urbanized upstream and naturalized downstream. Improvements to aquatic habitat will be constrained by the context of the site, as the water quality flowing from the urbanized watershed is degraded.

Data Constraints

Recommendations for Additional Studies:
The Characterization Study provided a focus on conditions within Mohawk Lake and in the immediate areas of the canal and outflow channel. The Characterization Study does not cover areas relative to the Shallow Creek pond or Rawdon Street pond (ID#1 and ID#2 respectively), however the Rawdon Street pond is proposed outside of the existing aquatic environment, and therefore no further aquatic investigations are recommended at this time. It is recommended that the field survey program be extended to further characterize conditions within Shallow Creek pond area, the identified tributary, and within the Grand River proper. A fish community survey program to collect information is recommended. Aquatic habitat characterization will be carried out by following the Ministry of Transportation/Fisheries and Oceans Canada/MNRF fisheries protocol. This will include collection of data pertaining to the general morphology of the reach (bankfull depth, channel width, and stream gradient), instream and riparian vegetation, occurrences of seeps or springs, general description of substrates as they relate to potential fish habitat, and flow. Information collected will be used to identify fisheries constraints and evaluate impacts on existing fisheries resources (as needed).

A complete understanding of the system will enable a broader understanding and identification of all constraints and sensitivities, in order to focus remediation efforts. Surveys within the Grand River should also focus on evaluating habitat potential for the identified SAR, in order to confirm future permitting and approval requirements under applicable provincial and federal legislation.

Environmental Impact Studies (EIS) will need to be prepared through coordination with the Grand River Conservation Authority (GRCA) and an approved terms of reference (TOR) to facilitate the implementation of the various project recommendations.

2.8.2.2 Terrestrial Ecosystem

The results of the program undertaken as part of the Characterization Study identified 26 (twenty-six) Ecological Land Classification (ELC) polygons comprised of 23 (twenty-three) vegetation community types. The identified communities were varied and ranged from highly disturbed areas to natural forests and wetlands. One (1) of the communities (ref. S2S3) is considered to be a rare vegetation community: Fresh-Moist Lowland Black Walnut Deciduous Forest (FOD4-7), according to the *Significant Wildlife Habitat Technical Guide* (2000). This community was found in three (3) locations: steep slope on north shore of Mohawk Lake, in between Mohawk Road and the existing hydro corridor, and around Beach Road adjacent to the Grand River.

The Mohawk Lake and Oxbow Wetland Complex was evaluated and as per the *OWES, Southern Manual* was not considered to be significant. This evaluation was last undertaken in 2000. In light of recent species up-listing [Eastern Wood-Pewee *(Contopus virens)*] and new documentation of species [Snapping Turtle *(Chelydra serpentina)* and Blanding's Turtle *(Emydoidea blandingii)*] from when the initial wetland evaluation was undertaken, the current evaluation would consider the wetland to be provincially significant. The reclassification of the wetland would have policy implications if it were considered a Provincially Significant Wetland (PSW). The extent of the wetland, as defined in the Characterization Study, would also require a further evaluation to determine if smaller wetland features could be included as part of the larger system, as Snapping and Painted Turtles *(Chrysemys picta marginata)* were observed in these smaller wetland features. The outcome of the current wetland evaluation, being undertaken as part of the Characterization Study, recommended that the existing wetland evaluations be updated according to OWES.

The results of the botanical survey undertaken during the Characterization Study identified a total of 260 species, with 179 being native species and 81 introduced species. No SAR were identified, however, four (4) species of provincial significance were recorded: Ohio Buckeye *(Aesculus glabra)*, Tall Boneset *(Eupatorium altissimum)*, Pignut Hickory *(Carya glabra)* and Sharp-leaved Goldenrod *(Solidago arguta var. arguta)*. Locally rare species that were identified included: Carpenter's Square *(Scrophularia marilandica)*, Columbia Watermeal *(Wolffia columbiana)* and Pale-leaved Wood Sunflower *(Helianthus strumosus)*. Observations of introduced species included Common Buckthorn *(Rhamnus cathartica)*. Common Buckthorn is considered to be invasive and was present in the understory in many communities throughout the study area. Other invasive species observed include Garlic Mustard *(Alliaria petiolate)*, Common Reed *(Phragmites australis)* and Periwinkle *(Vinca minor)*. The Characterization Study noted that previous studies recommended the implementation of an Invasive Species Management Plan.

Breeding bird surveys undertaken during for the Characterization Study identified a total of 62 species, which included four (4) SAR: Chimney Swift *(Chaetura pelagica)*, Barn Swallow *(Hirundo rustica)*, Wood Thrush *(Hylocichla mustelina)* and Eastern Wood-pewee. Additionally, the Caspian Tern (*Hydroprogne caspia*), which is provincially rare, was identified during surveys. Caspian Tern is included in the Characterization Study Breeding Bird Table (Table 5.3.1), however this species is not included in the Appendix E-7, Species-at-Risk and Species of Conservation Concern Screening Table. However, Caspian Tern is included in Appendix E-8 – Significant Wildlife Habitat Screening Table, the Tern is identified as a potential species within Colonially – Nesting Bird Breeding Habitat (Ground). The assessment determined that the required habitat for this significant wildlife habitat category is not present within the study area. Background records (eBird) identified the potential for three (3) additional species of special concern: Bald Eagle *(Haliaeetus leucocephalus)*, Red-headed Woodpecker *(Melanerpes erythrocephalus)* and Horned Grebe *(Podiceps auritus)* and one (1) provincially rare species, Great Black-backed Gull (*Larus marinus*). The eBird observations are year-round and any particular record could include migrant individuals or winter residents and does not explicitly confirm the species is breeding.

Incidental mammal observations included: Eastern Grey Squirrel (*Sciurus carolinensis*), Eastern Chipmunk *(Tamias striatus)* and White-tailed Deer *(Odocoileus virginianus)*. Of note, there is potential for bats species to be present in the study area; however, such investigations were not undertaken as part of the Characterization Study. A local resident conducted surveys throughout the study area and reported the following additional species: Beavers (*Castor Canadensis*), Eastern Cottontail (*Sylvilagus floridanus*), feral and domestic cats (*Felis catus*), Red Fox (*Vulpes vulpes*), Muskrats (*Ondatra zibethicus*), Virginia Opossum (*Didelphis virginiana*) and Raccoons (*Procyon lator*).

Herpetofauna surveys were undertaken as part of the Characterization Study. A total of six (6) survey stations identified five (5) frog species over three (3) monitoring events. No full chorus calls were recorded with many stations having no call (11 of 18 station events). Identified species were all considered to be secure.

Extirpated, Endangered and Threatened species and their habitat are protected under the provincial *Endangered Species Act* (*ESA, 2007*). Special Concern species are listed under the *ESA, 2007*, however they are not allotted habitat or species protection under the *ESA, 2007*. The result of the SAR screening, as presented in the Characterization Study, confirmed the presence of 11 terrestrial SAR and species of conservation concern within the study area: Barn Swallow, (Threatened) Chimney Swift (Threatened), Eastern Wood-pewee (Special Concern), Wood Thrush (Special Concern), Monarch *(Danaus plexippus)* (Special Concern), Pignut Hickory (S3), Ohio Buckeye (S1), Sharp-leaved Goldenrod (S3), Tall Boneset (S1), Blanding's Turtle (Threatened) and Snapping Turtle (Special Concern). Potential habitat for other terrestrial SAR was also identified, including: Bald Eagle, Golden-winged Warbler (*Vermivora chrysoptera*) (Special Concern), Northern Bobwhite *(Colinus virginianus)* (Endangered), Red-headed Woodpecker, Yellow-breasted Chat *(Icteria virens)* (Endangered), Rapids Clubtail *(Gomphus quadricolor)* (Endangered), American Badger (*Taxidea taxis*) (Endangered), bats species (Endangered), Eastern Ribbonsnake (*Thamnophis sauritus*) (Special Concern) and Butternut *(Juglans cinerea)* (Endangered).

Confirmed Significant Wildlife Habitat (SWH), as reported in the Characterization Study, included Rare Vegetation Communities (Fresh-Moist Lowland Black Walnut Deciduous Forest), Bald Eagle and Osprey Nesting, Foraging and Perching Habitat, Amphibian Breeding Habitat (Wetlands), and Specialized Habitat for Wildlife: Special Concern and Rare Wildlife Species. Potential SWH within the study area included: Raptor Wintering

Area, Bat Maternity Colonies, Turtle Wintering Areas and Turtle Nesting Areas, Reptile Hibernaculum, and Shrub/Early Successional Bird Breeding Habitat.

Recommended Habitat Enhancements

- Develop and implement an Invasive Species Management Plan;
- Develop and implement an Edge Management Plan for associated woodlands, particularly the Black Walnut Lowland Deciduous Forest (FOD7-4) which is considered a rare vegetation community according to the *Significant Wildlife Habitat Technical Guide* (2000);
- Develop and create Butterfly habitat by enhancing existing meadow habitat with removal of invasive species and new plantings of suitable native species (e.g. Common Milkweed);
- Create new turtle nesting areas and basking opportunities through placement of sand and gravel beds, as well as logs;
- Enhance existing vegetation communities with a native species planting program combined with the Invasive Species Management Plan through creation of a Landscape Restoration Plan; and
- Depending on level of habitat present, potential creation of raptor habitat or perching structures.

Constraints related to terrestrial natural heritage recommendations:

- Should the Mohawk Lake and Oxbow Wetland Complex be designated a PSW, this will represent a significant constraint to the site, as a 120m PSW adjacent lands setback would restrict development and adjacent land use opportunities.
- Construction activities and site disturbance may result in delays for habitat creation, as a native species planting program may be destroyed in the process of remediation works. Similar effects should be considered if a maintenance program or regular dredging is proposed.
- Mohawk Lake and Mohawk Canal is located in an increasingly urbanizing environment. Terrestrial habitat should consider wildlife fencing and site design that redirects wildlife away from vehicular traffic and urbanized areas.

Data Constraints

The Characterization Study provided a focus on conditions within Mohawk Lake and in the immediate areas of the canal and outflow channel. The Characterization Study does not cover areas relative to the Shallow Creek SWM retrofit or Rawdon Street SWM retrofit (ID#1 and ID#2 respectively). It is recommended that the field survey program be extended to further characterize conditions within the future Shallow Creek and Rawdon Street SWM retrofits.

Recommendations for Additional Studies:

- Should the works proposed near or within the Mohawk Lake and Oxbow Wetlands, evaluation of these wetlands should be updated to include recent SAR records; the results of this evaluation would be expected to change the status of the wetland complex, making it a PSW. Consultation should occur with the MNRF to confirm the PSW designation. It is important to note these features are not adjacent or within 120 m of the proposed Shallow Creek and Rawdon pond areas;

- Completion of a two (2) season (spring and summer) botanical inventory and evaluation and mapping of the existing vegetation communities using the Ecological Land Classification (ELC) system for southern Ontario (Lee 1998);
- Completion of breeding bird surveys consistent the Ontario Breeding Bird Atlas (two surveys timed 15 days apart between late May and 10 July);
- Search for Reptile hibernaculum to document burrows, rock piles, old stone fences, abandoned crumbling foundations, and wetlands to confirm absence and presence;
- Potential maternity roost habitat has been documented in the Characterization Study. It is recommended that MECP be consulted regarding information required to determine mitigation for tree removal, should tree removals be proposed. ;
- Evaluation of wildlife habitat features, potentially significant wildlife habitat, general extent of habitat use and potential linkage functions between the natural areas, particularly for SAR, to the extent feasible;
- Butternut field survey to confirm the presence or absence of species. No parent Butternut were observed during the field investigations in the Characterization Report. However, several young walnut species were noted in communities 10 and 11 that exhibited signs of a Butternut Hybridity. Confirmation should be made through another field survey with the potential submission of DNA samples to MNRF. It is important to note these features are not adjacent or within 120 m of the proposed Shallow Creek and Rawdon pond areas, however, given their proximity a search for Butternut is recommended which would occur in tandem with the recommended three (3) season botanical inventory; and
- A tree inventory to document the trees that may be impacted by future construction activities shall also be completed.

Overall, an Environmental Impact Study (EIS) will need to be prepared through coordination with the GRCA through an approved TOR to facilitate the project moving forward. The above noted recommended studies will serve as part of the EIS or completed separately and included within the EIS. As noted in the Environmental Assessment Report, in response to the review of draft project documentation, GRCA indicated that Wetland boundaries will need to be delineated by a qualified consultant and subsequently verified by the GRCA..

2.8.3 Linkages (Features and Function)

Based on the information provided, it is evident that the adjacent land uses have contributed to increased sedimentation in Mohawk Lake along with potential contaminants from the multiple outfalls along the banks. Each of these adjacent land uses contributed to the alteration of the water quality of Mohawk Lake and, subsequently, the fish and benthic population. Improvements to better manage land use influences on Mohawk Lake will help improve the aquatic habitat and overall function .

As it pertains to the terrestrial ecosystem, the east and west canal, are more than 20 m wide in most instances in the Study Area. a 20 m break between two features is considered large enough to separate the features, per the Natural Heritage Reference Manual (2010). For example, a break in a woodland canopy that is 20 m or greater, results in the delineation of two separate woodlands. Therefore, based on the existing Study Area, those features on the north shoreline are separated from those along the south shoreline. A better understanding of the linkages between groundwater and hydrologic functions and their role and influence in adjacent wetland function is needed. Furthermore, the role of groundwater in the interaction with legacy landfills is also important and in need of further study.

It is expected that through environmental rehabilitation, the linkages between water resources, existing natural heritage features, and surface water features may be improved to be more functional and sustainable. Rehabilitation will allow for improvements to the riparian habitat along the banks and help link those communities between the shorelines.

2.9 Potential Sources of Contamination

As part of the Characterization Study, industrial properties and landfill sites surrounding Mohawk Lake and Mohawk Canal were assessed as potential contaminant sources. Seven (7) abandoned landfills, one (1) active landfill, and eighteen (18) industrial properties were assessed by Gore & Storrie (1995) based on relative location to Mohawk Lake and Mohawk Canal, groundwater flow, historical and current uses of the site and the associated manufacturing processes.

2.9.1 Landfill Sites

The impact from the majority of landfill sites is expected to be minimal due to the size of the sites, distance from Mohawk Lake and Mohawk Canal, and direction of groundwater flow. Monitoring of groundwater is recommended as well as the stabilization of erosion sites to reduce the potential for contaminant transport. Three (3) landfill sites were identified as having potential impacts on Mohawk Lake and Mohawk Canal.

The landfill located adjacent to Shallow Creek is the site of the former canal turning basin and a former coal gasification plant. A subsurface soil and fill investigation determined the site was significantly contaminated with PAHs, and groundwater samples were also contaminated. Groundwater was identified to be flowing towards Shallow Creek Park, but not contributing to the baseflow of East Ward Creek. Remedial action was not deemed necessary at the time of assessment as there was no direct contact with the waste, however PAH contamination may have occurred by physical transport of the contaminated soils through erosion and transport from upstream areas.

Recommendations by Gore & Storrie (1995) to reduce potential further contamination included:

- Monitor future construction work to avoid hydraulic transportation of the soils from the construction site;
- Remediate identified erosion sites to reduce potential for contamination transport;
- Continue to monitor groundwater flow to understand groundwater system; and

- Analyze sediment samples from upstream tributary storm sewers to identify PAH contaminated sediments and potential contribution sources.

The landfill located in Mohawk Park has been used for tree, leaf and street sweeping remnants, which do not pose a significant source of contamination. It is recommended however that dumping be ceased, and erosion sites be stabilized.

The Mohawk Street Landfill, located to the southeast of Mohawk Lake, is active and the only municipally owned landfill in Brantford. Groundwater flows generally to the southeast, away from Mohawk Lake, with leachate collection systems and a bentonite barrier installed around much of the landfill. Mohawk Lake is not considered to be significantly impacted, however landfill leachate has somewhat affected the upper aquifer and there is potential for the contaminant plume to move towards the Grand River and Morrison Road, near Mohawk Road.

2.9.2 Industrial Properties

The majority of the industrial properties proximate to Mohawk Lake and Canal were identified as not expected to have a significant impact on Mohawk Lake or Mohawk Canal, with the exception of the following sites:

- Sonoco Products of Canada is located on the north banks of Mohawk Canal with stormwater discharging from the property into the canal. Water from the canal is used as non-contact cooling water and discharged back into the canal and lake; ongoing monitoring is recommended to ensure discharge is of an acceptable quality and temperature.
- The former P.U.C. building, also sited on the north banks of Mohawk Canal, has likely impacted the quality of the surface soils and the West Canal, however impacts are expected to be minimal.
- The Canada Glue Company site, located to the south of the East Canal, has likely impacted the surface soils however due to the direction of groundwater flow is unlikely to impact Mohawk Lake and Mohawk Canal.
- The Greenwich Mohawk Brownfield site underwent a remediation program to address soil contaminants, including petroleum, hydrocarbons, xylenes, lead and underground storage tanks, which was completed in 2017.

3.0 Future Land Use and Growth

3.1 Documentation Review

The population of the City of Brantford is projected to grow by an additional 48,000 residents by the year 2036, an increase from the current population of 104,000 residents (ref. Growth Plan 2017, Schedule 3). This is expected to be accompanied by an additional 20,410 new dwellings units, and employment growth is projected to include an additional 23,000 jobs by the year 2036, an increase from the current 49,000 jobs (ref. Greater Golden Horseshoe Forecast to 2041- Appendix B: Detailed Forecast Results, prepared by Hemson Consulting for the Province of Ontario).

The Mohawk Lake and Canal Cleanup and Rehabilitation Project, and the long-term management of the lake and canal, will need to account for this additional growth and the impacts associated with intensification and new development within the tributary subwatershed. In order to gain a better understanding of the future land use and growth impacts, the following documents have been reviewed:

- City of Brantford Official Plan- Draft, 2016;
- Brantford Waterfront Master Plan, 2010; and
- Mohawk Lake District Planning Study, 2017.

A summary of identified growth areas is provided in Section 3.2. Future growth areas are presented graphically in Drawing 7.

3.2 Summary of Identified Growth Areas

3.2.1 City of Brantford Official Plan, Draft 2016

The City of Brantford Official Plan provides a statement of goals, objectives and policies that guide the City's growth and change around physical development and future land use. The Official Plan is currently under review; it was originally developed in 1988 and last amended in 2018. An entirely new Official Plan, the Draft Official Plan Version 1, was released in July 2016, which is not yet in effect and remains under review. As such, the Official Plan developed in 1988 that has been continuously amended over the years remains the City's legal document. For the purposes of the current study, the Draft Official Plan 2016 has been reviewed, as the intent for this study is to understand future growth patterns conformance with existing policies.

Schedule 1- Growth Management identifies growth and intensification areas within the City boundaries, which include the Built-Up Area, Greenfield Area, Future Urban Growth Area, and Core Natural Area. Within the Built-Up Area, the Downtown Urban Growth Centre and Intensification Corridor areas as the primary designated growth areas. In relation to the Mohawk Lake and Mohawk Canal study area, these areas are located upstream to the north and northwest of the subject lands and are expected to impact surface water runoff. The lands directly adjacent to the study area are designated Existing Stable Neighbourhood, where development will be limited and consist primarily of the development of vacant lots and minor infill (Official Plan, Part 1, 3.4(i)). This form of development is not anticipated to have significant effects on the surface water runoff or erosion hazards and is not considered a significant concern to this project.

Erosion Site #1, (ref. Characterization Study, 2019) Shallow Creek, is located within the Downtown Urban Growth Centre, where much of the surface water will be directed to Shallow Creek via surface water runoff and storm sewer outfalls. Additional development in this area may result in a higher quantity and poorer quality of stormwater runoff and may exacerbate the erosion conditions already occurring at this location. Mitigation measures should be considered in future scenarios.

Schedule 5-1- Floodplain identifies the banks of Mohawk Lake and Mohawk Canal and the lands to the south as Special Policy Area 1, and the lands to the southeast of the east canal as Floodway Policy Area. The Floodway Policy Area (Official Plan, Part 1, 7.2.1) states that development is to be limited to public infrastructure, flood control works, and structures associated with open space uses (Official Plan, Part 1, 7.2.1.b). Special Policy Area 1 contains restrictions on the form of development, generally prohibiting sensitive uses such as emergency services and structures with basements.

Schedule 5-3 Steep Slope and Erosion Hazard identifies the majority of the banks of Mohawk Lake and Mohawk Canal as Steep Slopes and Erosion Hazard, including parts of Mohawk Park, Glebe Farm Indian Reserve, and the areas surrounding Tributary 1. This designation requires the areas be generally maintained in their natural state, with the exception of some development subject to approval by the GRCA, geotechnical assessments and other appropriate studies, and appropriate erosion and siltation control measures during construction (Official Plan, Part 1, 7.3).

Schedule 6- Landfill Sites identifies the active and abandoned landfill sites in the City and classifies the abandoned sites into four (4) categories. These sites should be further investigated to determine their potential role in both current and previous sources of contamination to water and sediment quality.

Schedule 9- Bikeway and Trails Network Plan identifies the existing and proposed network of multi-use trails and on-street routes. The proposed routes should be taken into consideration when developing the Drainage Plan and Master Plan.

Schedule 11- Modified Policy Areas classifies the study area as Area 5- Mohawk Lake/ Greenwich Mohawk District Area, which encourages a mix of uses and further detailed planning studies to provide direction to the redevelopment of the area (Official Plan, Part 2, 1.5).

3.2.2 Brantford Waterfront Master Plan, 2010

The Brantford Waterfront Master Plan provides a framework to protect and enhance the Grand River and its tributaries by protecting the natural features, trails, and access to water, and allowing for appropriate development on adjacent land. The Master Plan includes a Waterfront vision statement, guiding principles, Waterfront Master Plan, and implementation strategy, which incorporate the Official Plan policies.

The Natural Heritage Framework identifies the study area as Core Environmental Features and Potential Restoration Area, Glebe Farm Indian Reserve as a Significant Vegetation Community, and other portions of the study area as Woodland.

The Parks Framework identifies Mohawk Park as a Destination Park (as does The Destination Framework) and identifies a Linear River Edge Open Space along the banks of Mohawk Lake and Mohawk Canal on both the north and south banks. The

Waterfront Master Plan provides background on the important history of Mohawk Park, and its role as a major focus of the Waterfront Master Plan, as the continuous greenway has the potential to provide nodes of recreational activity and provides park vistas for nearby locations.

The Access Framework identifies a proposed and existing Primary Waterfront Trail, which has been assumed to be synonymous with the Linear River Edge Open Space. The existing trail currently runs along the north and south banks of the eastern portion of Mohawk Lake and the east canal. A new 3 km portion of the Primary Waterfront Trail is proposed on the north side of Mohawk Lake and Mohawk Canal from Mohawk Park to Clarence Street, as well as a green street connection along the south of the lake and canal along Greenwich Street. The development of these trails will require coordination and approval with the Six Nations of the Grand River. Waterfront trails and parks often attract large numbers of visitors and may also attract additional development. The creation of the Primary Waterfront Trail may initiate development, which should be considered in the Drainage Plan and Master Plan.

The Heritage & Culture Framework identifies areas of Archaeological Potential, as well as areas of Mohawk Park, Lake and Canal, and Hydro Generation Station Ruins as Cultural Heritage Resources; this is discussed in more detail in the Characterization Report and Cultural Heritage Landscape Feasibility Study.

The Cultural Corridor Framework identifies much of the study area as a Major Natural Cultural Heritage Interpretation & Recreation Destination, and the east canal and south side of the west canal as a Focus of Cultural Heritage Interpretation.

The Destination Framework identifies Mohawk Park as a Sports Field destination. The Plan proposes the branding of the Waterfront Cultural Corridor for overall promotion of the area as a tourism destination and suggests marketing efforts could be undertaken in partnership with destination marketing activities in the region. The Plan discusses a variety of economic development opportunities, and coordination with the City's Economic Development Strategy, both of which could bring further growth and development to the area.

The Neighbourhoods & Districts Framework identifies several areas classified as Potential Development Areas within and surrounding the study area. The Plan identifies the lands north of Glebe Farm Indian Reserve and adjacent to the south bank of the West Canal as Potential Development Areas. These areas do not align with the areas identified for growth in the Growth Management Plan. The Waterfront Master Plan does not elaborate on how these areas were identified as Potential Development Areas.

The Implementation Plan recommends a range of projects and initiatives, including the following initiatives specific to Mohawk Park: the preparation of a forest management plan, removal of invasive plants from natural areas, implementation of wildlife crossings, upgrade of park facilities, and removal of the fence around the perimeter of the park.

3.2.3 Mohawk Lake District Planning Study, Ongoing

The Mohawk Lake District Planning Study was initiated as a result of the City of Brantford Strategic Plan in order to guide development and revitalization in the Mohawk Lake District. The ultimate goal for the area is to create a vibrant, mixed-use urban neighbourhood, focusing on economic development needs and growth. The Mohawk

Lake District Plan will include a District Plan Report, a series of technical studies, and implementing planning documents (i.e. Design Guidelines, an Official Plan Amendment and Zoning By-law Amendment). The Mohawk Lake District Plan Background Study, 2018, has been developed, and three (3) preliminary concept plans were presented to the public, each with a different vision for the Greenwich Mohawk Site. All information regarding the Mohawk District Plan are available on the City of Brantford's website at https://www.brantford.ca/en/your-government/mohawk-lake-district-plan.aspx.

The Greenwich Mohawk Site is a 20.59-hectare brownfield site located on the lands to the south of the West Canal. The site consists of three (3) properties all owned by the City, previously vacant industrial lands. The City decided to remediate the lands in order to initiate private sector interest and completed the remediation program in 2017. All buildings associated with the vacant industrial lands were demolished, with the exception of the Canadian Military Heritage Museum and the Timekeeper's Office Buildings, which is designated under the Ontario Heritage Act. The Spur Railway line also traverses the lot.

The Mohawk Lake District Draft Overall Preferred Plan has been developed. The Draft Overall Preferred Plan proposes development at the Greenwich Mohawk Site which includes mixed-use developments of low and mid-rise residential, institutional and cultural, and open spaces. New trails and parks have been identified, as well as focal points throughout the district. As part of the implementation of the plan, the site will undergo significant development in the future and the impacts of which should be accounted for in the creation of the Drainage Plan and Master Plan.

4.0 Hydrologic and Hydraulic Model Development

4.1 Subwatershed Characteristics and Previous Modelling and Monitoring

The Characterization Study (October 2019) provides a general overview of the drainage systems and drainage area characteristics of the Mohawk Lake and Mohawk Canal subwatershed. The report references the previously completed Mohawk Lake Rehabilitation Project Reporting Series, specifically the Stormwater Management Study Report (Gore & Storrie Ltd, 1995) and the hydrologic/hydraulic analysis work completed as part of the Master Servicing Plan (Volume V – Stormwater Master Plan, BluePlan, 2014).

The Mohawk Lake subwatershed is depicted in Drawing 8. As per the Characterization Study (Aquafor Beech, October 2019), a total drainage area of 839 ha is indicated, which differs from the 1995 Stormwater Management Study Report (Gore & Storrie), which indicated a total of 754.7 ha (the majority of which (702.7 ha) drains to the West Canal upstream of Mohawk Lake). The drainage area consists of a mixture of land use types, including residential, commercial, industrial, and open space/parklands. The subwatershed does not contain any stormwater management facilities, nor any oil/grit separator units.

Beyond Mohawk Lake and Mohawk Canal, there are generally no open channel drainage systems, given the history of development and related watercourse enclosures. Two (2) tributaries are noted at the downstream limits of the subwatershed, however only one (Tributary 1) actually drains directly into the Mohawk Canal system; The other (Tributary 2) outlets directly to the Grand River in close proximity to the Mohawk Canal outlet. The balance of the subwatershed is drained by urban drainage systems, comprised of storm sewers and overland flow (although overland flow paths do not appear to have been specifically assessed to date).

A discussion of the constraints associated with the previous hydrologic modelling for the Mohawk Lake subwatershed is provided in Section 2.3 of the current report. Ultimately, Wood was requested by the City of Brantford to develop an updated hydrologic model using the InfoSWMM modelling platform. Subsequent sections of this report describe the model building process in greater detail.

4.2 Hydrologic Modelling

4.2.1 Subcatchment Boundaries

Given the previously noted issues with the base subcatchment boundaries in the previously completed InfoSWMM modelling (by others), a revision to the subcatchment boundaries was considered warranted. The number of subcatchments and large variation in size included in the previous modelling was considered excessive. Based on the total subwatershed drainage area (900 ha +\-), a target value of 1 ha +\- per subcatchment was considered more reasonable, or a total number of subcatchments less than 1,000 (i.e. less than half the number included in the previous modelling).

A number of different sources of topographic data is available for the Mohawk Lake subwatershed to support the preparation of updated drainage boundaries using automated GIS techniques. In total there are three (3) potential datasets available and considered for use in establishing the updated geometry of subcatchment boundaries:

1. LiDAR – Digital Terrain Model Lake Erie (2016-18) LIO Dataset prepared by the Ministry of Natural Resources and Forestry (MNRF)
2. Southwestern Ontario Ortho-photography Project (SWOOP) 2015 Digital Elevation Model prepared by the Ministry of Natural Resources and Forestry (MNRF)
3. 2x2 DEM Mosaic (as applied by Aquafor Beech in Mohawk Lake Characterization Study) as received from the City of Brantford (source data and date unknown).

The LiDAR DTM for Lake Erie is the most recent data source and includes a 50 cm raster representing the bare-earth terrain derived from a classified LiDAR point cloud, which has been hydro-flattened using water body breaklines. The horizontal coordinate system is Universal Transverse Mercator (UTM) zone 17. The Horizontal datum of this dataset is the North American Datum of 1983 Canadian Spatial Reference System epoch 2010 (NAD83(CSRS)). The vertical coordinate system of this dataset is based on the Canadian Geodetic Vertical Datum 2013 (CGVD2013) of the Geodetic Survey Division and is measured in meters above mean sea level.

The SWOOP 2015 DEM is a 2 m resolution raster from the Raw LAS vector elevation dataset. It should be noted that this DEM does not represent the full 'bare-earth' elevation surface. While the 'steam-rolling' algorithm has allowed for some raised features to be reduced closer to 'bare-earth' elevations (e.g. small buildings, small blocks of forest cover), many features are still raised above ground surface, such as larger buildings, larger forest stands and other raised features. The horizontal coordinate system of the DEM is Universal Transverse Mercator (UTM) zone 17. The horizontal datum of the DEM is the North American Datum of 1983 (NAD83). The vertical coordinate system of the DEM is based on the Canadian Geodetic Vertical Datum 1928 (CGVD28) of the Geodetic Survey Division and is measured in meters above mean sea level.

The 2x2 DEM Mosaic provided by the City, is, as the name suggests, a 2 m resolution raster dataset. The dataset applies the same Horizontal and the Vertical datum as the SWOOP dataset. It is unknown if these data were obtained through the SWOOP program, or another source of data.

Initially, Wood considered the application of the most recent Lake Erie DTM dataset for subcatchment boundary delineation, however the results indicated that due to the finer spatial resolution of the dataset (50 cm vs. 2 m), the level of detail was much higher than the other datasets (approximately 16x). Since the target subcatchment area for the delineation was set around 1 ha, this very high level of detail yielded very rough and jagged subcatchment boundaries due to localized differences in topography, similar to the issues noted with the drainage boundaries in the previously completed hydrologic modelling (by others). A separate issue with the application of the Lake Erie DTM is that the vertical datum (CGVD2013) is very recent (2013) and shows notable differences to the older CGVD28 (1928) vertical datum which is, and has been used widely across Canada, including the City of Brantford.

Considering these constraints, the applicability of other datasets has been explored. The SWOOP dataset has a more consistent vertical datum with that used in the City of Brantford but does not represent full ‘bare-earth’ elevations. This can result in distorted subcatchment boundaries depending on the difference between projected elevations and the actual bare-earth elevations.

The 2x2 DEM mosaic dataset was ultimately considered the most appropriate. This dataset has a raster resolution of 2 m which creates smoother subcatchment boundary lines for the subcatchment delineation process and it also applies the GCVD28 as its vertical datum, which is more consistent with the previously applied datum in the City of Brantford. The data also match well in terms of elevation accuracy when compared against other available geographic data in the study area and seems to represent the bare-earth elevation more accurately, as compared to the SWOOP 2015 dataset. Given the preceding rationale, and the fact that the 2x2 DEM mosaic was previously applied for the Characterization Study, this source of data was considered the most appropriate for the delineation of updated subcatchment boundaries.

To establish subcatchment boundaries, the 2x2 DEM Mosaic was applied as the base DEM/topographic data source. Storm Sewer Manholes were used as guidance to the GIS tool to define the subcatchment boundary targets. In general, storm sewer maintenance holes were considered to be the outlet/target for that subcatchment and subsequently the entire study area was divided into smaller subcatchments based on the proximity and the number of such outlets. Since the majority of the study area is located in an urban setting, the road network and hence the minor system guide the subcatchment boundaries more significantly as compared to rural areas. Following the delineation of initial subcatchment boundaries, minor adjustments have been made based on the aerial imagery and use of Google Streetview™, as well as Wood’s engineering judgement. The overall boundary of the study area has been verified based on the minor system network, DEM/contour data and previous modelling work (by others).

Based on the preceding process, a total of 1,174 subcatchments have been created covering the total contributing drainage area of 930.7 ha to the downstream limits of Mohawk Canal, at its confluence point with the Grand River. This results in an average subcatchment size of 0.8 ha results, which is considered reasonably close to the initial target area of 1 ha. During the process of updating the subcatchment boundaries, all the subcatchment of size smaller than 0.01 ha (100 sq. m) have been merged with the nearest adjacent subcatchment based on the topographic data. Subcatchments in open areas (such as parks, NHS etcetera) have generally been merged together where warranted to simplify the routing operations. Based on the preceding, the smallest subcatchment within the study area is 0.01 ha and the largest is 33.98 ha, with an average of 0.8 ha, as noted previously.

The resulting subcatchment boundary plan is presented in Drawing 8.

4.2.2 Imperviousness and Land Use

After defining the subcatchment boundaries, subcatchment parameters for the hydrologic modelling have been determined. In general, particularly for urban areas, subcatchment imperviousness is the critical parameter with respect to the simulation of runoff response. In order to reasonably assess different land use scenarios, imperviousness should be based on land use information.

Land use for the study area was included as part of the Characterization Study Report (October 2019 – Figure 5.4). This data source was originally considered for the purposes of developing imperviousness estimates for the hydrologic modelling. Notwithstanding, a number of potential issues have been identified with the data. The land use layer does not include the right of way limits for any of the roadways, which would require them to be added/updated manually. A number of other parcels and properties are shown as data gaps/blanks on the mapping which would require manual adjustment. Further, upon review of available aerial photography and other data sources, the identified land uses in several areas did not appear to match with actual conditions. In some cases, this was attributable to irregular and overlapping boundary limits. For example, on many urban intersection locations, multiple triangular features are shown although, the property lots are generally rectangular in shape. Further, it has been noted that the features in the land use plan are characterized very broadly although there are differences within the land use category. For example, parks, cemetery, school etc. are contained in a category referred to as “open space” although generally schools have larger built up (impervious) areas compared to parks.

Based on the preceding, alternative sources of land use data mapping have been explored. Based on this review, the City of Brantford’s Zoning District Mapping has been considered to be the preferred data source. Although technically different from a land use plan, a zoning plan indicates the current and intended use of the land area within City of Brantford. The dataset is complete without any data gaps or duplicate/missing features or irregular or overlapping boundaries. The dataset is also broadly classified into various groups which match well with the actual land use, based on aerial imagery and verifications completed by Wood. Corresponding preliminary imperviousness values for each land use category are presented in Table 4.1, based on Wood’s hydrologic modelling experience in other areas in Southern Ontario. Land use areas are presented graphically in Drawing 9 (attached).

Table 4.1: Estimated Imperviousness Values For Existing Land Use Conditions (Uncalibrated)

Land Use	Imperviousness (%)	Area in hectares [% of Total Drainage Area][1]
Automobile Service Commercial Zone	80	1.93 [0.2]
Community Centre Commercial Zone	90	10.77 [1.2]
Convenience Commercial Zone	80	2.00 [0.2]
Core Commercial Zone	85	31.56 [3.4]

Table 4.1: Estimated Imperviousness Values For Existing Land Use Conditions (Uncalibrated)		
Land Use	**Imperviousness (%)**	**Area in hectares [% of Total Drainage Area][1]**
Development Constraint Zone	5	0.39 [0.0]
Fringe Core Commercial Zone	95	11.05 [1.2]
General Commercial Zone	85	42.88 [4.6]
General Industrial Zone	60	105.8 [11.4]
Industrial Commercial Zone	60	1.32 [0.1]
Institutional Major Zone	65	10.71 [1.2]
Institutional School Zone	65	19.04 [2.0]
Institutional Services Zone	75	2.55 [0.3]
Mixed Commercial Residential Zone	87	18.3 [2.0]
Neighbourhood Centre Commercial Zone	90	3.13 [0.3]
New Format Commercial Zone	90	0.13 [0.0]
Open Space Cemetery Zone	10	16.56 [1.8]
Open Space Restricted Zone	5	5.32 [0.6]
Open Space Type 1 Zone	20	97.3 [10.5]
Residential Cluster Dwelling Zone	80	3.94 [0.4]
Residential Conversion Zone	70	197.23 [21.2]
Residential High Density Zone	75	17.73 [1.9]
Residential Medium Density Type A Zone	70	43.6 [4.7]
Residential Medium Density Type B Zone	70	9.88 [1.1]
Residential Type 1B (15 metre) Zone	65	124.57 [13.4]
Residential Type 1C (12 metre) Zone	65	87.89 [9.4]
Residential Type 1D (9 metre) Zone	65	8.85 [1.0]
Residential Type 2 Zone	70	12.8 [1.4]
Residential Type 3 Zone	70	2.93 [0.3]
Six Nations of the Grand River Territory	10	40.15 [4.3]

[1] The total Drainage area is 930.7 ha.

Based on the results presented in Table 4.1, there are five (5) primary land use zones (those which represent greater than 5% of the total drainage area:

- Residential Conversion Zone (197.23 ha or 21.2%)
- Residential Type 1B (15 metre) Zone (124.57 ha or 13.4%)
- General Industrial Zone (105.8 ha or 11.4%)
- Open Space Type 1 Zone (97.3 ha or 10.5%)
- Residential Type 1C (12 metre) Zone (87.89 ha or 9.4%)

Residential Conversion Zone refers to a large swath of existing detached residential in close proximity to the downtown core, generally bounded by Grey Street and Stanley Street to the north and east respectively, and by Mohawk Canal to the south.

It should be noted that the imperviousness values presented in Table 4.1 represent preliminary values and have been reviewed further as part of the subsequent model calibration effort (ref. Section 5), as well as the assessment of future land use conditions (ref. Section 8).

4.2.3 Infiltration

The Characterization Study (Final Report) provides a general description and characterization of the soils, overburden, hydrogeology and groundwater for the Mohawk Lake and Mohawk Canal area.

The Characterization Study has documented the geology of the study area based on previous investigations and ten (10) boreholes advanced at Mohawk Lake, including wells (seven (7) sites; three (3) nested).

Generally, the soils from the ten (10) boreholes comprise a predominantly sandy fill overlying silty clay. The fill is generally 2 – 3 m thick, but at one (1) location exceeded 6.5 m thick. These boreholes are mapped by the Ontario Geological Survey (OGS) in alluvium (south of Mohawk Lake) or laminated glaciolacustrine deposits (north of Mohawk Lake). Except for two (2) boreholes (MW#7 nested well site), none of the new boreholes are located within the potential development areas of the study area.

The potential development areas are mapped by the OGS to lie in the following overburden units:

- Modern alluvial deposits of the Grand River comprising unsubdivided muck, clay, silt, sand and gravel;
- Older alluvial deposits comprising sand and gravel; and
- Coarse-textured glaciolacustrine deposits.

Based on previous reports, Aquafor Beech (2018) estimated the overburden to be about 20 m thick resting on the Silurian bedrock of the Salina Formation.

Ontario Soils Mapping for the majority of the study area is not available; mapping is generally categorized as “Urban” and thus no soils data are provided. Adjacent areas consist primarily of soils from the Brant, Tuscola, Berrien, and Brantford soil series. The generalized profile of these soils prepared by the Ministry of Agriculture and Food have been reviewed; these soils are primarily comprised of silt and clay. These soils generally have a medium to low hydraulic conductivity and infiltration potential and would be categorized as US SCS Class “C” soils.

All of the previously completed InfoSWMM/InfoWorks ICM modelling for the Mohawk Lake subwatershed and City-Wide has utilized the Horton Method for the simulation of infiltration. For consistency, it has been assumed that the same methodology should be applied in the updated hydrologic modelling. The Horton Method utilizes an exponential decay equation, with a maximum initial and final saturated hydraulic conductivity (both in mm/hr) defined, along with a corresponding rate of decay. The minimum infiltration rate should generally correspond with the saturated hydraulic conductivity of the soil.

Based on the classification of class “C” soils, and typical Horton’s Equation parameters available from the MTO’s Drainage Management Manual (1997 – Design Chart 1.13), initial infiltration parameters have been determined, and are presented in Table 4.2. It has been assumed that the soils for the subwatershed would likely be relatively uniform, thus the same parameters have been applied throughout.

Table 4.2: Horton’s Equation Infiltration Parameters

Parameter	Characterization Study and City-Wide Calibration Study (Aquafor Beech - 2017/2018)	Base Parameters (Wood – 2019)
Horton Maximum Infiltration Rate (mm/hr)	270	125
Horton Minimum Infiltration Rate (mm/hr)	25	5
Horton Decay Parameter (1/hr)	2	2

As evident, the base infiltration parameters selected by Wood, based on the foregoing rationale and surveys, are generally lower than those from the Characterization Study and City-Wide Calibration Study, although the decay parameter remains consistent. Notwithstanding, similar to base imperviousness values, it should be noted that the preliminary values have been applied for base parameterization only and have been reviewed as part of the subsequent model calibration effort (ref. Section 5).

4.2.4 Other Hydrologic Modelling Parameters

A number of other hydrologic modelling parameters are required to support model development. Key parameters include subcatchment length/width, subcatchment slope, Manning’s roughness coefficients for overland flow, sub-area routing percentage, and depression storage. These parameters have been developed as follows:

Subcatchment Length:

The subcatchment length in InfoSWMM represents the overland flow length for the conceptual rectangular subcatchment unit. For smaller subcatchments, the subcatchment length can be directly measured, in larger subcatchments it is typically estimated using empirical equations, given the additional impact of attenuation and routing. The simulated runoff from the hydrologic model is moderately sensitive to this parameter.

Given the large number of subcatchments for the subject model, direct measurement of overland flow length is not considered practical nor necessary. Rather, subcatchment lengths have been initially estimated based on length to width ratio. In general practice, this ratio of L/W is typically between 1:5 and 5:1, and up to 10:1 in some cases. For the purpose of initial model parameterization, a ratio of 1:5 has been selected and applied to all the subcatchments. Thus, overland flow length is equal to the square root of the area (converted to m^2), divided by 5. In InfoSWMM, subcatchment width is subsequently calculated based on total subcatchment area divided by subcatchment length. As with other base hydrologic parameters, it should be noted that this parameter is subject to change as part of calibration.

Subcatchment Slope:

Based on Wood's experience, the simulated run-off from the hydrologic model is relatively less sensitive to this parameter. Slope was directed measured/estimated from the DEM for each subcatchment. Outlier values have been adjusted however, including those which were considered high (more than 20% slope), which were limited to this value (20%). A minimum slope of 2% also results, which is typical for urban residential grading.

Manning's Roughness Coefficient:

Based on Wood's experience, the simulated run-off from the hydrologic model is relatively less sensitive to this parameter. Given the urban nature of the study area, impervious areas would represent concrete or asphalt and most of the pervious area represents well-maintained lawns/grass. Based on the preceding, Manning's Roughness Coefficients of 0.014 for the impervious areas and 0.2 for the pervious areas have been applied.

Sub-area Routing:

Sub-area routing establishes the route that surface runoff takes through a subcatchment. For every subcatchment, sub-area routing is set to outlet by default which means the run-off generated by the impervious and pervious areas are routed directly to separate outlets without those areas interacting with each other. Using sub-area routing, some percentage of the impervious area can be routed across the pervious land segment, giving a secondary opportunity for attenuation and infiltration, and thereby mimicking typical urban conditions such as rooftop downspouts discharging to grassed areas. Based on Wood's experience, the simulated run-off from the hydrologic model can be sensitive to this parameter, as such, this parameter has been reviewed further as part of the model calibration effort (ref. Section 5). For base model development, the default outlet option (separated impervious and pervious land segments) has been assumed.

Depression Storage:

The simulated run-off from the hydrologic model is relatively less sensitive to this parameter. Depression storage refers to small low points in undulating terrain that can store precipitation that otherwise would become runoff. The precipitation stored in these depressions is then either removed through infiltration into the ground or by evaporation. Depression storage of 1 mm and 5 mm has been applied in the model to represent impervious and pervious land segment respectively of a subcatchment. These are typical values used for run-off simulation in an urban setting.

These additional hydrologic modelling parameters for the base model development are summarized in Table 4.3.

Table 4.3: Additional Hydrologic Modelling Parameters

Parameter	Value used in Current model update by Wood
Subcatchment Length: Width ratio	1:5
Subcatchment Slope (range-%)	2-20
Manning's 'n' - Impervious	0.014
Manning's 'n' - Pervious	0.2
Depression Storage – Pervious (mm)	5
Depression Storage – Impervious (mm)	1

4.3 Hydraulic Modelling

4.3.1 Minor (Storm Sewer) System

A base minor (storm sewer) system model was generated by others as part of the previously noted base InfoSWMM and InfoWorks ICM modelling. However, it is understood that the storm sewer system (including links representing conduits and nodes representing Maintenance Holes) was not thoroughly verified and was based primarily on available data from the City of Brantford's GIS database.

As part of this update, the previous base model has been imported as the primary hydraulic network for the urban area. Although Wood's scope of work did not include a detailed or complete review of the storm sewer system for accuracy, a scoped verification of selected areas has been completed against available datasets such as the "as built" drawings of storm sewers and the City's GIS database of the storm sewer network.

The GIS database provided by the City of Brantford ("swGravityMain") has been used for initial verification purposes. Upon review, the base model is relatively consistent with the attributes in the GIS database, which is expected, given that the initial base model was understood to have been developed based on the (then available) database from the City.

The following areas have been reviewed based on more detailed “as built” drawings:

1. Arthur Street (Drummond Street to Rawdon Street)
2. Colborne Street (Clarence Street to Alfred Street)
3. Colborne Street (Forest Road to Rowanwood Avenue)
4. Stanley Street (Nelson Street to Chatham Street, Colborne Street to Dalhousie Street, and Darlington Street to Wellington Street)

Minor modifications to the storm sewers in these areas (pipe connectivity, sizes, and inverts) have been undertaken based on the available drawings for these areas. A summary of storm sewer modelling updates is included in Appendix A.

As noted previously, it should be clearly understood that the preceding cursory review did not constitute a complete review or verification of the storm sewer network, as this was beyond the scope of the current study.

A key finding from the review of the storm sewer system is that maintenance hole rim elevations differ notably between those listed in the model (and in the City’s GIS database) and those available from the 2x2 DEM mosaic. Given the need to incorporate and model the major (overland flow) system, in order to properly estimate inflows to Mohawk Canal and Mohawk Lake under larger, more formative storm events, a reasonable representation of these values is important. In order to ensure consistency, maintenance hole rim elevations have been updated based on the elevation values in the 2x2 DEM mosaic. Notably, this adjustment did not necessitate any adjustment in storm sewer inverts to address unrealistic conditions (i.e. pipes above surface etcetera). The associated major (overland flow) system modelling, based on these adjusted values, is discussed further in Section 4.3.2.

For the modelled storm sewer links (total of 1,343 pipes), a default Manning’s Roughness coefficient of 0.013 has been applied, representative of PVC and concrete pipe. Corrugated Steel Pipe (CSP), where present, has applied a value of 0.024. Entry and exit loss coefficients, which are used to account for energy losses associated with changes in direction (bends) in maintenance holes, have not been included as part of the current modelling, given the focus of the current study (i.e. ensuring reasonable conveyance of flows to Mohawk Lake and Mohawk Canal, rather than an in-depth assessment of the storm sewer system performance).

4.3.2 Major (Overland Flow) System

A 1D-1D dual drainage approach (1-dimensional storm sewer and parallel 1-dimensional overland flow conduit) has been adopted in the updated modelling in order to allow for the routing of overland flows (i.e. in excess of the capacity of the minor (storm sewer) system. The estimated maintenance hole rim elevation for the storm sewer (as adjusted based on the 2m x 2m DEM mosaic, as described in Section 4.3.1) has been applied as the lowest/invert elevation of the major (overland flow system) i.e. roadways. Transects for various roadway configurations have been used to simulate the overland flow system as reasonably as possible. The transects modelled in the urban setting are composed of the right of way and adjacent property frontage. Hence, various types of transects of varying widths and roadway lanes have been applied throughout the urban area, representative of 2, 3, 4, and 5 lane roadway sections. Vertical extensions have been incorporated at the limits of the simulated overland flow sections to contain flow, given the current study purpose (i.e. conservative estimation of inflows to the Mohawk Lake and Mohawk Canal system). Further detailed study of potential spill areas would be required to assess actual conditions, which is beyond the scope of the current study.

The major system within open/pervious areas such as parks or cemetery has been assigned open channel transects (cross-sections) based on the DEM.

Since the initial major system was created based on the minor system, missing major system links have been identified in areas where no minor system present is present (i.e. headwater or major highways) or where the minor system is not connected to adjacent/nearby storm sewers (i.e. road intersections). Those missing links have been identified and added to connect adjacent areas and ensure spills are conveyed appropriately. In total, more than 150 of such links have been added manually to the updated modelling.

The major system and the minor system are connected through catchbasins which have been modelled as orifices. The database of existing catch basins and manholes has been provided by the City of Brantford. Using spatial analysis tools, Wood has identified the number of existing catchbasins and maintenance holes within each subcatchment. An equivalent orifice opening has been calculated and assigned based on that analysis (generally 0.125 m^2 per catchbasin based on the opening area of a standard catchbasin as per OPSD 400.020).

The simulated flows from the subcatchment elements are directed to junctions on the major system portion of the dual drainage (1D-1D) modelling. The flow can then enter into the minor system depending on the simulated inlet capacity or be routed overland.

Overall, a total of 1,558 elements have been included in the major system, which includes major/minor roads, ditches and swales.

4.3.3 Open Channel and Lake Elements

The base InfoSWMM/InfoWorks ICM modelling included open channel elements to represent the routing associated with these elements, including Mohawk Lake and Mohawk Canal in particular. Open channel elements within the subject modelling did not appear to have been updated to reflect the additional topographic and bathymetric survey completed as part of the Characterization Study (October 2019, Aquafor Beech). As such, open channel sections have been revised based on the updated HEC-RAS modelling completed as part of the Characterization Study, both upstream and downstream of Mohawk Lake.

In the current modelling, Mohawk Lake, and the associated weir/spillway control structure, is not included explicitly. Mohawk Lake would function as a storage unit (informal SWM facility); within InfoSWMM, this necessitates both a stage-surface area curve (to define available storage) and an outlet relationship (either based on physical hydraulic structures such as pipes, weirs and orifices, or as a defined stage-discharge relationship).

The storage information from the Characterization Study HEC-RAS modelling has initially been considered, however given areas of dead storage and other issues, it has been determined that this approach over-estimates potential storage capacity and renders the development of a representative stage-surface area curve problematic. Bathymetric survey data from the Characterization Study have been combined with topographic survey and DEM data for the surface features to create a combined surface and associated depth-surface area relationship. This curve has been incorporated into the modelling, along with an initial water depth, to represent the average permanent pool elevation in Mohawk Lake (198.0 m) to avoid counting dead storage.

The outlet control structure for Mohawk Lake is a three-sided grated spillway, which drains into a larger opening structure below. A log boom surrounds the intake. Former railway bridge embankments are located upstream of the intake structure along Mohawk Canal (the railway crossing appears to have been removed sometime between 1986 and 2003 based on historical aerial photography). A photograph of the structure is presented in Figure 4.1.

Figure 4.1: Mohawk Lake Outlet Control Structure (November 20, 2019)

The outlet control structure has been modelled as an outlet from the storage unit (Mohawk Lake) into the downstream section of Mohawk Canal, which ultimately outlets to the Grand River. A depth-discharge curve has been used to model the control structure accordingly based on the rating curve obtained from the Stormwater Management Study Report (Gore & Storrie Ltd, 1995 – ref. Figure 4.2). The curve suggests a base operating level of approximately 198.1 m (i.e. elevation below which no outflow occurs).

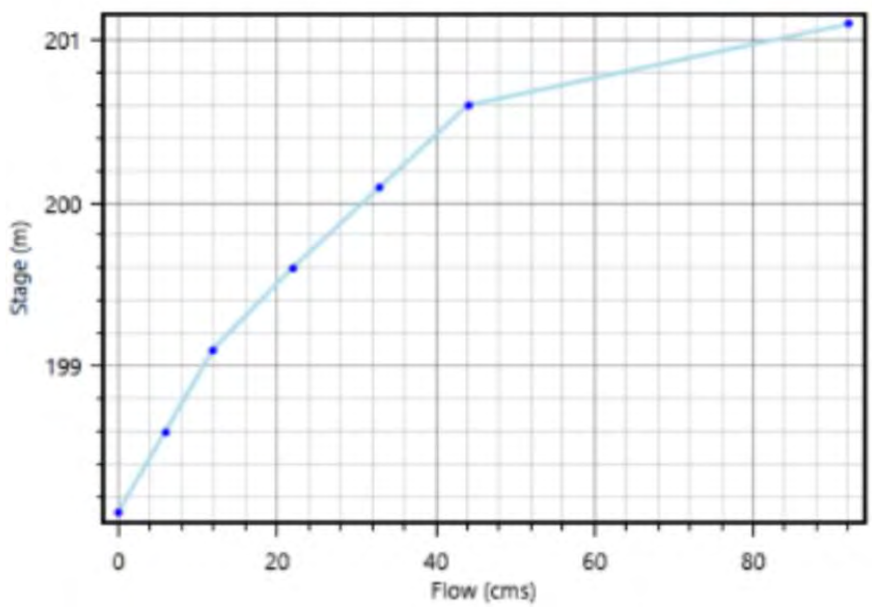


Figure 4.2: Stage-Discharge Relationship for Mohawk Lake (Gore & Storrie, 1995)

Given that all drainage areas west of the control structure outlet into Mohawk Lake, all major and minor system outlets upstream of this point, have been adjusted accordingly (i.e. to outlet directly into the storage element representing Mohawk Lake rather than to Mohawk Canal downstream of the Lake).

5.0 Model Calibration and Validation

5.1 Available Calibration Data

Available calibration data were described previously in Section 2.3; reference is therefore made to that section for a more thorough summary of calibration data. Data are generally available from two (2) separate studies, specifically the "Stormwater Flow Monitoring and System Model Calibration Study" (Aquafor Beech Ltd, and Thompson Flow Investigations Inc, January 2018), and the Mohawk Lake Characterization Study (October 2018, and subsequent monitoring data updates). Monitoring locations are presented in Drawings 10 (Stormwater Flow Monitoring and System Model Calibration Study) and 12 (Characterization Study) respectively.

Based on the discussion presented in Section 2.3, it has been considered that the data collected as part of the "Stormwater Flow Monitoring and System Model Calibration Study" (Aquafor Beech Ltd, and Thompson Flow Investigations Inc, January 2018) should form the primary basis of the model calibration effort, given the availability of rainfall and flow response data. The model calibration using these data is outlined further in Section 5.3.

It should be noted that this section and the TOR for this study, use the term "calibration" related to the process of checking simulated runoff response against actual observed runoff conditions based on field measurements. Typically for models to be "calibrated" several years' worth (10+) of field data would be required and notably this would also benefit from recording "major/significant" storms. Due to the short-term nature of field data collection for this study (1+1 years), it is considered more appropriate to characterize this process as model "validation"; notwithstanding the terms have been used interchangeably.

5.2 Sensitivity Analysis

Typically, prior to undertaking model calibration, a hydrologic parameter sensitivity analysis is beneficial to determine the sensitivity of each parameter (unique to that model) to change and the associated change in model output (i.e. what parameters result in the greatest changes in simulated peak flows and volumes due to modification). By understanding the most sensitive parameters unique to the subject model, model calibration can be streamlined to those key parameters.

Typically, the percent imperviousness for a subcatchment is the most sensitive parameter with respect to changes to both peak flows and runoff volume. In addition, soil infiltration parameters are also typically sensitive. As noted in Section 4.2.4, the "percent routed" parameter, which determines what percentage of the impervious land segment is routed across the pervious land segment (and thus further attenuated and given an opportunity to infiltrate) can also be highly sensitive. Based on the preceding, the following parameters have been selected for the sensitivity analysis:

- Imperviousness
- Percent Routed
- Horton's Maximum Infiltration Rate
- Horton's Minimum Infiltration Rate
- Overland Flow Length

For the purposes of the model sensitivity analysis, a reasonably sized storm event has been applied, namely the City of Brantford's 2-Year Design Storm Event (24-hour Chicago distribution). In order to capture the performance of the majority of the subwatershed, and given the purpose of the current study, the simulated results at Mohawk Lake (total inflow) has been applied as the comparative metric.

The range of the subcatchment parameter adjustments has been selected based on the source of the initial parameters, and their expected sensitivity, based on Wood's experience with previous hydrologic models. The identified adjustment ranges are presented in Table 5.1, along with the simulated impacts to both peak flow and runoff volume for the selected storm and location noted previously.

Table 5.1 Sensitivity Analysis – 2 Year Storm Event at Mohawk Lake

Subcatchment Parameters	Base Parameter Value	Parameter Adjustment Range (%)	Percent Change in Parameter of Interest (%)			
			Peak Flow		Runoff Volume	
			Low	High	Low	High
Imperviousness (%)	Based on Land Use Assumptions	-5% - +5%	-2.0	+1.9	-5.4	+4.6
Subarea Routing (%)	0	0% - 20%	0.0	-8.0	0.0	-18.6
Horton's Maximum Infiltration Rate (mm/hr)	125	-50% - +100%	+1.3	0.0	+2.2	0.0
Horton's Minimum Infiltration Rate (mm/hr)	5	-80% - +40%	0.0	0.0	0.0	0.0
Flow Length (m)	Assumed Ratio of 1:5	0% - 200%	0.0	-0.5	0.0	+0.1

The results indicate that the subcatchment imperviousness and subarea routing affect the peak flow and runoff volume to a much greater degree, as compared to other parameters. The results also indicate that the peak flow and runoff volume are relatively insensitive to the infiltration parameters, especially to Horton's minimum infiltration rate parameter, suggesting this limiting value is not achieved in the sensitivity analysis simulation. With respect to the maximum infiltration rate, the base value is already permitting full infiltration of runoff, thus increasing this value has no effect on simulated peak flow or runoff. A reduction in this value however does result in increased runoff volume and peak flows. Increasing overland flow length results in a reduction in simulated peak flows and runoff volumes by a relatively modest amount. Overall, both imperviousness and the subarea parameter are considered the most sensitive parameters and have been advanced for adjustment as part of the model calibration effort, as described in Section 5.3.

5.3 Model Calibration (Validation)

For the subject flow monitoring locations within the study area (FM1, FM2 and FM10 – refer to Drawing WR-3), two of the three available rain gauges have been considered for modelling Namely, the Pollution Control Centre (PCC) at 180 Greenwich St. and Brantford Tourism Centre (TCT) at 399 Wayne Gretzky Parkway. A total of six (6) rainfall events have been screened from the data set and considered for calibration (validation) of the model between October 2, 2016 and August 17, 2017. Some of the rain events have been screened based on the availability of the flow monitoring data.

Based on an initial review of the available rainfall and flow monitoring data, it has been noted that the recorded flow data led the rainfall data by several hours and is not temporally aligned. The reason for this misalignment is unknown, as there are no explanations/comments provided along with the datasets. For the current purpose of model calibration, the flow data have been “shifted” to ensure a more reasonable and logical alignment with the source rainfall data (i.e. the monitored runoff response should occur after the observed rainfall data in all cases).

Table 5.2 presents a summary of significant rainfall events that have been considered for the model calibration. As noted previously, some of these events have been screened for different flow gauges, depending on the availability and validity of the monitoring data.

Table 5.2 Significant Observed Rainfall Events for City-Wide Calibration Study Monitoring Period (2016-2017)

Date	Rain Gauge Source	Total Rainfall Depth (mm)	Event Duration (hours)	Peak Rainfall Intensity (mm/hr)[1]
02-Oct-16	PCC	11.8	19.5	9.6
03-Nov-16	PCC/TCT	12.6/12.4	5.0/5.5	12.0/14.4
20-Apr-17	PCC/TCT	47.8/47.2	13.5/13.5	60.0/28.8
01-May-17	PCC/TCT	19.6/20.4	12.5/8.0	31.2/16.8
21-May-17	PCC/TCT	17.0/14.4	17.5/17.5	43.2/38.4
13-Jul-17	PCC/TCT	31.2/34.0	3.0/3.5	50.4/69.6
17-Aug-17	PCC/TCT	22.2/22.2	7.0/7.5	31.2/40.8

1. Peak Rainfall Intensities based on a rain gauge time step of 5 minutes

Overall, the two (2) rainfall datasets generate relatively similar results, with the exception of some of the peak rainfall intensities, particularly for the April 20, 2017, May 1, 2017, and July 13, 2017 storm events. Given the availability of data, proximity to the study area, and for overall consistency, the data from the PCC gauge has been applied for the model calibration effort.

Prior to undertaking model calibration, a general review of the validity/reasonableness of the monitoring data has been undertaken. Volumetric runoff coefficients have been calculated, which represent the fraction of available water (i.e. rainfall) that becomes surface runoff. This is calculated as the volume of observed/monitored runoff divided by the product of the drainage area and the rainfall depth. For the observed data, baseflow was first separated from the flow hydrograph, to ensure a consistent comparison to simulated data on the basis of direct runoff only. Results are presented in Table 5.3. Refer to Drawing 10 for contributing drainage areas to each gauge.

Table 5.3 Calculated Volumetric Runoff Coefficients for Available Monitoring Data

Date	Total Rainfall – PCC Gauge (mm)	Calculated Volumetric Runoff Co-efficient		
		FM1 (189.5 ha)[1]	FM2 (117.5 ha)[1]	FM10 (316.6 ha)
02-Oct-16	11.8	0.22	0.18	NA
03-Nov-16	12.6	NA	0.15	0.18
20-Apr-17	47.8	0.21	NA	0.19
01-May-17	19.6	NA	NA	0.22
21-May-17	17.0	0.06	0.16	0.11
13-Jul-17	31.2	NA	0.11	0.22
17-Aug-17	22.2	0.14	0.21	0.13
AVERAGE	**NA**	**0.16**	**0.16**	**0.18**

1. FM1 and FM2 have a common area of subwatershed upstream of the intersection of Grey Street and Rawdon Street, where storm sewer flows appear to be divided relatively evenly between these two areas. However, based on a review of simulated model results, it appears that smaller, more frequent storm events are directed at a greater rate to the storm sewer along Rawdon Street (FM1) than to the storm sewer on Grey Street (FM2). Drainage areas have been calculated accordingly. The specific details of the storm sewer split at this location should however be verified using as-built drawings.

As evident from Table 5.3, the run-off coefficients derived from the monitored rainfall and flow data are generally consistent. There are some events for which the run-off coefficients at different locations are well above and below the calculated average, however are still within an acceptable range and hence are not considered as outliers. It should also be noted that the flow monitoring data are not available for all the events at all the monitoring locations. FM1 has the lowest number of available calibration events (4), while FM10 has maximum number of rainfall events with recorded flow (7). Gauge FM2 has six (6) potential calibration events. Given the preceding, all the potential events and locations in Table 5.3 have been considered for the calibration of the model.

Scatter plots (comparing simulated and observed results for all gauge data) for the storm events presented in Table 5.3 are presented in Figures 5.1 and 5.2 for peak flow and runoff volume respectively, for the initial uncalibrated modelling. Full hydrographs for uncalibrated conditions are included in Appendix B.

Trend line slope indicates how well the observed values and the simulated values match (i.e. a value far from +1 indicates a greater difference amongst corresponding values and a greater mismatch). Furthermore, the R^2 coefficient of determination provides a statistical measure which calculates the degree of scatter of the data; a value of 1 indicates perfect agreement. In theory, an ideal model would have a trend line slope and R^2 value equal to one. In practice, the closer these values are to unity, the better. A 'y' value for peak flow rate and total runoff volume greater than 1 indicates overestimation, while a value less than 1 indicates underestimation.

As evident from Figures 5.1 and 5.2, uncalibrated simulated peak flows and runoff volumes are in all cases too high as compared to observed values, which is not uncommon for uncalibrated modelling. Although the general trend is to over-estimation, a range of differences from the observed results is also evident; simulated peak flows of the uncalibrated model varied from -34.5% to +641.2%. Similarly, the simulated runoff volumes of the uncalibrated model varied from -35% to +683.6%. The uncalibrated model results indicate the need to adjust parameters, and specifically to reduce the magnitude of runoff.

Notwithstanding the differences in magnitude of peak flow and volume, it should be noted that the timing of the peak flows and the shape of the overall hydrographs are generally well matched with the observed values.

For the calibration of the model, only the identified “sensitive” parameters (as per Section 5.2) have been modified (imperviousness and percent impervious routed to pervious) which minimizes the degrees of freedom of model output and optimizes the overall calibration process. Hence, these two parameters (imperviousness and percent routed) have been modified individually and in combination until a reasonable correlation between observed and simulated results (peak flows and runoff volumes) has been achieved.

After multiple iterations, the adjustments presented in Table 5.4 have been considered to be the optimal parameter adjustments. Associated revised land use imperviousness values are presented in Table 5.5.

Representative scatter plots (for all storm events) are presented in Figures 5.3 and 5.4 for peak flow and runoff volume respectively. A summary of scatter plot statistics (trendline slope and coefficient of determination R^2) are presented in Table 3.6. Further calibration details (including scatter plots for individual gauges and hydrograph outputs) have been included in Appendix C.

Table 5.4 Calibration Adjustments to Hydrologic Parameters

Subcatchment Parameter	Initial Value	Calibrated Value
Subwatershed Average Imperviousness (%)	60.6	42.1
Percent of Impervious Area Routed to Pervious Area (%)	0	50

Figure 5.1: Peak Flow (m^3/s) Scatter Plot for Uncalibrated Conditions

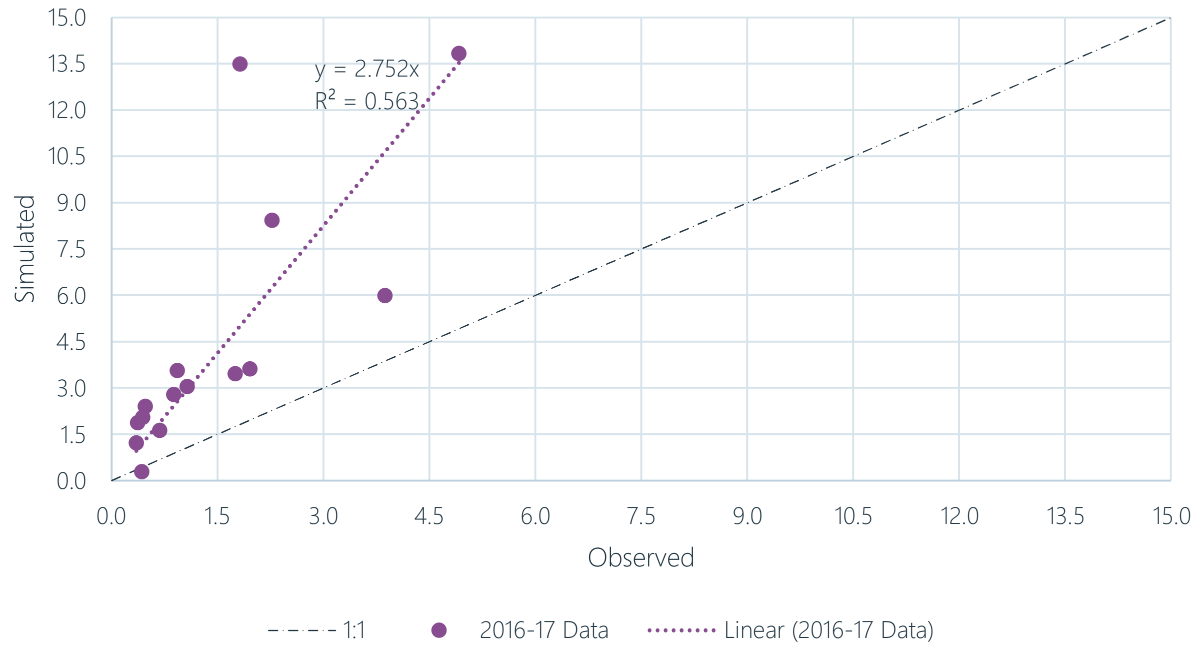


Figure 5.2: Runoff Volume (m^3) Scatter Plot for Uncalibrated Conditions

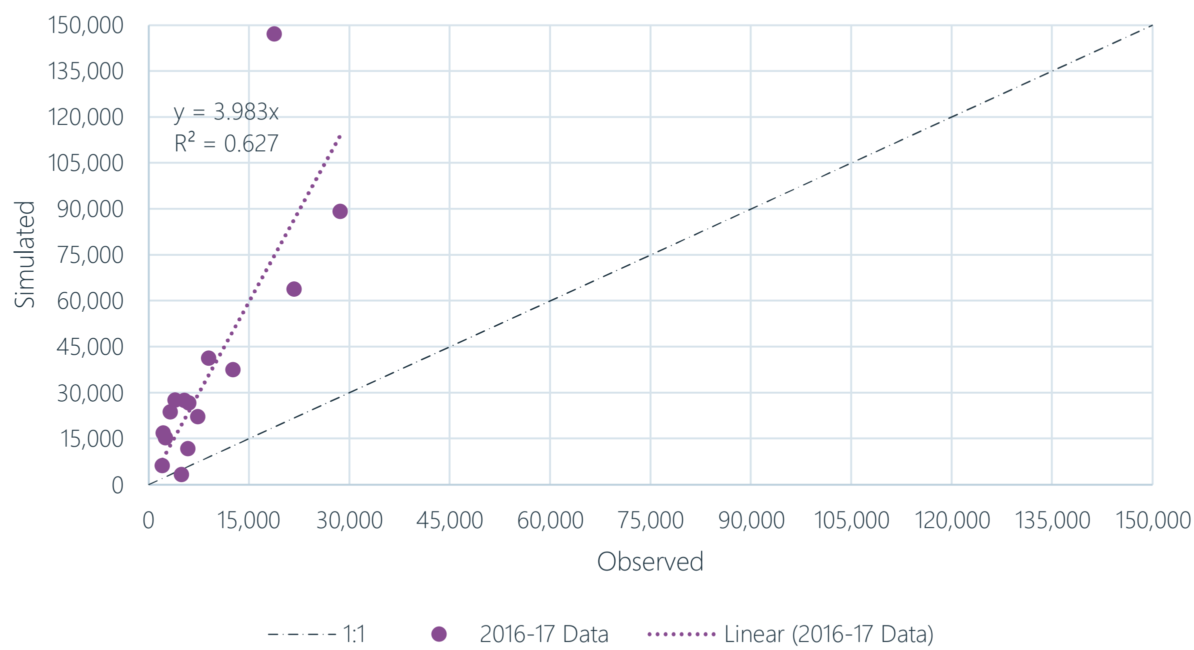


Table 5.5: Updated Imperviousness Values For Existing Land Use Conditions		
Land Use	Uncalibrated Imperviousness (%)	Calibrated Imperviousness (%)
Automobile Service Commercial Zone	80	60
Community Centre Commercial Zone	90	70
Convenience Commercial Zone	80	60
Core Commercial Zone	85	65
Development Constraint Zone	5	5
Fringe Core Commercial Zone	95	75
General Commercial Zone	85	65
General Industrial Zone	60	40
Industrial Commercial Zone	60	40
Institutional Major Zone	65	45
Institutional School Zone	65	45
Institutional Services Zone	75	55
Mixed Commercial Residential Zone	87	67
Neighbourhood Centre Commercial Zone	90	70
New Format Commercial Zone	90	70
Open Space Cemetery Zone	10	5
Open Space Restricted Zone	5	5
Open Space Type 1 Zone	20	5
Residential Cluster Dwelling Zone	80	60
Residential Conversion Zone	70	50
Residential High Density Zone	75	55
Residential Medium Density Type A Zone	70	50
Residential Medium Density Type B Zone	70	50
Residential Type 1B (15 metre) Zone	65	45
Residential Type 1C (12 metre) Zone	65	45
Residential Type 1D (9 metre) Zone	65	45
Residential Type 2 Zone	70	50
Residential Type 3 Zone	70	50

Table 5.5: Updated Imperviousness Values For Existing Land Use Conditions		
Land Use	**Uncalibrated Imperviousness (%)**	**Calibrated Imperviousness (%)**
Six Nations of the Grand River Territory	10	5

As per Table 5.5, overall subcatchment imperviousness has generally been reduced by up to 20% for higher impervious land uses (residential, commercial, industrial, institutional), while lower impervious land uses have been largely maintained at a lowest imperviousness of 5%. As per Table 5.4, these adjustments result in an overall average reduction in subwatershed imperviousness of 18.5% (from 60.6% to 42.1% on average). In conjunction with the preceding, sub-area routing (percentage of the impervious area routed to the pervious area) has been increased from 0 to 50% as part of the model calibration. This reflects a more reasonable assumption as to the fraction of impervious runoff which would be directed to pervious surfaces, particularly given the preponderance of residential land uses in the subwatershed.

Scatter plots comparing simulated and observed Peak Flow and Volume are presented in Figures 5.3 and 5.4 respectively. Comparison is made to the uncalibrated scatter plots presented previously in Figures 5.1 and 5.2. A comparison of statistical parameters is provided in Table 5.6.

Table 5.6 Simulation Scatter Plot Trend Line Results for Calibrated Modelling			
Calibration Feature	**Scenario**	**All Events[1]**	
		y	**R^2**
Total Runoff Volume	Uncalibrated	3.983	0.627
	Calibrated	1.240	0.886
Peak Flow Rate	Uncalibrated	2.752	0.563
	Calibrated	1.020	0.880

1: Excludes rainfall event of April 20, 2017 for gauge FM1 as data deemed unreliable.

As evident from Figures 5.3 and 5.4, the calibrated model yields peak flows and runoff volumes with an excellent match to observed values, while still maintaining a degree of conservativeness by ensuring trendline slopes of peak flow and runoff volume remain slightly greater than the line of perfect fit (>1) but still in close agreement (i.e. peak flows 2% greater, volumes 24% greater on average). The Coefficient of determination indicates a tight fit to the data, with values in the range of 0.88. Hydrograph comparisons (included in Appendix C) indicate a much-improved fit to observed flow responses under calibrated conditions. Overall, the calibration results indicate an excellent fit to the available monitoring data and generate a greater degree of confidence in the modelling results.

Figure 5.3: Peak Flow (m^3/s) Scatter Plot for Calibrated Model (All Points)

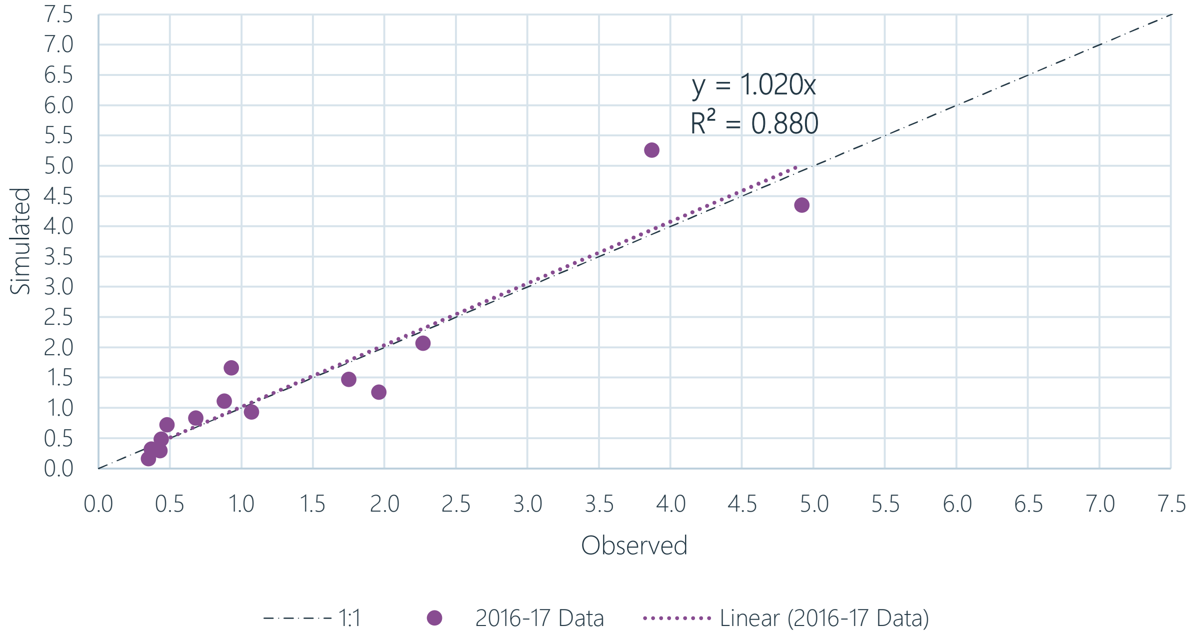


Figure 5.4: Runoff Volume (m^3) Scatter Plot for Calibrated Model (All Points)

6.0 Existing Conditions Modelling Results

6.1 Hydrology

6.1.1 Event-Based (Design Storms)

The updated calibrated hydrologic/hydraulic model described in Section 5 has been applied to determine peak flows and runoff volumes to the Mohawk Lake and Mohawk Canal. An initial comparison of results from previous studies has been completed. Estimated contributing drainage areas from available studies of the subwatershed are presented in Table 6.1.

Table 6.1 Contributing Drainage Areas to the Mohawk Lake and Mohawk Canal Subwatershed

Study	Drainage Area to West Canal (ha)	Drainage Area to Mohawk Lake (ha)	Drainage Area to Outlet to Grand River (ha)
Gore & Storrie (1995)	702.7	754.7	839.2
Aquafor Beech (2019)	732.6	866.0	921.0
Wood (2019)	700.9	872.6	930.7

As evident from Table 6.1, all three (3) studies generate relatively similar contributing drainage areas to the West Canal, which is the primary inlet to Mohawk Lake. Estimated drainage areas however differ more notably for the total contributing drainage area to Mohawk Lake, particularly between the Gore & Storrie (1995) and more recent studies (Aquafor Beech, 2019. The difference is considered partially attributable to the definition of the limits of Mohawk Lake itself. The control structure for Mohawk Lake is located some 500 m downstream of Mohawk Lake (along the East Canal). As part of the Gore & Storrie study (1995), it appears this additional section may have been excluded from the calculation of the contributing drainage area. The total contributing drainage area is also notably less for the Gore & Storrie study (1995); this appears to be attributable to measured differences in the contributing drainage area to the East Canal area.

As noted in Section 4.2.1, a notable difference also relates to the former Massey Ferguson property to the south of Mohawk Canal (and Greenwich Street), and north of the railway tracks. Both of the previous models noted in Table 4.1 included this area (20 ha +\-) as part of the subwatershed, however based on updated hydrologic modelling, this area would be internally draining, potentially due to the ongoing site remediation work as captured by the available topographic data. Although this area has been excluded from the existing conditions modelling, it is expected that due to the proximity of Mohawk Canal and lack of other direct drainage outlet, in the future following re-development, this area would drain towards Mohawk Canal (this is discussed further in Section 8).

Relevant storm sewer outfall locations are presented on Drawings 11 and 12. A summary of outfall characteristics is presented on both drawings, as well as in Table 6.2.

Prior to comparing and interpreting differences in the modelling results for the current study, (and potential differences for previously completed studies), it is informative to understand the technical basis of those modelling studies.

The Gore & Storrie (1995) hydrologic modelling was completed using the OTTHYMO model platform (hydrology only – no hydraulics). A 3-hour Chicago Storm (10-minute time step) was applied for the assessment of design storms/frequency events, based on rainfall intensity-duration-frequency (IDF) data from Environment Canada's Brantford MOE Station (data from 1961-1990). Hurricane Hazel (Regional Storm) was also simulated, based on saturated ground conditions (AMC-III) with the Horton's initial infiltration rate adjusted to match the saturated infiltration rate (13 mm/hr), and the last 12 hours of the storm simulated. A copy of the OTTHYMO modelling was requested by Wood however was not available from the City of Brantford. As such, the results presented in the reporting by Gore & Storrie (Table 5-1 and Table B-4 from the May 1995 report) have been assumed for the purposes of comparison.

The Aquafor Beech (2019) hydrologic/hydraulic modelling was completed in InfoWorks ICM (updated from the InfoSWMM model used in the Draft Characterization Study, October 2018), and applied a 24-hour Chicago Storm (5-minute time step) for the simulation of design storms/frequency events, based on the City of Brantford's current rainfall IDF data. The 12-hour version of Hurricane Hazel is included in the received InfoSWMM modelling (Draft Characterization Report Stage), thus it is assumed that this version was used for the simulation of the Regional Storm Event, with infiltration parameters adjusted to saturated conditions (AMC-III), although this is not clear from the Characterization Study (2019). It should be noted that as per Section 2.3, Wood has been unable to replicate the peak flow values presented in the Draft Characterization Study Report (2018) based on the InfoSWMM modelling supplied. For the purposes of the current study and comparison of results, it has been assumed that the results presented in the Final Characterization Study Report (October 2019 – Table 5.16) are governing.

Table 6.2 Storm Sewer Outfalls to Mohawk Canal and Mohawk Lake

Outfall	Pipe Size (mm Φ)	Drainage Area (ha)	Modelled Impervious (%)
OF-444A	2100	298.4	46.0
OF-444B	900	19.4	64.1
OF-44A	1050	11.3	63.7
OF-44B	750	4.3	62.4
OF-67	300	7.2	49.0
South St	450	2.1	49.7
Glanville Ave	300	2.8	50.0
OF-6A	300	6.4	47.3
OF-4	300	0.7	50.0
OF-194	1125	93.1 (109.1)	49.1 (48.0)
OF-222	1800	191.6 (207.6)	42.5 (42.5)
OF-38	450	5.5 (21.7)	38.9 (44.5)
OF-14A	375	4.7	42.8

Table 6.2 Storm Sewer Outfalls to Mohawk Canal and Mohawk Lake			
Outfall	**Pipe Size (mm Φ)**	**Drainage Area (ha)**	**Modelled Impervious (%)**
OF-6B	300	3.7	44.4
OF-15	375	3.7	46.3
OF-14	375	2.1	36.6

1. Note that certain outfalls have split drainage areas upstream; the first value indicates the primary (direct) drainage area, while the bracketed value indicated the total drainage area based on an assumed even distribution of drainage area for split areas.

A comparison of simulated peak flows at key nodes of interest from available studies is presented in Table 6.3. Full results from the updated hydrologic/hydraulic modelling completed by Wood along Mohawk Canal and Mohawk Lake are presented in Appendix D.

Table 6.3 Comparison of Simulated Peak Flows at Outfalls and Nodes of Interest from Available Studies

Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	2-Year Storm			100-Year Storm			Regional Storm		
		G&S	AB	Wood	G&S	AB	Wood	G&S	AB	Wood
OF-444A	11M484	14.52	NA	7.47	42.78	NA	17.17	33.75	NA	18.55
OF-444B	11M482	1.77	NA	0.99	4.47	NA	2.19	2.48	NA	2.02
Canal at East Ave	11M001OF	16.29	8.1	8.37 (0.15)	47.25	30.4	19.72 (0.82)	36.23	NA	21.42 (0.31)
OF-44A & OF-44B	10M097 and 10M043	1.02	4.0	0.68 (0.11)	2.72	13.9	1.25 (0.86)	2.12	17.4	0.79 (0.84)
OF-67	10M075	0.86	4.1	0.16 (0.03)	1.92	14.2	0.42 (1.07)	1.27	NA	0.41 (0.48)
Canal at Alfred St	10M079OF (10M044OF)	12.4	4.1	7.68	35.77	14.06	21.23	36.85	NA	25.23
South St	07M206	0.06	4.1	0.07	0.16	14.06	0.28	0.13	NA	0.22
OF-6A	09M007	0.15	4.1	0.16	0.34	14.3	0.19 (0.45)	0.23	NA	0.17 (0.58)
OF-4	08M003	0.32	3.8	0.01 (0.02)	0.71	14.6	0.04 (0.20)	0.47	NA	0.02 (0.09)
Canal at Murray St	08M004OF	10.56	3.8	4.79	33.49	14.58	18.87	36.39	NA	25.90
OF-194	07M193	4.19	6.1	2.33 (0.11)	11.82	18.3	3.58 (2.36)	10.81	NA	3.49 (3.22)
OF-222	06M221	10.15	7.2	4.10 (0.06)	29.96	25.4	8.45 (11.68)	24.34	35.5	6.89 (23.57)
West Canal at Lake Inlet	J12 (06M222OF)	19.64	9.01	7.96	62.77	25.37	27.99	74.46	33.52	53.63
OF-38	05M037	1.40	7.67	0.21 (0.01)	3.67	26.95	0.72 (0.45)	3.02	34.36	0.70 (0.22)

Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	2-Year Storm			100-Year Storm			Regional Storm		
		G&S	AB	Wood	G&S	AB	Wood	G&S	AB	Wood
OF-14A	04M013	0.35	7.31	0.07 (0.07)	1.17	25.67	0.58 (1.13)	0.76	34.48	0.44 (0.57)
OF-6B	03M005	0.12	7.32	0.12 (0.15)	0.32	25.85	0.35 (1.33)	0.27	NA	0.25 (0.56)
Tributary 1	JCT-68	NA	NA	1.74	NA	NA	8.50	NA	NA	8.49
OF-15	01M011	0.49	7.78	0.10 (0.01)	1.32	28.14	0.46 (0.22)	1.11	NA	0.42 (0.08)
OF-14B	01M013	0.09	7.79	0.03 (0.11)	0.25	28.2	0.15 (0.66)	0.20	NA	0.09 (0.31)
Lake Outlet at Locks Rd	01M14OF	4.82	9.35	9.09	17.64	27.78	35.94	61.18	40.17	65.90
At Grand River	JCT-74	4.82	9.66	9.61	17.64	29.21	40.52	61.17	44.63	68.49

Table 6.3 Comparison of Simulated Peak Flows at Outfalls and Nodes of Interest from Available Studies

1. Locations referenced are from the updated modelling (Wood, 2019); bracketed locations refer to results from the Characterization Study (Aquafor Beech, October 2019). Results from Gore & Storrie (1995) are for the outfalls unless otherwise noted.
2. For outfall locations, bracketed value indicates a major overland flow, non-bracketed value is storm sewer flow.

For the purposes of the current summary, the results for Hurricane Hazel have been developed based on an analogous method to Gore & Storrie (1995), [i.e. simulation of the 12-hour version of the storm event along with an adjustment to the initial infiltration rate to match that under saturated conditions (AMC-III)]. Typically, the full 48-hour version of the storm event and normal (AMC-II) moisture conditions should also be tested, consistent with Provincial (MNRF) policy.

The modelling results presented in Table 6.3 indicate that the updated modelling completed by Wood generally predicts lower peak flows than the original stormwater management report (Gore & Storrie, 1995); this may in part reflect the use of different duration design storms (3 hour for Gore & Storrie, 24 hours for Wood). The updated modelling completed by Wood also indicates higher peak flows than those presented in the Characterization Study Report (Aquafor Beech, 2019) with the exception of simulated peak flows for certain locations (end of West Canal in particular) for smaller storm events (2-year storm). The current (Wood, 2019) InfoSWMM modelling does indicate a reasonable degree of flow attenuation within the West Mohawk Canal, which tends to attenuate peak flows from storm sewer outfalls, particularly from smaller storm events, such as the 2-year storm.

Some of the differences for more formative storm events in particular, reflect the differences in assumptions around minor and major flow splits in the various models. The Gore & Storrie modelling was a purely hydrologic model (OTTHYMO) and as such did not account for minor/major flow splits or capacity constraints in these systems which would tend to attenuate flows. Contrarily the Aquafor Beech modelling included only the minor (storm sewer) system, thus does not account for major system flows in excess of storm sewer capacity, which is particularly a consideration for larger storm events such as the 100-year storm and the Regional Storm Event.

In addition, it should be noted that the Aquafor Beech modelling (2019) does not include any representation of the storage associated with Mohawk Lake or attenuation provided by the outlet control structure. As such, simulated peak flows downstream of the lake (at Locks Road and at the Grand River) should theoretically be relatively higher in that modelling as compared to Wood's (2019) modelling, which explicitly includes this feature. Notwithstanding, overall, the Wood (2019) model continues to predict higher flows in these locations, which likely reflects differences in hydrologic modelling assumptions.

Based on the current model simulation results, a Regional Storm peak flow of 53.63 m^3/s is predicted at the inlet to Mohawk Lake from the West Canal. Based on the contributing drainage area (7 km^2), this results in a normalized flow of 7.7 m^3/s per km^2. Based on Wood's experience in numerous Southern Ontario studies and preparation of comparison plots of normalized Regional Storm Flows, values in the range of 2 to 12 m^3/s per km^2 would be appropriate, hence falling into a reasonable range.

Full model results for key locations for the full range of storms are presented in Table 6.4. In addition to the full suite of typical design storm events (24-Hour Chicago Storms), a 25 mm storm event (4-hour Chicago Storm) has been assessed for erosion control and water quality considerations. In addition, a modified version of the Regional Storm has been included which excludes the Mohawk Lake storage function, consistent with current Provincial (MNRF, 2002) flood control policies.

Table 6.4 Simulated Peak Flows at Outfalls and Nodes of Interest (Wood, 2019)

Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	Simulated Peak Flow (m^3/s) for Storm Event								
		25 mm	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	Regional Storm	Regional Storm (No Storage)[3]
OF-444A	11M484	4.27	7.47	12.09	13.42	14.70	15.47	17.17	18.55	18.50
OF-444B	11M482	0.43	0.99	1.69	1.82	1.83	2.00	2.19	2.02	2.14
Canal at East Ave	11M001OF	4.68 (0.08)	8.37 (0.15)	14.07 (0.29)	16.69 (0.42)	18.89 (0.56)	18.10 (0.69)	19.72 (0.82)	21.42 (0.31)	21.72 (0.31)
OF-44A & OF-44B	10M097 and 10M043	0.68 (0.11)	0.68 (0.11)	0.73 (0.18)	0.83 (0.41)	0.91 (0.71)	1.04 (0.80)	1.25 (0.86)	0.79 (0.84)	1.48 (0.94)
OF-67	10M075	0.10 (0.02)	0.16 (0.03)	0.32 (0.12)	0.41 (0.29)	0.42 (0.65)	0.42 (0.86)	0.42 (1.07)	0.41 (0.48)	0.41 (0.46)
Canal at Alfred St	10M079OF (10M044OF)	4.11	7.68	13.57	16.92	17.40	19.93	21.23	25.23	26.98
South St	07M206	0.04	0.07	0.16	0.22	0.25	0.26	0.28	0.22	0.23
OF-6A	09M007	0.11 (0.00)	0.16 (0.00)	0.17 (0.01)	0.17 (0.01)	0.18 (0.11)	0.19 (0.26)	0.19 (0.45)	0.17 (0.58)	0.19 (0.56)
OF-4	08M003	0.00 (0.01)	0.01 (0.02)	0.01 (0.05)	0.02 (0.09)	0.03 (0.13)	0.04 (0.17)	0.04 (0.20)	0.02 (0.09)	0.02 (0.09)
Canal at Murray St	08M004OF	2.58	4.79	10.18	12.71	14.60	16.35	18.87	25.90	29.93
OF-194	07M193	1.67 (0.05)	2.33 (0.11)	3.66 (0.26)	3.85 (1.01)	3.73 (1.62)	3.63 (2.21)	3.58 (2.36)	3.49 (3.22)	4.06 (2.04)
OF-222	06M221	2.54 (0.04)	4.10 (0.06)	7.30 (0.45)	7.99 (1.41)	8.43 (3.38)	8.47 (6.91)	8.45 (11.68)	6.89 (23.57)	9.14 (18.36)
West Canal at Lake Inlet	J12 (06M222OF)	4.49	7.96	14.02	18.55	22.40	25.52	27.99	53.63	58.00
OF-38	05M037	0.14 (0.00)	0.21 (0.01)	0.40 (0.04)	0.65 (0.09)	0.71 (0.19)	0.72 (0.32)	0.72 (0.45)	0.70 (0.22)	0.71 (0.21)
OF-14A	04M013	0.05 (0.04)	0.07 (0.07)	0.17 (0.17)	0.29 (0.31)	0.41 (0.50)	0.52 (0.75)	0.58 (1.13)	0.44 (0.57)	0.44 (0.57)

Table 6.4 Simulated Peak Flows at Outfalls and Nodes of Interest (Wood, 2019)										
Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	Simulated Peak Flow (m^3/s) for Storm Event								
		25 mm	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	Regional Storm	Regional Storm (No Storage)[3]
OF-6B	03M005	0.08 (0.08)	0.12 (0.15)	0.25 (0.29)	0.25 (0.52)	0.25 (0.78)	0.28 (1.05)	0.35 (1.33)	0.25 (0.56)	0.26 (0.55)
Tributary 1	JCT-68	1.09	1.74	3.15	4.68	6.26	7.38	8.50	8.49	8.49
OF-15	01M011	0.06 (0.01)	0.10 (0.01)	0.23 (0.03)	0.36 (0.06)	0.45 (0.10)	0.47 (0.13)	0.46 (0.22)	0.42 (0.08)	0.42 (0.08)
OF-14B	01M013	0.02 (0.06)	0.03 (0.11)	0.05 (0.15)	0.08 (0.27)	0.11 (0.40)	0.13 (0.53)	0.15 (0.66)	0.09 (0.31)	0.09 (0.31)
Lake Outlet at Locks Rd	01M14OF	5.31	9.09	16.04	20.75	25.76	30.69	35.94	65.90	74.77
At Grand River	JCT-74	5.90	9.61	16.86	21.92	28.70	34.78	40.52	68.49	78.54

1. Locations referenced are from the updated modelling (Wood, 2019).
2. For outfall locations, bracketed value indicates a major overland flow, non-bracketed value is storm sewer flow.
3. Storage function of Mohawk Lake removed to determine unrestricted flows downstream

The updated peak flows presented in Table 6.4 have been used as part of the updated hydraulic modelling assessment in Section 6.2.

Of particular note are the large simulated major system (overland) flows to OF-222 (Sonoco Site – Stanley Street extension). The simulated major system flows increase notably for the 25-year storm event and above. This may reflect the limited capacity of the trunk sewer in this area, as per the minor system capacity plots presented previously (Drawings 13-15). The 100-year overland flow mapping indicates simulated conveyance depths of between 0.3 m and 0.5 m for this area, which would be expected to exceed the municipal ROW and also potentially impact the Sonoco property. A more detailed review of flood flow conveyance in this area may be warranted, including the potential for overland flows to mobilize or impact any contaminants of concern within the industrial site.

The simulated results indicate that for areas with larger contributing drainage areas, the Regional Storm would be the Regulatory Event, as is typically the case. The Regional Storm generates notably higher flows to Mohawk Lake in particular. For smaller, more localized drainage areas, the 100-year storm generates higher peak flows, given its higher peak rainfall intensity.

The removal of the storage function within Mohawk Lake has a minor impact on peaks flows upstream, due to the complex hydraulic routines within InfoSWMM which account for tailwater impacts. Flows downstream of Mohawk Lake are increased to a greater degree due to the removal of the storage function, as would be expected.

6.1.2 Continuous Simulation

Although the majority of the completed hydrologic analyses completed for this study are based on discrete events (the “design storm” approach), it is also considered informative to complete a simplified continuous hydrologic simulation. Continuous simulation assesses a long-term record of actual precipitation to better inform impacts under more frequent storm events (such as erosion) as well as the expected hydrologic cycle balance (i.e. a water budget). Given the lack of defined critical erosion thresholds for the receiving watercourses (i.e. Shallow Creek and the West Canal), the focus of the current continuous simulation is upon a simplified water budget.

The modelling has then been executed in continuous simulation mode for an “average” rainfall year. For the current simulation, hourly data from Environment Canada’s Royal Botanical Gardens (RBG) has been applied. Although the data are not directly from the Brantford area, the data are still considered reasonably representative of Southern Ontario meteorology and sufficient for the purposes of generating a typical “average year”.

InfoSWMM (and EPA-SWMM) provides several options for the simulation of evaporation:

- A complete time series can be specified:
  - Historic daily pan evaporation data are avaiable from a limited number of sites in Ontairo, however no data avilable for 1997 onwards (Environment Canada stopped collecting these data at that point)

  - Surrogate methods to gap fill beyond this point such as "average day" for prevoius period of record, or correlation with other parameters
  - Evaporation generally assumed to be zero for winter period (December-March inclusive)

- Monthly averages or constant values can also be assumed
- Alternatively, evaporation can be calculated using an empirical equation (Hargreaves Method) which correlates evaporation with air temperature data and solar radiation as a function of latitude and time of year.

Given the purpose of the current study, the application of monthly averages has been considered a reasonable approach. Average daily lake evaporation Climate Normals (1981 to 2010) are available per month for Environment Canada's RBG station (Climate ID 6153300); these values are considered reasonable for the current simulation. Results are presented in Table 6.5.

Table 6.5 Applied Evaporation Averages for Continuous Simulation

Month	Average Daily Lake Evaporation (mm)
January	0
February	0
March	0
April	2.3
May	3.4
June	4.2
July	4.2
August	3.3
September	1.8
October	0.7
November	0
December	0

It should be noted that while InfoSWMM is able to simulate evaporation from surface storage, it is not able to simulate evapotranspiration (ET) of the subsurface water storage without the use of an aquifer and groundwater modelling. Therefore, the reported continuous simulation results represent surface evaporation only and not true ET. However, it can be assumed that a portion of the simulated infiltration will in fact be evapotranspirated, therefore the water budget/balance can be assessed on a total losses basis (simulated infiltration + evaporation) to evaluate the subwatershed impacts in the absence of refined groundwater modelling.

It should also be noted that for a "true" continuous simulation, snowmelt processes should also be simulated, which necessitates a number of time series inputs (air temperature and wind speed), as well as snowpack accumulation parameters (including the impact of snowplowing activities). These processes have not been incorporated into the continuous simulation for this study, as the performance of the system is not anticipated to be impacted and given the core purpose of the continuous simulation (a simplified water budget analysis only).

Given that hourly precipitation data (rather than higher resolution data) have been applied (for a single year only), a comparison of peak flows is not considered warranted. The focus of the completed continuous simulation is upon a high-level water budget. Results are presented in Table 6.6.

Table 6.6 Existing Conditions Average Monthly and Annual Water Budget

Month	Precipitation (mm)	Runoff (mm)	Total Losses (mm)
January	89	40	47
February	78	55	22
March	22	15	6
April	108	23	87
May	80	15	65
June	75	12	63
July	89	17	71
August	55	10	46
September	74	14	60
October	91	17	74
November	36	8	29
December	83	32	48
Average Annual	**880**	**258**	**618**

The results presented in Table 6.6 indicate that approximately 30% of the total rainfall input would become runoff, which may be an under-estimate, considering the urbanized and uncontrolled nature of the Mohawk Lake subwatershed. The preceding results would suggest a total runoff volume of 2,401,980 m^3, based on the total system drainage area of 931 ha. The actual inflow to Mohawk Lake would be somewhat less, given the preceding includes Tributary 2 and downstream areas which do not drain directly to Mohawk Lake. The limitations of the simplified nature of the completed water budget analysis (single year simulation, no snowmelt, etcetera) should be noted, however the preceding estimate of annual surface runoff compares reasonably well to that from previous studies, including Gore & Storrie (1995) which estimated 2,748,000 m^3 of runoff-based inflow to Mohawk Lake. Similar results were generated as part of the analysis completed for the Characterization Study (Aquafor Beech, 2019) as well.

As previously discussed, InfoSWMM is not able to simulate evapotranspiration (ET) of the subsurface water storage without the use/application of an aquifer and groundwater modelling. Therefore, in the absence of detailed groundwater modelling, the reported total losses results represent the surface evaporation and infiltration only, under the assumption that a portion of the simulated infiltration will in fact be evapotranspirated. Further, the current hydrologic modelling does not include snowmelt processes, thus simulated water budget values for winter and early spring months do not include these processes.

The simulated water budget results presented in Table 6.6 indicate that approximately 70% of the average annual rainfall results in losses (infiltration, and evaporation) which represents deep percolation, storage in the upper zone for evapotranspiration, and surface evaporation, with total losses greatest during warm weather months, as would be expected; the remainder represents surface runoff.

6.1.3 Climate Change

A number of tools are publicly available to generate climate change forecasted rainfall totals. One such tool is the University of Western Ontario's (UWO) IDF Climate Change Tool. Future greenhouse gas emissions scenarios are uncertain and four (4) Representative Concentration Pathways (RCPs) have been developed which reflect commonly selected levels of greenhouse gas emission forcing scenarios. They range from RCP 2.6, a best-case scenario for greenhouse gas reductions, to RCP 8.5 which reflects no greenhouse gas reductions. RCP 4.5 and 6.0 are considered moderate emission reduction scenarios. For this study, the RCP 4.5 scenario has been selected for the development of the Climate Change IDF parameters, based on Wood's experience in other jurisdictions. A 2080 timeframe has been initially selected for projection of climate change rainfall, based on a simulated 40-year window of 2060 to 2100 for the UWO IDFCC tool (average of 2080). Data for Environment Canada's Brantford MOE station have been applied to represent local conditions.

With respect to the results from the UWO IDF Climate Change Tool, it is understood that UWO recently updated the IDF tool from version 2.0 to version 3.0, with the previously applied Gumbel probability distribution replaced by a GEV distribution in the more current version. This has resulted in an increase in predicted rainfall totals as compared to data extracted from previous versions of the tool which employed the Gumbel probability distribution. This should be noted in interpreting simulated results.

Wood has also explored the potential application of two (2) alternate climate change IDF tools to generate Climate Change IDF data; the Ministry of Transportation Ontario (MTO) IDF Curve Lookup tool and the Ontario Climate Change Data Portal (OCCDP). The MTO tool requires a target year and a coordinate location; the co-ordinates of the Brantford MOE building, along with the previously forecasted year of 2080. For the OCCDP tool, a time period of 2070-2099 has been applied for the RCP 4.5 emission forcing scenario, along with a grid location coinciding to the study area.

Climate change altered rainfall totals (24-hour duration) are presented in Table 6.7; absolute and relative differences to the base IDF total are presented in Tables 6.8 and 6.9 respectively.

Table 6.7 Comparison of Climate Change Generated Rainfalls - 24-hour Rainfall Depth (mm)						
IDF Data Source	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**
Existing Brantford MOE IDF Data	49.9	63.0	71.7	82.8	90.9	99.0
MTO IDF Curve Lookup	69.6	88.8	100.8	115.2	127.2	139.2
Ontario Climate Change Data Portal	NA	NA	NA	NA	NA	NA
UWO IDF Climate Change Tool 3.0	55.5	70.2	80.0	93.3	101.7	110.2

Table 6.8 Comparison of Climate Change Generated Rainfalls – 24-hour Rainfall Depth Increase (mm) in Comparison to Existing IDF Data						
IDF Data Source	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**
MTO IDF Curve Lookup	19.7	25.8	29.1	32.4	36.4	40.2
Ontario Climate Change Data Portal	NA	NA	NA	NA	NA	NA
UWO IDF Climate Change Tool 3.0	5.6	7.1	8.2	10.5	10.8	11.1

Table 6.9 24 hr Rainfall Depth Increase (%) in Comparison to Existing IDF Data						
IDF Data Source	**2 Year**	**5 Year**	**10 Year**	**25 Year**	**50 Year**	**100 Year**
MTO IDF Curve Lookup	39.5%	41.0%	40.6%	39.1%	39.9%	40.6%
Ontario Climate Change Data Portal	NA	NA	NA	NA	NA	NA
UWO IDF Climate Change Tool 3.0	11.2%	11.3%	11.4%	12.7%	11.9%	11.2%

These tables indicate notably different changes between Climate Change altered rainfall sources. The UWO IDF Climate Change Tool indicates increases of approximately 11%, whereas the MTO IDF curve tool indicates much more dramatic increases in rainfall depths of approximately 40%. The differences reflect the different methodologies and assumptions inherent in these tools and are estimates only.

It is suggested that in order to quantify the range of potential climate change impacts, all three (3) of the preceding climate-change altered IDF datasets be applied for the hydrologic modelling simulation of both existing and as of right land use conditions. In order to provide a range of potential impacts, simulated results for both the 2-year and 100-year storm event have been presented. Results have been presented for the primary nodes of interest along Mohawk Canal and Mohawk Lake

Table 6.10 Comparison of Simulated Peak Flows at Nodes of Interest using Climate Change Altered Rainfall

Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	2-Year Storm (m^3/s)				100-Year Storm (m^3/s)			
		Existing	MTO IDF	OCCDP	UWO IDFCC	Existing	MTO IDF	OCCDP	UWO IDFCC
Canal at East Ave	11M001OF	8.37	9.93	NA	8.61	19.72	18.20	NA	17.70
Canal at Alfred St	10M079OF (10M044OF)	7.68	9.56	NA	8.16	21.23	19.74	NA	18.05
Canal at Murray St	08M004OF	4.79	6.08	NA	4.96	18.87	17.33	NA	15.42
West Canal at Lake Inlet	J12 (06M222OF)	7.96	9.32	NA	8.27	27.99	28.86	NA	25.48
Tributary 1	JCT-68	1.74	1.94	NA	1.77	8.50	7.70	NA	6.44
Lake Outlet at Locks Rd	01M14OF	9.09	10.58	NA	9.39	35.94	34.10	NA	30.62
At Grand River	JCT-74	9.61	11.14	NA	9.88	40.52	37.28	NA	33.03

1. Locations referenced are from the updated modelling (Wood, 2019).

For the 2-year storm event, the simulated results indicate that increases in peak flows would be somewhat less than the corresponding relative increase in rainfall depths and intensities. For the UWO IDFCC tool, peak flows increase by only 3% on average, as compared to the 11% increase in rainfall depths. For the MTO IDF tool, peak flows increase by 19% on average, as compared to the 40% increase in rainfall depths.

Somewhat contradictory results are indicated for the 100-year storm event, with both sets of climate change altered rainfall data indicating consistent decreases in peak flows as compared to existing IDF data, particularly for the UWO IDFCC tool results (16% decrease). The reason for this result is uncertain and warrants further assessment. In some instances, hydrograph timing effects or upstream storage can mitigate expected increases in flow rates, however it is unclear if these reasons are the cause of the simulated decreases indicated in Table 6.10.

6.2 Hydraulics

6.2.1 Urban Drainage Systems

As per Section 6.1, the hydrologic model (InfoSWMM) has been executed for various design storm events and subsequently the results have been analyzed. Although the primary purpose of this study is not to characterize the performance of the urban drainage systems within the sub-watershed, such an analysis provides some insight into potential drainage conveyance system constraints, and also helps inform the development of an overall SWM strategy.

The limitations of the modelled storm sewer network should however clearly be understood. As outlined as part of the model development summary (Section 4), the modelled storm sewer network is generally consistent with the received data/modelling from previous studies. While spot checks have been completed for trunk sewer locations, the majority of the sewer system has not been reviewed or updated, beyond the revision of rim elevations to match DEM topography (to support the development of a consistent major overland flow system component within the model). Notwithstanding, it is considered that the simulated drainage system results are reasonable, given the consistency with previous modelling approaches, and the model calibration effort (as per Section 5).

Drawings 13, 14 and 15 present the simulated minor system (storm sewer) performance under the 2, 5 and 10-year design storm events respectively. Storm sewer system surcharging has been defined based on the simulated peak flow to the theoretical full flow capacity (based on Manning's Equation), as this is considered the best representation of system performance (since depth surcharging may simply be the result of tailwater/backwater conditions). As expected, the minor system is surcharged at fewer locations under a 2-year storm and is surcharged at increasingly more locations under the 5-year and 10-year storm events. In general, more downstream locations, are indicated surcharged which is generally consistent with the results presented in the Characterization Study (October 2019). Simulated results within the Characterization Study generally indicated a greater number of surcharged storm sewers as compared to the currently presented results.

Under a 2-year storm event, sections of trunk sewers from OF-44A, and OF-194 (Rawdon Street) and OF-222 (Stanley Street) indicate some surcharging. More extensive surcharging is indicated in OF-194 and OF-222 trunk sewers for the 5-year storm event, as well as surcharging in the OF-444A sewershed. Increased surcharging is again indicated for the 10-year event. A number of smaller storm sewer branches are indicated as remaining unsurcharged for the 10-year storm event, suggesting a greater conveyance capacity in these areas.

Drawing 16 presents the simulated major system (overland flow – roadways) performance under a 100-year design storm event. To better understand its performance, the major system flooding depth at junction nodes has been divided into four (4) depth increments:

- Simulated flooding depth less than 0.3 m
- Simulated flooding depth between 0.3 – 0.5 m
- Simulated flooding depth between 0.5 – 1.0 m
- Simulated flooding depth greater than 1.0 m

For most of the study area (1,087 out of 1,357 total junctions, or 80%), simulated results indicate depths less than 0.3 m for the 100-year storm event. Elevated depths are indicated along Mohawk Canal, as would be expected. One particular area of concern is the intersection of Rawdon St and Wellington St, where the topography indicates a localized depression without an outlet (verified by multiple DEM datasets). This ultimately results in large simulated ponding depths. Another location indicating elevated 100-year ponding depths is near the CNR crossing of Elgin Street (which is partly due to the ditch along the railway line) and near Grey St and Brock Street (local depression). No historic flooding information is available from the City of Brantford to confirm whether or not these locations have experienced surface flooding in the past. Based on the nature of the topography in these areas however, some degree of surface flooding would be expected during more formative storm events.

6.2.2 Open Channel

The hydrologic modelling results from Section 6.1 have been used to further review/assess flood levels and floodplain limits within the Mohawk Lake and Mohawk Canal area, primarily based on the updated hydraulic model (HEC-GeoRAS) developed as part of the Characterization Study (October 2019). As noted in Section 2.4, the supplied hydraulic modelling does not include Shallow Creek, thus hydraulic modelling is limited to Mohawk Canal and Mohawk Lake.

No floodlines were calculated as part of the 1995 Stormwater Management Study (Gore & Storrie), however the Regional Storm water surface elevation upstream of Locks Road (which should be equivalent to the water surface elevation within Mohawk Lake) is noted as 201.07 m. As per Table 5.19 from the Characterization Study (October 2019), the corresponding Regional Storm Event Flood Level is 199.36 m, some 1.71 m lower. This difference may be partially attributable to the notable difference in simulated peak flows prepared as part of the Characterization Study (2019), as compared to those of the Stormwater Management Study (1995). The generated water surface elevation of

199.36 m is consistent with the results within the HEC-RAS modelling provided to Wood by Aquafor Beech.

The modelling completed as part of the Characterization Study incorporates a rating curve boundary condition, as part of the most downstream cross-section (XS 1240), based on the stage-discharge relationship for Mohawk Lake from the 1995 Stormwater Management Study (Gore & Storrie, 1995). That rating curve suggests that for the Regional Storm Flow included in the modelling (34.48 m^3/s), the corresponding water level should in fact be much higher (between the ordinates of 200.1 and 200.6 m for 33 and 44 m^3/s respectively). The reason for the discrepancy in results is unclear. The modelling should potentially be revised to incorporate a fixed water level boundary condition based on the results of the rating curve and be re-verified to determine if elevated water surface elevations would result, as would be expected.

As discussed in previous sections, the modelling approach undertaken by Wood for Mohawk Lake differs from that of the Characterization Study. Whereas the Characterization Study incorporated the function of the Mohawk Lake control structure into the hydraulic (HEC-RAS) modelling and not in the hydrologic modelling (InfoSWMM), Wood has considered it more appropriate to incorporate this function into the hydrologic modelling, given that Mohawk Lake provides (informal) quantity control storage and attenuation. This approach is also more consistent with the hydrologic modelling completed as part of the 1995 Stormwater Management Study (OTTHYMO).

Water levels within Mohawk Lake would be primarily controlled based on the function of the control structure, given the flat grades in this area. Based on the approach proposed in the current study, expected flood levels within Mohawk Lake have been obtained directly from the InfoSWMM modelling. Simulated peak water surface elevations are presented in Table 6.5 accordingly. The same approach to the simulation of the Regional Storm Event (Hurricane Hazel), as described in Section 6.1, has again been applied.

In addition to the preceding, the updated HEC-GeoRAS modelling prepared as part of the Characterization Study (Aquafor Beech, 2019) has been updated to consider two (2) additional scenarios. Under the first scenario, the modelling has been used as received, with the exception of an update to the peak flow data to reflect the updated InfoSWMM modelling completed by Wood. Under the second additional scenario, the boundary conditions of the modelling have been revised to use a rating curve within the flow data boundary condition (rather than a normal depth boundary condition), with the rating curve within the geometry data for the last cross-section removed. Updated results for all of the preceding scenarios are presented in Table 6.5.

The flows from the current Subwatershed Study are based on the InfoSWMM modelling which includes the attenuation function of Mohawk Lake. It should be noted that as per Provincial Policy, stormwater management facilities and storage features should not be included in any hydrologic simulation of the Regional Storm Event for regulation purposes. However, as evident from the results presented in Table 6.4, while the peak flows generated for the Regional Storm upstream of Mohawk Lake differ slightly due to the complex hydraulic modelling routines in InfoSWMM (which account for tailwater conditions), the differences in peak flows are relatively minor. The major differences in flows would be downstream of the Mohawk Lake control structure, which is not included in the scope of the HEC-RAS hydraulic modelling. As such, the use of the flows presented in Table 6.4 is considered reasonable. However, in order to be conservative, and more consistent with Provincial Policy, the results for the Regional Storm without the storage reservoir in place have been applied to the updated HEC-RAS modelling in Table 6.11.

Table 6.11Simulated Peak Water Surface Elevations within Mohawk Lake

Scenario Reference Number	Modelling Scenario	Simulated Peak Water Surface Elevation (m)						
		2	5	10	25	50	100	Regional[2]
1	CS Flows (AB) - HEC-RAS[1]	198.31	198.47	198.63	198.92	199.09	199.24	199.56
2	SWS Flows (Wood) – HEC-RAS[1]	198.26	198.62	198.93	199.11	199.24	199.34	200.18
3	SWS Flows and Modified BC (Wood) – HEC-RAS[1]	198.81	199.26	199.50	199.69	199.84	199.95	200.83
4	InfoSWMM (Wood)	198.86	199.30	199.54	199.77	199.98	200.21	200.82

1. Average of simulated results at cross-sections 2710 (upstream) and 1914 (downstream)
2. SWS Flows for Regional Storm Event exclude storage function in InfoSWMM modelling; 2-100 year return period flows include it given nominal difference in peak flows to Mohawk Canal and Lake.

The simulated results for Scenarios 1 and 2 (reflecting peak flows from the Characterization Study and current Subwatershed Stormwater Plan respectively) indicate generally close agreement for the 2 through 100-year storm events, with an average difference of 0.14 m. The relatively good agreement may reflect the reasonable agreement in peak flows between the two studies, as well as the large surface area and storage volume available within Mohawk Lake, which is relatively insensitive to the differences in peak flows.

The simulated results for the Regional Storm Event for Scenarios 1 and 2 however indicate a greater difference, with the simulated peak water level in Mohawk Lake, some 0.62 m higher than the value indicated in the Characterization Study (Aquafor Beech, 2018). This is likely attributable to the notably higher peak flows generated by the Wood model (refer to Table 6.3). The currently estimated value of 200.18 m for Scenario 2 though is in better agreement with the value at Locks Road indicated in the Gore & Storrie (1995) study of 201.07 m, again considering the differences in simulated peak flows to Mohawk Lake from these two studies (refer to Table 6.3).

Scenario 3 revises the boundary conditions within the HEC-RAS modelling to apply a rating curve within the flow data, rather than a normal depth boundary condition (with a rating curve in the last cross-section in the geometry data). The simulated results indicate that this revision results in a consistently higher simulated peak water surface elevation, with results on average 0.60 m with the revised boundary condition. The resulting revised Regional Water Surface Elevation of 200.83 m is in closer agreement to the result of the Gore & Storrie (1995) study of 201.07 m noted previously (notwithstanding the difference in the source peak flows).

The results of Scenario 4 are sourced directly from the hydrologic modelling (InfoSWMM). This accounts directly (unsteady state) for the reservoir routing function of Mohawk Lake. The simulated results from this scenario indicate close agreement with those from HEC-RAS Scenario 3 (0.14 m or less), with the exception of the 100-year storm event which indicates a somewhat larger difference (0.26 m). This generally good agreement likely reflects the similar approach to boundary condition modelling (i.e. the rating curve for the outlet control structure) and suggests that Scenarios 3 and 4 give the most consistent, and most reasonable estimates of flooding extents within Mohawk Canal and Mohawk Lake.

The results from the Scenario 3 hydraulic modelling (HEC-RAS) have been applied to generate updated flood extent mapping. The DEM developed as part of the Characterization Study (Aquafor Beech, October 2019) has been applied for consistency. It should be noted that uniform strip patterns at the lowland areas south of Mohawk Lake have been observed in the elevation data provided (ref. Figure 6.1; area circled in red). These strip patterns likely would have been introduced into the DEM data by interpolation and therefore may not represent the actual ground elevations. The accuracy of the generated flood lines in the lowland area south of lake are dependent on the accuracy of the DEM data, thus this should be considered when interpreting the updated generated floodlines.

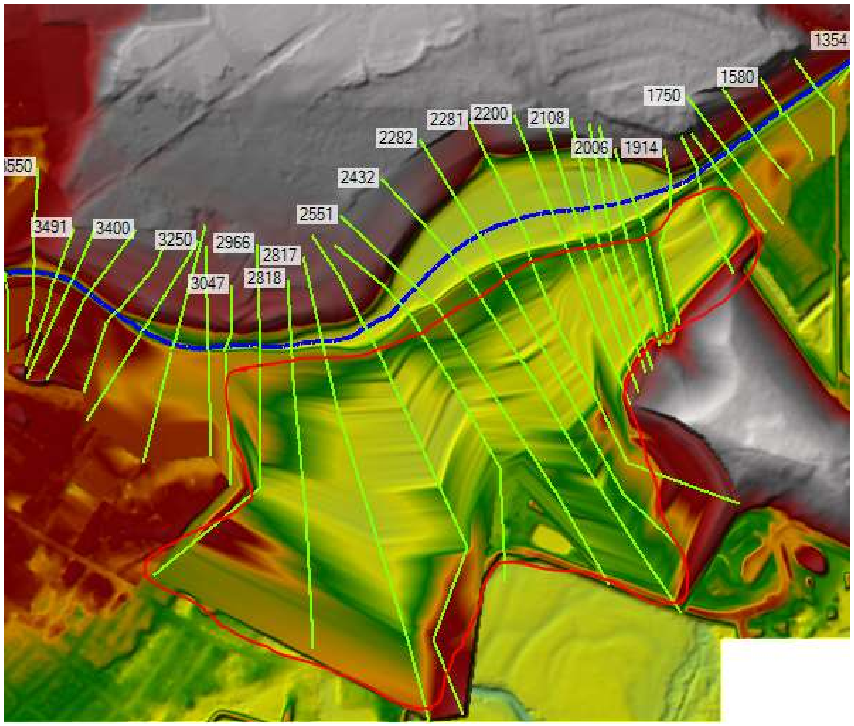


Figure 6.1: Patterns in DEM from Characterization Study (October 2019)

In addition to the preceding, based on a review of the modelling, levees have been added at three (3) locations where the channel flood level would not be sufficient to breach the top of bank elevation (XS 1645, 1750, 2605, and 3737). The updated floodplain mapping therefore reflects these changes. Results are shown graphically in Drawing 20 for the Mohawk Lake area.

Floodlines for the 2 through 10-year storm events are not included on Drawing 20, as the simulated flooding extents are restricted to the Mohawk Lake and Canal for these events. Flooding of the area to the south of Mohawk Lake is indicated beginning with the 25-year storm event. For the Regional Storm Event (Hurricane Hazel), a greater number of structures and locations are indicated as being inundated as compared to the Characterization Study (Aquafor Beech, October 2019) as previously summarized in Table 6.11. This includes four (4) additional properties fronting on Mohawk Street (both south and east of the lake), as well as the factory properties along Greenwich Street (Ingenia and Brant Screen Craft), as well as the property to the west, including the edge of the Canadian Military Museum.

Given the nature of the spill in this area, coupled 1-dimensional 2-dimensional (1D-2D) hydraulic modelling and associated floodplain mapping could be considered in the future to further confirm/validate the results of the current 1D mapping. The previously noted concerns regarding the base DEM should also be verified and addressed as part of any such effort.

It should be noted that the flood line is contained to the Mohawk Canal area upstream of Mohawk Lake, with the exception of the area upstream of Alfred Street. The results from the Scenario 3 hydraulic modelling (HEC-RAS – as per Table 6.5) have also been applied to assess the hydraulic conveyance capacity of the three (3) structures along the Mohawk

Canal – at Alfred Street, Murray Street, and Mohawk Street. Simulated results are presented in Table 6.12.

Table 6.12 Simulated Capacity of Hydraulic Structures along Mohawk Canal

Crossing Location	Surcharging Event	Overtopping Event
Alfred Street	< 2 Year	Regional Storm
Murray Street	> Regional Storm	> Regional Storm
Mohawk Street	Regional Storm	> Regional Storm

The simulated results indicate that the Murray Street and Mohawk Street crossings are adequately sized, with no overtopping indicated for any storm event, and surcharging only for the Regional Storm Event (for Mohawk Street). Conversely the Alfred Street crossing is notably undersized, with surcharging indicated for all storm events, and overtopping indicated for the Regional Storm Event. This location is therefore a priority for a structure upgrade, which could potentially be combined with channel reconstruction local to the crossing. It is suggested that the existing culvert (4.2 m span by 1.8 m rise) be replaced with a much wider open span bridge type structure, similar to that for the downstream Murray Street crossing. As per the City of Brantford's current 10-Year Capital Plan, the structure is identified as being scheduled for replacement in 2025 (City Project ID 000829).

A further consideration is tailwater/backwater impacts from the ultimate receiver, namely the Grand River. As noted, the hydraulic modelling completed for the Characterization Study does not incorporate such tailwater conditions, although the report does present a general comparison of Regulatory Floodplain Mapping from the GRCA with the results of the Characterization Study. In general, it is considered unlikely that peak water levels within the Grand River would occur simultaneously with peak levels in the Mohawk Lake system, given the large disparity in drainage areas and associated spatial distribution of rainfall. Further, the large difference in elevation at the Mohawk Lake Control Structure (static water level of 198.1 m upstream, Grand River water surface elevation of 189.0 m at the same location), backwater/tailwater is not expected to have a major impact on the generated flooding extents for the Mohawk Canal and Mohawk Lake system.

6.3 Water Quality

Stormwater quality inputs into Mohawk Lake are a key consideration as part of the overall study, including the subwatershed study. A characterization of existing contaminant concentrations is considered necessary to understand expected loadings, and to develop and assess a proposed stormwater quality management strategy for the subwatershed.

As per the Study Terms of Reference, water quality is to be assessed based on land use and estimated imperviousness, using simplified tools. Based on a Wood's review of potential analytical approaches, it is considered more supportable, and ultimately more direct to assess water quality using a simplified Event Mean Concentration (EMC) approach within the InfoSWMM modelling, based on estimated land use data (as per Drawing 9). This approach also facilitates the subsequent assessment of future land use conditions, and expected changes associated with re-development.

As noted, the Event Mean Concentration (EMC) approach has been applied, which utilizes the typical EMC values for different contaminants and different land uses defined in the Mohawk Lake Characterization Study (Table 5.39 – Aquafor Beech Limited, October 2019). The land use mapping applied for model parameterization (Drawing 9) has been consolidated into corresponding general land use classifications. Values are presented in Table 6.13 for initially modelled parameters, which include Totals Suspended Solids (TSS) and Total Phosphorous (TP).

Table 6.13 Estimated Event Mean Concentrations (EMCs) for Water Quality Parameters by Land Use

Land Use Classification	Average Modeled Imperviousness (%)	TSS (mg/L)	TP (mg/L)
Recreation and Open Space	5	72	0.25
Transportation (Railways and Roads)	75	89	0.30
Industrial	40	87	0.30
Commercial	67	77	0.25
Institutional	51	79	0.33
General/Residential	49	131	0.36

The current InfoSWMM modelling has applied these values (Table 6.13) along with corresponding land use mapping (zoning mapping) for the contributing subcatchments to determine estimated average EMCs for each subcatchment.

The modelling has then been executed in continuous simulation mode for an “average” rainfall year, consistent with the approach for the simplified continuous simulation/water budget analysis (Section 6.1.2). For the current simulation, hourly data from Environment Canada’s Royal Botanical Gardens (RBG) have been applied. Although the data are not directly from the Brantford area, the data are still considered reasonably representative of Southern Ontario meteorology and sufficient for the purposes of generating a typical “average year” estimate of contaminant loadings. Simulated water quality modelling results for primary storm sewer outfalls to Mohawk Canal and Mohawk Lake are presented in Table 6.14.

As evident from the results presented in Table 6.14, simulated water quality loadings generally correlate with contributing drainage area and imperviousness. As would be expected, water quality contaminant loadings are dominated by the three (3) primary storm sewer outfalls to the West Canal: OF-444A (38.7%), OF-194 (16.3%) and OF-222 (25.3%). Collectively, these three (3) outfalls represent 80% of the total loading to Mohawk Lake. As such, remediation of these areas is considered a high priority.

In addition to the preceding, it is noted that a Pollution Source Monitoring effort was completed as part of the Mohawk Lake Characterization Study, which through a process of iterative water quality sampling, identified several smaller catchment areas with relatively higher contaminant loading rates (Figure 5.135 from the Mohawk Lake Characterization Study, 2019). These more localized areas of higher relative contaminant loadings should also be targets for retroactive water quality treatment.

In addition to the preceding, the Characterization Study (October 2019) noted instances of observed sanitary waste in the storm sewer system in the vicinity of Rawdon Street and Bruce Street. A targeted cross-connection investigation in this area is likely warranted accordingly to identify and ultimately disconnect sources of sanitary flows to the storm sewer system. A broader City-wide effort for the elimination of cross-connections should also be considered. These measures are reviewed further in subsequent sections.

Table 6.14 Simulated Water Quality Modelling Results for Storm Sewer Outfalls to Mohawk Lake and Canal

Outfall	Area (ha)	% of Total Area	Imperv (%)	Average Annual TSS (kg)	% of Total TSS	Average Annual TP (kg)	% of Total TP
OF-444A	298.4	34.2	46.0	235,100	38.7	713	38.7
OF-444B	19.4	2.2	64.1	12,890	2.1	42	2.3
OF-44A	11.3	1.3	63.7	6,792	1.1	22	1.2
OF-44B	4.3	0.5	62.4	5,076	0.8	16	0.9
OF-67	7.2	0.8	49.0	5,150	0.9	15	0.8
South St	2.1	0.2	49.7	2,125	0.4	6	0.3
Glanville Ave	2.8	0.3	50.0	2,866	0.5	8	0.5
OF-6A	6.4	0.7	47.3	6,061	1.0	18	1.0
OF-4	0.7	0.1	50.0	235	0.1	1	0.1
OF-194	93.1 (109.1)	10.7	49.1 (48.0)	99,310	16.3	293	15.9
OF-222	191.6 (207.6)	22.0	42.5 (42.5)	153,700	25.3	474	25.7
OF-38	5.5 (21.7)	0.6	38.9 (44.5)	7,301	1.2	22	1.2
OF-14A	4.7	0.5	42.8	2,937	0.5	8	0.5
OF-6B	3.7	0.4	44.4	3,967	0.7	11	0.6
Tributary 1	57.7	6.6	43.8	29,850	4.9	88	4.8
OF-15	3.7	0.4	46.3	2,721	0.5	8	0.4
OF-14	2.1	0.2	36.6	788	0.1	2	0.1
Other Contributing Areas	157.9	18.1	46.0	31,318	5.2	93	5.0
Mohawk Lake	**872.6**	**100**	**NA**	**608,187**	**100**	**1,841**	**100**

7.0 Stormwater Management (SWM) Scenario Assessment

7.1 Alternative Assessment

7.1.1 Understanding

Based on the preceding sections, it is understood that the fundamental stormwater management concern for the Mohawk Lake subwatershed is water quality. Currently, there is no stormwater management within the subwatershed, including water quality treatment. As such, there is a legacy of accumulated sediment (with varying degrees of contamination) within Mohawk Canal and Mohawk Lake. The proposed SWM strategy developed as part of this report must therefore consider the most effective method to provide retroactive stormwater quality treatment.

Quantity control, including flood control and erosion control, are considered secondary requirements. Capacity restrictions have been identified within both the minor (storm sewer) system and major (overland flow – roadway) system, as part of the updated InfoSWMM modelling effort. Notwithstanding, given the lack of available publicly owned space, and the previously noted focus on the downstream Mohawk Canal and Lake system, it is expected that any retrofit quantity control would best be addressed through future roadway reconstruction and future infill developments, which are discussed further in Section 8.

7.1.2 Preferred Non-Structural Alternatives

A detailed review and screening of overall structural alternatives for the Mohawk Lake subwatershed, including SWM measures, is provided as part of the Environmental Assessment Report (Wood, 2020), a separate component of the Mohawk Lake and Mohawk Canal Functional Master Drainage and Restoration Study from the current Subwatershed Stormwater Plan. Reference is made to the EA report, including Table 7-4. Non-structural alternatives would include:

1. Public Education & Outreach
2. Street Sweeping
3. Salt Management Plan
4. Wildlife Management (Carp)
5. Landfill Contamination Study

All of the preceding are considered to be preferred alternatives, as per the EA (Wood, 2020), and should be considered further as part of the overall SWM strategy. Notwithstanding, Item 4 (Carp Management) is considered to be more of a direct issue with respect to the water and sediment quality within Mohawk Lake itself, rather than an issue with respect to overall stormwater management within the subwatershed and is therefore reviewed in greater detail as part of the EA, than the current study report.

7.1.3 Preferred Structural Alternatives

A detailed review and screening of overall structural alternatives for the Mohawk Lake subwatershed, including SWM measures, is provided as part of the Environmental Assessment Report (Wood, 2020), a separate component of the Mohawk Lake and

Mohawk Canal Functional Master Drainage and Restoration Study from the current Subwatershed Stormwater Plan. Reference is made to the EA report, including Table 7-3, which provides a review of structural stormwater management best management practices (BMPs), as well as Table 7-5, which provides an assessment of Alternative Design Concepts for SWM. In general, both end of pipe measures (retrofits), as well as a source and conveyance controls have been identified as preferred measures. It is considered that source and conveyance controls would be best implemented as part of future works, specifically road reconstructions and infill developments, which are discussed separately in Section 8. The focus of the current section is therefore on the remaining preferred alternatives for existing land use, end of pipe measures (retrofits).

As per Table 7-3 from the EA, the majority of the long-list of measures were considered to warrant further consideration, with only three (3) measures (upflow media filters, modular wetlands, and offline alum treatment) screened from further consideration. The remaining short-listed alternatives (sorted into common categories) include:

- Eliminate cross-connections
- LID BMPs
    - Exfiltration/infiltration
    - Reactor Walls and Beds
    - Bioretention
    - Alternative Concrete/pavement
    - Grass swales/bioswales
- End of pipe measures
    - Wetland/Stormwater treatment
    - Stormwater wet/irrigation ponds
    - Baffle box (including oil/grit separators)
    - Stormwater inlet treatment/catch basins
    - Energy dissipators

The testing and elimination of cross-connections is considered to be an extremely important SWM strategy. It is understood that the City of Brantford is undertaking steps towards this goal, including the specific areas noted in the Characterization Study (i.e. area around Rawdon Street and Bruce Street). Eliminating cross-connections remains a preferred alternative, however the benefit of this measure has not been directly assessed as part of the subsequent analyses, given the lack of information with respect to specific locations or associated environmental impact.

The remaining preferred alternatives have been broadly divided into two (2) categories: Low Impact Development Best Management Practices (LID BMPs, also typically referred to as source controls) and end of pipe measures.

Source controls (or LID BMPs) can be effective in providing water quality treatment, as well as quantity control, erosion control, and water balance benefits (particularly those where an infiltration component is incorporated). Source controls can include a variety of different approaches, including all of the previously noted measures. Source controls are however focused more on localized areas, rather than larger scale retrofit type projects, which is the focus of the current review of alternatives. It is therefore considered that source controls should be considered in greater detail as part of future construction projects, such as roadway reconstructions and infill/intensification re-developments. Source controls are therefore reviewed further in Section 8.

End of pipe measures would generally be expected to include SWM facilities (i.e. wet ponds and wetlands), as well as engineered systems (typically oil/grit separator units). Stormwater inlet treatment (such as CB Shield^{TM} inserts) is typically effective for localized areas only and would not likely be considered for stand-alone retrofit measures, but more likely as part of roadway reconstruction measures (discussed further in Section 8). As such, the generally preferred measures for existing conditions would be stormwater management facility (SWMF) outfall retrofits (i.e. wet ponds or wetlands) and oil/grit separators. These preferred alternatives are reviewed further in subsequent sections.

7.2 Review of Preferred End of Pipe Locations

7.2.1 Stormwater Management Facility (SWMF) Outfall Retrofits

7.2.1.1 Overview

Based on the overall screening of potential stormwater management alternatives presented in Section 7.1, end of pipe stormwater management facility (SWMF) outfall retrofits are considered to have the greatest potential to provide retroactive water quality treatment for drainage areas contributing to Mohawk Lake and Canal. SWMF retrofits can typically treat a much greater area than smaller measures such as oil/grit separators (as discussed in Section 7.2.2) or measures for individual roadways or sites (discussed further in Section 8).

Notwithstanding, SWMF retrofits are typically constrained by the availability of sufficient land to construct these measures. As would be expected, this is also the case for the Mohawk Lake subwatershed. Previous studies (Stormwater Management Study, Gore & Storrie, 1995) have proposed the application of in-lake treatment to overcome this constraint. In particular, the 1995 study recommended a forebay feature within the western portion of Mohawk Lake/West Canal as part of the preferred strategy. In general, although this approach would provide some treatment for the majority of the incoming flows via the West Canal, it would not provide treatment to benefit the West Canal itself. The potential ecological impacts of such an approach (specifically to the in-lake fisheries community) also require further assessment Such an approach would involve the construction of infrastructure, which would require regular maintenance, into the lower Canal and Lake system. This would be disruptive to both terrestrial and aquatic ecology features (including a potential Provincially Significant Wetland (PSW) at the eastern limits of the West Canal directly upstream of Mohawk Lake), given the need for frequent maintenance. Land ownership issues would need to be considered for works in that area (i.e. the Glebe property, which is owned by the Six Nations of the Grand River) and grading/space constraints (access via Greenwich Street may also be difficult). Notwithstanding, discussions with GRCA staff (February 19, 2020) have indicated that the GRCA has no fundamental opposition to the potential approach of online treatment within the canal, particularly focussed towards its upstream limits. Overall, any such approach would likely be best located upstream of the existing wetland feature (Glebe Lands) within the West Canal. Based on this perspective, it is recommended that this approach be short-listed for further consideration.

Notwithstanding, the primary focus of the current assessment has been upon SWMF retrofits upstream of the Mohawk Lake and Canal system. A long-list of potential SWMF outfall retrofits has been developed and is presented in Table 7.1; locations are shown in Drawing 17. Potential locations have been reviewed in greater detail for feasibility in subsequent sections.

Table 7.1 Long-List of Potential SWMF Outfall Retrofits

ID	Location	Sewershed(s)	Contributing Drainage Area (ha)
1	Shallow Creek Park (East Avenue to Mohawk Canal)	OF-444A and OF-444B	317.8
2	Shallow Creek Trail Area (Murray Street to Drummond Street)	OF-194 (Rawdon Street)	109.1[1]
3	Mohawk Park (Parking Area near Forest Road)	OF-38	21.7[2]
4	Glebe Lands (Between Glendale Drive Extension and Mohawk Canal)	OF-222	207.6[1]
5	Arrowdale Public Golf Course	OF-222	60.5

1. Assuming an even division of “Split1” area between OF-194 and OF-222
2. Assuming an even division of “Split2” and “Split3” areas between OF-38 and other sewersheds

7.2.1.2 Site 1: Shallow Creek Park

The largest sewershed within the Mohawk Lake subwatershed drains to OF-444A, with a contributing drainage area of 298.4 ha. The smaller OF-444B sewershed (19.4 ha) outlets at the same location, immediately downstream of East Avenue. The combined drainage area of 317.8 ha forms the beginning of Shallow Creek, a short 350 m section of more naturalized watercourse, upstream of the West Canal, which is downstream of the pedestrian bridge near Greenwich Street. Shallow Creek is bounded by Shallow Creek Park, which is primarily an open green space area, with a playground area further to the south along Alfred Street. The area is considered a high potential location for an end of pipe SWMF retrofit. The general area is presented in Figure 7.1.

Figure 7.1: Shallow Creek Park Potential SWMF Outfall Retrofit Area

Background issues regarding the Shallow Creek Park area have been discussed in Section 2. Some potential considerations with respect to the site:

- The area is designated as a Cultural Heritage Landscape by the City of Brantford.
- Shallow Creek has been noted as an active erosion site (#1) in the Characterization Study (October 2019 – refer to Figure 5.77 from that study), including local bank erosion, undermining of gabion baskets, and sand sediment supply from the upstream sewershed.
- There is a former landfill located adjacent/upstream of the Shallow Creek Park Site, which was infilled when the former canal turning basin in the area was decommissioned in 1950. The Characterization Study (October 2019) refers to a 36” storm sewer being installed in the bottom of the canal prior to filling; the status of this pipe is unknown.

- There is a former coal gasification plant (now Union Gas) to the north of Shallow Creek Park. An extensive study of this area was completed by Gore & Storrie (1995), which determined that coal tar wastes and PAH contamination were evident in this area and impacting groundwater, which generally flows towards Shallow Creek Park (south-westerly direction). Notwithstanding, it was noted that the groundwater elevation is generally much lower than Shallow Creek, thus there is no direct connection to baseflow or surface water. Further, it was noted that erosion in the creek could be an issue with respect to mobilizing contaminants.

Although the preceding issues must be clearly considered and accounted for as part of any retrofit design, they do not prevent the advancement of a SWMF retrofit in Shallow Creek Park. Given the larger contributing drainage area to the area, the availability of generally under-used open space (owned by the City of Brantford), and its grade elevation relative to the static water level of Mohawk Lake and Canal, this location is considered a priority for a SWMF retrofit. Based on a preliminary review, such a retrofit would be feasible; this is described in further detail in Section 7.2.1.7.

It is expected that excavation would be required to construct any such SWMF retrofit, particularly for the creation of a permanent pool. In addition to ensuring the careful removal and appropriate disposal of excavated materials, an impermeable liner would likely be required to isolate the SWMF from adjacent potentially contaminated areas. Opportunities to remediate contaminated areas and lands should however be advanced to the extent possible as part of any such SWMF retrofit. An expanded SWMF retrofit could also be considered through the acquisition and remediation of the former Union Gas site at 11 East Avenue, however this would require a further feasibility assessment.

It is assumed that the existing playground area to the south would be preserved/maintained as part of any such retrofit. Further, a revised trail access around the perimeter of any such SWMF retrofit would be required.

An additional consideration is the constrained nature of the most upstream portion of the channel, from approximately East Avenue (storm sewer outfalls) to the southerly limits of the former Union Gas property (approximately 80 m +\-). This section is constrained by the property width (approximately 22 m at its narrowest point) which includes the open channel, as well as a pedestrian trail access. This section of channel is currently lined with gabion baskets due to the width constraint, a portion of which are undermined and leaning into the channel. Given the preceding constraints, issues with sand deposition, as well as the greater potential for interaction with contaminated materials (given the proximity to the former coal gasification site), a short enclosure may be warranted in this area, which would then be directed to a SWMF retrofit. This would need to be considered further as part of preliminary and detailed design. As noted, this constraint could potentially be addressed through the acquisition and remediation of the Union Gas property at 11 East Avenue, however further review would be required, particularly with respect to site contamination.

Overall, Site 1 is considered a high priority location for a SWMF outfall retrofit and is recommended to be incorporated into the overall preferred solution.

7.2.1.3 Site 2: Shallow Creek Trail (Murray Street to Rawdon Street)

Two (2) of the larger storm sewer outfalls in the Mohawk Lake subwatershed are near one another; OF-194 (Rawdon Street – 1125 mm diameter storm sewer, 107.3 ha +\-), and OF-222 (Stanley Street/Rawdon Street – 1800 mm diameter storm sewer, 207.5 ha +\-). Limited City-held land is available for any potential SWMF retrofit in this area. A retrofit SWM facility (wet pond) could be considered for OF-2222 on the adjacent lands to the east (accessible by the Glendale Road extension), however the potential retrofit property (Glebe Farm) is owned by the Six Nations of the Grand River. This alternative is reviewed in greater in detail in Section 7.2.1.5 (Site 4). Site 2 (Shallow Creek Trail – Murray Street to Rawdon Street) has been advanced as a potential SWMF outfall retrofit for OF-194. A preliminary layout and area of the retrofit is presented in Figure 7.2.

Figure 7.2: Shallow Creek Trail (Rawdon Street) Potential SWMF Outfall Retrofit Area

As per Figure 7.2, the proposed retrofit strategy would involve the construction of a new storm sewer splitter maintenance hole along the existing 1125 mm diameter storm sewer, likely along the existing trail/pathway. A new (200 m +\- long) storm sewer would be constructed to direct low flows westerly towards the new SWMF retrofit. The new storm sewer would be constructed primarily underneath the existing trail, to minimize the amount of disturbance. While the entire property appears to be owned by the City of Brantford, it is noted that an industrial building is evident at the base of Drummond Street (ref. Figure 7.2); based on a review of aerial photography, this building was demolished in 2018 +/-. Based on the Characterization Study (October 2019), this location was the site of Robertson Restoration (Site 3 in that report) which was formerly used as a dry cleaning and dye operation. The Characterization Study notes that this site is “not expected to have a significant impact on Mohawk Lake or Mohawk Canal”. Assuming no significant issues with respect to contamination, the potential facility limits presented in Figure 7.2 could potentially be further extended to include the former building area, or alternatively this area could be used for other recreational purposes (playground or otherwise).

It should also be noted that the western portion of the site has previously been used for industrial purposes; the buildings on this portion of the site were removed sometime between 2006 and 2012 based on historical aerial photography. Based on a site visit completed by Wood (October 30, 2019), an abandoned tank/cistern is evident on the site. The Characterization Study (October 2019) notes that this location was the former P.U.C. building (Site 7 in that report) which was noted as having the potential to impact the West Canal. The report notes that any impacts are however expected to be minimal.

Most of the proposed retrofit site is noted as disturbed and therefore not requiring a Stage 2 Archaeological assessment; however, this may be required for areas along the trail. The edge of the trail is also noted as being part of the City's cultural heritage landscape. Works would need to either maintain or likely improve pedestrian access along the trail; it is assumed that the trail would serve as an approximate limit for the area of the potential retrofit, other than the need for a new outlet to Mohawk Canal in proximity to Murray Street, as per Figure 7.2. The existing storm sewer along Murray Street could also potentially be re-directed to the new SWMF, thus a new outfall would generally replace the existing outfall.

Based on a preliminary review, a retrofit at Site 2 is technically feasible; estimated treatment capacity is reviewed further in Section 7.2.1.7. Although feasible, it is noted that the grades along the north side of the potential SWMF retrofit are already generally at a 3H:1V slope. In order to ensure sufficient bottom width for a wet pond SWMF, it is expected that a retaining wall or other type of system would be required to steepen the north slope. This would need to be assessed further as part of subsequent preliminary and detailed design.

Overall, Site 2 is considered a high priority location for a SWMF outfall retrofit and is recommended to be incorporated into the overall preferred solution.

7.2.1.4 Site 3: Mohawk Park

A wet pond stormwater management facility retrofit within the eastern limits of Mohawk Park (along Forest Road) has been identified as part of previous studies, including the 1995 Stormwater Management Study (Gore & Storrie), which proposed a series of cascade pools along the slope of Mohawk Lake (refer to Figure C-7 from that study).

The site is considered ideal given public ownership, and the relatively smaller contributing drainage area, which is more amenable to an end of pipe SWM facility (OF-38; 450 mm diameter storm sewer, 5.5 ha plus an additional split drainage area of 16.2 ha, for a potential total of 21.7 ha +\-). A preliminary area of interest (1.0 ha +\-) is presented in Figure 7.3.

Figure 7.3: Mohawk Park Potential SWMF Outfall Retrofit Area

Based on a preliminary review, a retrofit SWMF in this location is considered feasible. The proposed SWMF retrofit would involve breaking into the existing storm sewer system between Forest Road and Mohawk Park, and re-directing it into a SWMF retrofit. It is considered preferable to re-direct the storm sewer within the park to avoid re-constructing Forest Road, particularly given that it appears to have been recently reconstructed (2017 +\-). An additional consideration is the large storm sewer drop structure within the park (11 m +\- deep). Available record drawings and the City's GIS data differ on the exact location of the drop; depending on the actual location, it may be necessary to undertake some further works within the roadway, in order to ensure the storm sewer is sufficiently shallow to re-direct into a surficial SWMF. Discharge from the pond would then be re-directed back into the storm sewer system to avoid construction along the north slope of Mohawk Lake to the extent possible.

There also appears to be a minor surface drainage swale within the park, along the edge of the parking lot; it is assumed that this feature will be re-directed into the pond as well. Based on discussions with City staff (October 23, 2019), it has been noted that there have been previous issues with erosion in this area which previously necessitated repairs; further details are required. It is assumed that the overflow from the SWMF would be directed towards the overland outlet from the swale on the far side of the pathway, however an assessment of this drainage feature will be required to determine if any additional works along the slope would be required.

Although feasible, a SWMF retrofit in Mohawk Park would need to consider many of the constraints noted in Section 2, in addition to the technical issues noted previously. These include:

- The area is designated as a cultural heritage landscape. A Stage 2 archaeological assessment is also recommended for undisturbed portions of the park (i.e. outside of the parking lot and trail).
- There is an abandoned landfill at the western limits of the proposed extents of work (referred to as Landfill F in the Characterization Study Report (October 2019)). Based on the preceding, the landfill was small (0.3 ha) and was used for tree and leaf removal, as well as street sweeping remnants. The report indicated that the materials disposed of at the site would not be expected to pose a significant source of contaminants, however further assessment is likely warranted.
- Adjacent forest area is indicated as confirmed significant wildland habitat (as per Drawing 6).

In addition, the works would need to consider the existing recreational uses of the park. This would include the existing gravel parking lot, the existing disc golf course (specifically hole 14, which runs parallel to the parking lot), and the existing trail/pathway.

Although a retrofit SWMF is considered feasible in this location, it is considered that sub-surface measures, specifically an oil/grit separator (potentially in combination with sub-surface storage and filtration chambers) may be preferred. Overall, the direct contributing drainage area to the outfall is only 5.5 ha (although flows are increased due to upstream split drainage areas, as per Drawing 11), which is the typical minimum size for a wet pond retrofit. The pipe size is similarly small (375 mm at the point of potential diversion). Sub-surface measures are considered preferable with respect to the required limits of work (i.e. avoid impacts to the adjacent forested area which may reduce ecological screening requirements and preserve the existing parking area (or some re-graded version). Given the deep storm sewer in this location, sub-surface techniques would also not be constrained/limited.

Based on the preceding, a SWMF outfall retrofit at Site 3 (traditional wet pond) has not been advanced further. End of pipe measures such as an OGS unit are reviewed in further detail as part of Section 7.2.2.

7.2.1.5 Site 4: Glebe Lands

The proposed retrofit for Site 2 (Shallow Creek Trail – Rawdon Street) would provide treatment for OF-194. Directly east of this outfall is OF-222, which is the second largest storm sewer outfall for the Mohawk Lake subwatershed (after OF-444A), with a contributing drainage area of 191.6 ha (not including a component of the “Split1” area, as per Drawing 11). A SWMF retrofit in this location would therefore provide a high level of overall water quality benefit to the Mohawk Lake subwatershed.

Providing a retrofit SWMF for this location is however primarily limited by a lack of publicly available land. OF-222 (1800 mm diameter storm sewer) is the outlet for the Stanley Street trunk storm sewer, which traverses the Sonoco property, the Glendale Avenue extension (22 m +\- wide), and a portion of the Glebe Lands, prior to discharging to the West Canal. Any potential SWMF retrofit would likely need to be located on the Glebe Lands, which would necessitate an agreement and likely land purchase from the Six Nations of the Grand. Further discussions would be necessary to determine the viability of this alternative. Given that no discussions have yet occurred, the potential feasibility of this alternative cannot currently be determined. As such, this site cannot be reasonably short listed or advanced for further consideration.

In addition to the primary land ownership issue, further assessments with respect to archaeology may be required. In addition, further natural heritage (ecology) assessment would also be expected to be required, as the area is located within a confirmed significant wildland habitat, and the shoreline area is considered part of a recommended Provincially Significant Wetland (PSW). Other technical studies would also likely be required, which are beyond the scope of the current study.

With respect to general feasibility, a conceptual layout has been presented in Figure 7.4. The general concept would involve the creation of a diversion storm sewer into a new SWMF, with a new outlet to be constructed to the West Canal. The existing 1800 mm diameter storm sewer has an invert elevation of approximately 197.16 m at the Glendale Avenue extension, which would be approximately 0.94 m lower than the operating level of Mohawk Lake (198.1 m). Similar to the proposed SWMF retrofit for Site 2 (Rawdon Street), it would be assumed that a partially submerged pipe would result, with a permanent pool elevation to be set slightly above the typical Mohawk Lake elevation of 198.1 m, to ensure adequate drainage. Existing grades along the subject area vary notably, from approximately 200 m to 211 m. Assuming a permanent pool elevation of 198.2 m +\-, this would necessitate a substantial cut, and associated earth excavation, which although technically feasible, would require a considerable construction effort and associated cost.

Although a SWMF outfall retrofit of OF-222 (Glebe Lands) would be highly effective to improve water quality to the Mohawk Lake and Canal area, given the large contributing drainage area, it cannot be reasonably advanced as a preferred solution at the current time. Discussions with the land owners (Six Nations of the Grand River) should be undertaken however to determine whether or not such a retrofit could be considered in the future. Depending on the outcomes of those discussions, further technical assessments and a preliminary design could be undertaken to determine the further feasibility of the retrofit, including an estimate of the actual lands required and the associated impacts.

Figure 7.4: Potential Glebe Lands SWMF Outfall Retrofit Area

7.2.1.6 Site 5: Arrowdale Golf Course

The preceding potential SWMF retrofit sites are all located at the downstream limits of the subwatershed along Mohawk Canal (including Shallow Creek). Opportunities to implement SWMF retrofits within upstream portions of the subwatershed have also been reviewed. However, given the urbanized and developed nature of the contributing subwatershed, potential areas are largely limited. A review of public lands (park areas) has been undertaken as part of this study. While potential land exists within Burnley Park (OF-444A sewershed) and the park area at Wellington Street and Puleston Street (OF-222 sewershed), these areas feature relatively minor upstream contributing drainage areas, and thus minimal treatment potential/capacity. A potential retrofit area has however been identified within the upper portion of the OF-222 sewershed within the Arrowdale Public Golf Course property, which is owned by the City of Brantford. The potential area of interest is presented in Figure 7.5.

Figure 7.5: Potential Arrowdale SWMF Outfall Retrofit Area

A trunk 900 mm diameter storm sewer is conveyed through both the adjacent Grand Erie Learning Alternatives property as well as the Arrowdale Golf Course. An estimated 60.5 ha of upstream drainage is served by the storm sewer, including surrounding industrial and commercial lands. Given the preceding, and the public ownership of the site, a SWMF retrofit in this location would be ideal. The retrofit could also be further expanded if property from the Grande Erie Learning Alternatives could be obtained, which is currently used for an athletic field.

An open SWMF retrofit in this location would be constrained by existing grading. The topography in the area of the Arrowdale Golf course is hilly, from an elevation of approximately 213 m at the eastern limits shown to approximately 209.5 m at the southern limits. In addition, the elevation of the storm sewer would need to be considered, which is approximately 4 m deep at the eastern limits of Campbell Street (invert elevation of approximately 205.5 m). While the storm sewer could potentially be diverted further upstream (at an elevation of approximately 206.3 m), the deeper grading required would limit the potentially available water quality volume.

A SWMF retrofit at Site 5 would therefore require further review and assessment. In addition, Brantford's City Council voted in December 2019 to sell the property, with re-development expected. There may remain some potential to incorporate retrofit water quality for external areas along with the required stormwater management measures for any new development, however this may not be feasible, pending the scope of any future re-development plans. It is considered that a more direct and simpler treatment approach would be to incorporate an oil/grit separator or equivalent treatment measure along the westerly branch of the trunk storm sewer at the upstream limits of the Arrowdale Golf Course (assuming the storm sewer would remain in this location); this location is also indicated on Figure 7.5 (vicinity of the storage building at the intersection of Rawdon Street and Freeborn Avenue). A similar treatment measure could be applied for the easterly branch. Oil/grit separator retrofits are reviewed in further detail in Section 7.2.2. Based on the preceding, Site 5 is not considered a preferred SWMF retrofit, however it should be considered as part of future study (or as part of any future re-development plans for the property).

7.2.1.7 Summary

Based on the preceding review, Site 1 (Shallow Creek Park) and Site 2 (Shallow Creek Trail – Rawdon Street) are considered to be the currently preferred SWMF outfall retrofits.

Site 3 (Mohawk Park) is still considered feasible, however it is suggested that an oil/grit separator and sub-surface measures are likely preferable to a wet pond SWMF; this location is assessed further in Section 7.2.2.

Site 4 (Glebe Lands) cannot be reasonably short-listed, as the site is not owned by the City of Brantford. Should discussions with the property owners (Six Nations of the Grand River) indicate a general agreement to advance the concept, it is suggested that the City of Brantford advance the design analyses for the site, given the potential water quality benefit to the Mohawk Lake subwatershed.

Site 5 (Arrowdale Golf Course) could potentially be considered for a SWMF (wet pond) retrofit, however further review and analysis is required, given considerations with respect to grading and the pending sale of the property. Similar to Site 3, it is suggested that an oil/grit separator and sub-surface measures are likely preferable in the interim; consideration of these measures is provided in Section 7.2.2.

As noted, a general feasibility review has been undertaken for all of the potential SWMF retrofits. Preliminary grading and potential water quality benefit has been quantified accordingly for the preferred locations (Sites 1 and 2). A summary is presented in Table 7.2.

Table 7.2 Preliminary Water Quality Performance of Preferred SWMF Outfall Retrofits

ID	Location	Sewershed(s)	Contributing Drainage Area (ha)	Preliminary Potential Permanent Pool Volume (m^3)	Approximate TSS Removal[2] (%)
1	Shallow Creek Park (East Avenue to Mohawk Canal)	OF-444A and OF-444B	317.8	6,737 m^3 (1.5 m depth)	50
2	Shallow Creek Trail Area (Murray Street to Drummond Street)	OF-194 (Rawdon Street)	109.1[1]	1,614 m^3 (1 m depth)	45

1. Assuming an even division of “Split1” area between OF-194 and OF-222
2. Based on Table 3.2 from Ministry of the Environment’s Stormwater Planning and Design Manual (2003) for 55% imperviousness

As retrofit SWMFs, it is not considered feasible to achieve “greenfield” standards for water quality treatment. In addition, the contributing drainage areas to the proposed SWMFs are much larger than those for typical wet pond SWMFs (i.e. 5 ha to 40 ha). The approximate TSS removal rates presented in Table 7.2 have been estimated based on an extrapolation of the Ministry of the Environment’s Stormwater Planning and Design Manual (2003) recommended permanent pool volumes for wet ponds (60, 70 and 80% treatment levels) based on the 55% imperviousness category using an exponential function. The results indicate that the proposed SWMFs would be estimated to achieve between 45 and 50% average annual TSS removal rates. Given the large contributing drainage areas, both proposed SWMF outfall retrofits would provide a notable water quality benefit. This is discussed and quantified further in Section 7.3.3.

7.2.2 Oil Grit Separators (OGS Units)

7.2.2.1 Long List of Locations

As noted in Section 7.2.1, although end of pipe SWMF outfall retrofits are generally preferred, given their lower cost and overall treatment capacity, there are a limited number of locations within the developed Mohawk Lake subwatershed where such features can be incorporated. As such, secondary measures within the upstream sewersheds are considered necessary to provide an additional level of water quality treatment. Oil/grit separator units (OGS units) are considered to be the preferred approach.

OGS units are pre-cast concrete chambers that are typically located online with existing storm sewers (although for larger areas, bypass/diversion structure are required to re-direct low flows to an OGS unit and ensure that higher flows continue to be conveyed by the storm sewer system). OGS units remove a portion of the suspended solids (and associated contaminants) within the storm water inflows through hydrodynamic or gravity settling action, depending on the manufacturer. Captured sediments are then stored within the unit for future removal, typically by a hydrovac truck. Given the size of the units, clean outs are typically required every 1-2 years but can be completed relatively quickly and affordably. OGS units can also be designed to capture floatable materials (i.e. oil/hydrocarbons and debris).

A long list of potential OGS retrofits has been developed for consideration. The long list has been developed independently of future planned roadway reconstructions (refer to Section 8.1.2), with the expectation that proposed OGS retrofits will form a separate, secondary method to regain water quality control/treatment within the Mohawk Lake subwatershed. The long-list of potential OGS locations has therefore generally been developed based on the following initial considerations:

- Is the contributing drainage area (and outfall) proximal to Mohawk Lake and Canal?
- Was the area identified as having poorer water quality in the Characterization Study (2019)?
- Is the drainage area higher in imperviousness or have a land use with an expected higher contaminant concentration (commercial/industrial)?
- Is the OGS located within a sewershed where no end of pipe SWMF (as per Drawing 17) is proposed?
- Is the OGS located in an area where no roadway reconstruction (10-year Capital Plan – refer to Section 8.1) is planned?
- Is the drainage area a reasonable size for treatment by an OGS unit (generally between 2 and 10 ha)?

The resulting long-list of potential OGS retrofits is presented in Table 7.3, along with notes regarding potential considerations for the proposed location. Locations are presented graphically in Drawing 18.

Table 7.3 Long-List of Potential OGS Retrofits

ID	Sewershed(s)	Contributing Drainage Area (ha)	Note
1	OF-44A	11.3	Fully submerged storm sewer. Access via private property. Could be placed along Newport Street instead.
2	OF-44B	4.3	Partially submerged storm sewer. Need to assess potential utility conflicts along Greenwich Street.
3	OF-67	7.2	Could be located on Alfred Street or in Park area (park area work may require Stage 2 Archaeology). Potentially undersized pipe (300 mm diameter) may require upgrade in combination.

Table 7.3 Long-List of Potential OGS Retrofits			
ID	Sewershed(s)	Contributing Drainage Area (ha)	Note
4	South Street	2.1	Could be located on Alfred Street or in Park area (park area may require Stage 2 Archaeology). Limited contributing drainage area.
5	Glanville	2.8	Could be located on Glanville Ave or Riddolls Ave (unpaved road/trail). Small contributing drainage area.
6	OF-4	0.7	Need to consider potential utility conflicts on Murray Street. Small contributing drainage area. Would need to consider future Murray Street Bridge Repairs. Could potentially be re-directed into future SWMF retrofit (ID #2) instead.
7	OF-6A	6.4	Could be located on Cayuga Street or Greenwich Street. Potentially undersized pipe (300 mm diameter) may require upgrade in combination.
8	OF-38	5.5[1]	Substantial additional drainage area from upstream “split” areas. Could be considered instead of potential SWM retrofit (ID #3), could be implemented in park or roadway. Potentially undersized pipe (375 mm diameter) may require upgrade in combination, also consideration of drop MH in park. Could potentially require Stage 2 Archaeology. Need to consider former landfill use in the area.
9	OF-14A	4.7	Could be located in Forest Road ROW, potentially outside of travelled roadway if sufficient space (to the south). Direct outfall to Mohawk Lake.
10	OF-6B	3.7	Could be located in Forest Road ROW. Smaller contributing drainage area. Potentially undersized pipe (300 mm diameter0 may require upgrade in combination.
11	OF-15	3.7	Could be located in Beach Road ROW. Smaller contributing drainage area.
12	OF-14	2.1	Could be located along trailway or on Beach Road. Smaller contributing drainage area. Potential need for Stage 2 Archaeology.
13	OF-222	16.8	Larger contributing drainage area may require bypass structure. Likely preferable to locate on

Table 7.3 Long-List of Potential OGS Retrofits			
ID	**Sewershed(s)**	**Contributing Drainage Area (ha)**	**Note**
			Arrowdale Golf Course property outside of Rawdon Street ROW. Located in area of identified poor water quality by Characterization Study. Would be located upstream of potential SWMF retrofit i(ID#5) thus would need to consider overlap.
14	OF-222	13.5	Larger contributing drainage area. Located in area of identified fair water quality by Characterization Study. Would need to consider potential utility conflicts along Bruce Street.
15	OF-222	10.0	Located in area of identified poor water quality by Characterization Study. Construction would be difficult given arterial nature of Henry Street and storm sewer location at primary driveway access to private residential area.
16	OF-444A	12.0	Would be located along Bruce Street ROW; need to consider utility conflicts. Easier construction on dead-end street. Larger contributing drainage area with industrial land use. Located in area of identified poor water quality by Characterization Study.
17	OF-222	9.5	Could be located within Colborne Street ROW but off travelled lanes of roadway (grassed area). Would need to consider potential utility conflicts. Potentially undersized storm sewer (375 mm diameter). Located in area of identified poor water quality by Characterization Study, large commercial and high impervious area.
18	OF-222	13.9	Larger contributing drainage area. Would be located along Mary Street ROW; would need to consider utility conflicts. Located in area of identified fair water quality by Characterization Study, primarily industrial land use.
19	OF-444A	14.6	Larger contributing drainage area. Would be located along Grey Street ROW (arterial road); would need to consider utility conflicts. Located in a mixed industrial/commercial/residential area including Brantford VIA rail station.
20	OF-444B	7.7	Located along Market Street ROW; would need to consider utility conflicts. Primarily

Table 7.3 Long-List of Potential OGS Retrofits			
ID	Sewershed(s)	Contributing Drainage Area (ha)	Note
			commercial and residential land use. Could place further downstream but increased pipe size and drainage area (12.0 ha if placed on south side of Darling Street).
21	OF-444A	2.8	Smaller contributing drainage area, but largely commercial area. Would be located along Charlotte Street ROW; would need to consider utility conflicts. Potentially undersized storm sewer (300 mm diameter).
22	OF-194	7.5	Located along Arthur Street ROW; would need to consider utility conflicts. Primarily residential land use. Good drainage area size.
23	OF-194	9.0	Located along Mary Street ROW; would need to consider utility conflicts. Good drainage area size.
24	OF-444A	10.6	Located along Grand St ROW; would need to consider utility conflicts. Good drainage area size, mix of commercial and residential land use.

1. Does not include a portion of “Split2” area (16.6 ha) and “Split3” area (15.7 ha).

7.2.2.2 Screening of Preferred Locations

The long list of potential OGS retrofit sites, presented in Table 7.3, has been further assessed and screened to determined preferred (short-listed) locations. Locations have been screened using some of the general drainage area characterization and benefit criteria noted in the previous section, as well as further criteria with respect to construction feasibility and other related issues. Considered criteria for the identification of preferred (short-listed) locations and associated ranking area as follows:

- Drainage Area Characterization and Overall Benefit
    - Is the drainage area a reasonable size for treatment by an OGS unit, and also providing a greater degree of treatment (i.e. preferably > 5 ha)?
    - Was the area identified as having poorer water quality in the Characterization Study (2019)?
    - Is the drainage area higher in imperviousness or with a land use with an expected higher contaminant concentration (commercial/industrial)?
    - Is the contributing drainage area (and outfall) proximal to Mohawk Lake and Canal?
    - Is the OGS located within a sewershed where no end of pipe SWMF is proposed?

- Construction Feasibility
  - How large is the storm sewer? Is it likely to require upgrading for conveyance capacity?
  - Is the storm sewer partially or fully submerged?
  - Where would the OGS be located? Would significant utility conflicts be expected? Would construction have a major impact on traffic?
  - What follow up/supporting studies may be required to support construction (Stage 2 Archaeology, geotechnical, etcetera)

The preceding criteria have been applied to identify higher priority locations for OGS retrofits, and also to rank the relative priority of the preferred (short-listed) OGS retrofits. The results of this prioritization are presented in Table 7.4.

Table 7.4 Short-List of Higher Priority Potential OGS Retrofits

Rank	ID	Sewershed(s)	Pipe Size (mm)	Contributing Drainage Area (ha)	Modelled Imperviousness (%)
1	13	OF-222	900	16.8	43.0
2	16	OF-444A	600	12.0	38.2
3	17	OF-222	375	9.5	49.5
4	2	OF-44B	750	4.3	62.4
5	1	OF-44A	1050	11.3	63.7
6	20	OF-444B	900	7.7	68.3
7	18	OF-222	600	13.9	43.5
8	14	OF-222	525	13.5	47.0
9	8	OF-38	375	5.5 (21.7)[1]	38.9
10	3	OF-67	300	7.2	49.0
11	7	OF-6A	300	6.4	47.3
12	9	OF-14A	375	4.7	42.8

1. Direct drainage area and drainage area assuming even split of upstream areas “Split2” and “Split3”.

As evident from Table 7.4, the long-list of 24 potential OGS retrofit sites has been short-listed to 12 preferred locations and ranked according to the overall benefit/priority. The highest priority locations are those within areas identified as having poor water quality from the Characterization Study (October 2019), as it is considered that this actual monitoring data provide the best indication of priority locations for water quality treatment. Locations which outlet directly to, or in close proximity to Mohawk Canal and Mohawk Lake (particularly those which contribute to the upstream limits of Mohawk Canal and thus may have the greatest overall negative impact) are also considered high priority locations for retrofit. Locations with the OF-222 sewershed are also considered to be higher priority, since an end of pipe SWMF outfall is not currently proposed for this location (refer to discussion in Section 7.2.1 – Site 4 (Glebe Lands)). As noted, the proposed high priority locations are all in locations not identified as part of the City of Brantford’s 10-year capital road reconstruction plans (refer to Section 8.1), thus these measures would be undertaken as separate capital works. This is discussed in greater detail as part of the implementation plan in Section 10.

7.3 Analysis of Preferred Alternatives

7.3.1 Hydrology

The preferred alternatives, outlined in Section 7.2, are primarily focused around water quality improvements, given that this is understood to be the primary issue of concern within the Mohawk Lake and Canal system. The proposed oil/grit separator (OGS) units would provide quality control only and would not provide any quantity control restriction. The proposed end of pipe wet pond SWMFs could however be designed to incorporate some degree of quantity control function. Full "post to pre" peak flow control is not considered feasible given the available land area and contributing drainage area; further, such an approach is not likely warranted given the downstream location of Mohawk Canal and Mohawk Lake and the inherent attenuative function already provided by the Mohawk Lake control structure. Quantity control for erosion control purposes, specifically the incorporation of extended detention storage, may however be feasible and beneficial. Extended detention requirements have been estimated and summarized in Table 7.5. The preceding does not however consider any potential extended detention storage online within the West Canal, as discussed previously in Section 7.2.1.1. This should be considered as part of future study.

Table 7.5 Estimated Extended Detention Storage Requirements

ID	Location	Sewershed(s)	Drainage Area (ha)	Preliminary Potential Permanent Pool Volume (m^3)	Typical ED Storage[2] (m^3)	ED Storage to Achieve 24-Hour Drawdown[3] (m^3)
1	Shallow Creek Park (East Avenue to Mohawk Canal)	OF-444A and OF-444B	317.8	6,737 m^3 (1.5 m depth)	12,712 m^3	4,758 m^3 (0.43 m^3/s)
2	Shallow Creek Trail Area (Murray Street to Drummond Street)	OF-194 (Rawdon Street)	109.1[1]	1,614 m^3 (1 m depth)	4,364 m^3	2,303 m^3 (0.22 m^3/s)
NA	**TOTAL**	**NA**	**426.9**	**8,351**	**17,076**	**7,061**

1. Assuming an even division of "Split1" area between OF-194 and OF-222
2. Based on 40 m3/ha as per 2003 SWM Planning and Design Manual
3. Based on minimum flow of 0.01 m^3/s for Site 1 and 0.001 m^3/s for Site 2 (based on magnitude of contributing drainage area) to avoid including excessively small recession period flows

The results indicate a notable difference in the extended detention requirement between the typical 40 m^3/ha and the modelling generated value required to achieve a 24-hour drawdown time. As noted in Table 7.5, a minimum flow rate has been used for the estimation of the 24-hour extended detention time, to avoid including excessively small flows. Should a different minimum flow criterion be applied, required storage volumes and associated discharges would vary accordingly. The results presented in Table 7.5 are however considered a reasonable estimate of erosion control volume requirements.

It should be noted that specific critical erosion flows for individual reaches was not completed as part of the Characterization Study (October 2019). Further study could be completed to determine whether or not the general 24-hour drawdown is sufficient, or whether a reduced (or increased) criteria should be considered with respect to erosion mitigation measures.

7.3.2 Hydraulics

Given that the primary preferred alternatives involve only minor potential quantity controls (erosion control where feasible, as outlined in the previous section), no supplementary analyses of urban systems (i.e. storm sewers and overland flow routes) or open channel systems (i.e. Mohawk Canal and Lake) is considered necessary. Further consideration may be warranted as part of future land use conditions (ref. Section 8).

7.3.3 Water Quality

The potential water quality benefit of the preferred alternatives has been assessed further, based on the estimated average annual TSS removal rate for each measure. The approximate potential permanent pool volume, and associated TSS removal rate (treatment percentage) were presented previously in Table 7.2. These results have been combined with the results of the water quality simulation in the InfoSWMM modelling, to determine the associated potential average annual TSS removal. Results are presented in Table 7.6. Potential water quality treatment from any online feature within the West Canal (as discussed previously in Section 7.2.1.1) has not been assessed as part of the current evaluation. This should be considered as part of future study.

Table 7.6 Potential TSS Removal from Preferred SWMF Outfall Retrofits						
ID	Location	Sewershed(s)	Contributing Drainage Area (ha)	Approximate TSS Removal[2] (%)	Simulated Average Annual TSS (kg)	Potential Average Annual TSS Removal (kg)
1	Shallow Creek Park (East Avenue to Mohawk Canal)	OF-444A and OF-444B	317.8	50	247,990	120,912[3]
2	Shallow Creek Trail Area (Murray Street to Drummond Street)	OF-194 (Rawdon Street)	109.1[1]	45	99,310	44,690
NA	**TOTAL**	**NA**	**426.9**	**NA**	**347,300**	**165,602**

1. Assuming an even division of "Split1" area between OF-194 and OF-222
2. Based on Table 3.2 from Ministry of the Environment's Stormwater Planning and Design Manual (2003) for 55% imperviousness
3. Not including TSS removed by proposed OGS units (as per Table 7.6)

The results presented in Table 7.6 indicate that SWMF 1 (Shallow Creek Park) would have the largest TSS removal, with an estimated annual removal of 120,912 kg, as compared to 44,690 kg for SWMF 2 (Rawdon Street). The total estimated average annual TSS removal of 165,602 kg would represent 27% of the total average annual estimated TSS loading of 608,187 kg to Mohawk Lake, as per Table 6.8. This would represent a substantial level of treatment for the currently untreated Mohawk Lake subwatershed.

The estimated water quality benefit of the proposed short-listed OGS retrofits has been assessed in a similar manner. While specific sizing has not been completed for the short-listed OGS locations, it has been generally assumed that a 50% treatment rate (average annual TSS removal) should be achievable. The resulting simulated TSS loading for the short-listed locations (from the InfoSWMM modelling), and associated estimated average annual TSS removal masses, are presented in Table 7.7.

The simulated results indicate the largest individual removal of 8,930 kg for OGS ID 14; the average annual removal mass is 3,573 kg. If all twelve (12) short-listed OGS retrofits were to be constructed, the total estimated TSS removal mass would be 42,877 kg. The results in Table 7.7 are notably less than those for the SWMF retrofits presented in Table 7.6; the total for twelve (12) OGS retrofits is still less than the single

Site 2 SWMF retrofit. The Site 1 retrofit (Shallow Creek Park) would provide a far greater estimated average annual TSS removal, approximately equal to 30 OGS units. The simulated results suggest that while OGS retrofits are certainly beneficial, particularly in targeting priority areas with identified poor water quality, the priority for implementation should likely remain with the end of pipe SWM facilities identified herein.

Table 7.7 Potential TSS Removal from Short-Listed OGS Retrofits

Sewershed(s)	OGS ID	Contributing Drainage Area (ha)	Simulated Average Annual TSS (kg)	Potential Average Annual TSS Removal (kg)[1]
OF-444A	16	12.0	7,952	3,976
OF-444B	20	7.7	4,381	2,191
OF-222	13	16.8	10,150	5,075
OF-44A	1	11.3	6,294	3,147
OF-44B	2	4.3	5,076	2,538
OF-67	3	7.2	2,550	1,275
OF-6A	7	6.4	6,061	3,031
OF-222	14	13.5	17,860	8,930
OF-222	17	9.5	3,881	1,941
OF-222	18	13.9	11,310	5,655
OF-38	8	5.5 (21.7)[2]	7,301	3,651
OF-14A	9	4.7	2,937	1,469
TOTAL	**NA**	**112.8 (129.0)[2]**	**85,753**	**42,877**

1. Based on assumed 50% treatment/removal capacity for OGS units.
2. Direct drainage area and drainage area assuming even split of upstream areas “Split2” and “Split3”.

8.0 Future Conditions Assessment

8.1 Future Condition Changes

8.1.1 Understanding

The preceding stormwater management (SWM) plan (Section 7) has focused on the implementation of measures under existing land use conditions. The proposed measures, primarily SWM facility outfall retrofits (wet ponds) and oil/grit separator (OGS) unit retrofits, have been identified in key locations across the subwatershed. These measures constitute proposed capital works, independent of other planned construction works or future changes in land use within the subwatershed.

This section documents the assessment of opportunities to further improve SWM within the subwatershed through expected future development. These changes have been broadly grouped into two (2) primary categories: roadway reconstructions (City-led) and infill/intensification development (privately-led). These changes, and the associated proposed SWM measures, are discussed further in subsequent sections.

8.1.2 Roadway Reconstructions

Roadway reconstructions are a common capital expenditure and construction project for municipalities, including the City of Brantford. These projects provide a core opportunity to retro-actively provide stormwater management (SWM) for the Mohawk Lake subwatershed and realize the benefits from treated runoff to the lake system. SWM measures may be provided for the subject direct roadway corridors, or potentially also for external areas draining through the reconstruction area in the case of trunk storm sewers.

Wood has reviewed the City of Brantford's 2019 Operating and Capital Budget, (available on the City's website). Appendix G of that document includes the 2019 City-Wide 10 Year Capital Budget Forecast (2019-2028). Roadway reconstruction projects are listed under both "Other/New/Studies" and "State of Good Repair". In some instances, the proposed budgets for the roadway reconstructions are notably lower, suggesting either a scoped reconstruction or potentially a design effort only (not construction). Notwithstanding, for the purposes of the current assessment, it has been assumed that all of the roadway reconstruction projects listed in the 10 Year Capital Plan would (or could) potentially be constructed in that time frame.

Identified roadway reconstruction projects within the Mohawk Lake subwatershed are presented in Drawing 19. A summary of projects by sewershed outfall is presented in Table 8.1.

As evident from Table 8.1, the majority of the planned roadway reconstruction works are generally correlated with the primary storm sewersheds. This includes the drainage sheds draining to OF-444A, OF-194, and OF-222, which collectively represent 13,455 m of roadway reconstruction, or 87% of the total planned works within the Mohawk Lake subwatershed. Planned roadway reconstruction works within the OF-222 sewershed are considered to be a particular priority, given that no end of pipe SWMF retrofits are currently proposed for that system (given that Site 4 – Glebe Lands necessitates further discussions with the land owner, Six Nations of the Grand River).

As per Table 8.1, the potential drainage area for which SWM measures could be provided has been approximated as a 40 m width of direct drainage. This is intended to reflect typical grading/drainage limits, which would include the roadway right-of-way plus split drainage from adjacent residential lots. This calculation is inherently approximate only for the purpose of this assessment; at the time of design there would need to be more detailed calculations to confirm drainage limits accordingly. In many locations, the roadway being reconstructed may also include a larger trunk storm sewer conveying drainage from other external areas, which would provide an opportunity for retroactive treatment of these additional areas as well, where feasible. Notwithstanding, based on the preceding assumption, roadway reconstructions would provide the opportunity to establish SWM for approximately 62.0 ha of direct drainage, which represents approximately 7% of the total drainage area to Mohawk Lake.

Table 8.1 Summary of Proposed Roadway Reconstructions (10-Year Capital Plan)

Outfall	Pipe Size (mm Φ)	Reconstruction Length (m)	Approximate Direct Drainage Area (ha)[1]
OF-444A	2100	6,527	26.1
OF-444B	900	1,167	4.7
OF-44A	1050	0	0
OF-44B	750	0	0
OF-67	300	0	0
South St	450	0	0
Glanville Ave	300	0	0
OF-6A	300	150	0.6
OF-4	300	0	0
OF-194[2]	1125	3,464	13.9
OF-222[2]	1800	3,464	13.9
OF-38[3]	450	731	2.9
OF-14A	375	0	0
OF-6B	300	0	0
OF-15	375	0	0
OF-14	375	0	0
TOTAL	**NA**	**15,503**	**62.0**

1. Based on an approximate 40 m width of direct drainage (ROW limit + residential frontage)
2. Road reconstruction within “Split1” assumed to all be directed to OF-194
3. Road reconstruction within “Split2” assumed to all be directed to OF-38

Roadway reconstruction projects offer the opportunity to implement multiple different types of SWM measures, depending on the specific opportunities and constraints of the subject roadways. Conveyance controls (including LID BMPs) should be a primary focus, given the potential for enhanced water quality treatment and secondary benefits with respect to quantity and erosion control. Where larger roadway right-of-ways permit, surface features such as bioretention areas, enhanced grassed swales, and permeable pavement (asphalt, concrete or paving stones) could be considered. In more constrained areas, sub-surface measures, including exfiltration pipes, soil retention systems (i.e. Silva Cells™) and filter media could be considered.

Notwithstanding the preceding, the implementation of source controls (LID BMPs) is also dependent on-site conditions, including the properties of sub-surface soils (permeability and potential contamination) groundwater, and depth to bedrock (typically not an issue within the subject study area). A further consideration, with respect to the wide-spread implementation of source controls, is the potential impacts to the water budget/water balance and inflows to Mohawk Canal and Mohawk Lake. This is discussed in further detail in Section 8.2.

More traditional, engineered SWM controls may also be considered in combination, or as stand-alone measures, to complement source controls. Additional OGS retrofits could be considered accordingly, including bypass systems as necessary, for larger trunk storm sewers (space permitting). More localized measures, such as catchbasin inserts (CB Shield™) and maintenance hole inserts with sumps (i.e. SAFL Baffle™).

In all cases, the type and extent of SWM controls for roadway reconstructions would be dependent on specific site opportunities and constraints and the transportation needs of the roadway designers. Notwithstanding, the City of Brantford should make efforts to ensure that SWM controls are considered and incorporated within all new roadway reconstruction projects in the Mohawk Lake Subwatershed. A quantification of the potential SWM benefits is discussed further in Section 8.2.

8.1.3 Private Re-Development

Section 3 provides an overview of expected future growth and re-development potential within the study area. Expected growth and re-development areas have also been presented graphically in Drawing 7. Potential growth areas include:

a. Urban Growth Centre (Downtown)
b. Intensification Corridors (Development along major arterials, including West Street, Charing Cross Street, Henry Street, Colborne Street, and Wayne Gretzky Parkway)
c. Additional Potential Development areas (area around downtown, as well as area south of Colborne Street to Glenwood Drive)
d. Mohawk Lake District Plan areas

Although not presented on Drawing 7, the potential re-development of the Arrowdale Golf Course lands would also represent a large area of potential land use change within the subwatershed. This represents some 19 ha of potential re-development area within the OF-222 (Stanley Street) sewershed area.

A break-down of the preceding potential growth areas by sewershed is presented in Table 8.2. It should be noted that the information presented in Table 8.2 is based solely on the identified re-development area limits and does not account for the existing land use (i.e. downtown areas which are already commercial zones); this is assessed further in Section 8.2.

As evident from Table 8.2, the majority of the potential re-development is associated with drainage areas contributing to OF-444A and OF-222. Notable re-development areas are also associated with OF-444B and OF-44A, and more minor amounts with the remaining areas.

The preceding does not include re-development of the former Massey Ferguson site, which is expected to drain towards Mohawk Lake and Canal under future conditions; this is discussed further in Section 8.2.

It should be noted that there is also the potential for further infill/intensification developments throughout the subwatershed, however for the purposes of the current study, it has been assumed that the preceding would be the primary focus areas of growth and re-development for the foreseeable future.

It is further unknown at what rate or along what timelines the preceding areas would be expected to re-develop. Assumptions regarding changes in land use with respect to these analyses are discussed further in Section 8.2.

Table 8.2 Summary of Potential Re-Development Areas

Outfall	Total Drainage Area (ha)	Urban Growth Area (ha)	Intensification Corridors (ha)	Additional Potential Development (ha)	Mohawk Lake District Plan (ha)	Total Potential Development Area (ha)
OF-444A	298.4	58.1	51.3	-	0.3	99.5
OF-444B	19.4	19.4	-	-	-	19.4
OF-44A	11.6	11.3	-	3.9	1.4	11.3
OF-44B	4.3	4.1	-	0.9	2.7	4.2
OF-67	7.2	0.4	-	-	-	0.4
OF-6A	6.4	-	-	-	0.6	0.6
OF-194	93.1 (109.1)[1]	-	2.6	1.8	-	4.4
OF-222	191.6 (207.6)[1]	-	43.2	32.6	-	60.4
TOTAL TO MOHAWK LAKE[2]	**872.6**	**93.3**	**97.1**	**39.2**	**5.0**	**200.2**

1. "Split1" drainage area is split between OF-194 and OF-222.
2. Some of the potential growth areas overlap, and as such the sum of development areas may not exactly equal. Total drainage area includes additional existing non-development areas.

8.2 Analysis of Future Conditions

8.2.1 Hydrology

In order to assess the potential impacts of future land use conditions within the Mohawk Lake subwatershed, updated hydrologic modelling is required. In order to consider a “worst case” scenario, a future “uncontrolled” conditions scenario has been undertaken to assess the potential impacts to the Mohawk Canal and Lake system.

The potential changes in imperviousness and runoff potential associated with roadway reconstructions is expected to be relatively minimal, as major changes to coverage is unlikely given the restrictions associated with existing ROWs. It is suggested that any proposed road widening should incorporate on-site quantity controls to ensure that post-development to pre-development peak flow, at a minimum, is maintained. Retroactive quantity controls for roadways have not been directly considered as part of the current assessment. It is suggested that these measures be considered on a project by project basis and be considered in particular for locations with identified conveyance system deficiencies (as per Section 6). Although quantity controls for roadway reconstructions are becoming increasingly common in Southern Ontario (particularly where source controls are incorporated as part of the overall SWM strategy), available space within the roadway right-of-way can limit their implementation.

More notable potential changes in imperviousness and runoff potential would be associated with re-development (infill/intensification) within the subwatershed. It should be noted that for certain heavily urbanized (and impervious) areas, including the downtown core area, minimal to no change in net imperviousness would be expected. In other areas, more notable changes would be expected. It has been assumed that existing park and open space areas would be preserved, thus re-developments would be limited to the conversion of lower density/impervious areas to a higher density/impervious coverage. For the purposes of the current assessment, it has been assumed that re-developed areas (where no better information exists) would likely fall into the coverage range of High Density Residential to Commercial, which is estimated to be in the range of 75% to 90% imperviousness (uncalibrated) or 55% to 70% (calibrated), as per Table 5.5. Thus, an average imperviousness value of 65% (calibrated) has been assumed for re-development areas, equivalent to “General Commercial Zone”. For the purpose of this assessment, it has been assumed that where re-development areas have been identified, imperviousness would increase (at a minimum) to this value; if the existing imperviousness is greater than this value then no change has been incorporated.

The exception is the Mohawk Lake District Plan area, where defined land uses are specified. In those areas, the closest approximation to City standard zoning designations (and associated assumed imperviousness) has been applied. As noted in Sections 4.2.1 and 6.1, previous hydrologic models included this area (20 ha +\-) as part of the subwatershed, however based on updated hydrologic modelling for existing conditions, this area would be internally draining, potentially due to the ongoing site remediation work as captured by the available topographic data. The area is therefore excluded under existing conditions.

It is expected that under future conditions, a portion of the overall site would be expected to drain towards Mohawk Lake and Canal. Based on the previous hydrologic modelling, and overall topography, it is expected that the area on the north side of the CNR tracks would drain towards Mohawk Lake and Canal under future conditions, while the balance of the area to the south would not. This additional drainage area has therefore been included under future conditions, based on the preceding land use assumptions from the Mohawk Lake District Plan.

Any potential re-development of the Arrowdale Golf Course property has also not been included, given the current uncertainty with respect to potential built form.

Modelled differences in drainage and impervious area between existing and assumed future conditions are presented in Table 8.3.

Table 8.3 Summary of Estimated Land Use Changes Under Future Conditions

Outfall	Total Existing Drainage Area (ha)	Modelled Existing Impervious Area (ha)	Total Future Drainage Area (ha)	Modelled Future Impervious Area (ha)	Additional Modelled Impervious Area (ha)
OF-444A	298.4	137.3	298.4	145.1	7.8
OF-444B	19.4	12.4	19.4	12.5	0.1
OF-194	93.1 (109.1)[1]	52.4	109.1	53.3	0.9
OF-222	191.6 (207.6)[1]	88.2	207.6	96.5	8.3
Mohawk District	N/A	N/A	13.0	3.0	3.0
TOTAL TO MOHAWK LAKE[2]	**872.6**	**367.8**	**885.6**	**387.9**	**20.1**

1. “Split1” drainage area is split between OF-194 and OF-222.
2. Some of the potential growth areas overlap, and as such the sum of development areas may not exactly equal. Total drainage area includes additional existing non-development areas.

The information in Table 8.3 indicates that the proposed re-development changes under future conditions would be estimated to increase the contributing drainage area by 13.0 ha (i.e. the Mohawk Lake District Plan development area) and increase total direct imperviousness by 20.1 ha, or approximately 5%, as compared to existing conditions. Resulting peak flows at nodes of interest for this future land use scenario are presented in Table 8.4 (uncontrolled conditions).

Table 8.4 Comparison of Simulated Peak Flows at Outfalls and Nodes of Interest between Existing and Future Uncontrolled Land Use Conditions										
Location (Gore & Storrie, 1995)	InfoSWMM Reference[1]	2-Year Storm			100-Year Storm			Regional Storm		
		Exist	Future	Change	Exist	Future	Change	Exist	Future	Change
OF-444A	11M484	7.47	8.76	**+1.29**	17.17	17.43	**+0.26**	18.55	18.55	**0.00**
OF-444B	11M482	0.99	0.89	**-0.10**	2.19	2.23	**+0.04**	2.02	2.07	**+0.05**
Canal at East Ave	11M001OF	8.37 (0.15)	9.81 (0.15)	**1.44 (0.00)**	19.72 (0.82)	19.25 (0.82)	**-0.47 (0.00)**	21.42 (0.31)	21.34 (0.31)	**-0.08 (0.00)**
Canal at Alfred St	10M079OF (10M044OF)	7.68	8.57	**+0.89**	21.23	20.4	**-0.83**	25.23	25.63	**+0.40**
Canal at Murray St	08M004OF	4.79	5.287	**+0.50**	18.87	19.45	**+0.58**	25.90	26.43	**+0.53**
OF-194	07M193	2.33 (0.11)	2.31 (0.11)	**-0.02 (0.00)**	3.58 (2.36)	3.61 (2.44)	**+0.03 (+0.08)**	3.49 (3.22)	3.41 (3.39)	**-0.08 (+0.17)**
OF-222	06M221	4.10 (0.06)	4.77 (0.17)	**+0.67 (0.11)**	8.45 (11.68)	8.62 (12.52)	**+0.17 (+0.84)**	6.89 (23.57)	6.88 (23.56)	**-0.01 (-0.01)**
Mohawk District	S1428	N/A	0.45	**N/A**	N/A	1.76	**N/A**	N/A	1.87	**N/A**
West Canal at Lake Inlet	J3550 (06M222OF)	7.96	8.74	**+0.78**	27.99	28.73	**+0.74**	53.63	54.76	**+1.13**
Lake Outlet at Locks Rd	01M14OF	9.09	9.82	**+0.73**	35.94	37.09	**1.15**	65.90	68.52	**+2.62**
At Grand River	JCT-74	9.61	10.33	**+0.72**	40.52	41.64	**+1.12**	68.49	73.42	**+4.93**

1. Values in brackets represent major system (overland) flows.

The results presented in Table 8.4 are understandably variable depending on the location in the subwatershed. For some of the storm sewer outfalls, the simulated change under future land use conditions is negligible or actually represents a slight decrease in flows. This result is considered attributable to the smaller scale of expected re-development, and in some case hydrograph timing effects. For some of the larger storm outfalls, or where an increased proportion of re-development is anticipated (such as systems draining to OF-444A or OF-222), a more pronounced simulated increase in peak flows is evident, particularly for smaller, more frequent storm events (such as the 2-year event). The preceding results indicate the importance of erosion controls in particular for the overall SWM strategy for re-developments.

For locations along the West Canal and Mohawk Lake, consistent increases in peak flows are indicated for smaller storm events (2-year storm), however minor decreases are indicated for more formative storm events at these same locations (100-year and Regional Storm). At locations further downstream along the West Canal (i.e. beyond Murray Street), a consistent simulated increase for all events is indicated, including for the Regional Storm Event.

The preceding results are based on an "uncontrolled" scenario, (i.e. no quantity control measures in place). For re-developments, on site quantity controls, to a minimum of "post-development to pre-development" peak flow control is a standard requirement and is expected to be applied for new developments (re-development). This ensures that there is no detrimental impact to drainage conveyances systems, which as noted in previous sections have capacity restrictions in certain areas. The preceding simulated results also indicate the need for control of smaller more frequent events (i.e. erosion control), as well as flood control, particularly for downstream locations along Mohawk Lake and Mohawk Canal. The City of Brantford may also consider applying over-control for infill/intensification sites in such areas, to recover conveyance system capacity.

Quantity control storage requirements and associated impacts to downstream receivers have not been directly assessed as part of the current hydrologic modelling effort. Due to the high resolution of subcatchment elements (average area of 0.8 ha), and the extent of the anticipated future development, a total of 231 storm elements would need to be incorporated into the modelling, which is considered excessive and beyond the scope of the current study. The City should consider conducting this assessment as part of future updates.

On site quantity controls would be expected to primarily rely on sub-surface storage, as infill/intensification development typically involves high impervious coverage and maximized available land area. Such controls could therefore potentially be combined with source control measures (LID BMPs), similar to the potential application to roadway reconstruction projects.

In addition to considerations of potential site constraints (soil permeability, groundwater, etcetera), the implementation of source controls (LID BMPs) for re-development should also consider the overall potential impact to the water balance/water budget within the subwatershed. Previous analyses (refer to Section 2) have noted that in general, Mohawk Lake appears to receive a notable amount of groundwater-based inflow (18% a percentage of the total inflow). In addition, additional inflow (of clean water) to Mohawk

Canal and Mohawk Lake has been considered beneficial to overall water quality, by increasing circulation and decreasing residence time. Widespread implementation of infiltration-based LID BMPs may impact these patterns, given the typically longer time frame associated with deep infiltration and lateral movement of groundwater. As such, LID BMPs should potentially consider a predominant focus on filtration-based approaches, rather than infiltration-based approaches. This philosophy would ensure that the water quality and flow attenuation benefit is achieved, while still ensuring that sufficient clean water is directed to Mohawk Lake to aid in circulation.

8.2.2 Hydraulics

The preceding hydrologic analyses have focused on the Future Uncontrolled scenario only (i.e. no quantity controls in place). As noted, quantity controls for roadway reconstructions would likely be restricted to areas where a road widening is proposed, or where a known conveyance system capacity restriction exists. Quantity controls would be primarily instituted for infill/intensification developments.

The performance of the urban drainage systems (i.e. storm sewers and overland flow routes) under the future uncontrolled scenario have not been assessed, given the preceding understanding (i.e. that on-site quantity controls would be required, and thus updated mapping would not be representative of expected conditions).

Open channel hydraulics (i.e. Mohawk Lake and Mohawk Canal) have however been assessed using the updated future uncontrolled scenario flows outlined in Section 8.2.1. This has primarily been completed for the purposes of assessing the impact to the Regional Storm (Regulatory) Floodplain, which as per Provincial policy (MNRF, 2002), excludes any quantity controls. Updated hydraulic results (water surface elevations) have been generated for the full range of return period flows (2 through 100-year storm events), as well as the Regional Storm Event, and have also considered both the results from the HEC-RAS and InfoSWMM modelling. Results are presented in Table 8.5.

Table 8.5 Simulated Peak Water Surface Elevations within Mohawk Lake under Existing and Future Scenarios

Modelling Approach	Land Use Scenario	Simulated Peak Water Surface Elevation (m)						
		2	5	10	25	50	100	Regional[2]
HEC-RAS1	Existing Conditions	198.81	199.26	199.50	199.69	199.84	199.95	200.83
	Future Uncontrolled	198.96	199.33	199.53	199.73	199.87	199.98	200.84
	Difference	**+0.15**	**+0.07**	**+0.03**	**+0.04**	**+0.03**	**+0.03**	**+0.01**
InfoSWMM	Existing Conditions	198.86	199.30	199.54	199.77	199.98	200.21	200.82

Table 8.5 Simulated Peak Water Surface Elevations within Mohawk Lake under Existing and Future Scenarios

Modelling Approach	Land Use Scenario	Simulated Peak Water Surface Elevation (m)						
		2	5	10	25	50	100	Regional[2]
	Future Uncontrolled	198.92	199.35	199.57	199.81	200.06	200.26	200.85
	Difference	**+0.06**	**+0.05**	**+0.03**	**+0.03**	**+0.08**	**+0.05**	**+0.03**

1. Average of simulated results at cross-sections 2710 (upstream) and 1914 (downstream). HEC-RAS modelling applies rating curve boundary condition and updated SWS flows, analogous to Scenario 3 from Table 6.11.
2. SWS Flows for Regional Storm Event exclude storage function in InfoSWMM modelling; 2-100 year return period flows include it given nominal difference in peak flows to Mohawk Canal and Lake.

The simulated results in Table 8.5 indicate that the water surface elevations would be expected to increase under the future uncontrolled land use scenario, as would be expected, given the simulated increase in peak flows along Mohawk Lake and Mohawk Canal. Consistent with the simulated changes in peak flows, the largest changes in the water surface elevation are observed for less formative (and more frequent) storm events. A smaller increase in water surface elevation is indicated for the Regional Storm Event, which likely reflects the more extensive floodplain in that scenario, as opposed to smaller storm events, which are confined to the primary canal and lake area. In general, the simulated results from the updated HEC-RAS and InfoSWMM modelling are reasonably consistent.

8.2.3 Water Quality

In order to assess the potential water quality benefit of stormwater management for future re-developments within the Mohawk Lake Subwatershed (i.e. roadway reconstructions and infill re-developments), a similar approach to that for existing conditions (Section 7.3) has been employed.

With respect to roadway reconstructions, Wood has conducted a review of a selected number (approximately 20+/-) typical roadway right-of-way widths to assess an "average" contaminant loading for these types of systems based on the simulated water quality modelling results. Premised on this approach, an average annual TSS loading of 907 kg/ha has been determined. This value has been applied to approximately quantify the estimated existing TSS loading from the identified roadway areas.

The potential average annual TSS removal (water quality benefit) achievable for roadway reconstructions cannot be definitively established, as each site would differ with respect to site opportunities and constraints (including space within the right-of-way, utilities, surficial soils, groundwater, etcetera). In some cases, where a treatment train approach could be applied, a higher degree of quality control treatment (i.e. "Enhanced" treatment, or 80% average annual TSS removal) may be feasible. In other locations, this may not be feasible. It is considered however that at a minimum, some form of engineered solution (i.e. oil/grit separator or catchbasin inserts) should be feasible, which should be able to achieve at least 50% average annual TSS removal. The potential water quality benefit for roadway reconstructions has been calculated on that basis; the results are presented in Table 8.6.

Table 8.6 Summary of Estimated Water Quality Benefit for Roadway Reconstructions				
Outfall	Reconstruction Length (m)	Approximate Direct Drainage Area (ha)[1]	Simulated Average Annual TSS (kg)	Potential Average Annual TSS Removal (kg)[4]
OF-444A	6,527	26.1	23,685	11,843
OF-444B	1,167	4.7	4,235	2,117
OF-6A	150	0.6	544	272
OF-194[2]	3,464	13.9	12,570	6,285
OF-222[2]	3,464	13.9	12,570	6,285
OF-38[3]	731	2.9	2,653	1,326
TOTAL	**15,503**	**62.0**	**56,257**	**28,129**

1. Based on an approximate 40 m width of direct drainage (ROW limit + residential frontage)
2. Road reconstruction within "Split1" assumed to all be directed to OF-194
3. Road reconstruction within "Split2" assumed to all be directed to OF-38
4. Based on assumed 50% treatment/removal for subject drainage area

The results indicate that a total of 28,129 kg of average annual TSS loading could potentially be removed from the Mohawk Lake subwatershed based on the preceding assumptions. This represents approximately 65% of the estimated benefit through the implementation of short-listed OGS retrofits (Table 7.7). As noted, it may be feasible to increase the water quality treatment potential for individual projects where the implementation of source controls (LID BMPs) or treatment of externally contributing areas can be achieved.

For proposed re-developments, it is suggested that the approach of providing water quality treatment for only the "new" impervious surface would be insufficient and may in fact worsen water quality conditions within the subwatershed. Even with a treatment train approach, typical water quality measures would at best achieve "Enhanced" (80% average annual) TSS removal, which would leave some portion of the "new" impervious area as untreated. Given the intent to leverage re-developments as an opportunity to improve overall water quality conditions within the subwatershed, it is recommended that re-developments be required to provide water quality treatment (80% or "Enhanced" criteria) for all of the reconstructed impervious area, specifically roadways, parking areas, and paved surfaces (since these areas are the primary sources of water quality contaminants). Rooftop areas are typically considered as "clean" runoff, provided that roof drainage can be separated out from other sources of stormwater from the site.

With respect to infill developments, Wood has conducted a review of a selected number (approximately 6+/-) typical commercial type areas to assess an "average" contaminant loading for these types of areas based on the simulated water quality modelling results.

Based on this approach, an average annual TSS loading of 663 kg/ha has been determined. This value is notably less than that for roadway areas presented previously 907 kg/ha). This likely reflects the assumed event mean concentration (EMC) values in Table 6.13 (i.e. 77 mg/L for commercial areas and 131 mg/L for general/residential areas).

In order to estimate the potential water quality benefit from implementing the preceding management approach (i.e. policy to mandate treatment for full redevelopment areas) within the Mohawk Lake subwatershed, some overall assumptions are necessary. An estimated split of existing land use to be re-developed has been generated for each sewershed area, as indicated in Table 8.7. This has been used to estimate the existing TSS loading for each sewershed, based on the preceding average loading rates by land use classification. The estimated future TSS loading has been calculated using the commercial loading rate and an assumed "Enhanced" removal rate (80% average annual TSS removal). The difference in TSS loading has then been calculated as the difference between these values. The results are presented in Table 8.7.

Table 8.7 Summary of Estimated Water Quality Benefit for Infill Re-Developments

Outfall	Total Drainage Area (ha)	Total Potential Development Area (ha)	Estimated Residential Commercial Split	Estimated Existing Average Annual TSS Loading (kg)	Estimated Future Average Annual TSS Loading (kg)	Estimated Average Annual TSS Reduction (kg)
OF-444A	298.4	99.5	50 / 50	78,108	13,194	64,914
OF-444B	19.4	19.4	0 / 100	12,862	2,572	10,290
OF-44A	11.6	11.3	0 / 100	7,492	1,498	5,994
OF-44B	4.3	4.2	0 / 100	2,785	557	2,228
OF-67	7.2	0.4	100 / 0	363	53	310
OF-6A	6.4	0.6	100 / 0	544	80	465
OF-194	93.1 (109.1)[1]	4.4	100 / 0	3,991	583	3,407
OF-222	191.6 (207.6)[1]	60.4	50 / 50	47,414	8,009	39,405
TOTAL	**632.0 (664.0)[1]**	**200.2**	**NA**	**153,558**	**26,547**	**127,011**

1. "Split1" drainage area is split between OF-194 and OF-222.

The preceding indicates that the implementation of retroactive stormwater quality controls for infill/intensification re-developments offers a significant overall potential benefit in TSS loading reduction to the Mohawk Lake. This reflects the area of potential re-development (200.2 ha) and also the proposed stricter TSS removal criteria ("Enhanced" or 80% average annual TSS removal). Some of the estimated TSS reduction is also considered attributable to the estimated lower TSS generation rate for commercial type properties, as opposed to residential type properties. Although the values presented in Table 8.7 are approximate only, the results suggest a large benefit associated with mandating retroactive stormwater quality controls for such areas.

The preceding does not include the Mohawk Lake District area, as this area would represent a new drainage system input to the subwatershed. It is recommended that the previous criteria of "Enhanced" treatment (80% average annual TSS removal) again apply to this area, and potentially a stricter criterion of "no net impact" (i.e. 100% treatment, given the drainage area addition). This would be similar to the approach applied for the approach adopted for Hamilton Harbour Remediation Action Plan (HHRAP; i.e. MOE Policy 2), and generally involves off-site measures or cash-in-lieu to achieve.

9.0 Impact Assessment

9.1 Cultural Heritage and Archaeology

Potential site alterations are anticipated to be primarily related to restoration (implementation of stormwater management controls) as opposed to active development, as the principal portions of land included in the designation include Mohawk Park, which is designated as a Core Natural Area in the Draft Official Plan 2016, and the shorelines, which are designated a SPA within the Draft Official Plan 2016, where development is largely prohibited. The recommendations for works with respect to SWMF outfall retrofits would be located partially in this designated area (ref. Drawing 2) and will require appropriate design considerations in order to ensure recommendations are in keeping with the intent of the CHL designation.

Consultation should occur between the City of Brantford Heritage Planner, the Heritage Committee, and the Indigenous groups to ensure their views are incorporated into the proposed recommendations for the site. The CHL designation area abuts the Glebe Farm Indian Reserve on the east and south sides, further emphasizing the importance of consultation with Six Nations of the Grand River (SNGR).

The Canadian Military Heritage Museum is located within a potential development area, specifically the Greenwich Mohawk Site (ref. Figure 5), which is expected to drain to Mohawk Lake under future conditions (other features in the area are not expected to contribute to the subwatershed). Preliminary concept plans developed as part of the Mohawk Lake District Area Plan in May 2018 designated all sites as Institutional and Cultural areas, addressing the potential development limitations associated with a cultural heritage designation.

None of the sites identified for Stage 4 AA (ref Drawing 2) are located within the subwatershed limits of Mohawk Lake itself, but rather are located on the periphery, in areas which drain directly to the Grand River.

With respect to the proposed SWMF retrofits, reference is made to Figure 17 ("Suggested Stage 2 Strategy") from the Stage 1 Archaeological Assessment (Wood, 2019). Site 1 (Shallow Creek Park) would be entirely located within an area designated as "disturbed" and thus is not expected to require further assessment. Site 2 (Rawdon Street outfall) is largely located in a similarly designated areas, however the proposed diversion storm sewer would be located in an area of "Unploughable Land – Stage 2 Archaeological Assessment Recommended", which would require further consideration at the future design stage.

As noted, the feasibility of the Site 4 SWMF outfall retrofit (Glebe Lands) requires further discussions with the landowner (Six Nations of the Grand River). Additional archaeological investigations may be required to support this project, should agreement be reached to advance the project further.

9.2 Geology, Hydrogeology and Groundwater

Shallow Creek Park abuts the north side of the West Canal and was determined by Gore & Storrie (1995) to be affected by coal tar wastes with associated PAH contamination of groundwater. Given the proposed retrofit SWM facility within Shallow

Creek Park, the potential for mobilization of existing groundwater contamination or introduction of new groundwater contamination must be considered. Construction in the potential development lands may also cause soil erosion, which may lead to runoff with high, and potentially contaminated suspended load being discharged to Mohawk Lake and Mohawk Canal. These factors must be considered as part of the design and ultimate design of the SWMF retrofit.

The industrial and land fill sites identified as potential sources of contamination (ref. Drawing 5) have likely influenced the groundwater quality in the area. The Greenwich Mohawk Site has undergone remediation and does not require additional site assessment. Development occurring in other potential development lands will require a site condition assessment for soil and groundwater contamination to determine risk of contaminant mobilization in groundwater.

The potential development lands within the study area are a relatively small proportion of the overall subwatershed of Mohawk Lake. Groundwater flow rate and quality changes associated with changes to the potential development lands may have a relatively small effect on the overall water balance and water quality of Mohawk Lake and Mohawk Canal, when compared to the inputs from the urban surface subwatershed. Given the minor scale of the development, it is considered unlikely to directly affect flow rates or water quality of the Grand River to the south of the study area. Future development in the upstream subwatershed should be required to implement stormwater controls to mitigate potential impacts to the groundwater quality of the overall watershed.

Any potential change in the elevation of the Mohawk Lake outlet control structure may potentially have a greater effect, as it is likely to change the balance of groundwater discharge to surface water versus surface water exfiltration to groundwater at Mohawk Lake.

9.3 Fluvial Geomorphology

The south shore of the West Canal consists of artificial slopes with locally undercut banks. The abutting lands are identified as potential development areas in the Waterfront Master Plan, designated as Residential and General Employment lands in the Draft Official Plan 2016, and include the proposed Primary Waterfront Trail. Future development in these areas has the potential to exacerbate the ongoing erosion conditions of the south shore. Future development works should include stormwater management controls to prevent further bank erosion and improve the existing bank conditions through restoration.

A significant portion of the study area falls within the GRCA's Regulation Limit, including the majority of the potential development areas south of the canal-lake system. Development will be restricted by GRCA policies in these areas and Special Policy Area policies in the Erosion & Hazard Limit SPA areas.

Two (2) of the three (3) erosion sites are located in the tributaries to the Outfall draining to the Grand River and are adjacent to residential properties. Due to the minor scale of these sites and their location downstream of the canal-lake system, they are unlikely to be a cause of sedimentation for the canal-lake system, and accordingly unlikely to be a significant focus of this project. Should restoration works be proposed in these areas, they will need to consider the impacts to adjacent residential properties.

The third erosion site is located upstream of the West Canal adjacent to Shallow Creek Park, in the location of a proposed SWMF outfall retrofit (Site 1). As noted previously, erosion in this area has the additional potential risk of mobilizing contaminated materials. As part of the design for the SWMF retrofit, the approach to addressing erosion in this area will need to be determined, including reinforcement or lining, or potentially a partial enclosure, particularly given the constrained channel width for the most upstream section and the occurrence of sediment deposition (sand) in this location. The design should also consider potential elements that could be integrated into the design to enhance the aesthetic and recreational value of the park.

9.4 Hydrology and Stormwater Management

As noted previously, the Mohawk Lake subwatershed is completely developed, and lacks any formal stormwater management (quantity) or erosion controls. Mohawk Lake itself generally acts as an informal stormwater management facility for the contributing drainage area.

Aa strategy has been outlined herein to provide retroactive and ongoing stormwater management (SWM), including new capital works and other works tied to future construction work (road reconstruction and future infill/intensification re-development). The strategy considers both flood control and erosion control. The proposed strategy should be used to plan any future works within the Mohawk Lake subwatershed.

9.5 Hydraulics

The updated floodplain mapping for the Mohawk Lake and Mohawk Canal area indicates that flooding of the lands to the south of Mohawk Lake would be expected for the 25-year storm event and greater. Typically, re-development within floodplain areas is prohibited by the local Conservation Authority (GRCA). Notwithstanding, as noted the area in question is designated a Special Policy Area (SPA) by the GRCA, which can permit some re-development, subject to certain restrictions/requirements. Typically, flood-proofing is required for any re-developments, and certain types of vulnerable land uses may not be permitted. Updated 1D-2D hydraulic modelling and floodplain mapping may also be considered to better delineate the flood hazard specifically from Mohawk Lake and Mohawk Canal in this area.

9.6 Water Quality

Consistent with Section 9.4, the Mohawk Lake subwatershed is completely developed, and lacks any formal stormwater management (quality) controls. Mohawk Lake itself generally acts as an informal stormwater management facility for the contributing drainage area.

A strategy to provide retroactive and ongoing stormwater management (SWM) has been developed, including new capital works and works tied to future construction work (road reconstruction and future infill/intensification re-development). The strategy is primarily focused upon quality control given the purpose of the current study. The proposed strategy should be used to plan any future works within the Mohawk Lake subwatershed.

9.7 Sediment Quantity and Quality

An assessment of sediment quantity and quality was completed as part of the Characterization Study (October 2019), and reviewed/discussed further as part of the separate Environmental Assessment Report (Wood, 2020). Options for sediment removal and disposal from the Lake and Canal are reviewed further as part of that study but will need to be further refined as part of subsequent design works. The proximity of disposal sites and the associated costs of transporting and relocating significant quantities of impacted materials will need to be considered in the assessment of restoration alternatives.

In addition to potentially contaminated sediment within Mohawk Lake and Mohawk Canal, contamination of surficial soils in the locations of proposed SWMF outfall retrofits (Site 1 – Shallow Creek Park and Site 2 – Rawdon Street) will also require further testing and assessment as part of subsequent design works.

The implementation of the proposed SWM strategy for the Mohawk Lake subwatershed, specifically with respect to stormwater quality control, should ensure that sediment loads (and associated contamination) are steadily reduced over time.

9.8 Natural Environment

As noted herein, the Characterization Study provided a focus on existing conditions within Mohawk Lake and in the immediate areas of the canal and outflow channel. The Characterization Study does not cover areas relative to the Shallow Creek pond or Rawdon Street pond (ID#1 and ID#2, respectively). As findings relative to these areas are not well understood, exact impacts cannot be identified at present. As part of the future design for the SWMF retrofit(s) an EIS[2] will be required to address associated impacts which may include but not be limited to: impacts to fish and fish habitat during construction, impacts to trees and associated vegetation, impacts to wildlife and wildlife habitat, and potential impacts to SAR (if they exist). The design should include efforts for habitat enhancements where feasible.

In relation to other aspects of the project, the following additional impacts shall be considered:

The Mohawk Lake and Oxbow Wetland has been recommended for a PSW designation in the Characterization Study (2019) (Appendix A) and is situated along the north shores of the West Canal and designated as a Core Natural Area in the Draft Official Plan 2016. A PSW designation would represent a significant constraint to the site, as a 120m PSW adjacent lands setback would restrict development and adjacent land uses. The Glebe Farm Indian Reserve, the Greenwich Mohawk Site, Mohawk Lake and Canal, Shallow Creek Park, the proposed Primary Waterfront Trail and additional adjacent lands would fall under this 120m PSW adjacent lands setback. While development is not prohibited, an impact assessment would be required to demonstrate

2 Grand River Conservation Authority's *Environmental Impact Study (EIS) Guidelines and Submission Standards for Wetlands (2005)* provide guidance on developing EIS

the functionality of the PSW would not be impacted, along with further additional studies.

The identified osprey nest is located within the Greenwich Mohawk Site in an area designated as Existing Industrial and Other Uses in all three (3) concept plans developed as part of the Mohawk Lake District Plan. The Master Plan represents an opportunity to enhance the nesting location.

Rare Vegetation Communities are located in areas designated Core Natural Area in the Draft Official Plan 2016. Rare Vegetation Communities are a form of SWH and therefore development should include a setback from the edge of the delineated boundary. The setback should be large enough to limit edge effects and not include trails.. Setbacks should include restoration of the Rare Vegetation Communities, to promote the development of the core area of the Rare Vegetation Communities, provides an opportunity to preserve permable areas to improve water retention, moisture uptake and water quality within the subwatershed.

As noted herein, additional studies have been recommended to further characterize the Mohawk Lake, Canal and additional systems (i.e., Shallow Creek). Findings relative to these studies are not well understood at the present time, and as such, exact impacts cannot be identified herein. As part of the design, an EIS will be required to address associated impacts, which may include but not limited to: impacts to fish and fish habitat during construction, impacts to vegetation communities, impacts on wildlife and wildlife habitat, and potential impacts to SAR (if they exist). Further, as noted in Section the Environmental Assessment Report, in response to the review of draft project documentation, GRCA noted that wetland boundaries would need to be delineated by a qualified consultant and subsequently verified by the GRCA. The design should include efforts for habitat enhancements where feasible.

9.9 Potential Sources of Pollution

Legacy industrial activities and landfills were likely a pollutant source for the Mohawk Lake and Mohawk Canal. The majority of these sites are no longer active or have undergone remediation (ref. Drawing 5). The Greenwich Mohawk Site was remediated in 2017 and is slated for redevelopment in the Mohawk Lake District Plan. Legacy industrial sites that are identified for redevelopment will require similar remediation activities.

The landfill site located adjacent to Shallow Creek Park was identified to be significantly contaminated but not requiring remedial action at the time of the assessment in 1995. As noted previously, the proposed SWMF retrofit in Shallow Creek Park will need to consider these impacts carefully as part of the investigative works and subsequent design phase.

Sonoco Products of Canada operations include stormwater discharging from the property into the canal and water from the canal being used as non-contact cooling water and discharged back into the canal and lake. Operations should continue to be monitored to ensure discharge is of an acceptable quality and temperature. Should the Mohawk Lake and Oxbow Wetland Complex be designated a PSW, potential restrictions may be applicable.

It is understood that no further dumping is being undertaken by the City of Brantford for the landfill located within Mohawk Park, which largely contains street sweeping remnants. Restoration activities or recreational opportunities proposed within Mohawk Park should consider the potential for contaminant mobilization, and potential relocation for the dumping site. An oil/grit separator has been identified as a preferred alternative in this location, as opposed to a SWMF retrofit (wet pond) which should minimize the degree of disturbance

10.0 Implementation and Monitoring Plan

10.1 Implementation Plan

10.1.1 Prioritization and Scheduling

As part of the previous sections of this report, an overall preferred stormwater management (SWM) strategy has been developed for the Mohawk Lake subwatershed. In order to ensure the success of this plan, a staged implementation plan is necessary, which identifies and ranks the highest priority measures, and sets reasonable time frames for the implementations of these and lesser priority works. The current implementation plan is focused upon those measures related to the SWM strategy; a separate implementation plan has been prepared for those works within Mohawk Lake and Canal themselves, related to overall remediation of these features (ref. Environmental Assessment Report, Wood, 2020). The EA report has also prepared an overall prioritization of all works, including those related to the subwatershed SWM strategy and those for the Lake and Canal directly. As noted previously, future consideration should be given to the potential to utilize the upstream portion of the West Canal for quality control treatment, as well as channel restoration opportunities, if feasible.

A clear distinction for the prioritization and implementation plan for the Subwatershed Stormwater Plan relates to the three (3) categories of proposed measures, namely:

a. Structural measures - driven by future construction in the subwatershed (as per Section 8)
b. Non-Structural measures – overall best management practices (as per Section 7)
c. Structural measures - stand-alone capital works by the City of Brantford (as per Section 7)

For category “a” (driven by future construction works), no specific implementation plan is necessary, beyond City staff enforcing and applying the proposed additional SWM criteria for these works. The criteria would, as noted, apply both to City-led projects (primarily roadway reconstructions, potentially some limited public site development) and privately-led projects (infill/intensification re-developments). A priority would be placed on confirming what internal policy changes would be necessary to support this new direction/requirement, and whether any type of resolution or City Council endorsement would be necessary. Potential cost implications (for City-led projects) would be a separate consideration and is reviewed further in Section 10.1.2.

For category ”b” (non-structural measures), these are measures that could generally be implemented immediately by City staff, subject to funding availability (as per Section 10.1.2). Similar to category “a”, it would need to be confirmed whether or not any type of resolution of City Council or other form of endorsement would be necessary.

The focus of the implementation plan is therefore largely on category “c”, namely proposed structural measures based on existing conditions. With respect to cross-connections, it is understood (based on communication with staff) that the City has a program in place to address these concerns. Notwithstanding, given the specific noted concern from the Characterization Study (area around Rawdon and Bruce Street), targeted investigations and remediation of this area are considered warranted, and should potentially be treated as such in the implementation plan. Further, a longer-term supplemental program of field testing for cross-connections within the Mohawk Lake subwatershed should be considered and has been incorporated into the proposed implementation plan accordingly.

The primary proposed capital works as part of this category of works involve SWMF outfall retrofits (wet ponds) and OGS retrofits, as detailed in Section 7. As noted previously, the potential to utilize a portion of the West Canal for online quality control treatment should also be considered, but will require further study. A short-listed (i.e. prioritized) list of preferred alternatives has also been developed as part of the previous assessments. With respect to SWMF outfall retrofits, the implementation plan must consider both the design phase (and associated supporting studies/works), as well as the construction phase for the prioritized sites. Other sites require further review and consultation to assess feasibility. For the proposed OGS retrofits, it is considered that the design scope is much more streamlined and can be reasonably expedited.

A key consideration for the overall project timelines and priorities is the requirements of Federal Government funding agreements with the City of Brantford for the design and implementation of prioritized projects. As such, a high priority is placed upon advancing identified high priority works within the current Federal and City budgets and timelines.

The proposed implementation plan has been divided accordingly into short terms works (approximately 2020/2021) and medium to long-term works (approximately 2022-2029). Works within the short-term time frame (approximately 2020/2021) have been further divided into high priority works (those which are tied to the previously noted Federal funding timelines) and other short-term works (not tied to the Federal funding timelines, but which should still occur within the approximate 2020/2021 timeframe). Short term works are presented in Tables 10.1 and 10.2 respectively. Longer-term works (approximately 2022-2029) are presented in Table 10.3. Preliminary cost estimates have also been included in the Tables; costing is discussed further in Section 10.1.2 (Detailed Cost Estimates for certain measures have been provided in Appendix E).

In general, the short-term implementation plan includes the highest priority items from the SWM alternative assessment, including SWMF outfall retrofits and OGS retrofits. Given the large contributing drainage areas of the majority of the proposed OGS retrofits (generally 10 ha +\-) a larger construction cost of $300,000 per site has been assumed. Notwithstanding this cost is considered an estimate only (Class D as per the Canadian Construction Association (CCA) Guidelines) and would be further refined as part of subsequent detailed design and tender preparation based on the specific characteristics of each site.

The design and construction of the Shallow Creek Park Outfall retrofit is also a high priority measure as per Table 10.1. Preliminary construction cost estimates for the Shallow Creek Park Retrofit as well as the next highest priority SWMF outfall retrofit (Rawdon Street) have been prepared and are included in Appendix E. These are conceptual (CCA Class D) cost estimates only and assume non-contaminated material for off-site removal. Should the material be contaminated and require landfill disposal, additional costs would be incurred. This will be reviewed and refined as part of the detailed design effort.

In addition to structural measures, non-structural BMPs and policy measures have also been advanced as high priority measures for short-term implementation. It has been assumed that the implementation of revised SWM criteria for re-developments would be completed by City staff and thus not require any capital budget expenditure.

The incorporation of SWM measures into scheduled roadway reconstruction works in the short-term (approximately 2020/2021) have also been included. One (1) project from the Capital Budget is listed as a 2019 project (Elgin Street – CN Overpass to Rawdon Street); it is unknown if the design for this work has been completed or tender issued, which may render it difficult to incorporate water quality measures into the design. A review of potential water quality treatment options for roadways, and associated additional costs for SWM, is provided in Appendix E. In general, an additional SWM cost of $150,000 has been allocated for roadways with direct drainage areas less than 5 ha, a larger additional SWM cost of $300,000 has been allocated for projects greater than 5 ha. Notwithstanding these costs are considered estimates only (Class D or lower) and would necessarily be further refined as part of subsequent detailed design and tender preparation based on the specific characteristics of each site.

A detailed investigation and repair for the identified cross-connection issue in the vicinity of Rawdon Street and Bruce Street (as per the Characterization Study, October 2019) is proposed as another short-term measure. A preliminary amount for investigations in subsequent years has also been included; it is suggested that the City incrementally assess portions of the subwatershed each year to determine whether any additional cross-connections are present. Given that the potential number of such cross-connections is unknown, no specific budget for remedial works has been included in the current estimate.

Table 10.1 Subwatershed SWM Strategy – High Priority Measures for Short-Term Implementation Plan						
Priority	Project Type	Project ID	Location	Activity	Class EA	Estimated Cost
1	OGS Retrofits	TBD	3 Highest Priority Locations	Detailed Design	A/A+	$465,000
2	SWMF Outfall Retrofits	1	Shallow Creek Park	Detailed Design	B	
3	Watercourse Restoration and Retrofit[2]	NA	Mohawk West Canal Restoration and Retrofit	Detailed Design	B	
1[3]	OGS Retrofits	TBD	3 Highest Priority Locations	Construction	N/A	$900,000[1]
2[3]	SWMF Outfall Retrofits	1	Shallow Creek Park	Construction	N/A	$4,500,000[1]
3	Watercourse Restoration and Retrofit	NA	Mohawk West Canal Restoration and Retrofit (Upstream)	Construction	N/A	TBD

1. Construction costs are conceptual estimates only (Class D Cost Estimate as per CCA guidelines) and assumes non-contaminated material for removal (with respect to SWMF outfall retrofits). Refer to Appendix E for cost breakdown. Construction cost estimate will be further refined as part of detailed design process
2. Refer to Environmental Assessment Report (Wood, 2020) for further detail. May include some combination of channel restoration and online quality control treatment, as discussed in previous sections.
3. Construction priority same as design priority

Table 10.2 Subwatershed SWM Strategy – Other Measures for Short-Term Implementation Plan						
Priority	**Project Type**	**Project ID**	**Location**	**Activity**	**Class EA**	**Estimated Cost**
4	Development SWM Policy	N/A	Subwatershed (or City-Wide)	SWM Requirements for Developments	N/A	$0*
5	Cross-Connection Investigation	N/A	Rawdon Street and Bruce Street	Assessment and Potential Remediation	A/A+	$50,000
6		N/A	Various areas of subwatershed	Assessment	A/A+	$25,000
7	SWMF Outfall Retrofits	2	Shallow Creek Trail (Rawdon Street)	Detailed Design	B	$150,000
8		4	Glebe Lands	Feasibility Review	N/A	$20,000
9		5	Arrowdale Public Golf Course	Feasibility Review	N/A	$20,000
10	OGS Retrofits	TBD	1 of Remaining High Priority Locations	Design and Construction	A/A+	$300,000
11	SWM for Road Reconstruction	000870	Elgin Street (CN Overpass to Rawdon Street)	Design and Construction	A/A+	$150,000
12		001344	Palace Street (Brant to Duke)	Design and Construction	A/A+	$150,000
13		000349	Chatham Street (Stanley to Fourth)	Design and Construction	A/A+	$150,000
14		001122	Drummond Street (Dead End to Park)	Design and Construction	A/A+	$150,000
15		001490	Rawdon Street (Wellington to Grey)	Design and Construction	A/A+	$150,000

For the medium-long term implementation plan (approximately 2022-2029), the highest priority item would be the construction of the Rawdon Street SWMF outfall retrofit (along Shallow Creek Trail). Provisional amounts for the design of the other SWMF outfall retrofits have been included (Glebe Lands and Arrowdale Public Golf Course), however both would be subject to a further feasibility assessment, and also require the determination of capital funding sources, given the comparatively higher expected costs. As such, no construction cost estimates have currently been included.

Similar to the proposed approach to site development SWM, it is assumed that a review of street sweeping procedures would be undertaken by City staff and thus not require any capital expenditure. Should additional street sweeping works eventually be recommended (as is considered likely), this additional cost would likely need to be accommodated within the City's operations budget.

Both a road salt management plan, and landfill contamination study have also been proposed, however preliminary capital expenditures for these items have been estimated.

The currently proposed implementation plan assumes that following approximately 2020, one (1) of the remaining high priority OGS retrofits is designed and constructed per year, such that all 12 of the preferred locations are constructed by the end of the medium long-term implementation period (i.e. within 10 years).

Other works would be expected to continue on an annual basis, including incorporating SWM measures into planned roadway reconstruction projects, and ongoing cross-connection testing.

Table 10.3 Subwatershed SWM Strategy – Medium to Long-Term Implementation Plan						
Priority	Project Type	Project ID	Location	Activity	Class EA	Estimated Cost
20	SWMF Outfall Retrofits	2	Shallow Creek Trail (Rawdon Street)	Construction	N/A	$4,700,000[1]
21		5	Arrowdale Public Golf Course	Detailed Design[2]	B	$150,000
22		4	Glebe Lands	Detailed Design[2]	B	$200,000
23		5	Arrowdale Public Golf Course	Construction*	N/A	TBC[2]
24		4	Glebe Lands	Construction*	N/A	TBC[2]
25	OGS Retrofits	TBD	Remaining High Priority Locations (1 per year - 8 total)	Design and Construction	A/A+	$2,400,000[1]
26	Cross-Connection Investigation	N/A	Various areas of subwatershed (annual review)	Annual Assessment	A/A+	$200,000
27	Studies	N/A	Subwatershed (or City-Wide)	Street Sweeping - Policy and Capability Review	N/A	$0*
28		N/A	Entire Subwatershed (Potentially City-Wide)	Road Salt Management Plan	N/A	$50,000
29		N/A	Subwatershed (or City-Wide)	Landfill Contamination Study	N/A	$100,000
30	SWM for Road Reconstruction	000068	Buffalo Street (Rushton to West)	Design and Construction	A/A+	$150,000
31	SWM for Road Reconstruction	000343	Grey Street (Fourth to Wayne Gretzky)	Design and Construction	A/A+	$150,000
32	SWM for Road Reconstruction	001135	Nelson Street (Stanley to Park)	Design and Construction	A/A+	$150,000
33	SWM for Road Reconstruction	001343	Drummond Street (Dalhousie to Chatham)	Design and Construction	A/A+	$150,000

Table 10.3 Subwatershed SWM Strategy – Medium to Long-Term Implementation Plan						
Priority	**Project Type**	**Project ID**	**Location**	**Activity**	**Class EA**	**Estimated Cost**
34	SWM for Road Reconstruction	001190	Charlotte Street (Dalhousie to Colborne)	Design and Construction	A/A+	$150,000
35	SWM for Road Reconstruction	001190	Clarence Street (Dalhousie to Colborne)	Design and Construction	A/A+	$150,000
36	SWM for Road Reconstruction	001190	Colborne Street (Brant to Dalhousie)	Design and Construction	A/A+	$300,000
37	SWM for Road Reconstruction	001190	Dalhousie Street (Brant to Colborne)	Design and Construction	A/A+	$300,000
38	SWM for Road Reconstruction	001190	King Street (Dalhousie to Colborne)	Design and Construction	A/A+	$150,000
39	SWM for Road Reconstruction	001190	Queen Street (Dalhousie to Colborne)	Design and Construction	A/A+	$150,000
40	SWM for Road Reconstruction	001149	Chatham Street (Park to Murray)	Design and Construction	A/A+	$150,000
41	SWM for Road Reconstruction	000971	Clarence Street (Colborne to West)	Design and Construction	A/A+	$300,000
42	SWM for Road Reconstruction	000338	Sheridan Street (Rawdon to Fourth)	Design and Construction	A/A+	$150,000
43	SWM for Road Reconstruction	001345	Pearl Street (St James to West)	Design and Construction	A/A+	$150,000
44	SWM for Road Reconstruction	000832	Wayne Gretzky Parkway (Lynden to Colborne)	Design and Construction	A/A+	$300,000
45	SWM for Road Reconstruction	000406	Alfred Street (Colborne to Dalhousie)	Design and Construction	A/A+	$150,000
46	SWM for Road Reconstruction	001342	Aylmer Street (Darling to Chatham)	Design and Construction	A/A+	$150,000
47	SWM for Road Reconstruction	000015	Brighton Ave (Huron to Superior)	Design and Construction	A/A+	$150,000
48	SWM for Road Reconstruction	001139	Darling Street (Queen to Market)	Design and Construction	A/A+	$150,000

Table 10.3 Subwatershed SWM Strategy – Medium to Long-Term Implementation Plan						
Priority	**Project Type**	**Project ID**	**Location**	**Activity**	**Class EA**	**Estimated Cost**
49	SWM for Road Reconstruction	001347	Dundas Street (St Paul to West)	Design and Construction	A/A+	$150,000
50	SWM for Road Reconstruction	00905 and 00906	Stanley Street and Rawdon Street	Design and Construction	A/A+	$150,000
51	SWM for Road Reconstruction	001142	Usher Street (Main to Dead End)	Design and Construction	A/A+	$150,000
52	SWM for Road Reconstruction	001349	West Street (Dundas to Charing Cross)	Design and Construction	A/A+	$150,000
53	SWM for Road Reconstruction	001306	Charing Cross Street (West to Henry)	Design and Construction	A/A+	$150,000
54	SWM for Road Reconstruction	001138	Rawdon Street (Dalhousie to Wellington)	Design and Construction	A/A+	$150,000

1. Construction costs are conceptual estimates only (Class D Cost Estimate as per CCA guidelines) and assumes non-contaminated material for removal (with respect to SWMF outfall retrofits). Refer to Appendix E for cost breakdown. Construction cost estimate will be further refined as part of detailed design process
2. Design costs for SWMF retrofits 4 and 5 are preliminary only and subject to outcomes of further investigations/studies/agreements. Given the uncertainty no construction cost estimates have been prepared for these alternatives.

10.1.2 Costing and Financing

10.1.2.1 Costing/Budgeting for Short-Term Projects

A summary of the estimated costing for Short-Term Stormwater Management Strategy Projects (approximately 2020/2021) has been provided previously in Tables 10.1 and 10.2 (Short-Term Projects).

As noted previously, a key consideration is the availability of a Federal Government funding grant to support the construction of the highest priority measures in 2020/2021. This includes three (3) high priority OGS retrofits, and the Shallow Creek SWMF retrofit.

10.1.2.2 Costing/Budgeting for Medium to Long-Term Projects

A summary of the estimated costing for Medium to Long-Term Stormwater Management Strategy Projects – (approximately 2022-2029) has been provided previously in Table 10.3.

Construction of the proposed Rawdon Street (Shallow Creek Trail) SWMF Outfall retrofit is the largest budget item with respect to medium to long-term projects and would require specific consideration of potential funding sources.

A key unknown relates to the potential construction costs associated with SWMF outfall retrofits at sites 4 and 5 (i.e. Glebe Lands and Arrowdale Golf Course). As noted previously, the potential construction of Sites 4 and 5 remains preliminary and would require a feasibility assessment and further consultation, (particularly due to the pending sale of the golf course lands), which is proposed to be completed as part of the short-term works. More detailed cost estimates for these projects would be developed as part of those feasibility assessments.

Beyond the estimated annual additional SWM costs for road reconstructions, certain types of projects reflect the same typical annual works – one (1) OGS retrofit per year ($300,000 annually – Class D Cost Estimate as noted previously; should be refined as part of detailed design) and cross-connection investigations ($25,000 annually), as well as the estimated budget for additional SWM measures for roadway reconstruction projects ($150,000 to $300,000 depending on the estimated project extents).

10.1.2.3 Financing Options

A general overview of potential funding sources for proposed water quality measures is provided herein. The preceding has assumed that the majority of future funding would be sourced from the City's Capital Budget (which in turn would be funded from the City's General Tax Base), however multiple potential options for funding should be considered.

General tax base:

The City's tax levy is used in part to support the City's storm water services on an annual basis. The most common municipal funding practice for maintaining municipal storm water management infrastructure not related to proposed development is property taxes. Property taxes are established based upon the value of private properties and the services provided and may be adjusted over time based upon changing property values and operating costs by the Municipality.

Development Charges:

Development Charges represents funding based on percentage levied from all new developments for new municipal services. Development Charges are assigned to new developments, based upon the anticipated costs to implement (and maintain) the requisite infrastructure to support the new development. Development Charges are obtained at the time of development implementation to cover the cost of the required new infrastructure, hence it is not considered a viable source of revenue to support the construction of stormwater retrofit works not directly related to development activities, unless a “cash-in-lieu” approach for an adjacent development can be leveraged.

Storm Water User Pay Rates (Storm Water Utility):

Storm Water User Pay Rates are charged to users for runoff discharged from their property based on land use classification, property size, estimated impervious area and the intensity of runoff contribution to the City's storm water management system infrastructure. Storm Water User Pay Rates (also referred to as Storm Water Utility Fees) have been widely implemented across the United States for decades and have become an increasingly popular source of dedicated storm water funding in Canada. Similar programs have been initiated or are being studied in various Municipalities within Ontario such as Waterloo, London, Kitchener, Richmond Hill, St. Thomas, Aurora, Brampton, Mississauga, Vaughan, Windsor and Cambridge.

The revenue generation capacity of a Storm Water User Pay Rate or Storm Water Utility Fee is similar to that of the real property tax, except that the utility fee is directly linked to the impervious surface cover or another measurable characteristic, rather than assessed value. Determining a legally defensible rate needed to generate revenue sufficient to finance the local storm water needs would require the local government to engage in a “Storm Water Utility Rate Study”. During such a study, important policy decisions are made that can have significant implications for the selected rate. An important first step in the process is to determine the average impervious land cover in square metres for a single-family residential lot. Although it is common for all single family lots to be charged a flat fee, the Equivalent Residential Unit (ERU) can be applied to all other classifications of land. In addition to technical determinations, local governments must address a range of policy questions that ultimately impact the structure of the utility, as well as the storm water utility rate.

Grant Opportunities:

Funding from upper level governments can sometimes be available to help offset the cost of storm water management infrastructure improvements. The City of Brantford is currently leveraging such a grant from the Federal Government to complete the current study, and also to implement the highest priority measures in 2020/2021.

Other examples of government grant programs are the Province's Municipal Infrastructure Investment Initiative through Infrastructure Ontario and the recent Federal Infrastructure Stimulus funding, including the Clean Water and Wastewater (CWW) program.

While grant opportunities should be leveraged to the extent possible to support retrofit water quality measures, they do not represent a steady or long-term source of available funding.

Other Considerations:

Ultimately, the City of Brantford will need to determine internally how best to fund the capital costs for the proposed projects on a long-term basis.

In addition to capital costs, the City should also consider the longer-term operations and maintenance costs of the proposed stormwater quality control measures. To be effective, the proposed measures will require periodic maintenance, particularly inspections and clean-outs of oil/grit separators, which have a limited sediment holding capacity before performance is compromised (typically 1-2 years).

10.2 Monitoring Plan

10.2.1 Overview

In addition to the development of an overall stormwater management (SWM) strategy (and associated implementation plan), a monitoring plan is considered important. A monitoring plan allows for evidence-based confirmation and validation of the effectiveness of the proposed SWM strategy over time. In some cases, the monitoring plan may also identify potential deficiencies or shortcomings and permit adaptive management to mitigate these potential issues.

Field monitoring should build upon the data collected as part of the Characterization Study (Aquafor Beech, October 2019), which would generally be expected to serve as the baseline condition for comparison to future monitoring works. Specific recommendations with respect to sub-disciplines are noted in the following sections.

10.2.2 Geology, Hydrogeology and Groundwater

The present groundwater level data collected for Mohawk Lake provides sufficient data to delineate baseline water level conditions. However, a single round of groundwater quality sampling does not provide enough information on the potential seasonal variations in groundwater quality. To confirm groundwater quality baseline conditions at Mohawk Lake, groundwater quality should be sampled and analyzed for summer and freshet conditions, in addition to the fall results already collected. The existing groundwater monitoring network should be sufficient for monitoring changes to the groundwater system at Mohawk Lake in response to any implemented changes to the subwatershed stormwater management. Prior to implementation the following monitoring frequency should be commenced:

- Groundwater level monitoring of all monitoring wells on a monthly basis (or with logger);

- Groundwater quality monitoring events for spring freshet, summer and fall conditions.

The monitoring should be continued one (1) year after completion of stormwater management works. The requirement for longer-term monitoring should be assessed following completion of this monitoring.

Development occurring in other potential development lands will require a site condition assessment for soil and groundwater contamination to determine risk of contaminant mobilization in groundwater. Additional groundwater monitoring may need to be implemented based on the results of these site condition assessments.

10.2.3 Fluvial Geomorphology

A total of three (3) erosion sites were identified in the Characterization Study (October 2019). Of these, two (2) were located on tributaries which although within the Mohawk Lake subwatershed, are generally considered to be outside of the primary area of interest (i.e. areas draining directly to Mohawk Lake). The third erosion site is located within Shallow Creek Park, where a SWMF retrofit (Site 1) is proposed. The form of the erosion mitigation and associated channel design will be determined as part of the subsequent detailed design phase. Notwithstanding, baseline channel monitoring for the ultimately re-aligned channel should be implemented. In addition, potential adjustment/re-alignment and dredging of the West Canal is proposed for future works (ref. Environmental Assessment Report, Wood, 2020). Baseline channel monitoring for the re-designed channel should also be incorporated in that case.

Post-construction channel monitoring would be expected to consider the installation of erosion control pins and control cross-sections to monitor on-going stream adjustments over time as compared to the (new – reconstructed) baseline condition. Annual field measurements of the control sections would be combined with the completion of a photographic inventory to assess any potential visual changes. These monitoring works would then determine the stability of the re-constructed channel sections, and whether any further

Further requirements for fluvial geomorphological monitoring should also be considered as part of the detailed design effort for construction projects and associated permitting requirements.

10.2.4 Hydrology and Flow

Baseline water level and flow monitoring was incorporated into the Characterization Study (Aquafor Beech, October 2019). A total of four (4) gauges were installed at various locations along Mohawk Canal (west and east branches) as shown in Drawing 12. Ultimately, a rating curve (water level – flow relationship) could only be established at one (1) location (FM-1, downstream of the Mohawk Lake control structure). For other locations, the backwater/tailwater from Mohawk Lake (FM2/3) and potential issues with backwater and groundwater losses (FM4) prevented the establishment of defined rating curves. As such, the data from the Characterization Study provide a reasonable basis for typical water level variations, but not flows. Flow monitoring data for upstream areas within the sewershed are available from the City-Wide Storm Flow Monitoring and

System Model Calibration Study (AB/TQI, 2018), which was the basis for the current InfoSWMM model calibration (as per Section 5).

Overall, the primary focus of the preferred stormwater management strategy is upon water quality, although erosion control, and quantity control for upstream works (which could impact existing drainage system capacity) are also a concern. As such, the proposed monitoring plan for hydrology/flows within the Mohawk Lake subwatershed is two-fold:

- Periodic flow monitoring within storm sewers in the upstream sewershed (potentially at the same locations from the 2018 study) to support further model calibration and also in any areas where retrofit quantity controls are planned (site re-developments, road reconstruction or otherwise) both under pre-construction and post construction conditions.
- Monitoring of any end of pipe SWMF retrofits to assess functionality and conformance with the intended design. This would be expected to include inflow monitoring, as well as water level monitoring within the permanent pool, and potentially outflow monitoring as well.

Water level gauges should be located in sites where a rating curve can reasonably be established through the collection of periodic velocity measurements and channel geometry. It is recommended that the gauging be completed for warm weather months in the year (April to November typically), and be complemented by a site rainfall gauge, to obtain local rainfall data to support subsequent analyses.

10.2.5 Water Quality

The focus of the current project is on water quality hence monitoring measures for the overall subwatershed are considered necessary. Specific water quality monitoring requirements for Mohawk Canal and Lake are addressed in further detail as part of the separate EA Report (Wood, 2020).

With respect to subwatershed water quality monitoring, it is understood that the City of Brantford currently undertakes spot water quality measurements as part of its existing programs. This program should be continued to collect baseline quantity and quality monitoring at selected outfalls to Mohawk Lake and Mohawk Canal, with the intent to establish current conditions and thereby monitor/track the improvements over time. As such, monitoring work should also be targeted to locations where capital works are planned (i.e. SWMF or OGS retrofits) to similarly establish a baseline condition in these locations. Once the proposed measures are implemented, a monitoring program specific to that location should be undertaken. This would be expected to involve the collection of grab samples both upstream and downstream of the facility, in order to directly quantify the performance, and compare against the approved design. Such a program is frequently a requirement of the Ministry of the Environment, Conservation and Parks (MECP) for new Environmental Compliance Approvals (ECAs).

Separately from the preceding, there is also value in undertaking investigative sampling programs, such as the pollution tracking monitoring completed as part of the Characterization Study (October 2019). Such programs involve rounds of sampling, moving further upstream in the sewershed, to identify areas of particular concern. Such programs may aid in adjusting and targeting priorities and need for future retrofit works.

10.2.6 Sediment Quantity and Quality

No specific sediment quantity and quality sampling is recommended as part of the subwatershed stormwater plan. Separate sediment quantity and quality sampling is however recommended to support the proposed works along Mohawk Canal and Mohawk Lake, specifically potential future strategic removal of sediment and lake bed re-contouring works and any potential retrofit works along the West Canal.

Future sediment quantity and quality monitoring would however be required on an ongoing basis for constructed retrofit measures, including SWMF retrofits and OGS retrofits. For SWMF retrofits, this would be expected to take the form of periodic bathymetric surveys, to monitor the accumulation of sediment within wet pond areas and forecast clean-out frequency. Following construction, an initial survey should likely be completed within 2 years of construction, with subsequent surveys to occur less frequently (every 5 years) or as indicated by the estimated rate of sedimentation.

A similar assessment should be conducted on an annual basis for OGS units, which have a much more limited sediment holding capacity. Annual inspections should be completed in either the early spring or late fall, to confirm the need for clean-out, based on the Manufacturer’s recommendations. Ideally all OGS units should be designed with a 2-year holding capacity, however similar to SWM facilities, the actual rate of sedimentation will need to be confirmed through field measurements.

10.2.7 Natural Environment

The Characterization Study does not cover areas relative to the Shallow Creek or Rawdon Street SWM retrofits (ID#1 and ID#2 respectively). The Rawdon Street retrofit is proposed outside of the existing aquatic environment, and therefore, no further aquatic investigations have been recommended at this time. In order to properly identify constraints and inform future design, additional monitoring is recommended, which includes the following:

- Completion of a two (2) season (spring and summer) botanical inventory and evaluation and mapping of the existing vegetation communities using the Ecological Land Classification (ELC) system for southern Ontario (Lee 1998);
- Completion of breeding bird surveys consistent the Ontario Breeding Bird Atlas (two surveys timed 15 days apart between late May and 10 July);
- Potential maternity roost habitat has been documented in the Characterization Study. It is recommended that MECP be consulted regarding information required to determine mitigation for tree removal, should tree removals be proposed.
- For Shallow Creek (ID #1 only) A fish community survey program to collect information is recommended. Aquatic habitat characterization will be carried out by following the Ministry of Transportation/Fisheries and Oceans Canada/MNRF fisheries protocol. This will include the collection of data pertaining to the general morphology of the reach (bankfull depth, channel width, and stream gradient), instream and riparian vegetation, occurrences of seeps or springs, general description of substrates as they relate to potential fish habitat, and

flow. Information collected will be used to identify fisheries' constraints and evaluate impacts on existing fisheries resources (as needed).

- An evaluation of wildlife habitat features, potentially significant wildlife habitat, general extent of habitat use and potential linkage functions between the natural areas, particularly for SAR, to the extent feasible;
- Search for Reptile hibernaculum to document burrows, rock piles, old stone fences, abandoned crumbling foundations, and wetlands to confirm absence and presence;
- Butternut field survey to confirm the presence or absence of species. No parent Butternut were observed during the field investigations in the Characterization Report. However, several young walnut species were noted in communities 10 and 11 that exhibited signs of a Butternut Hybridity. Confirmation should be made through another field survey with the potential submission of DNA samples to MNRF. It is important to note these features are not adjacent or within 120 m of the proposed Shallow Creek and Rawdon pond areas, however, given their proximity a search for Butternut is recommended which would occur in tandem with the recommended three (3) season botanical inventory; and
- A tree inventory to document the trees that may be impacted by future construction activities shall also be completed.

Given the works that will likely be associated with the Shallow Creek retrofit (ID#1), a project screening process following that outlined by DFO will be required to identify whether a request for review will be required. Similarly, in the event SAR are identified, consultation and review with MECP and potentially DFO (aquatic SAR) will also be required.

Post-construction monitoring will be identified within the EIS in relation to the field work findings and through further consultation with regulatory agencies. Monitoring requirements may be further identified as part of permitting or approval requirements. At a minimum, some form of monitoring will likely be associated with any vegetation plantings as part of the project, as identified in the warranty period proposed for the project. Similarly, monitoring requirements may also be identified pending design of habitat enhancements identified herein to ensure functionally. All monitoring requirements shall be reviewed during the next phases of the project.

11.0 Summary and Recommendations

11.1 Summary

The Subwatershed Stormwater Plan has involved an analysis of the existing Mohawk Lake subwatershed, in order to understand opportunities and constraints related to remediation and develop a prioritized plan to address the identified issues. The Subwatershed Stormwater Plan is one of the three (3) components of Phase 2 of the overall Mohawk Lake Project, termed the Functional Master Drainage and Restoration Study (ref, Figure 1.1). The other two (2) components, the Environmental Assessment and Master Plan, are intended to integrate with each other to provide an overall coordinated direction towards future implementation and design and construction. The current Subwatershed Stormwater Plan has focused upon the following:

- A new hydrologic/hydraulic model has been developed in InfoSWMM in order to better assess estimated flow responses and drainage system capacity within the subwatershed
  - The model incorporates a dual drainage functionality (storm sewers and roadways) in order to represent conveyance of more formative storm events and allow for an assessment of overland flow system deficiencies
  - The model has been calibrated against available flow monitoring data from the City-Wide Model Calibration Study (2018) to ensure reasonable modelling outputs and associated assessment, including development of preferred alternatives
- The new InfoSWMM modelling has been used to assess estimated inflows to Mohawk Canal and Mohawk Lake and the various storm sewer outfalls under a variety of conditions including
  - Design Storm Events
  - Continuous Simulation (for annual water budgeting)
  - Climate Change altered rainfall (to assess potential changes in flows)
- The InfoSWMM modelling has been used to assess the hydraulic capacity and performance of the drainage system, including
  - Minor (storm sewer) system capacity for the 2, 5 and 10 year storm events
  - Overland flow conveyance capacity for the 100-year storm event
  - Expected peak operating levels within Mohawk Lake for all frequency events
- The previously developed HEC-RAS hydraulic modelling (from the Characterization Study, October 2019) has been updated as part of the current study
  - Flows from the more current InfoSWMM modelling have been employed
  - Model boundary conditions have been updated to better reflect the expected performance of the Mohawk Lake outlet control structure
  - Updated estimated floodplain extents and flood levels have been generated accordingly

- The InfoSWMM modelling has been used to estimate water quality contaminant loadings
  - A simplified Event Mean Concentration (EMC) approach has been applied, based on the suggested EMCs from the Characterization Study (October 2019)
  - The model has been used to characterize existing contaminant loadings from different storm sewer outfalls, and to support the assessment of alternative measures

The preceding components of the Subwatershed Stormwater Plan have all involved the generation of analytical modelling tools to better understand and characterize existing conditions within the Mohawk Lake subwatershed and provide a numerical basis to assess and quantify potential alternative measures.

Based on the results of the preceding analyses and previous background review (including the Characterization Study, October 2019), it is understood that the fundamental stormwater management issue for the Mohawk Lake subwatershed relates to degraded stormwater runoff and a lack of quality control. The alternative assessment review completed as part of the current study, has used this understanding to guide the overall long-listing and short-listing of preferred alternatives.
The completed alternative assessment has also considered non-structural measures (policies and management approaches), as well as structural measures (infrastructure and construction), under both existing and future land use conditions. A preferred suite of alternatives has been developed accordingly. An implementation plan (10-year time frame) has been developed, including preliminary costing information to support decision making by the City of Brantford.

A summary of the preferred alternatives and associated recommendations in provided in Section 11.2.

11.2 Recommendations

Preferred alternatives have been separated into both short-term works (Approximately 2020+) and medium to longer-term works (2022-2029). To summarize the proposed recommendations:

- **Short Term (Approximately 2020+)**
  - **Non-Structural Measures**
    - Update the City of Brantford's SWM policies for re-developments within the Mohawk Lake subwatershed to require "enhanced" quality control (80% average annual TSS removal) for the full impervious area (not only "new" impervious area). Erosion control and quantity control should also be implemented.
  - **Structural Measures**
    - Highest Priority Works
      - Design and construct the highest priority three (3) oil/grit separator (OGS) retrofits in 2020;
      - Design and construct a SWMF retrofit at Shallow Creek Park

            - Undertake the detailed design of a re-alignment, clean-out, and possible water quality retrofit of the upstream portion of the West Mohawk Canal (refer to the separate EA study for details)
        - Other Short-Term Works
            - SWMF Outfall Retrofits
                - Undertake the detailed design of the SWMF retrofit along Shallow Creek Trail (Rawdon Street)
                - Undertake feasibility reviews for SWMF retrofits in the Glebe Land and Arrowdale Golf Course (noting pending sale)
            - Design and construct the next highest priority OGS retrofit (1 additional unit annually)
            - Undertake a focused cross-connection investigation of the area around Rawdon Street and Bruce Street where sanitary waste has been identified in the storm sewer system (as per the Characterization Study, October 2019) and remediate the issue if possible
            - Implement stormwater quality control measures (source controls and or end of pipe measures) into planned roadway reconstruction works

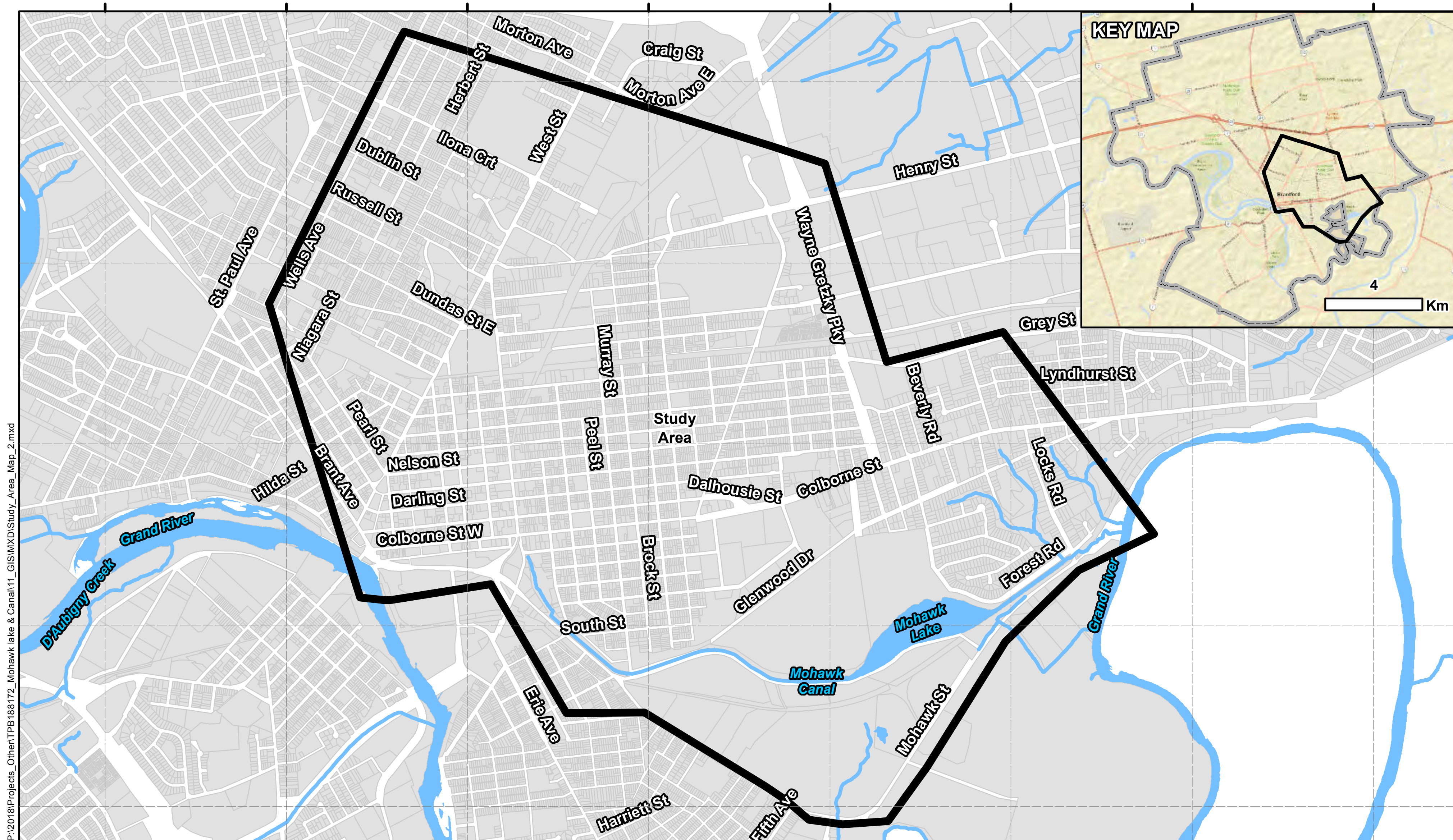
- **Medium to Longer Term (Approximately 2022-2029)**
    - Non-Structural Measures
        - Continue to enforce the City's new SWM policies for re-developments
        - Review City Street Sweeping policies and consider enhanced street sweeping for the Mohawk Lake subwatershed
        - Develop and implement a Road Salt Management Plan for the subwatershed, or potentially City-Wide
        - Undertake a Landfill Contamination Study and implement any associated findings
    - Structural Measures
        - SWMF Outfall Retrofits
            - Construct the SWMF retrofit along Shallow Creek Trail (Rawdon Street)
            - Undertake the detailed design and construction (if feasible) of the SWMF retrofits on the Glebe Lands and Arrowdale Golf Course, if feasible
        - Continue to construct one (1) high priority OGS retrofit each year
        - Continue to undertake cross-connection testing in different areas of the Mohawk Lake subwatershed to identify any potential areas of concern and remediate the issues where possible
        - Implement stormwater quality control measures (source controls and or end of pipe measures) into planned roadway reconstruction works

It is clearly understood that given the capital expenditure requirements for the preceding works, the City will need to explore a variety of potential funding sources. A review of potential funding sources has been provided as part of the Subwatershed Stormwater Plan.

In addition to the preceding, recommendations have been provided for future monitoring works, in order to verify the effectiveness of the proposed measures. This includes both baseline and post-construction monitoring, including hydrogeology, hydrology, ecology, water and sediment quality, and other related disciplines.

The analytical tools developed as part of the current study (hydrologic, hydraulic, and water quality modelling) should continue to be updated and refined to support the analysis of future mitigation measures and also incorporate development changes, including both City-led and private works. This will ensure the modelling tools have longevity and will provide useful information to verify the effectiveness of proposed works. As noted in previous sections, the storm sewer data included within the modelling (based on the original Master Servicing Plan, 2014) are understood to require further review. A data review and update should be completed as part of future works.

Drawings



LEGEND

- Study Area
- Watercourse
- Waterbody
- PropertyParcel

0 0.3 0.6 1.2 1.8 2.4 3 Kilometres

NOTES:
- Regulation Limit from GRCA Open Data, 2019
- Key Map topography from ESRI

Datum: NAD83
Projection: UTM Zone 17N

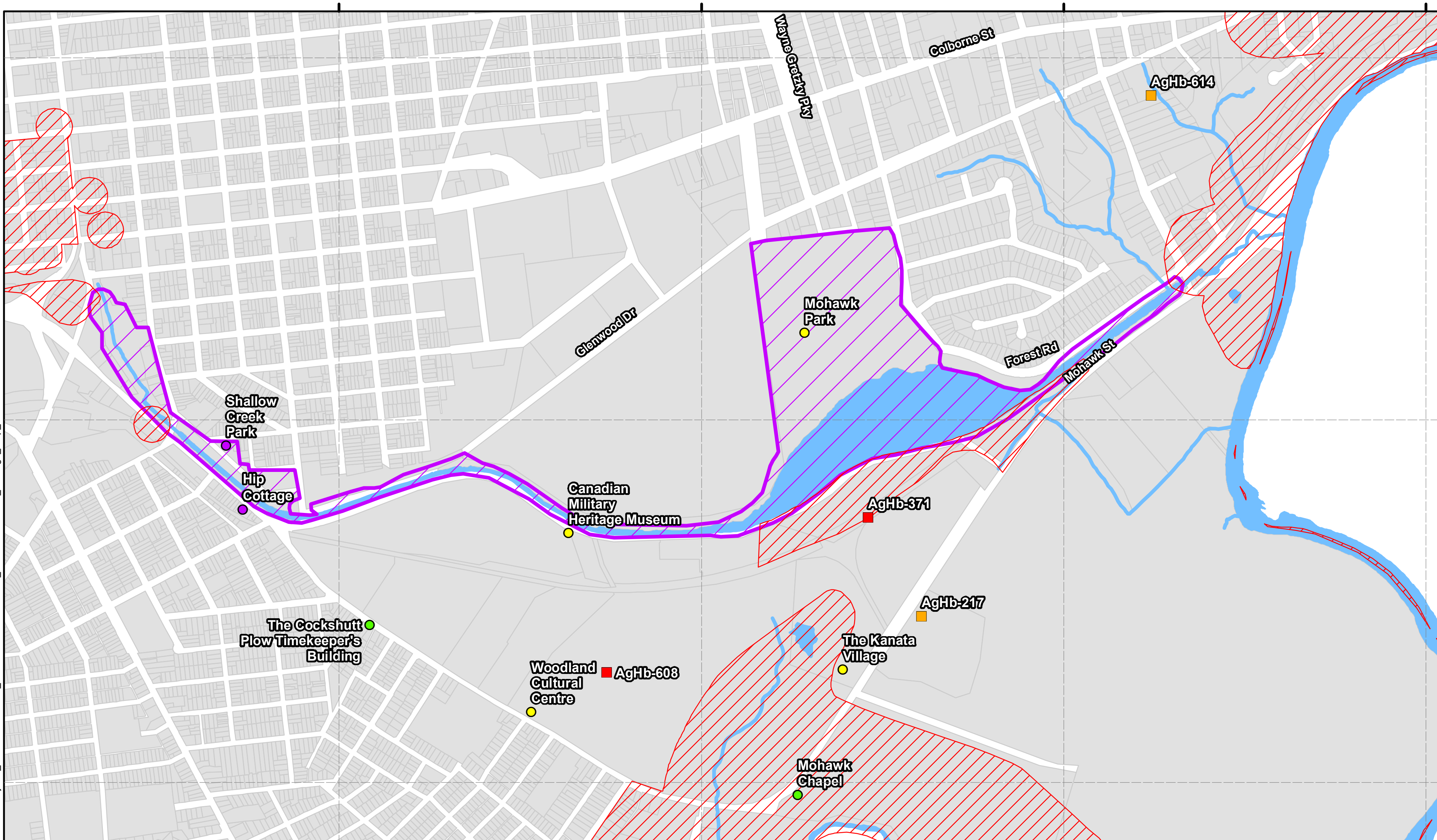
N W E S

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Study Area Map

PROJECT Nº: TPB188172	**DRAWING: 1**
SCALE: 1:30,000	DATE:December 2019



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LEGEND

- Watercourse
- Waterbody
- Property Parcel
- Archaeological Potential
- Cultural Heritage Landscape Designation

Cultural Heritage Site of Significance

- Designated
- Listed
- Potential for Designation

Archaeological Assessment (AA) Status

- No Further AA Required
- Stage 4 AA Required

0 0.15 0.3 0.6 0.9 1.2 1.5 Kilometres

NOTES:

Datum: NAD83
Projection: UTM Zone 17N

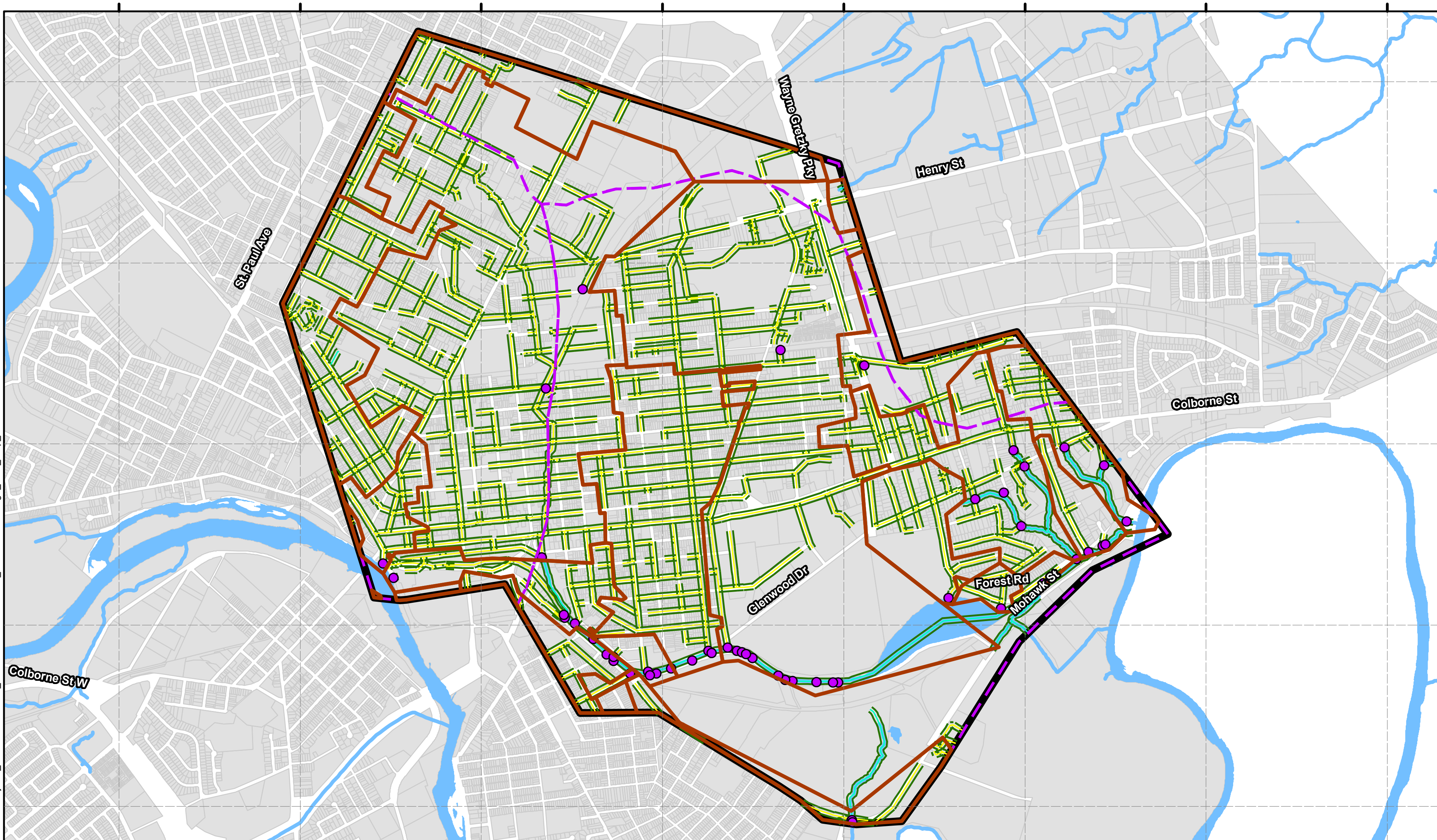
N W E S

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Cultural Heritage and Archaeological Constraints Mapping

PROJECT N°: TPB188172	DRAWING: 2
SCALE: 1:15,000	DATE: December 2019



LEGEND

- Study Area
- Watercourse
- Waterbody
- PropertyParcel
- Subcatchment Basin (GRCA)
- Stormwater Sewershed
- Open Drain
- Gravity Pipe
- Discharge Point

NOTES:
Regulation Limit from
GRCA Open Data, 2019

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Drainage Area Map

Datum: NAD83
Projection: UTM Zone 17N

N W E S

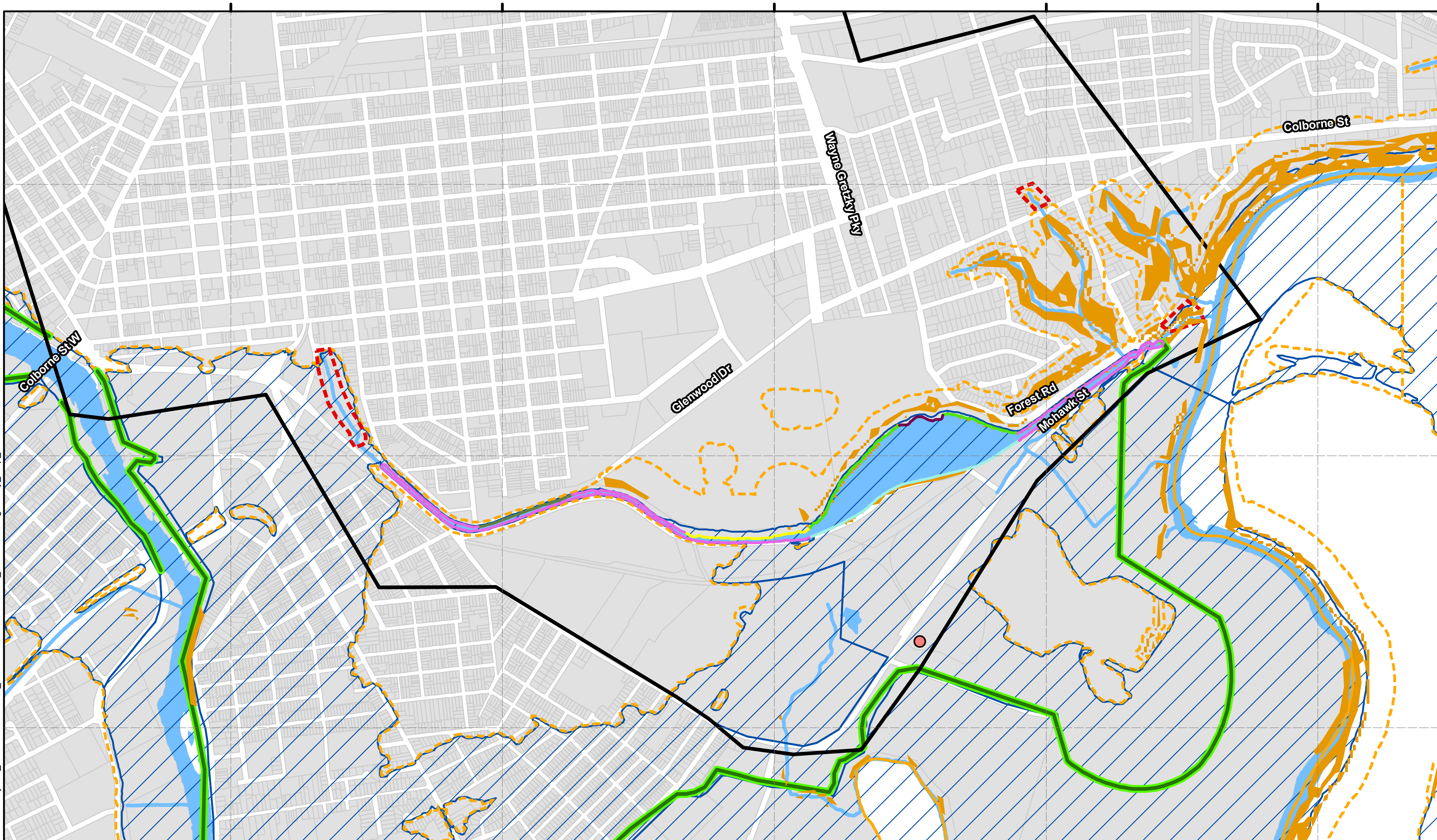
PROJECT Nº: TPB188172

DRAWING: 3

SCALE: 1:30,000

DATE:December 2019

0 0.3 0.6 1.2 1.8 2.4 3
Kilometres



LEGEND

- Brantford Water Pollution Control Plant
- Study Area
- Watercourse
- Waterbody
- Property Parcel
- Dyke System (City of Brantford Waterfront Master Plan)

Bank Assessment

- Natural Slope and Shoreline
- Natural Riparian Bench Shoreline Marsh
- Artificial Bench Shoreline Access
- Artificial Slope with Locally Undercut Banks
- Artifical Slope with Locally Eroded Banks
- Artifical Banks

- Erosion Site
- Regulation Limit
- Slope Hazard
- Regulatory Floodplain

NOTES:
Regulation Limit from GRCA Open Data, 2019

Datum: NAD83
Projection: UTM Zone 17N

0 0.2 0.4 0.8 1.2 1.6 2 Kilometres

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

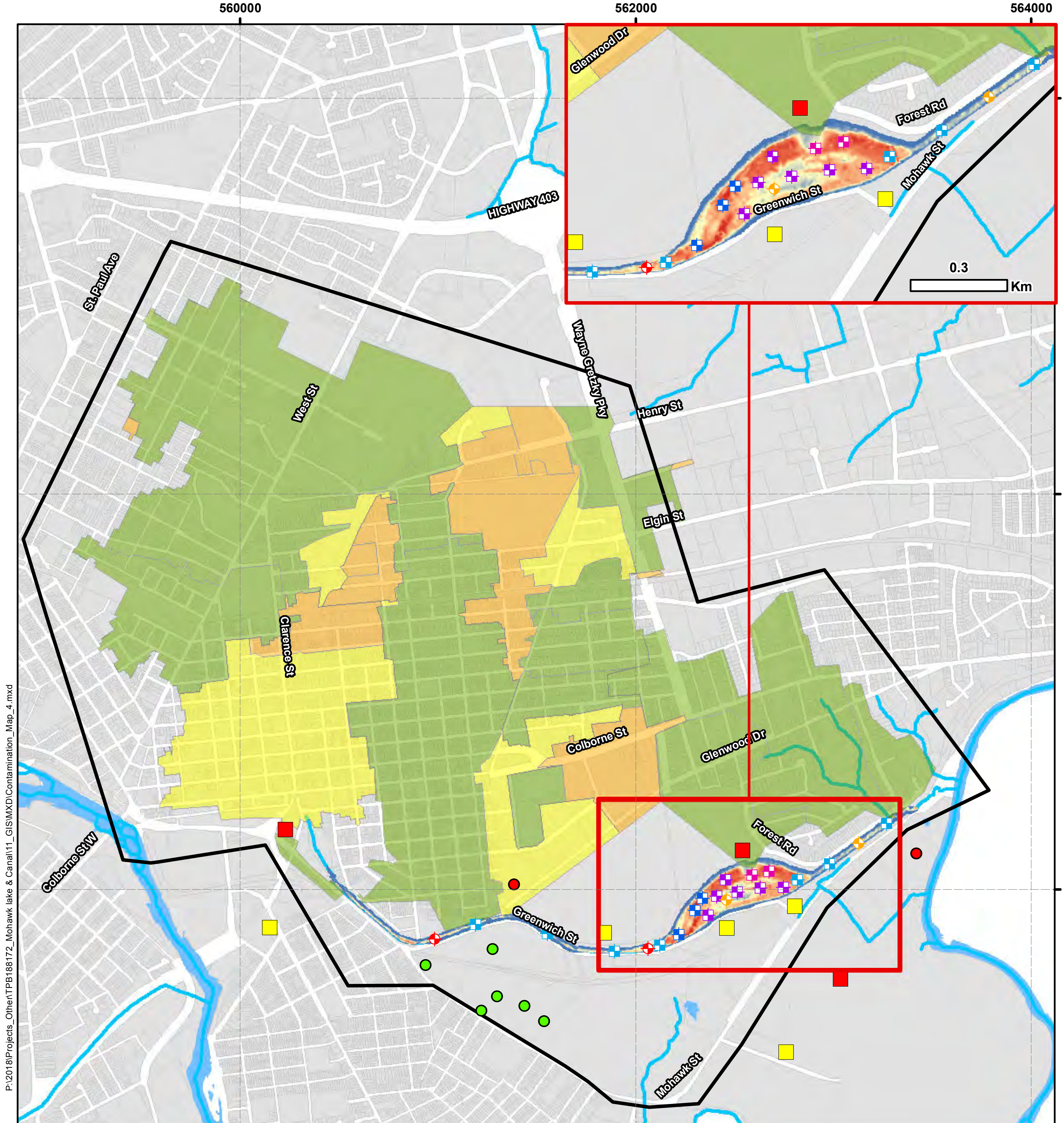
Regulation Mapping

PROJECT N°: TPB188172

DRAWING: 4

SCALE: 1:20,000

DATE:December 2019



LEGEND

- Study Area
- Watercourse
- Waterbody
- Property Parcel

Water Quality in Lake and Canal

- WQ Standard Exceedances
- WQ Standard Significant Exceedances

Water Quality in Upstream Watershed

- Good
- Fair
- Poor

Identified Pollutant Sources

- Active Industrial Site
- Remediated Site
- Active Landfill
- Abandoned Landfill

Sediment Sampling Station

- Pending Results
- Severe - 2 Parameter Exceedances
- Severe - 1 Parameter Exceedances
- Exceeds Lowest Effect Exceedances

Sediment Depth

High : 2.34

Low : -0.38

0 0.2 0.4 0.8 1.2 1.6 2 Kilometres

NOTES:

Datum: NAD83
Projection: UTM Zone 17N

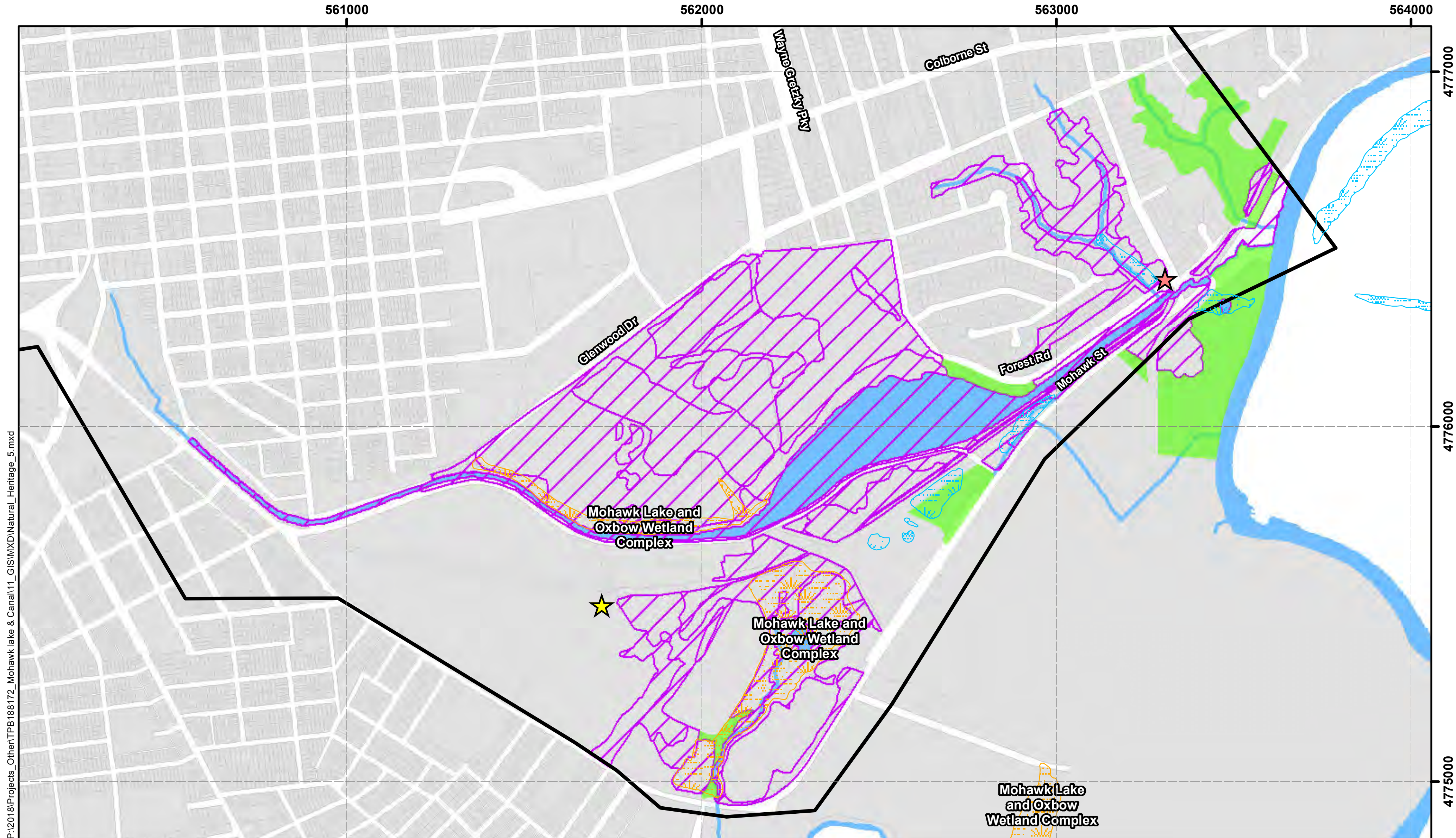
N W E S

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Stormwater Quality and Contamination Map

PROJECT N^{o}: TPB188172	**DRAWING: 5**
SCALE: 1:26,000	DATE: December 2019



LEGEND

- Study Area
- Watercourse
- Waterbody
- Property Parcel
- Rare Vegetation Community (Provincially Significant)
- Confirmed Significant Wildland Habitat
- Wetland (Non - PSW)
- Provincially Significant Wetland (Recommended)
- Osprey Nest
- Barn Swallow Nest

NOTES:
Regulation Limit from GRCA Open Data, 2019

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Natural Heritage Map

Datum: NAD83
Projection: UTM Zone 17N

N E S W

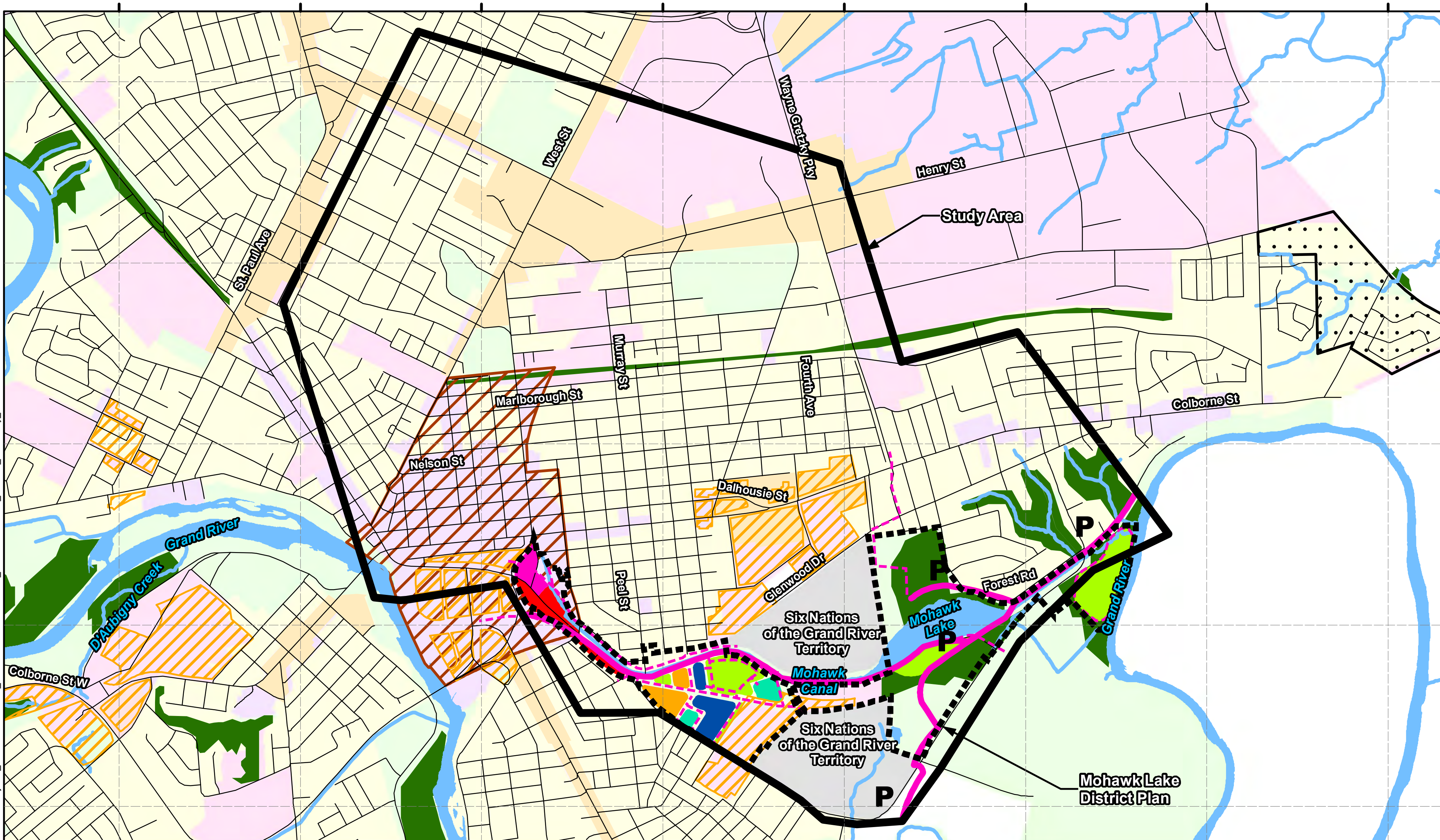
PROJECT N°: TPB188172

DRAWING: 6

SCALE: 1:15,000

DATE:December 2019

0 0.15 0.3 0.6 0.9 1.2 1.5 Kilometres



P:\2018\Projects_Other\TPB188172_Mohawk lake & Canal\11_GIS\MXD\Future_Growth_Summary_2.mxd

LEGEND

- Study Area
- Mohawk Lake District Plan
- Watercourse
- Waterbody
- Primary Waterfront Trail (Existing)
- Proposed Trail
- P Parking (Proposed)

Land Use Designation

- Greenfield Area
- Intensification Corridor
- Urban Growth Centre

Built-Up Area

- Comunity Commercial Centre
- Employment Land
- Employment Area
- Core Natural Area
- Existing Stable Neighbourhood

Development

Proposed Development

- Enhanced Mixed Use Gateway
- Institutional
- Mixed Commercial
- Mixed Use Corridor
- Museum
- Potential New Park

Potential Development

- Potential Development Area

0 0.3 0.6 1.2 1.8 2.4 3 Kilometres

NOTES:
- Regulation Limit from GRCA Open Data, 2019
- Proposed development from Mohawk Lake District Plan - Overall Draft Preferred Plan

Datum: NAD83
Projection: UTM Zone 17N

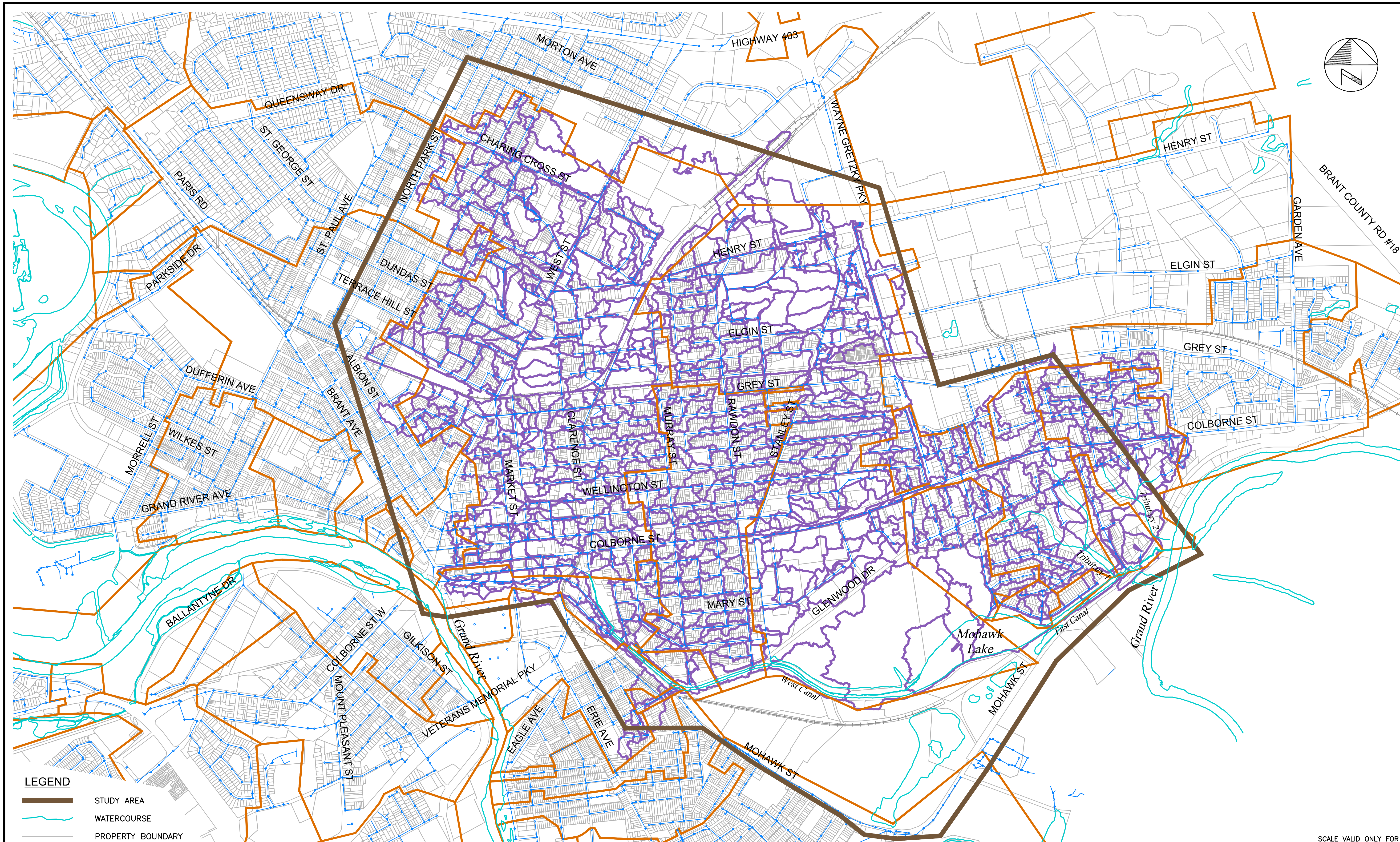
N E S W

wood.

MOHAWK LAKE AND CANAL SUBWATERSHED STORMWATER PLAN REPORT

Future Growth Summary

PROJECT N°: TPB188172	DRAWING: 7
SCALE: 1:30,000	DATE:December 2019



MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY
CITY OF BRANTFORD

SUBCATCHMENT BOUNDARY PLAN

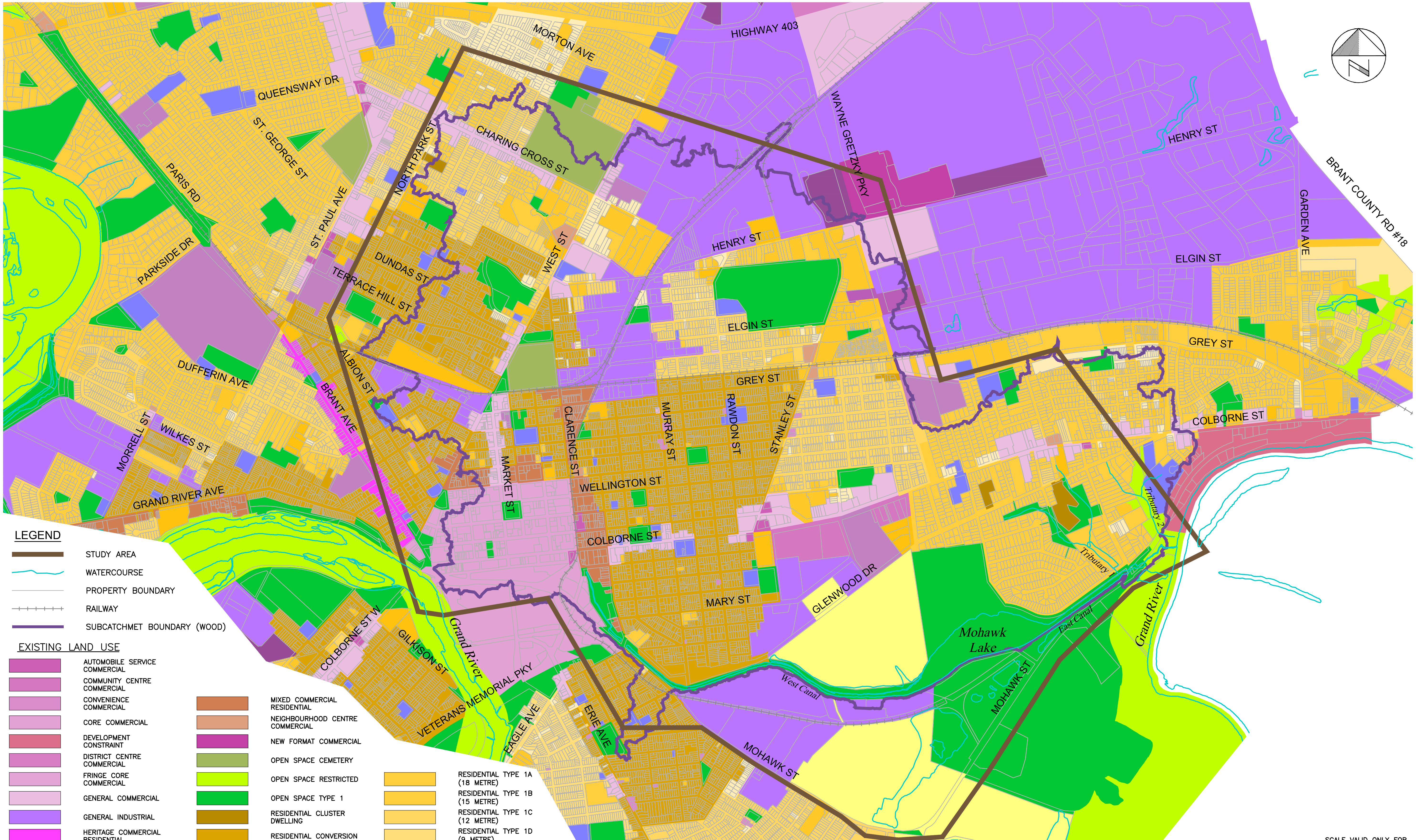
wood.

Scale 1:10000
0 100 200 400

Consultant File No. TPB188172

Drawing No. 8

Path: P:\2018\Projects\TPB188172 - Mohawk Lake & Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 8 SubCatchment.dwg
Plotted By: mike.loncar
Last Saved By: mike.loncar
Plotted: 2019-12-04
Last Saved: 2019-12-04



MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY
CITY OF BRANTFORD

EXISTING LAND USE PLAN

wood.

Scale 1:10000 (0 100 200 400)

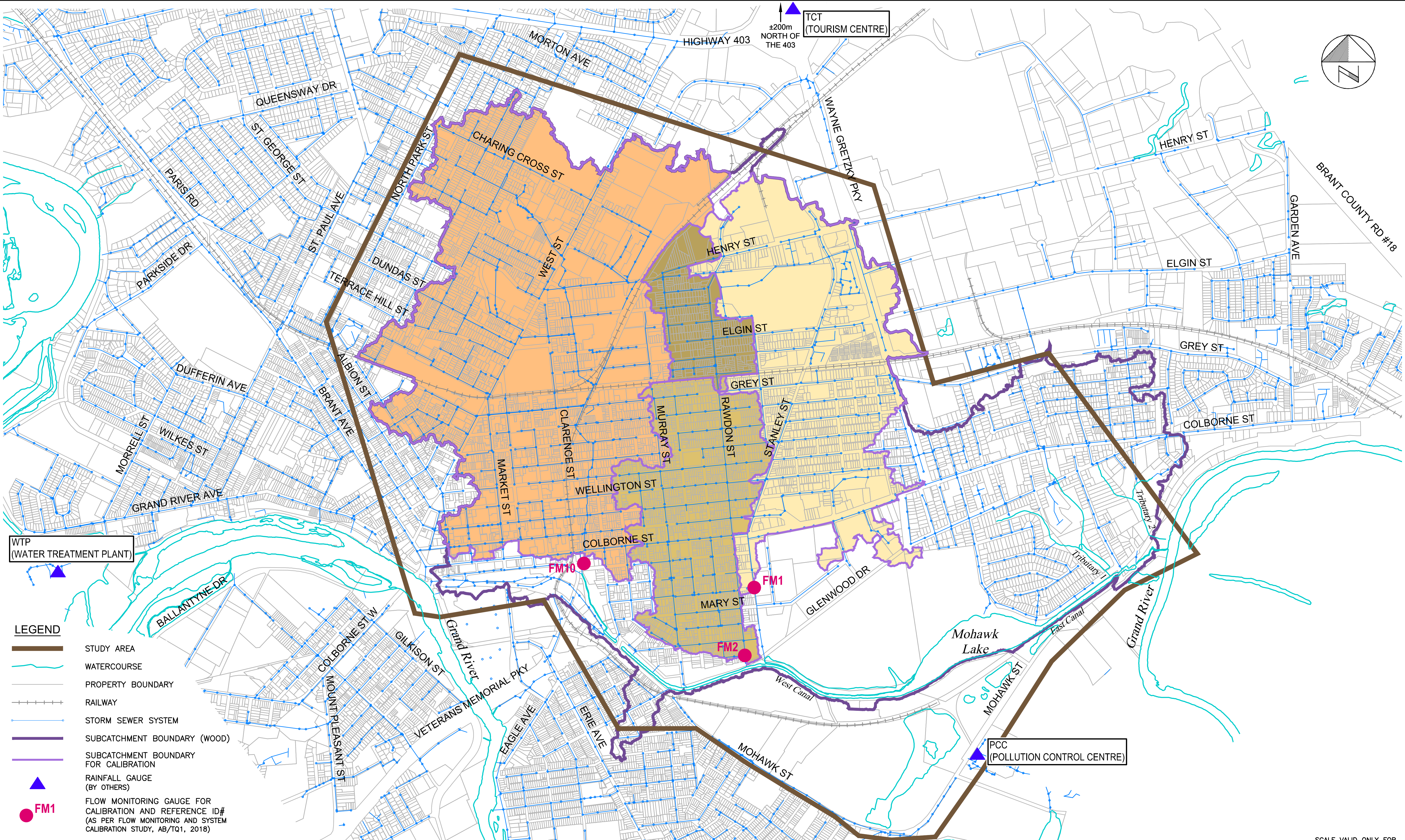
Consultant File No. TPB188172

Drawing No. 9

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 9 LandUse.dwg

Plotted: 2019-12-04 Last Saved: 2019-12-04

Plotted By: mike.loncar Last Saved By: mike.loncar

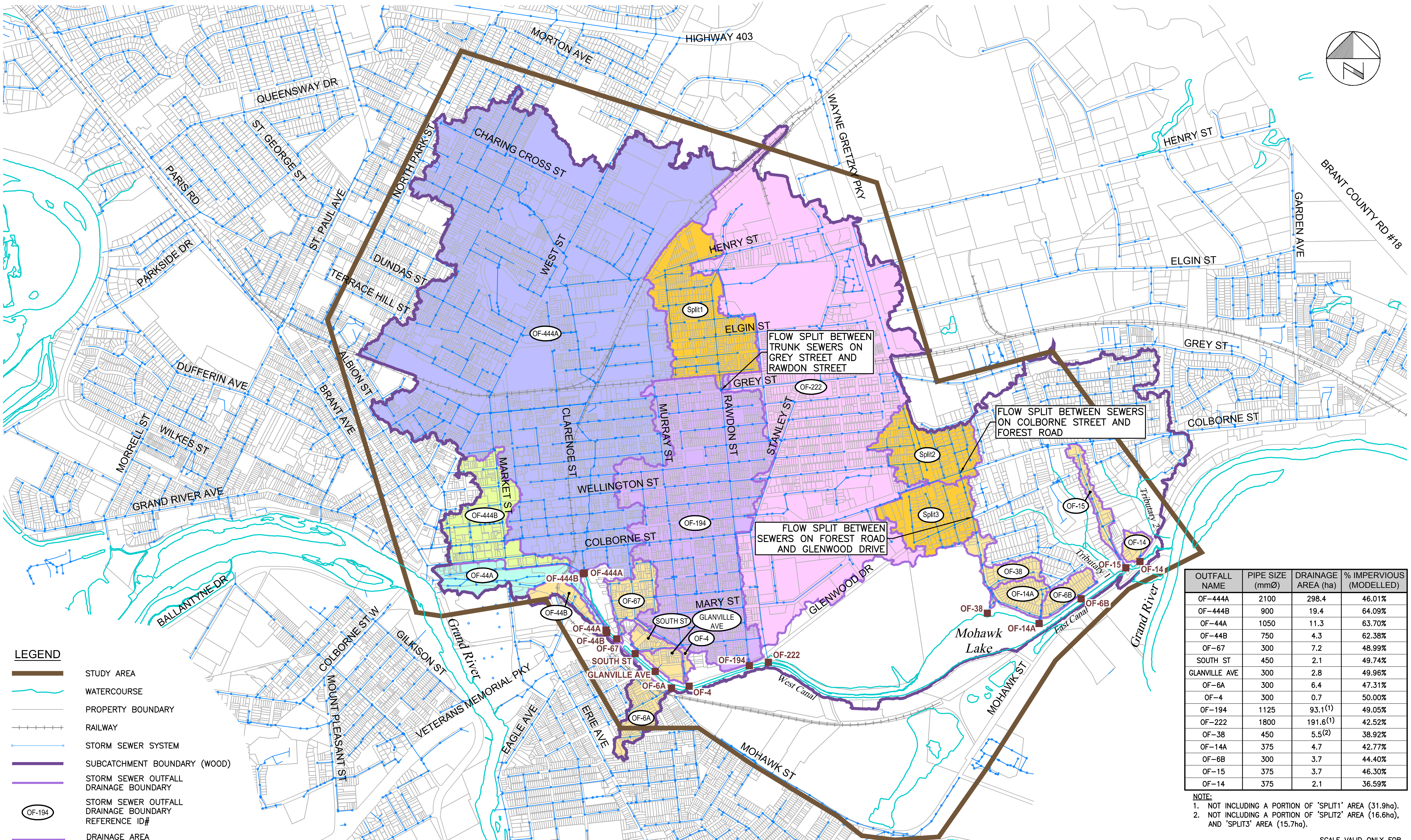


SCALE VALID ONLY FOR 24"x36" VERSION

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY CITY OF BRANTFORD	FLOW CALIBRATION PLAN	wood.	Scale 1:10000 (0 100 200 400)
			Consultant File No. TPB188172
			Drawing No. 10

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Mohawk Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 10 Calibration.dwg

Plotted: 2019-12-04 Plotted By: mike.lancar
Last Saved: 2019-12-04 Last Saved By: mike.lancar



OUTFALL NAME	PIPE SIZE (mmØ)	DRAINAGE AREA (ha)	% IMPERVIOUS (MODELLED)
OF–444A	2100	298.4	46.01%
OF–444B	900	19.4	64.09%
OF–44A	1050	11.3	63.70%
OF–44B	750	4.3	62.38%
OF–67	300	7.2	48.99%
SOUTH ST	450	2.1	49.74%
GLANVILLE AVE	300	2.8	49.96%
OF–6A	300	6.4	47.31%
OF–4	300	0.7	50.00%
OF–194	1125	93.1(1)	49.05%
OF–222	1800	191.6(1)	42.52%
OF–38	450	5.5(2)	38.92%
OF–14A	375	4.7	42.77%
OF–6B	300	3.7	44.40%
OF–15	375	3.7	46.30%
OF–14	375	2.1	36.59%

NOTE:

1. NOT INCLUDING A PORTION OF 'SPLIT1' AREA (31.9ha).
2. NOT INCLUDING A PORTION OF 'SPLIT2' AREA (16.6ha), AND 'SPLIT3' AREA (15.7ha).

SCALE VALID ONLY FOR 24"x36" VERSION

LEGEND

- STUDY AREA
- WATERCOURSE
- PROPERTY BOUNDARY
- RAILWAY
- STORM SEWER SYSTEM
- SUBCATCHMENT BOUNDARY (WOOD)
- STORM SEWER OUTFALL DRAINAGE BOUNDARY
- OF-194 — STORM SEWER OUTFALL DRAINAGE BOUNDARY REFERENCE ID#
- DRAINAGE AREA TO SINGLE OUTFALL (LESS THAN 10ha)
- SPLIT DRAINAGE AREA TO MULTIPLE OUTFALLS
- OF-14 — STORM SEWER OUTFALL LOCATION AND REFERENCE ID# (AS PER GORE & STORRIE, 1995)

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY
CITY OF BRANTFORD

STORM SEWER OUTFALL DRAINAGE AREA PLAN

wood.

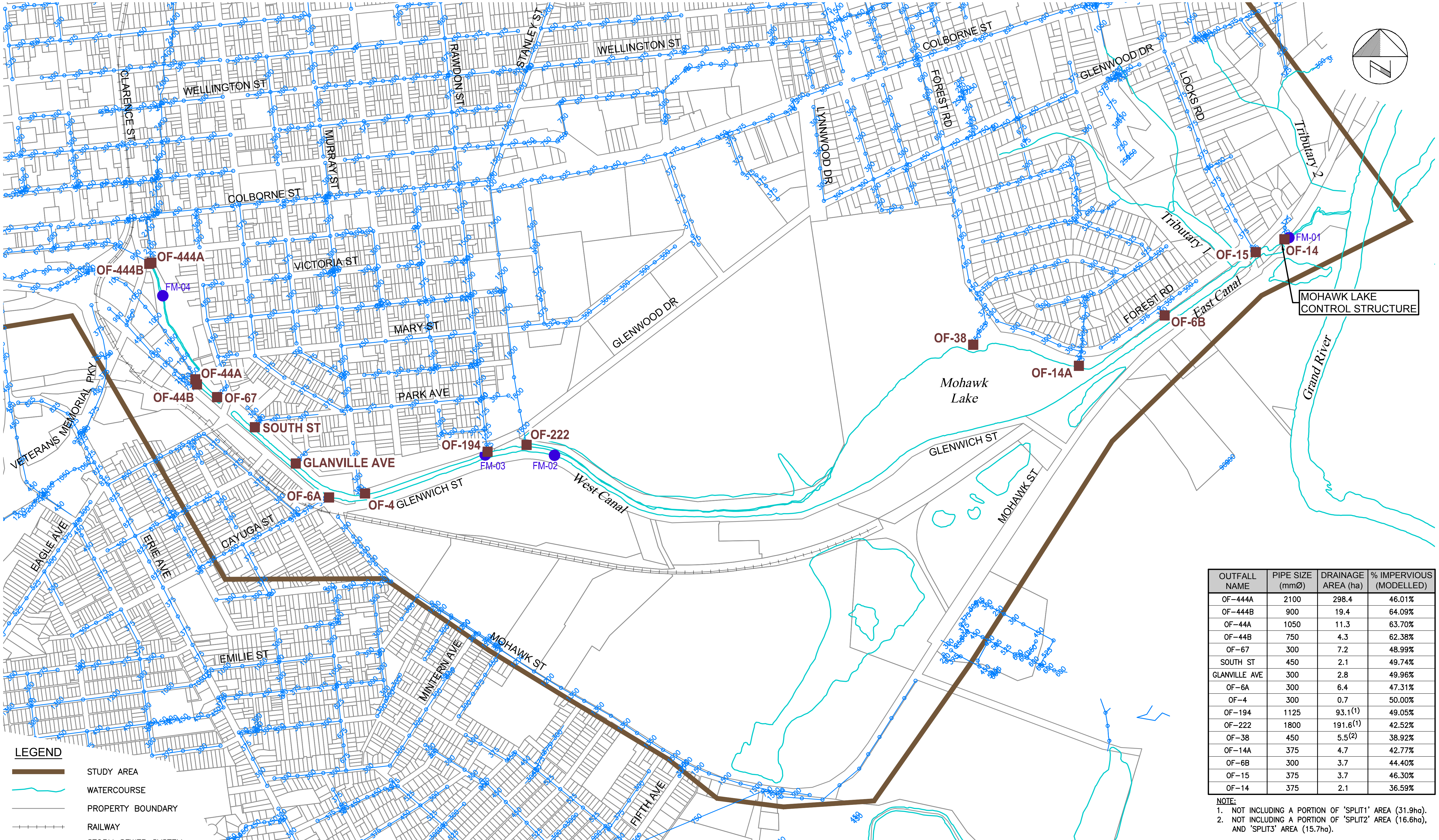
Scale 1:10000 (0 100 200 400)

Consultant File No. TPB188172

Drawing No. 11

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 11 OutfallDA.dwg

Plotted: 2019-12-04 Plotted By: mike.lancar
Last Saved: 2019-12-04 Last Saved By: mike.lancar



OUTFALL NAME	PIPE SIZE (mmØ)	DRAINAGE AREA (ha)	% IMPERVIOUS (MODELLED)
OF–444A	2100	298.4	46.01%
OF–444B	900	19.4	64.09%
OF–44A	1050	11.3	63.70%
OF–44B	750	4.3	62.38%
OF–67	300	7.2	48.99%
SOUTH ST	450	2.1	49.74%
GLANVILLE AVE	300	2.8	49.96%
OF–6A	300	6.4	47.31%
OF–4	300	0.7	50.00%
OF–194	1125	93.1(1)	49.05%
OF–222	1800	191.6(1)	42.52%
OF–38	450	5.5(2)	38.92%
OF–14A	375	4.7	42.77%
OF–6B	300	3.7	44.40%
OF–15	375	3.7	46.30%
OF–14	375	2.1	36.59%

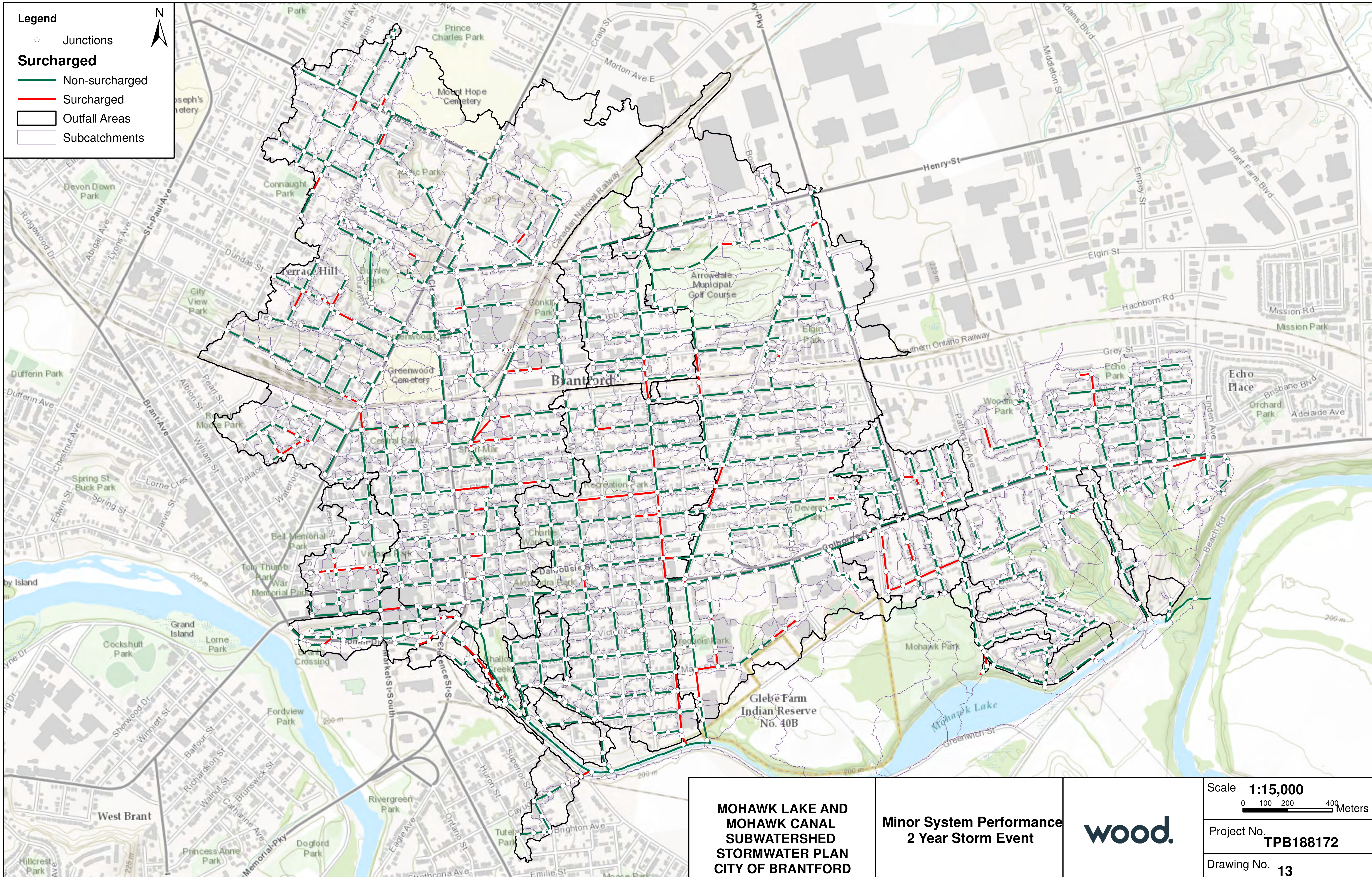
NOTE:
1. NOT INCLUDING A PORTION OF 'SPLIT1' AREA (31.9ha).
2. NOT INCLUDING A PORTION OF 'SPLIT2' AREA (16.6ha), AND 'SPLIT3' AREA (15.7ha).

LEGEND

- STUDY AREA
- WATERCOURSE
- PROPERTY BOUNDARY
- RAILWAY
- STORM SEWER SYSTEM WITH PIPE DIAMETER (mm)
- OF-14 STORM SEWER OUTFALL LOCATION AND REFERENCE ID# (AS PER GORE & STORRIE, 1995)
- FM-01 FLOW MONITORING LOCATION AND REFERENCE ID# (AS PER CHARACTERIZATION STUDY, AQUAFOR BEECH, 2018)

SCALE VALID ONLY FOR 24"x36" VERSION

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY CITY OF BRANTFORD	STORM SEWER OUTFALL LOCATION PLAN	wood.	Scale 1:5000 (0 50 100 200); Consultant File No. TPB188172; Drawing No. 12



MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STORMWATER PLAN CITY OF BRANTFORD

Minor System Performance 2 Year Storm Event

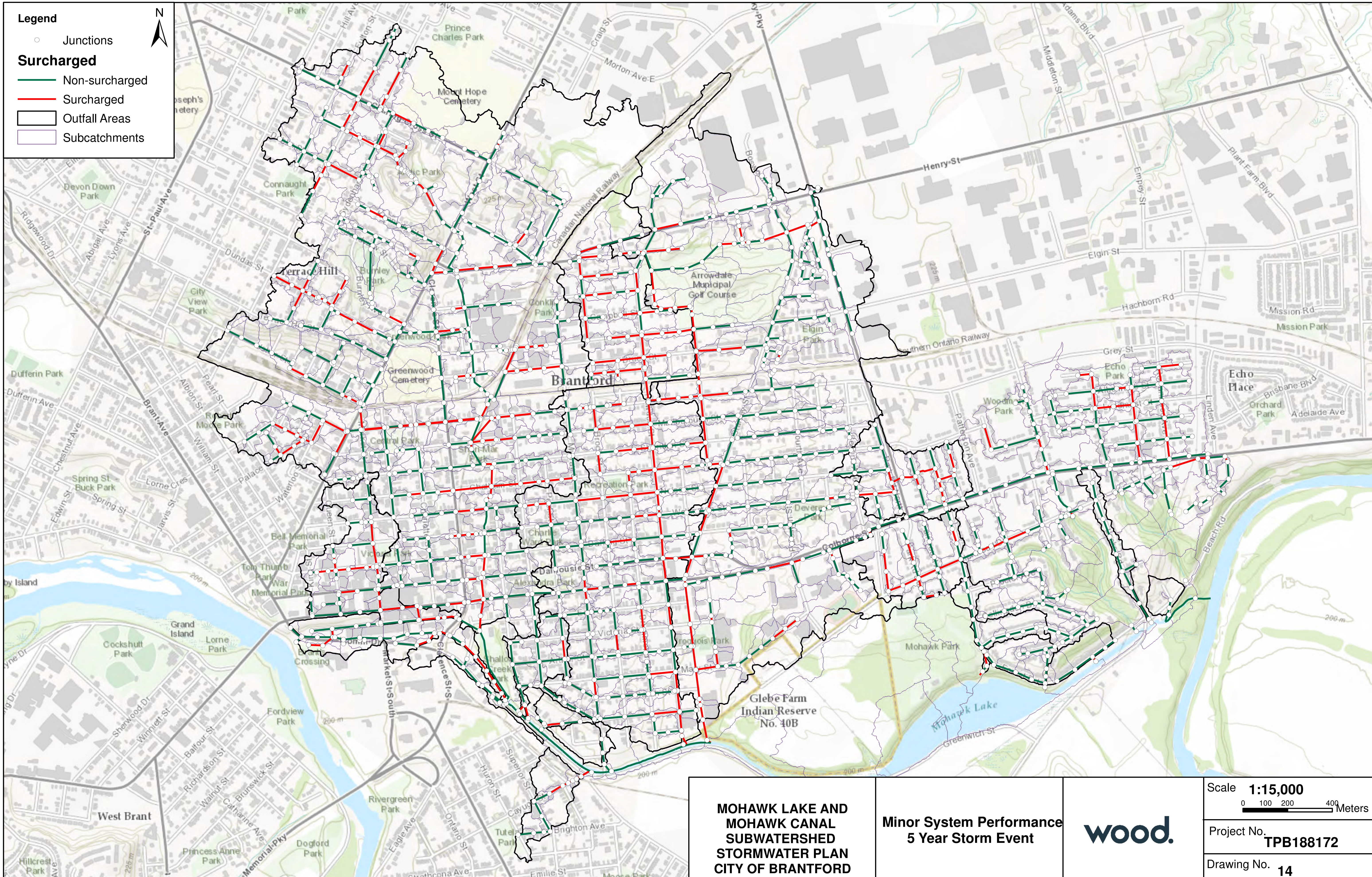
wood.

Scale **1:15,000**

0 100 200 400 Meters

Project No. **TPB188172**

Drawing No. **13**



MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STORMWATER PLAN
CITY OF BRANTFORD

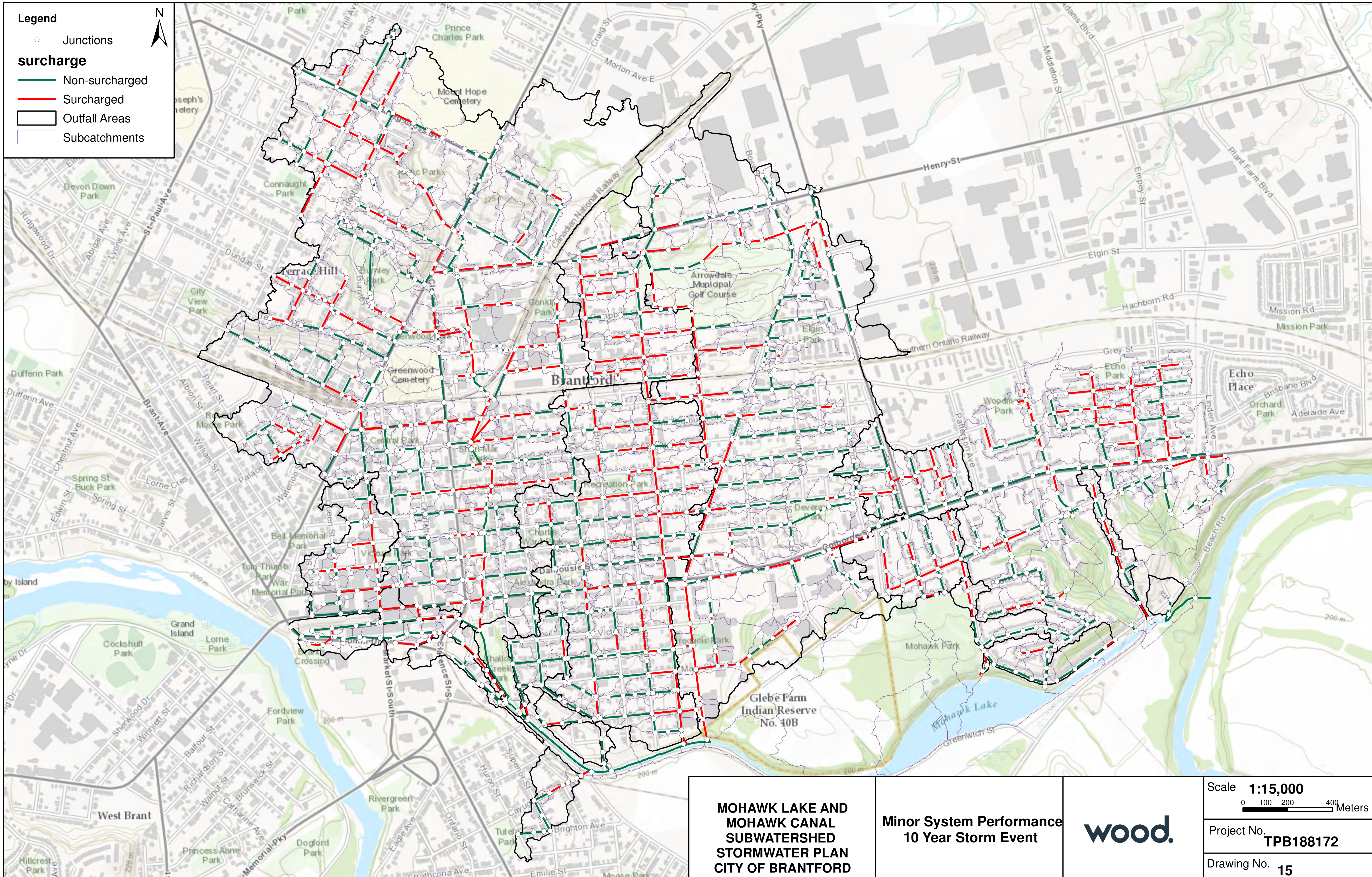
Minor System Performance
5 Year Storm Event

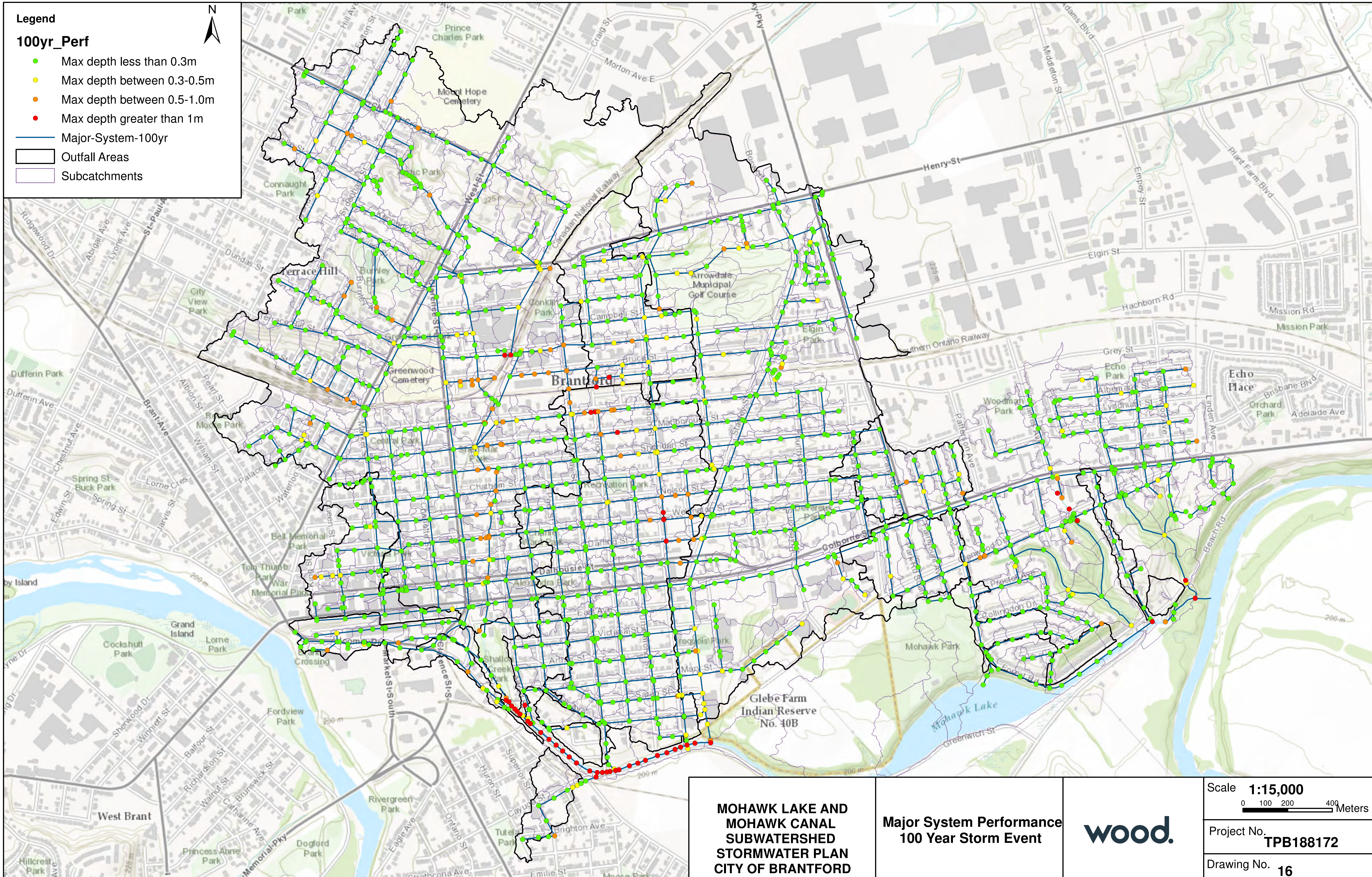
wood.

Scale 1:15,000
0 100 200 400 Meters

Project No. TPB188172

Drawing No. 14


Legend
Junctions
surcharge
Non-surcharged
Surcharged
Outfall Areas
Subcatchments
N
Brantford
MOHAWK LAKE AND
MOHAWK CANAL
SUBWATERSHED
STORMWATER PLAN
CITY OF BRANTFORD
Minor System Performance
10 Year Storm Event
wood.
Scale 1:15,000
0 100 200 400 Meters
Project No. TPB188172
Drawing No. 15



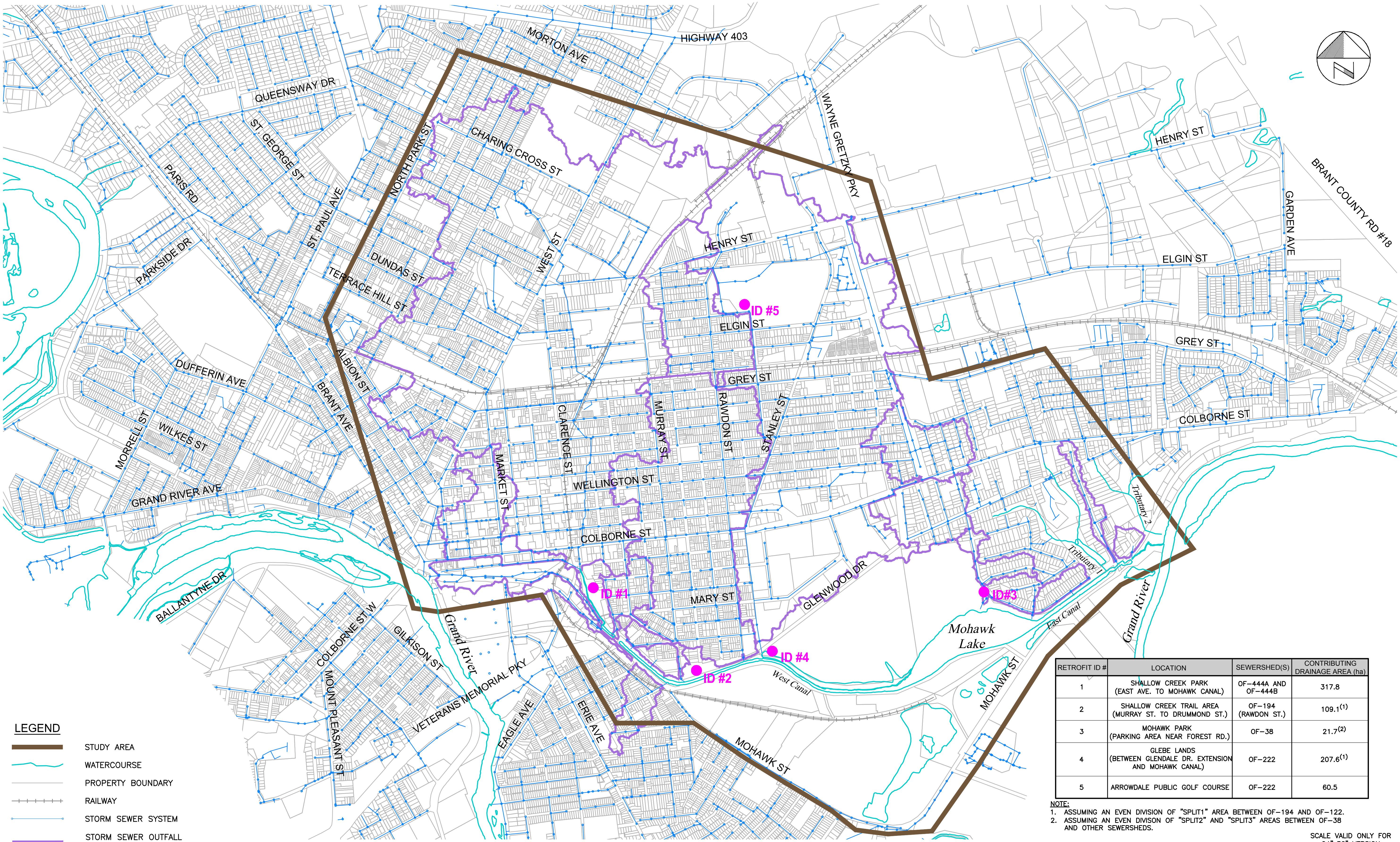
MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STORMWATER PLAN CITY OF BRANTFORD

Major System Performance 100 Year Storm Event

wood.

Project No. TPB188172

Drawing No. 16



LEGEND

- STUDY AREA
- WATERCOURSE
- PROPERTY BOUNDARY
- RAILWAY
- STORM SEWER SYSTEM
- STORM SEWER OUTFALL DRAINAGE BOUNDARY
- ID # — POTENTIAL SWM FACILITY OUTFALL RETROFIT LOCATIONS AND REFERENCE NUMBER

RETROFIT ID #	LOCATION	SEWERSHED(S)	CONTRIBUTING DRAINAGE AREA (ha)
1	SHALLOW CREEK PARK (EAST AVE. TO MOHAWK CANAL)	OF–444A AND OF–444B	317.8
2	SHALLOW CREEK TRAIL AREA (MURRAY ST. TO DRUMMOND ST.)	OF–194 (RAWDON ST.)	109.1(1)
3	MOHAWK PARK (PARKING AREA NEAR FOREST RD.)	OF–38	21.7(2)
4	GLEBE LANDS (BETWEEN GLENDALE DR. EXTENSION AND MOHAWK CANAL)	OF–222	207.6(1)
5	ARROWDALE PUBLIC GOLF COURSE	OF–222	60.5

NOTE:
1. ASSUMING AN EVEN DIVISION OF "SPLIT1" AREA BETWEEN OF–194 AND OF–122.
2. ASSUMING AN EVEN DIVISON OF "SPLIT2" AND "SPLIT3" AREAS BETWEEN OF–38 AND OTHER SEWERSHEDS.

SCALE VALID ONLY FOR 24"x36" VERSION

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY
CITY OF BRANTFORD

POTENTIAL SWM FACILITY OUTFALL RETROFIT PLAN

wood.

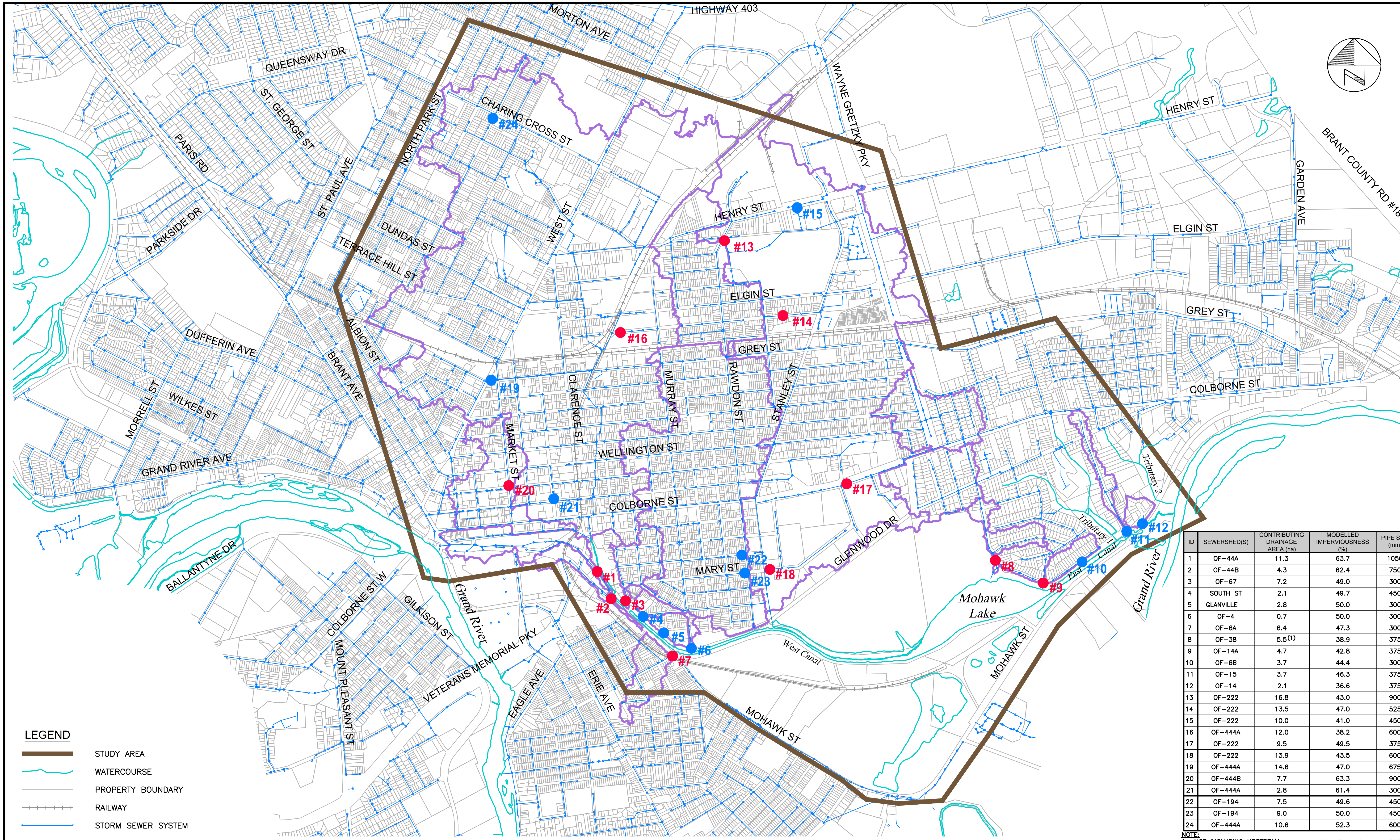
Scale 1:10000 (0 100 200 400)

Consultant File No. TPB188172

Drawing No. 17

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 17 SWM Outfall Retrofit.dwg

Plotted: 2019-12-04 Plotted By: mike.lancar
Last Saved: 2019-12-04 Last Saved By: mike.lancar



ID	SEWERSHED(S)	CONTRIBUTING DRAINAGE AREA (ha)	MODELLED IMPERVIOUSNESS (%)	PIPE SIZE (mm)
1	OF–44A	11.3	63.7	1050
2	OF–44B	4.3	62.4	750
3	OF–67	7.2	49.0	300
4	SOUTH ST	2.1	49.7	450
5	GLANVILLE	2.8	50.0	300
6	OF–4	0.7	50.0	300
7	OF–6A	6.4	47.3	300
8	OF–38	5.5(1)	38.9	375
9	OF–14A	4.7	42.8	375
10	OF–6B	3.7	44.4	300
11	OF–15	3.7	46.3	375
12	OF–14	2.1	36.6	375
13	OF–222	16.8	43.0	900
14	OF–222	13.5	47.0	525
15	OF–222	10.0	41.0	450
16	OF–444A	12.0	38.2	600
17	OF–222	9.5	49.5	375
18	OF–222	13.9	43.5	600
19	OF–444A	14.6	47.0	675
20	OF–444B	7.7	63.3	900
21	OF–444A	2.8	61.4	300
22	OF–194	7.5	49.6	450
23	OF–194	9.0	50.0	450
24	OF–444A	10.6	52.3	600

NOTE:
1. NOT INCLUDING UPSTREAM SPLIT DRAINAGE AREAS.

SCALE VALID ONLY FOR 24"x36" VERSION

LEGEND

- STUDY AREA
- WATERCOURSE
- PROPERTY BOUNDARY
- RAILWAY
- STORM SEWER SYSTEM
- STORM SEWER OUTFALL DRAINAGE BOUNDARY
- #10 HIGH PRIORITY OGS RETROFIT AND REFERENCE NUMBER
- #10 LOW PRIORITY OGS RETROFIT AND REFERENCE NUMBER

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY
CITY OF BRANTFORD

POTENTIAL OGS RETROFIT PLAN

wood.

Scale 1:10000
0 100 200 400

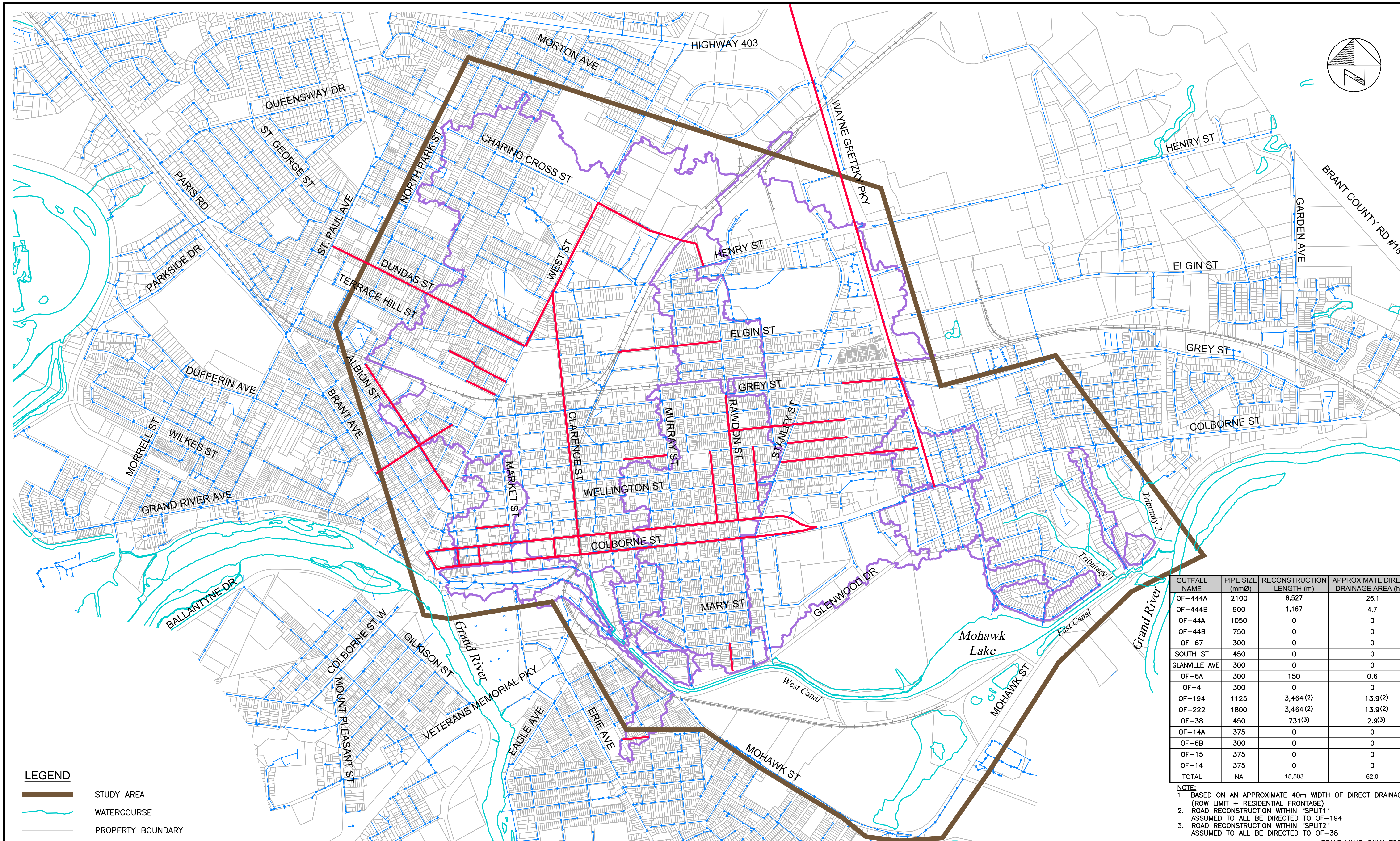
Consultant File No.
TPB188172

Drawing No.
18

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Canal Drainage\06_DES-ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019-09\Dwg 18 OGS Retrofits.dwg

Plotted By: mike.lancar
Last Saved By: mike.lancar

Plotted: 2019-12-05
Last Saved: 2019-12-04



OUTFALL NAME	PIPE SIZE (mmØ)	RECONSTRUCTION LENGTH (m)	APPROXIMATE DIRECT DRAINAGE AREA (ha)(1)
OF–444A	2100	6,527	26.1
OF–444B	900	1,167	4.7
OF–44A	1050	0	0
OF–44B	750	0	0
OF–67	300	0	0
SOUTH ST	450	0	0
GLANVILLE AVE	300	0	0
OF–6A	300	150	0.6
OF–4	300	0	0
OF–194	1125	3,464 (2)	13.9 (2)
OF–222	1800	3,464 (2)	13.9 (2)
OF–38	450	731 (3)	2.9 (3)
OF–14A	375	0	0
OF–6B	300	0	0
OF–15	375	0	0
OF–14	375	0	0
TOTAL	NA	15,503	62.0

NOTE:
1. BASED ON AN APPROXIMATE 40m WIDTH OF DIRECT DRAINAGE (ROW LIMIT + RESIDENTIAL FRONTAGE)
2. ROAD RECONSTRUCTION WITHIN "SPLIT1" ASSUMED TO ALL BE DIRECTED TO OF–194
3. ROAD RECONSTRUCTION WITHIN "SPLIT2" ASSUMED TO ALL BE DIRECTED TO OF–38

SCALE VALID ONLY FOR 24"x36" VERSION

LEGEND
- STUDY AREA
- WATERCOURSE
- PROPERTY BOUNDARY
- RAILWAY
- STORM SEWER SYSTEM
- STORM SEWER OUTFALL DRAINAGE BOUNDARY
- PLANNED ROADWAY RECONSTRUCTIONS (10–YEAR CAPITAL PLAN)

MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STUDY CITY OF BRANTFORD	10-YEAR CAPITAL ROADWAY RECONSTRUCTION PLAN	wood.	Scale 1:10000 (0 100 200 400) Consultant File No. TPB188172 Drawing No. 19

Path: P:\2018\Projects\TPB188172 – Mohawk Lake & Canal Drainage\06_DES–ENG\01_CAD\02_DWGS\05_WR\01_PROJ\2019–09\Dwg 19 Roadway.dwg
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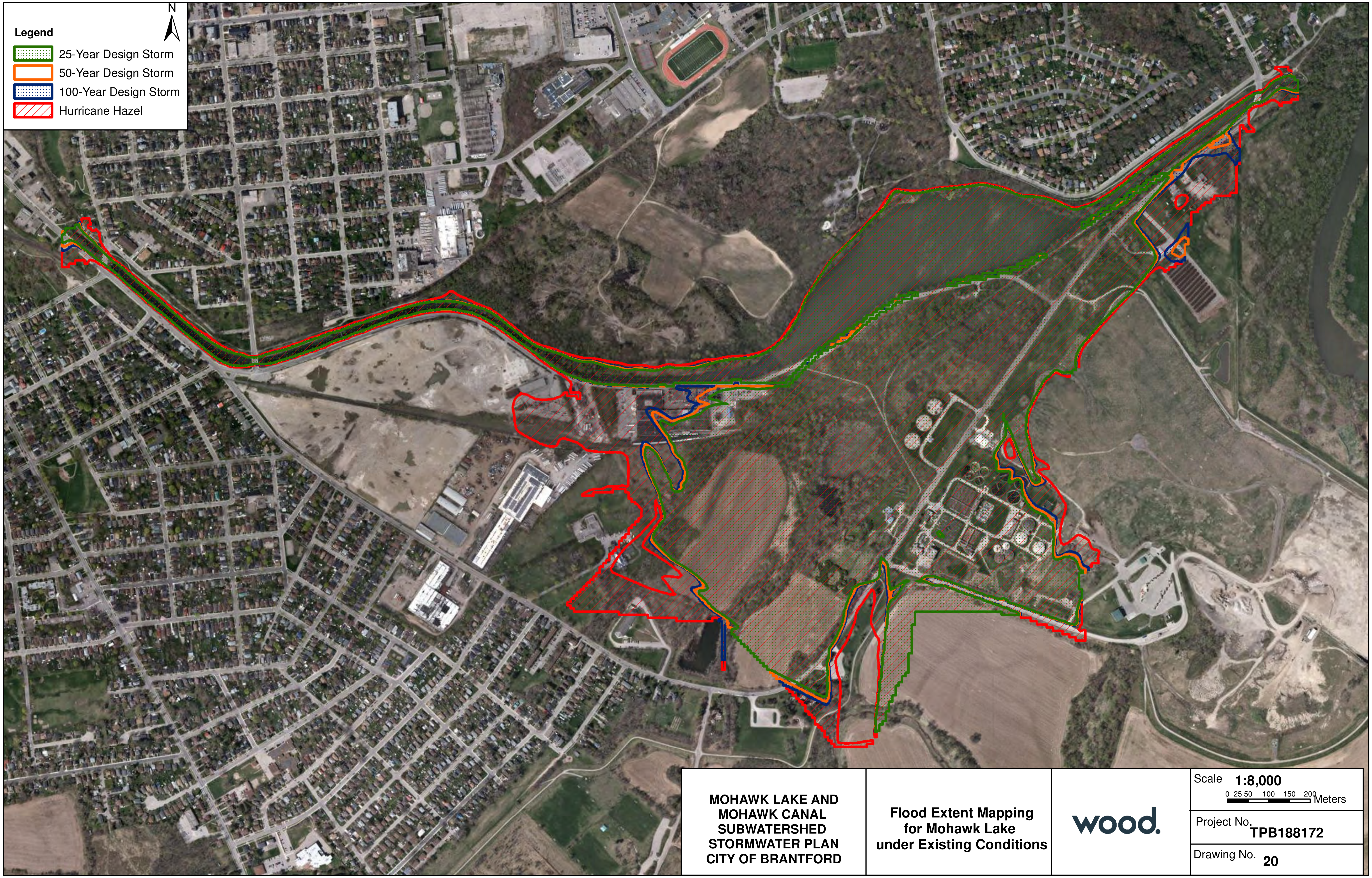
Last Saved By: mike.lancar
Plotted: 2019–12–04
Last Saved: 2019–12–04



MOHAWK LAKE AND MOHAWK CANAL SUBWATERSHED STORMWATER PLAN CITY OF BRANTFORD

Flood Extent Mapping for Mohawk Lake under Existing Conditions

wood.

Scale 1:8,000

0 25 50 100 150 200 Meters

Project No. TPB188172

Drawing No. 20

Appendix A: Model Storm Sewer Data

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
01F001	219.57	222.00	221.46	0.54	219.57	221.46
01F002	219.27	221.80	220.55	1.25	219.27	220.55
01F003	219.00	222.55	221.56	0.99	219	221.56
01F050	218.70	220.75	219.91	0.84	218.7	219.91
01F051	218.61	221.04	220.66	0.38	218.61	220.66
01F052	218.48	220.90	220.42	0.48	218.48	220.42
01F053	218.17	221.07	220.31	0.76	218.17	220.31
01G001	219.92	222.18	221.46	0.72	219.92	221.46
01G002	219.34	222.28	221.66	0.62	219.34	221.66
01G003	220.56	222.76	221.68	1.08	220.56	221.68
01G004	218.88	222.55	221.63	0.92	218.88	221.63
01G005	219.54	223.00	221.82	1.18	219.54	221.82
01G006	219.43	223.00	221.84	1.16	219.43	221.84
01G007	219.39	223.00	221.69	1.31	219.39	221.69
01G008	219.22	223.00	221.90	1.10	219.22	221.9
01G009	219.31	223.00	221.39	1.61	219.31	221.39
01G010	218.65	223.00	222.11	0.89	218.65	222.11
01G011	218.41	223.00	221.81	1.19	218.41	221.81
01G012	218.26	222.81	221.76	1.05	218.264	221.76
01G013	218.02	222.83	221.73	1.10	218.02	221.73
01G014	217.95	222.81	221.99	0.82	217.95	221.99
01G015	219.47	222.88	221.55	1.33	219.47	221.55
01G016	219.21	222.87	221.74	1.13	219.21	221.74
01G017	218.93	223.00	221.60	1.40	218.93	221.6
01G018	218.66	222.85	221.91	0.93	218.66	221.91
01G019	220.07	222.51	221.53	0.98	220.07	221.53
01G021	218.37	221.96	221.07	0.89	218.366	221.07
01G022	218.65	222.00	221.62	0.38	218.65	221.62
01G023	218.14	221.86	221.16	0.70	218.14	221.16
01G024	219.71	222.00	221.48	0.52	219.71	221.48
01G025	220.00	222.27	221.50	0.77	220	221.5
01G026	219.94	222.01	221.68	0.33	219.94	221.68
01G027	219.33	222.00	221.70	0.30	219.33	221.7
01G028	217.59	222.43	221.70	0.73	217.59	221.7
01G029	217.16	221.98	221.40	0.58	217.16	221.4
01G030	217.92	222.46	221.37	1.09	217.92	221.37
01G031	216.74	221.89	220.85	1.04	216.74	220.85
01G032	219.11	221.98	221.13	0.85	219.11	221.13

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
01G033	216.34	222.03	221.27	0.76	216.34	221.27
01G034	215.99	222.00	221.32	0.68	215.99	221.32
01G035	219.34	221.78	220.79	0.99	219.34	220.79
01G036	219.30	222.00	220.90	1.10	219.3	220.9
01G037	219.06	221.75	220.94	0.81	219.06	220.94
01G039	218.93	221.53	220.92	0.61	218.93	220.92
01G040	218.53	222.00	220.98	1.02	218.53	220.98
01G041	217.90	221.79	221.11	0.68	217.9	221.11
01G042	217.46	221.97	221.42	0.55	217.46	221.42
01G043	215.61	222.00	221.55	0.45	215.61	221.55
01G044	215.27	221.92	221.36	0.56	215.27	221.36
01G045	214.84	221.87	221.05	0.82	214.84	221.05
01G046	214.71	221.73	221.05	0.68	214.71	221.05
01G047	213.99	221.06	220.56	0.50	213.99	220.56
01G048	213.93	221.02	220.51	0.51	213.93	220.51
01G049	213.78	220.08	220.25	-0.18	213.78	220.25
01G050	217.49	219.21	218.95	0.26	217.49	218.95
01G052	219.07	221.43	220.90	0.53	219.07	220.9
01G053	216.70	221.48	221.14	0.34	216.7	221.14
01G054	216.23	221.30	220.74	0.56	216.23	220.74
01G055	213.74	219.86	220.23	-0.37	213.74	220.23
01G056OF	213.67	219.39	214.81	4.58	213.67	214.81
01G057	219.57	221.86	220.93	0.93	219.57	220.93
01G058	219.79	221.25	220.85	0.40	219.79	220.85
01G059	219.40	221.77	221.06	0.71	219.4	221.06
01G060	219.43	221.54	221.03	0.51	219.43	221.03
01G061	219.14	221.01	220.71	0.29	219.14	220.71
01G062	218.87	222.00	220.72	1.28	218.87	220.72
01G063	219.38	221.64	221.05	0.59	219.38	221.05
01G064	218.82	221.01	220.63	0.38	218.82	220.63
01G065	219.53	222.11	221.33	0.78	219.53	221.33
01G066	219.28	222.12	221.56	0.56	219.28	221.56
01G067	219.48	221.97	220.75	1.22	219.48	220.75
01G068	219.34	222.00	221.32	0.68	219.34	221.32
01G069	218.53	222.05	221.22	0.83	218.53	221.22
01G070	218.18	221.00	220.54	0.46	218.177	220.54
01G071	218.18	221.58	221.06	0.52	218.177	221.06
01G072	218.16	221.95	220.97	0.98	218.163	220.97

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
01G073	218.14	221.41	221.24	0.17	218.14	221.24
01G074	217.95	221.36	221.01	0.35	217.95	221.01
01G075	215.56	218.52	219.17	-0.65	215.56	219.17
01G076	213.82	215.00	210.11	4.89	208.93	210.11
01G077OF	212.79	213.79	209.53	4.26	208.53	209.53
01G081	218.55	220.67	219.99	0.68	218.548	219.99
01G082	218.33	220.01	219.62	0.39	218.327	219.62
01G083	218.22	220.16	219.59	0.57	218.22	219.59
01G084OF	216.40	216.90	215.53	1.37	215.03	215.53
01M001	218.82	221.90	221.04	0.86	218.82	221.04
01M002	218.44	221.84	220.96	0.88	218.44	220.96
01M003	217.96	221.12	220.41	0.71	217.96	220.41
01M004	217.50	221.00	220.28	0.72	217.5	220.28
01M005	216.80	219.79	219.17	0.62	216.8	219.17
01M006	216.70	220.75	219.98	0.77	216.7	219.98
01M007	214.44	218.60	218.00	0.60	214.44	218
01M008	215.82	218.67	217.93	0.74	215.82	217.93
01M009	209.33	213.52	213.04	0.48	209.33	213.04
01M010	202.62	207.08	206.72	0.36	202.62	206.72
01M011	199.35	202.04	201.69	0.35	199.35	201.69
01M012	199.11	201.10	200.49	0.61	199.11	200.49
01M013	198.82	200.21	200.45	-0.24	198.82	200.45
01M014OF	192.27	200.00	198.89	1.11	192.268	198.89
01M015OF	192.40	200.00	198.98	1.02	192.397	198.98
02M001	224.75	228.98	228.54	0.44	224.75	228.54
02M002	225.00	227.56	226.57	0.99	225	226.57
02M003	223.45	226.08	225.48	0.60	223.45	225.48
02M004	224.00	227.00	226.70	0.30	224	226.7
02M007	223.02	225.78	225.03	0.75	223.024	225.03
02M008	222.33	224.75	224.10	0.65	222.33	224.1
02M012	222.47	224.38	224.13	0.25	222.47	224.13
02M013	222.10	224.27	223.73	0.54	222.1	223.73
02M014	222.01	224.48	223.60	0.88	222.01	223.6
02M015	221.57	224.00	223.06	0.94	221.57	223.06
02M016	222.00	224.00	223.48	0.52	222	223.48
02M017	221.70	224.00	223.32	0.68	221.7	223.32
02M018	221.97	224.14	223.64	0.50	221.97	223.64
02M019	221.53	224.00	223.24	0.76	221.53	223.24

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
02M020	221.35	224.00	223.46	0.54	221.35	223.46
02M021	221.71	224.00	223.42	0.58	221.71	223.42
02M022	221.12	224.00	223.20	0.80	221.12	223.2
02M023	221.91	224.14	223.61	0.53	221.91	223.61
02M024	221.69	224.00	223.36	0.64	221.69	223.36
02M025	221.52	224.07	223.03	1.04	221.52	223.03
02M026	221.47	223.93	222.83	1.10	221.47	222.83
02M027	221.31	223.99	223.18	0.81	221.31	223.18
02M028	221.01	224.00	223.28	0.72	221.01	223.28
02M029	220.79	224.00	222.89	1.11	220.79	222.89
02M030	220.64	224.00	222.93	1.07	220.64	222.93
02M031	221.82	224.14	224.19	-0.05	221.82	224.19
02M032	221.33	224.00	223.24	0.76	221.33	223.24
02M033	220.49	223.89	222.82	1.07	220.49	222.82
02M034	219.98	223.80	223.28	0.52	219.98	223.28
02M035	219.65	223.55	222.94	0.61	219.65	222.94
02M036	219.53	223.36	222.77	0.59	219.53	222.77
02M037	218.99	223.00	222.53	0.47	218.99	222.53
02M038	217.19	223.00	221.76	1.24	217.19	221.76
02M039	220.70	223.00	222.55	0.45	220.7	222.55
02M040	220.41	223.11	222.35	0.76	220.41	222.35
02M042	220.28	223.00	222.35	0.65	220.28	222.35
02M043	220.13	223.00	222.27	0.73	220.13	222.27
02M044	220.00	223.00	222.05	0.95	220	222.05
02M045	219.93	223.00	221.76	1.24	219.93	221.76
02M046	220.79	223.90	222.30	1.60	220.79	222.3
02M047	220.62	223.00	222.39	0.61	220.62	222.39
02M048	219.95	223.00	222.00	1.00	219.95	222
02M049	219.54	223.00	221.52	1.48	219.54	221.52
02M050	219.26	223.00	221.34	1.66	219.26	221.34
02M051	218.77	222.41	221.08	1.33	218.77	221.08
02M052	216.83	221.78	221.20	0.58	216.83	221.2
02M053	219.12	222.02	221.93	0.09	219.12	221.93
02M054	216.70	221.57	221.03	0.54	216.7	221.03
02M055	216.64	222.00	220.71	1.29	216.64	220.71
02M056OF	216.03	221.10	220.80	0.30	216.03	220.8
02M057	220.68	223.10	222.53	0.57	220.68	222.53
02M058	218.70	222.62	221.97	0.64	218.7	221.97

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
02M059	218.57	222.36	221.47	0.88	218.57	221.47
02M060	219.89	222.52	221.50	1.02	219.89	221.5
02M061	219.10	221.74	221.21	0.52	219.1	221.21
02M062	218.82	222.31	221.30	1.01	218.82	221.3
02M063	218.52	222.38	221.50	0.88	218.52	221.5
02M064	217.57	220.44	219.53	0.91	217.57	219.53
02M065OF	217.39	220.10	217.88	2.22	217.39	217.88
02M066	218.75	221.28	220.44	0.84	218.75	220.44
02M067	218.60	221.02	220.32	0.70	218.6	220.32
02M068	218.06	220.39	220.20	0.19	218.06	220.2
02M069OF	214.75	216.24	216.37	-0.13	214.75	216.37
02M070	218.39	220.09	219.84	0.25	218.39	219.84
02M071OF	213.42	218.58	216.56	2.02	213.424	216.56
02M072	219.49	220.68	220.65	0.03	219.49	220.65
02M073	219.69	222.55	221.76	0.79	219.69	221.76
02M074	219.20	222.08	221.71	0.37	219.2	221.71
02M075	218.92	222.02	221.48	0.54	218.92	221.48
02M076	218.63	221.36	220.85	0.51	218.63	220.85
02M077	218.25	220.95	220.12	0.83	218.25	220.12
02M078	218.09	220.67	219.49	1.18	218.09	219.49
02M079	218.27	220.78	219.88	0.90	218.27	219.88
02M080	217.98	220.90	219.76	1.14	217.98	219.76
02M081	218.20	221.16	219.66	1.50	218.2	219.66
02M082	217.58	220.57	219.35	1.22	217.58	219.35
02M083	216.99	218.60	218.41	0.19	216.99	218.41
02M084	216.66	219.54	218.89	0.65	216.66	218.89
02M085	216.47	220.04	218.97	1.07	216.47	218.97
02M086	216.22	220.20	219.05	1.15	216.22	219.05
02M087	215.96	219.68	218.59	1.09	215.96	218.59
02M088	217.52	220.00	219.09	0.91	217.52	219.09
02M089	216.78	220.00	218.91	1.09	216.78	218.91
02M090	216.23	220.00	219.00	1.00	216.23	219
02M091	215.76	220.00	218.69	1.31	215.76	218.69
02M092	215.38	220.00	218.52	1.48	215.38	218.52
02M093	215.16	220.00	218.63	1.37	215.16	218.63
02M094	207.59	217.29	217.13	0.16	207.59	217.13
02M095	206.37	209.59	209.26	0.33	206.37	209.26
02M098	223.19	224.72	223.97	0.75	223.19	223.97

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
02M098OF	203.94	208.09	205.81	2.28	203.94	205.81
02M099	222.61	224.81	223.86	0.95	222.614	223.86
02M100	222.27	224.79	224.05	0.74	222.27	224.05
02M101	222.30	224.41	223.67	0.74	222.3	223.67
02M102	222.37	224.73	223.81	0.92	222.371	223.81
02M103	223.45	225.69	224.86	0.83	223.45	224.86
02M104	223.73	226.46	225.52	0.94	223.725	225.52
02M105	224.95	227.22	226.17	1.05	224.95	226.17
02M106	217.12	219.85	219.98	-0.13	217.12	219.98
02MC001	219.50	221.00	219.33	1.67	217.83	219.33
02MC002	218.50	221.00	219.56	1.44	218.5	219.56
02MC003	218.00	221.00	220.46	0.54	218	220.46
02MC004SC	217.50	222.00	220.54	1.46	217.5	220.54
03M001	200.05	201.93	201.36	0.57	200.05	201.36
03M002	199.61	201.57	201.31	0.26	199.61	201.31
03M003	201.91	204.82	204.08	0.74	201.91	204.08
03M004	199.74	202.14	201.46	0.68	199.74	201.46
03M005	199.27	201.85	201.07	0.78	199.27	201.07
03M006OF	192.80	201.00	199.25	1.75	192.796	199.25
04M001	216.59	219.44	218.51	0.93	216.59	218.51
04M002	216.50	219.71	218.76	0.95	216.5	218.76
04M003	218.05	221.18	220.03	1.15	218.05	220.03
04M004	216.20	220.50	219.50	1.00	216.2	219.5
04M005	214.94	219.71	218.56	1.15	214.94	218.56
04M006	213.00	215.41	216.42	-1.01	213	216.42
04M007	205.89	209.38	208.71	0.67	205.89	208.71
04M008	211.75	214.52	213.78	0.74	211.75	213.78
04M009	210.04	213.07	212.53	0.54	210.04	212.53
04M010	208.48	211.49	210.63	0.86	208.48	210.63
04M011	206.55	209.80	208.95	0.85	206.55	208.95
04M012	204.81	208.02	207.45	0.57	204.81	207.45
04M013	204.35	206.30	206.02	0.28	204.35	206.02
04M014OF	193.16	201.00	200.10	0.90	193.161	200.1
05M001	221.47	224.03	223.54	0.49	221.47	223.54
05M002	221.21	223.91	222.65	1.26	221.21	222.65
05M003	220.95	223.36	222.67	0.69	220.95	222.67
05M004	220.68	223.00	222.98	0.02	220.68	222.98
05M005	220.37	223.00	222.48	0.52	220.37	222.48

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
05M006	221.81	224.03	223.83	0.20	221.81	223.83
05M007	220.79	223.61	222.51	1.10	220.79	222.51
05M008	220.64	223.35	222.14	1.21	220.64	222.14
05M009	220.84	223.00	223.15	-0.15	220.84	223.15
05M010	220.79	223.48	222.69	0.79	220.79	222.69
05M011	220.23	222.97	222.16	0.81	220.23	222.16
05M012	221.50	223.75	222.92	0.83	221.5	222.92
05M013	221.00	222.95	222.16	0.79	221	222.16
05M014	220.50	222.97	222.23	0.74	220.5	222.23
05M015	221.07	223.07	223.23	-0.16	221.07	223.23
05M016	220.17	222.94	222.25	0.69	220.17	222.25
05M017	219.95	222.89	221.96	0.93	219.95	221.96
05M018	220.51	223.14	222.91	0.23	220.51	222.91
05M019	219.99	222.97	222.26	0.71	219.99	222.26
05M020	219.97	222.96	222.04	0.92	219.97	222.04
05M021	218.85	222.18	221.71	0.46	218.85	221.71
05M022	218.92	222.23	221.73	0.50	218.92	221.73
05M023	219.19	222.51	221.26	1.25	219.19	221.26
05M024	219.58	222.72	221.96	0.75	219.58	221.96
05M025	219.04	223.00	222.06	0.94	219.04	222.06
05M026	218.66	222.52	221.87	0.65	218.66	221.87
05M027	218.03	221.34	220.85	0.49	218.03	220.85
05M028	217.19	219.75	219.25	0.50	217.19	219.25
05M029	214.29	217.00	216.57	0.43	214.29	216.57
05M030	217.78	220.68	219.51	1.17	217.78	219.51
05M031	216.82	219.90	218.82	1.07	216.82	218.82
05M032	215.50	218.57	217.30	1.27	215.5	217.3
05M033	214.41	217.30	215.97	1.33	214.41	215.97
05M034	212.32	215.70	215.21	0.49	212.32	215.21
05M035	203.25	215.09	214.49	0.60	203.25	214.49
05M036	202.72	212.39	212.20	0.19	202.72	212.2
05M037	199.27	207.32	205.81	1.51	199.27	205.81
05M038OF	193.54	197.00	200.17	-3.17	193.542	200.17
05M039	220.35	223.20	222.58	0.62	220.35	222.58
05M040	220.55	223.71	223.05	0.66	220.55	223.05
05MC001SF	219.02	222.50	221.37	1.13	219.02	221.37
05MC002SC	220.00	223.00	221.87	1.13	220	221.87
05MC003	220.50	223.00	221.62	1.38	220.5	221.62

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
05MC004	221.00	223.00	221.60	1.40	221	221.6
05MC005	221.50	223.00	221.82	1.18	221.5	221.82
06M001	224.43	227.00	226.19	0.81	224.43	226.19
06M002	224.12	227.00	226.59	0.41	224.12	226.59
06M003	223.46	225.98	225.58	0.40	223.46	225.58
06M004	224.79	227.57	227.04	0.53	224.79	227.04
06M005	223.38	226.34	225.85	0.48	223.38	225.85
06M006	219.27	222.21	221.98	0.23	219.27	221.98
06M007	217.67	221.69	220.36	1.32	217.67	220.36
06M008	215.52	221.00	219.94	1.06	215.52	219.94
06M009	214.76	218.04	217.02	1.02	214.76	217.02
06M010	213.85	218.12	217.10	1.02	213.85	217.1
06M011	209.28	210.90	210.24	0.66	209.28	210.24
06M012	209.06	211.55	210.41	1.14	209.06	210.41
06M013	207.99	211.74	210.36	1.38	207.99	210.36
06M014	209.71	221.00	219.41	1.59	209.71	219.41
06M015	209.66	219.54	218.40	1.14	209.66	218.4
06M016	206.89	211.46	210.64	0.82	206.89	210.64
06M017	224.40	227.74	226.83	0.90	224.4	226.83
06M018	224.02	226.63	226.07	0.56	224.02	226.07
06M019	223.34	225.77	225.62	0.15	223.34	225.62
06M020	222.81	225.66	225.43	0.23	222.81	225.43
06M021	222.37	225.48	224.95	0.53	222.37	224.95
06M022	221.76	225.00	224.61	0.39	221.76	224.61
06M023	222.21	225.46	224.80	0.66	222.21	224.8
06M024	221.62	225.22	224.62	0.60	221.62	224.62
06M025	220.95	225.00	224.25	0.75	220.95	224.25
06M026	220.78	223.45	222.63	0.82	220.78	222.63
06M027	217.14	222.95	222.05	0.90	217.14	222.05
06M028	221.74	224.60	224.13	0.47	221.74	224.13
06M029	220.52	223.11	222.57	0.54	220.52	222.57
06M030	223.57	226.02	225.48	0.54	223.57	225.48
06M031	222.15	225.19	224.23	0.96	222.15	224.23
06M032	220.87	224.09	223.16	0.93	220.87	223.16
06M033	216.69	222.03	221.52	0.51	216.69	221.52
06M034	215.00	220.31	219.27	1.04	215	219.27
06M035	221.52	224.32	223.89	0.43	221.517	223.89
06M036	219.56	222.29	221.71	0.57	219.56	221.71

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M037	218.42	221.27	220.38	0.89	218.42	220.38
06M038	217.56	220.95	219.96	0.99	217.56	219.96
06M039	213.79	219.29	218.26	1.03	213.79	218.26
06M042	212.53	217.17	216.14	1.03	212.53	216.14
06M043	211.20	214.77	213.67	1.10	211.2	213.67
06M044	210.13	215.48	214.02	1.45	210.13	214.02
06M045	209.06	217.83	218.10	-0.27	209.06	218.1
06M046	207.87	211.91	210.77	1.14	207.87	210.77
06M047	206.59	210.00	209.49	0.51	206.59	209.49
06M048	206.17	209.25	208.76	0.49	206.17	208.76
06M049	205.94	209.00	208.31	0.69	205.94	208.31
06M053	205.23	210.64	210.00	0.64	205.23	210
06M054	216.61	219.16	218.44	0.71	216.61	218.44
06M055	210.16	214.29	213.48	0.81	210.16	213.48
06M056	204.85	210.14	209.50	0.64	204.85	209.5
06M057	206.24	209.89	208.67	1.22	206.24	208.67
06M058	205.63	208.92	207.85	1.07	205.63	207.85
06M059	214.05	217.39	216.34	1.05	214.05	216.34
06M060	210.60	212.57	212.28	0.29	210.6	212.28
06M061	210.01	211.81	211.18	0.63	210.01	211.18
06M062	207.62	210.94	210.10	0.84	207.62	210.1
06M064	208.50	211.16	209.99	1.17	208.5	209.99
06M065	207.38	210.66	210.02	0.63	207.38	210.02
06M066	208.30	210.92	209.63	1.29	208.3	209.63
06M067	207.25	210.50	209.66	0.84	207.25	209.66
06M069	207.35	209.97	209.08	0.89	207.35	209.08
06M071	207.20	210.05	209.02	1.03	207.2	209.02
06M072	207.07	209.88	208.82	1.05	207.07	208.82
06M073	206.90	209.67	208.92	0.75	206.9	208.92
06M074	206.10	209.00	208.09	0.91	206.097	208.09
06M075	206.21	209.00	207.39	1.61	206.21	207.39
06M076	205.80	209.00	208.02	0.98	205.8	208.02
06M077	205.75	209.00	208.18	0.82	205.746	208.18
06M078	205.65	209.14	208.16	0.98	205.65	208.16
06M079	205.47	209.49	208.33	1.16	205.47	208.33
06M080	205.26	209.21	208.37	0.84	205.26	208.37
06M081	208.46	210.82	210.08	0.74	208.46	210.08
06M088	205.82	209.00	207.44	1.56	205.82	207.44

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M089	205.62	209.00	207.34	1.66	205.62	207.34
06M091	205.55	208.02	207.27	0.75	205.55	207.27
06M092	205.43	208.65	207.04	1.61	205.43	207.04
06M093	204.88	208.62	207.43	1.19	204.88	207.43
06M095	205.30	207.39	206.08	1.31	205.3	206.08
06M096	205.18	207.33	206.70	0.63	205.18	206.7
06M097	204.90	207.75	206.49	1.26	204.9	206.49
06M098	206.00	207.93	207.15	0.78	206	207.15
06M099	204.65	207.93	207.01	0.92	204.65	207.01
06M100	204.30	207.99	207.14	0.85	204.3	207.14
06M101	203.66	207.98	207.26	0.72	203.656	207.26
06M107	203.21	206.90	206.34	0.56	203.21	206.34
06M108	203.05	207.66	206.41	1.25	203.05	206.41
06M109	203.04	207.51	206.70	0.81	203.04	206.7
06M110	202.91	207.90	206.92	0.98	202.91	206.92
06M111	222.69	226.74	225.51	1.23	222.69	225.51
06M112	222.30	226.88	226.07	0.81	222.3	226.07
06M113	221.91	226.54	226.13	0.41	221.91	226.13
06M114	221.05	225.82	224.48	1.34	221.05	224.48
06M115	223.29	226.20	225.58	0.62	223.29	225.58
06M116	220.41	225.74	224.92	0.82	220.41	224.92
06M117	219.40	224.76	224.30	0.45	219.4	224.3
06M118	217.57	221.31	220.54	0.77	217.57	220.54
06M119	212.08	216.66	215.60	1.06	212.08	215.6
06M120	209.90	214.55	213.36	1.19	209.9	213.36
06M121	207.61	211.92	210.87	1.05	207.61	210.87
06M122	204.68	211.05	210.34	0.71	204.68	210.34
06M123	203.81	210.00	208.26	1.74	203.81	208.26
06M124	203.18	208.87	208.13	0.74	203.18	208.13
06M125	222.00	226.33	225.60	0.73	222	225.6
06M126	216.42	220.17	219.60	0.57	216.42	219.6
06M127	211.87	215.78	214.75	1.03	211.87	214.75
06M128	211.04	216.53	214.99	1.53	211.04	214.99
06M129	207.44	212.29	211.46	0.83	207.44	211.46
06M130	204.74	209.14	208.17	0.97	204.736	208.17
06M131	202.95	207.99	207.18	0.81	202.947	207.18
06M132	202.47	208.06	207.28	0.78	202.47	207.28
06M135	225.36	228.00	227.03	0.97	225.36	227.03

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M136	225.04	227.85	227.29	0.56	225.04	227.29
06M137	218.80	220.76	220.44	0.32	218.8	220.44
06M138	212.32	215.69	214.12	1.57	212.32	214.12
06M139	209.38	212.62	210.82	1.80	209.38	210.82
06M140	206.50	209.55	208.50	1.05	206.5	208.5
06M141	205.16	208.80	207.73	1.07	205.16	207.73
06M142	226.00	228.48	228.11	0.37	226	228.11
06M143	225.34	227.72	227.23	0.49	225.34	227.23
06M144	224.68	227.01	226.21	0.80	224.68	226.21
06M145	218.60	223.82	222.18	1.64	218.6	222.18
06M146	217.74	220.11	219.52	0.59	217.74	219.52
06M147	216.44	218.67	218.17	0.50	216.44	218.17
06M148	211.15	214.62	214.05	0.57	211.15	214.05
06M149	206.39	208.97	208.42	0.55	206.39	208.42
06M150	205.54	207.93	206.93	1.00	205.54	206.93
06M152	219.36	222.55	221.26	1.29	219.36	221.26
06M153	217.87	221.19	220.61	0.58	217.87	220.61
06M154	211.29	213.93	213.02	0.91	211.29	213.02
06M155	206.18	208.98	208.38	0.60	206.18	208.38
06M156	204.39	207.94	207.01	0.93	204.39	207.01
06M157	200.64	206.65	206.04	0.61	200.64	206.04
06M158	219.46	223.63	222.80	0.83	219.46	222.8
06M159	218.85	221.06	220.90	0.16	218.85	220.9
06M160	216.56	217.83	217.83	0.00	216.56	217.83
06M161	214.84	217.35	216.71	0.64	214.84	216.71
06M162	211.11	213.44	213.03	0.41	211.11	213.03
06M163	207.01	209.07	208.96	0.11	207.01	208.96
06M164	204.70	206.99	206.37	0.62	204.7	206.37
06M165	200.49	206.00	205.37	0.63	200.493	205.37
06M166	200.08	205.48	204.94	0.53	200.08	204.94
06M167	216.56	223.64	223.22	0.42	216.56	223.22
06M168	213.00	217.95	217.23	0.72	213	217.23
06M169	211.37	216.61	216.11	0.50	211.37	216.11
06M170	210.35	216.15	215.19	0.95	210.35	215.19
06M171	217.12	219.12	218.22	0.90	217.12	218.22
06M172	209.00	215.11	214.70	0.41	209	214.7
06M173	207.68	210.63	209.99	0.64	207.68	209.99
06M174	206.51	209.51	208.82	0.69	206.51	208.82

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M175	205.12	208.76	208.09	0.67	205.12	208.09
06M176	204.04	206.98	206.49	0.49	204.04	206.49
06M177	203.95	207.30	206.97	0.33	203.95	206.97
06M178	203.64	207.39	206.79	0.60	203.64	206.79
06M179	202.57	208.44	208.25	0.19	202.57	208.25
06M180	202.45	207.33	207.06	0.27	202.45	207.06
06M181	202.13	205.35	205.07	0.28	202.13	205.07
06M182	201.67	205.16	204.61	0.55	201.67	204.61
06M183	199.71	204.77	204.06	0.71	199.71	204.06
06M184	199.49	204.86	203.89	0.97	199.49	203.89
06M185	199.44	204.89	203.41	1.48	199.44	203.41
06M186	221.61	224.34	223.90	0.44	221.61	223.9
06M187	221.26	224.38	223.91	0.47	221.26	223.91
06M188	221.07	224.49	223.66	0.82	221.07	223.66
06M189	220.98	224.33	223.68	0.65	220.98	223.68
06M190	220.45	224.10	223.71	0.39	220.45	223.71
06M191	220.85	223.06	222.44	0.62	220.85	222.44
06M192	220.62	223.39	222.19	1.20	220.62	222.19
06M193	220.44	223.48	222.64	0.84	220.44	222.64
06M194	219.97	223.27	222.85	0.42	219.97	222.85
06M195	219.24	222.98	222.55	0.43	219.24	222.55
06M196	214.85	221.20	220.83	0.36	214.85	220.83
06M197	218.47	221.28	220.48	0.80	218.47	220.48
06M198	214.32	219.79	219.15	0.64	214.32	219.15
06M199	211.33	215.05	214.83	0.22	211.33	214.83
06M200	206.58	212.21	212.20	0.01	206.58	212.2
06M201	204.45	209.47	209.10	0.37	204.45	209.1
06M202	202.16	207.28	207.16	0.12	202.16	207.16
06M203	201.71	206.00	205.85	0.15	201.71	205.85
06M204	200.94	205.89	204.36	1.53	200.94	204.36
06M205	198.80	204.68	203.83	0.85	198.8	203.83
06M206	198.80	203.00	201.74	1.26	198.8	201.74
06M207	198.49	201.97	201.53	0.44	198.49	201.53
06M208	218.28	222.00	220.69	1.31	218.28	220.69
06M209	217.93	221.79	220.81	0.98	217.93	220.81
06M210	216.81	219.90	219.52	0.38	216.81	219.52
06M211	212.52	216.24	215.56	0.68	212.52	215.56
06M212	208.03	211.17	210.55	0.62	208.03	210.55

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M213	203.74	206.48	206.06	0.42	203.74	206.06
06M214	199.73	202.85	202.57	0.28	199.73	202.57
06M215	201.88	205.00	203.62	1.38	201.88	203.62
06M216	200.70	203.29	202.41	0.88	200.7	202.41
06M217	200.07	202.15	201.71	0.44	200.07	201.71
06M218	199.47	201.88	201.17	0.71	199.47	201.17
06M219	197.61	201.93	200.97	0.96	197.61	200.97
06M220	197.53	202.78	200.58	2.20	197.53	200.58
06M221	197.24	201.81	200.66	1.15	197.24	200.66
06M222OF	195.40	199.00	199.67	-0.67	195.398	199.67
06M223	220.75	225.95	225.19	0.76	220.75	225.19
06M224	205.63	209.27	208.53	0.74	205.628	208.53
06M225	209.48	212.10	211.37	0.73	209.48	211.37
06M226	212.47	215.67	214.79	0.88	212.47	214.79
06M227	218.85	221.89	221.35	0.54	218.85	221.35
06M228	224.90	227.84	227.23	0.61	224.9	227.23
06M229	225.08	228.09	227.47	0.62	225.08	227.47
06M230	225.42	228.10	227.67	0.43	225.42	227.67
06M233	201.15	207.73	206.85	0.88	201.147	206.85
06M234	201.11	207.84	206.84	1.00	201.107	206.84
06M236	205.67	208.91	207.59	1.32	205.672	207.59
06M237	206.16	210.00	207.97	2.03	206.162	207.97
06M238	204.67	209.76	210.26	-0.50	204.674	210.26
06M239	203.76	207.53	207.29	0.24	203.755	207.29
06M240	203.49	208.43	207.06	1.37	203.493	207.06
06M241	203.72	207.99	207.22	0.77	203.722	207.22
06M242	206.50	209.00	207.94	1.06	206.496	207.94
06M243	205.31	209.00	208.00	1.00	205.307	208
06M244	206.47	209.00	208.30	0.70	206.465	208.3
06M245	207.10	209.75	209.12	0.63	207.095	209.12
06M246	208.63	212.45	211.12	1.33	208.63	211.12
06M250	226.57	228.74	227.88	0.86	226.574	227.88
06M251	226.22	228.50	227.57	0.93	226.215	227.57
06M252	225.83	228.52	227.62	0.90	225.827	227.62
06M253	202.12	206.62	206.21	0.41	202.12	206.21
06M254	221.68	225.06	224.16	0.90	221.682	224.16
06M255	221.55	224.53	223.93	0.60	221.547	223.93
06M256	222.49	225.99	224.96	1.03	222.485	224.96

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06M257	222.15	226.08	224.22	1.86	222.151	224.22
06M258	206.67	212.59	209.94	2.65	206.67	209.94
06M259	205.54	210.00	209.54	0.46	205.54	209.54
06M260	218.00	220.00	219.33	0.67	218	219.33
06M261	200.14	202.19	201.65	0.54	200.141	201.65
06M262	199.34	201.97	201.28	0.69	199.341	201.28
06M264	205.27	210.66	210.05	0.60	205.27	210.05
06M265	205.80	209.04	208.61	0.43	205.8	208.61
06M266	204.29	209.00	207.56	1.44	204.29	207.56
06M267	204.70	209.00	207.90	1.10	204.7	207.9
06M268	205.14	208.69	208.20	0.49	205.14	208.2
06M269	206.33	209.93	209.15	0.78	206.33	209.15
06M270	204.06	209.00	207.66	1.34	204.056	207.66
06M271SF	215.27	220.44	219.45	0.99	215.27	219.45
06M272SF	214.11	220.15	218.91	1.24	214.11	218.91
06M273SF	212.82	216.89	215.68	1.21	212.82	215.68
06M274SF	211.20	216.13	215.49	0.64	211.2	215.49
06M275SF	212.84	218.26	217.02	1.24	212.84	217.02
06M276	221.03	224.22	223.70	0.52	221.027	223.7
06M277	222.64	225.27	224.50	0.77	222.64	224.5
06M278	222.31	225.00	224.58	0.42	222.31	224.58
06M279	200.27	206.00	205.31	0.69	200.27	205.31
06M280	203.40	206.00	205.39	0.61	203.4	205.39
06M282	200.70	203.69	202.73	0.96	200.7	202.73
06M283	218.85	222.29	221.60	0.69	218.85	221.6
06M284	221.00	223.00	222.71	0.29	221	222.71
06M285	221.50	223.00	222.81	0.19	221.5	222.81
06M286	222.00	223.00	222.52	0.48	222	222.52
06MC001	225.00	227.00	226.24	0.76	225	226.24
06MC002	224.95	227.00	226.39	0.61	224.95	226.39
06MC003	224.90	227.00	225.66	1.34	224.9	225.66
06MC004	224.75	227.00	225.47	1.53	224.751	225.47
06MC005	223.56	226.00	225.07	0.93	223.56	225.07
06MC006	223.05	226.00	224.71	1.29	223.048	224.71
06MC007	223.10	226.00	225.77	0.23	223.1	225.77
06MC008	222.25	224.00	223.17	0.83	222.253	223.17
06MC009	221.96	225.00	223.27	1.73	221.962	223.27
06MC010	220.88	223.00	222.68	0.32	220.88	222.68

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
06MC011	220.83	224.00	222.35	1.65	220.83	222.35
06MC012	220.90	224.00	222.90	1.10	220.9	222.9
06MC013	220.95	226.00	225.36	0.64	220.95	225.36
06MC014	221.00	227.00	226.18	0.82	221	226.18
06MC016	215.50	217.00	216.33	0.67	215.5	216.33
06MC017	215.00	217.00	216.62	0.38	215	216.62
06MC018	214.00	217.00	215.91	1.09	214	215.91
06MC019	213.00	217.00	215.70	1.30	213	215.7
06MC021	215.00	219.00	216.26	2.74	215	216.26
06MC022	215.50	219.00	216.59	2.41	215.5	216.59
06MC023	216.00	217.00	216.30	0.70	216	216.3
06MC024	225.00	227.00	226.05	0.95	225	226.05
06MC025	215.00	222.00	218.19	3.81	215	218.19
06MC026SF	214.04	217.49	216.44	1.05	214.04	216.44
07M008	204.37	206.88	206.06	0.82	204.37	206.06
07M009	204.24	206.22	205.66	0.56	204.24	205.66
07M010	204.23	206.10	205.60	0.50	204.23	205.6
07M011	205.05	207.85	206.47	1.38	205.05	206.47
07M013	204.17	206.84	206.15	0.69	204.17	206.15
07M014	204.11	206.41	205.53	0.88	204.11	205.53
07M015	204.03	206.12	205.29	0.83	204.03	205.29
07M016	203.73	205.82	205.19	0.63	203.73	205.19
07M017	203.72	205.50	205.40	0.10	203.72	205.4
07M018	203.11	206.22	205.39	0.83	203.11	205.39
07M019	203.10	206.12	205.21	0.90	203.096	205.21
07M020	202.95	206.83	205.84	0.99	202.95	205.84
07M021	206.06	209.30	208.29	1.01	206.06	208.29
07M022	205.43	208.57	207.34	1.23	205.43	207.34
07M024	204.35	207.12	206.11	1.01	204.345	206.11
07M025	204.53	207.77	206.32	1.45	204.53	206.32
07M026	204.03	207.00	205.95	1.05	204.03	205.95
07M027	201.92	206.52	205.37	1.15	201.92	205.37
07M033	205.09	208.78	207.92	0.86	205.089	207.92
07M034	201.74	208.00	206.76	1.24	201.735	206.76
07M035	203.99	207.00	206.06	0.94	203.99	206.06
07M036	203.59	207.00	205.76	1.24	203.59	205.76
07M038	201.58	206.00	205.19	0.81	201.58	205.19
07M039	203.83	206.92	206.33	0.59	203.83	206.33

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
07M040	203.57	206.57	206.23	0.34	203.57	206.23
07M041	203.02	206.19	205.44	0.75	203.02	205.44
07M042	203.01	206.00	204.95	1.05	203.01	204.95
07M043	202.90	205.97	204.92	1.05	202.9	204.92
07M044	202.77	205.64	204.86	0.78	202.77	204.86
07M045	202.62	205.12	204.84	0.28	202.62	204.84
07M046	201.44	204.68	204.56	0.12	201.44	204.56
07M047	208.50	211.00	210.52	0.48	208.5	210.52
07M048	208.08	211.00	210.40	0.60	208.08	210.4
07M050	205.10	208.18	206.82	1.36	205.1	206.82
07M052	205.79	208.98	207.82	1.16	205.79	207.82
07M053	204.61	207.91	206.57	1.34	204.61	206.57
07M054	204.14	207.00	206.45	0.55	204.14	206.45
07M055	204.02	207.00	206.18	0.82	204.02	206.18
07M057	203.84	207.00	205.88	1.12	203.84	205.88
07M060	205.80	208.52	207.81	0.71	205.8	207.81
07M061	203.11	207.00	205.67	1.33	203.11	205.67
07M062	202.70	206.18	205.31	0.87	202.7	205.31
07M063	202.44	206.00	205.17	0.83	202.44	205.17
07M067	201.08	204.59	204.23	0.36	201.08	204.23
07M068	200.85	205.00	204.02	0.98	200.85	204.02
07M069	208.02	211.50	210.60	0.90	208.02	210.6
07M070	206.68	209.16	208.87	0.29	206.68	208.87
07M072	206.16	208.64	207.97	0.66	206.16	207.97
07M074	205.25	207.70	206.59	1.11	205.25	206.59
07M076	203.79	206.47	205.27	1.19	203.79	205.27
07M078	202.41	205.51	204.84	0.67	202.41	204.84
07M079	202.11	205.06	204.40	0.66	202.11	204.4
07M080	201.97	206.00	204.64	1.36	201.97	204.64
07M081	201.56	205.00	204.44	0.56	201.56	204.44
07M082	200.84	205.00	204.01	0.99	200.84	204.01
07M084	208.15	211.18	210.43	0.75	208.15	210.43
07M085	208.00	211.72	210.55	1.17	208	210.55
07M086	208.06	211.00	210.15	0.85	208.06	210.15
07M087	207.72	211.73	210.58	1.15	207.72	210.58
07M090	207.13	210.71	209.61	1.10	207.13	209.61
07M091	206.13	208.94	208.50	0.44	206.13	208.5
07M092	205.18	205.58	204.68	0.90	204.279	204.68

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
07M093	204.43	205.00	204.06	0.94	203.49	204.06
07M094	200.53	204.75	203.98	0.77	200.53	203.98
07M095	208.75	211.00	210.27	0.73	208.75	210.27
07M096	208.54	211.00	209.94	1.06	208.54	209.94
07M097	207.15	209.86	209.42	0.44	207.15	209.42
07M098	206.96	208.82	208.40	0.42	206.96	208.4
07M099	204.52	206.97	206.24	0.73	204.52	206.24
07M100	201.32	204.82	203.70	1.12	201.32	203.7
07M101	200.32	205.81	205.18	0.63	200.32	205.18
07M102	209.49	212.00	211.19	0.81	209.49	211.19
07M103	209.43	212.00	211.20	0.80	209.43	211.2
07M108	208.72	211.43	210.72	0.71	208.72	210.72
07M110	210.19	212.00	211.48	0.52	210.19	211.48
07M111	209.53	212.00	211.26	0.74	209.53	211.26
07M112	209.09	212.00	211.02	0.98	209.09	211.02
07M113	208.50	211.00	210.77	0.23	208.5	210.77
07M114	207.80	211.00	209.91	1.09	207.8	209.91
07M115	206.82	210.40	209.26	1.14	206.82	209.26
07M116	205.94	209.59	208.52	1.07	205.94	208.52
07M117	205.37	208.26	207.51	0.75	205.37	207.51
07M118	204.09	207.48	206.39	1.09	204.09	206.39
07M119	200.06	205.77	204.90	0.87	200.06	204.9
07M122	208.29	210.67	210.68	-0.01	208.29	210.68
07M123	208.09	211.00	210.45	0.55	208.09	210.45
07M124	207.82	210.78	210.21	0.56	207.82	210.21
07M125	207.64	210.38	209.99	0.38	207.64	209.99
07M126	207.40	210.68	209.85	0.83	207.4	209.85
07M127	207.18	210.22	209.47	0.74	207.18	209.47
07M128	208.36	210.95	210.69	0.26	208.36	210.69
07M129	207.74	212.00	210.36	1.64	207.74	210.36
07M130	207.17	209.95	209.37	0.58	207.17	209.37
07M137	200.93	204.00	203.48	0.52	200.925	203.48
07M142	209.12	212.00	211.22	0.78	209.12	211.22
07M143	208.76	210.98	210.66	0.32	208.76	210.66
07M144	209.96	211.94	211.32	0.62	209.956	211.32
07M148	209.39	212.00	211.30	0.70	209.39	211.3
07M149	208.89	211.57	211.16	0.41	208.89	211.16
07M150	208.45	210.22	209.92	0.30	208.45	209.92

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
07M154	205.11	207.53	207.20	0.33	205.11	207.2
07M157	201.60	204.00	203.57	0.43	201.6	203.57
07M176SF	198.39	200.90	200.06	0.84	198.39	200.06
07M187	200.35	203.00	200.49	2.51	200.347	200.49
07M189	209.42	211.00	202.85	8.15	201.27	202.85
07M190	208.81	210.00	202.51	7.49	201.32	202.51
07M191	206.86	208.00	200.87	7.13	199.73	200.87
07M192	198.47	200.91	200.13	0.78	198.47	200.13
07M193	198.39	201.71	200.21	1.50	198.39	200.21
07M194OF	195.54	200.00	200.11	-0.11	195.539	200.11
07M195	209.05	211.00	210.16	0.84	209.05	210.16
07M196	208.80	211.12	210.29	0.83	208.8	210.29
07M197	204.64	205.10	204.39	0.71	203.932	204.39
07M198SF	208.00	211.00	209.59	1.41	208	209.59
07M199SF	207.00	209.00	208.68	0.32	207	208.68
07M202	201.42	207.27	206.34	0.93	201.423	206.34
07M203	201.39	206.99	206.29	0.70	201.39	206.29
07M204	202.80	208.52	207.51	1.01	202.8	207.51
07M205	200.40	202.82	202.03	0.79	200.4	202.03
07M206	199.90	203.05	202.95	0.10	199.895	202.95
07M207OF	196.48	201.00	200.14	0.86	196.48	200.14
07M208	199.48	205.11	203.59	1.52	199.48	203.59
07M209	199.32	203.15	202.49	0.66	199.32	202.49
07M210	199.08	203.00	202.12	0.88	199.08	202.12
07M211	198.76	203.00	201.92	1.08	198.76	201.92
07M212	198.51	201.96	201.60	0.36	198.51	201.6
07M213	198.51	202.58	201.14	1.44	198.51	201.14
07M215	209.06	211.11	210.72	0.39	209.06	210.72
07M216	209.66	212.00	211.63	0.37	209.66	211.63
07M217	205.21	208.19	207.38	0.81	205.208	207.38
07M218	204.49	207.58	206.58	1.00	204.492	206.58
07M219	205.78	208.00	206.94	1.06	205.78	206.94
07M220	203.33	206.58	205.89	0.69	203.33	205.89
07M221	204.97	207.04	206.32	0.72	204.97	206.32
07M222	202.51	205.14	204.80	0.34	202.512	204.8
07M223	202.75	205.00	204.11	0.89	202.75	204.11
07M224	201.40	204.00	203.42	0.58	201.404	203.42
07M225	200.60	202.98	202.73	0.25	200.6	202.73

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
07M226	200.46	202.97	202.64	0.33	200.456	202.64
07M227	202.07	205.00	204.50	0.50	202.07	204.5
07M228	202.38	204.55	204.47	0.08	202.38	204.47
07M229	202.73	205.86	205.31	0.55	202.73	205.31
07M230	208.64	212.00	211.41	0.59	208.644	211.41
07M231	208.01	210.52	210.30	0.22	208.01	210.3
07M232	201.07	203.45	203.13	0.32	201.068	203.13
07M233	204.05	206.78	206.29	0.49	204.045	206.29
07M234	203.43	206.00	204.85	1.15	203.429	204.85
07M235	203.15	206.00	205.20	0.80	203.15	205.2
07M236	202.69	206.00	205.15	0.85	202.69	205.15
07M237	204.23	207.00	206.38	0.62	204.234	206.38
07M238	202.13	208.00	206.76	1.24	202.134	206.76
07M239	209.97	212.56	211.82	0.73	209.966	211.82
07M240	208.93	212.00	211.18	0.82	208.93	211.18
07M241	209.46	212.51	211.74	0.77	209.458	211.74
07M242SF	201.53	206.00	205.20	0.80	201.53	205.2
07M245	202.75	206.23	205.27	0.96	202.747	205.27
07M246SF	198.64	201.97	201.48	0.49	198.64	201.48
07M247SF	198.51	202.27	201.14	1.13	198.51	201.14
07M248SF	199.08	203.00	202.12	0.88	199.08	202.12
07M249	209.45	212.60	211.72	0.88	209.452	211.72
07M250	200.84	205.00	204.04	0.96	200.84	204.04
07M252SF	198.51	202.00	201.11	0.89	198.51	201.11
07M254	209.28	211.91	211.32	0.59	209.278	211.32
07M255	209.11	212.00	211.09	0.91	209.109	211.09
07M256	208.91	211.57	210.98	0.59	208.911	210.98
07M257	208.87	211.49	210.99	0.49	208.87	210.99
07M258	207.52	210.68	210.47	0.21	207.52	210.47
07M259	206.72	209.07	208.89	0.18	206.72	208.89
07M260	204.07	206.67	206.32	0.35	204.065	206.32
07M261	201.32	203.36	202.98	0.38	201.319	202.98
07M262	199.27	202.42	201.31	1.11	199.265	201.31
07M263	199.18	202.22	201.47	0.75	199.18	201.47
07M264	200.44	203.08	202.47	0.61	200.44	202.47
07M265	200.24	203.12	202.99	0.13	200.24	202.99
07M266	209.60	212.00	211.29	0.71	209.6	211.29
07M267	209.88	213.00	211.02	1.98	209.88	211.02

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
07M268	207.39	210.64	209.89	0.75	207.39	209.89
07M269	206.84	209.27	208.44	0.83	206.84	208.44
07M270	204.30	207.00	205.98	1.02	204.299	205.98
07M271	204.19	206.91	206.23	0.68	204.191	206.23
07M272SF	199.28	203.12	202.49	0.63	199.28	202.49
08M001	205.86	208.85	208.34	0.51	205.86	208.34
08M002	202.63	205.67	204.89	0.78	202.63	204.89
08M003	201.63	203.64	203.19	0.44	201.63	203.19
08M004OF	195.98	202.00	198.37	3.63	195.984	198.37
09M001	200.61	204.15	203.37	0.78	200.61	203.37
09M002	200.32	203.00	202.04	0.96	200.32	202.04
09M003	200.13	203.00	201.79	1.21	200.13	201.79
09M004	200.10	203.00	201.85	1.15	200.1	201.85
09M005	200.01	203.00	202.06	0.94	200.01	202.06
09M006OF	196.10	201.00	198.50	2.50	196.099	198.5
09M007	199.91	202.94	202.14	0.80	199.91	202.14
10M001	203.00	208.00	206.80	1.20	203	206.8
10M002	202.00	211.00	209.07	1.93	202	209.07
10M003	201.00	208.00	206.34	1.66	201	206.34
10M004	200.00	208.00	206.23	1.77	200	206.23
10M005	199.00	206.00	202.83	3.17	199	202.83
10M006	209.00	211.00	204.98	6.02	202.98	204.98
10M008	209.00	211.00	203.94	7.06	201.94	203.94
10M010	208.50	209.00	201.17	7.83	200.67	201.17
10M011	208.00	213.00	201.03	11.97	196.03	201.03
10M012	198.28	202.05	201.51	0.54	198.28	201.51
10M013	198.24	202.33	200.66	1.67	198.24	200.66
10M014	198.23	202.00	201.28	0.72	198.23	201.28
10M015	197.70	202.00	201.36	0.64	197.7	201.36
10M016	193.24	202.00	200.93	1.07	193.24	200.93
10M017	193.23	202.00	201.02	0.98	193.23	201.02
10M018	193.29	202.00	200.94	1.06	193.29	200.94
10M019	193.27	202.00	200.66	1.34	193.27	200.66
10M020	197.62	202.74	200.94	1.80	197.62	200.94
10M021	197.56	204.80	204.34	0.46	197.56	204.34
10M022	197.52	201.93	200.60	1.33	197.52	200.6
10M033	199.00	200.00	199.90	0.10	199	199.9
10M035	198.75	201.00	200.00	1.00	198.75	200

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
10M036	198.50	201.00	200.42	0.58	198.5	200.42
10M037	199.00	201.00	200.11	0.89	199	200.11
10M038	198.50	201.00	199.72	1.28	198.5	199.72
10M041	197.82	201.00	200.34	0.66	197.82	200.34
10M042	197.71	201.00	200.66	0.34	197.71	200.66
10M043	197.44	201.00	200.92	0.08	197.44	200.92
10M044OF	196.74	199.00	198.06	0.94	196.735	198.06
10M048	210.10	212.21	211.79	0.42	210.1	211.79
10M050	209.90	213.00	211.93	1.07	209.9	211.93
10M051	210.02	212.16	211.45	0.71	210.02	211.45
10M052	209.82	212.72	211.91	0.81	209.82	211.91
10M054	209.94	212.08	211.94	0.14	209.943	211.94
10M056	210.39	213.31	212.72	0.59	210.39	212.72
10M058	209.39	212.00	211.88	0.12	209.385	211.88
10M069	210.54	212.85	212.08	0.77	210.54	212.08
10M070	210.16	212.48	212.03	0.45	210.159	212.03
10M074	205.35	208.17	207.67	0.50	205.35	207.67
10M075	200.68	202.99	202.34	0.65	200.68	202.34
10M076	202.70	205.01	204.55	0.46	202.7	204.55
10M077	206.83	210.01	209.69	0.32	206.83	209.69
10M078	210.11	213.40	212.58	0.82	210.11	212.58
10M079OF	196.65	201.00	199.50	1.50	196.652	199.5
10M084	197.44	201.87	201.03	0.84	197.44	201.03
10M085	197.37	202.65	201.43	1.22	197.37	201.43
10M086	197.27	202.81	202.27	0.54	197.27	202.27
10M087	197.23	202.23	202.10	0.13	197.23	202.1
10M088	199.00	201.00	200.46	0.54	199	200.46
10M089	197.21	202.16	201.06	1.10	197.213	201.06
10M090	197.12	201.99	200.64	1.35	197.116	200.64
10M091	197.03	201.26	200.49	0.77	197.025	200.49
10M093OF	196.75	198.00	198.81	-0.81	196.754	198.81
10M094	209.00	211.00	206.88	4.12	204.88	206.88
10M095	196.93	200.75	200.20	0.55	196.933	200.2
10M096	196.88	201.00	199.88	1.12	196.877	199.88
10M097	196.80	201.00	200.38	0.62	196.798	200.38
10M098SF	197.30	202.86	202.16	0.69	197.3	202.16
10M099	197.84	202.71	202.20	0.51	197.842	202.2
10M100	198.15	201.88	201.59	0.29	198.148	201.59

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
10M101	198.40	202.00	201.15	0.85	198.395	201.15
10M102	198.82	202.15	201.93	0.22	198.82	201.93
10M103	210.98	214.00	212.66	1.34	210.98	212.66
11G557	204.63	207.07	206.56	0.51	204.625	206.56
11M001	237.50	239.00	237.56	1.44	237.5	237.56
11M001OF	199.64	201.00	202.04	-1.04	199.64	202.04
11M002	237.00	239.00	237.63	1.37	237	237.63
11M003	236.00	239.00	237.62	1.38	236	237.62
11M004	235.00	238.00	236.99	1.01	235	236.99
11M005	238.33	241.00	240.33	0.67	238.33	240.33
11M006	236.96	239.95	239.54	0.41	236.96	239.54
11M007	236.81	239.16	238.62	0.54	236.81	238.62
11M008	236.48	239.15	238.70	0.45	236.48	238.7
11M009	236.18	238.63	238.15	0.48	236.18	238.15
11M010	236.00	237.00	237.28	-0.28	236	237.28
11M011	235.50	238.00	237.16	0.84	235.5	237.16
11M012	235.00	239.00	236.62	2.38	235	236.62
11M013	235.00	239.00	237.29	1.71	235	237.29
11M014	234.58	238.00	237.32	0.68	234.58	237.32
11M015	234.36	238.13	236.93	1.20	234.36	236.93
11M016	234.52	236.93	236.69	0.24	234.52	236.69
11M017	234.21	236.99	236.55	0.43	234.21	236.55
11M018	234.08	237.05	236.01	1.04	234.08	236.01
11M019	235.25	237.88	237.19	0.69	235.25	237.19
11M020	234.86	237.00	236.73	0.27	234.86	236.73
11M021	233.77	235.60	235.47	0.13	233.77	235.47
11M022	233.75	235.82	235.43	0.39	233.75	235.43
11M023	233.64	236.72	235.77	0.95	233.64	235.77
11M024	234.85	237.00	236.29	0.71	234.85	236.29
11M026	235.09	237.59	236.60	0.99	235.09	236.6
11M027	234.39	237.00	236.62	0.38	234.385	236.62
11M028	234.37	238.00	236.88	1.12	234.37	236.88
11M029	236.01	239.00	238.05	0.95	236.01	238.05
11M030	235.39	237.93	237.25	0.68	235.39	237.25
11M031	234.90	238.00	237.44	0.56	234.9	237.44
11M032	234.90	236.96	236.34	0.62	234.9	236.34
11M035	233.74	238.19	237.68	0.51	233.74	237.68
11M036	233.58	238.14	237.63	0.51	233.58	237.63

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M037	233.40	236.55	236.10	0.45	233.4	236.1
11M038	232.86	235.86	235.05	0.81	232.86	235.05
11M039	234.26	236.59	235.85	0.74	234.26	235.85
11M040	233.99	236.00	235.50	0.50	233.99	235.5
11M041	233.71	235.66	235.09	0.57	233.71	235.09
11M042	235.07	238.00	237.08	0.92	235.07	237.08
11M043	233.35	237.31	236.55	0.76	233.35	236.55
11M044	233.09	235.86	235.20	0.66	233.09	235.2
11M045	232.11	235.51	234.97	0.54	232.11	234.97
11M046	231.79	236.44	236.07	0.37	231.79	236.07
11M047	230.91	236.60	235.64	0.96	230.91	235.64
11M048	232.03	234.61	233.53	1.08	232.03	233.53
11M049	231.70	235.59	234.81	0.78	231.7	234.81
11M050	230.49	236.25	235.50	0.75	230.49	235.5
11M051	228.32	232.02	230.23	1.79	228.32	230.23
11M052	226.31	230.92	228.49	2.43	226.31	228.49
11M053	224.35	228.19	227.22	0.97	224.35	227.22
11M054	222.47	225.98	225.78	0.20	222.47	225.78
11M055	220.74	224.39	224.20	0.19	220.74	224.2
11M056	218.97	222.81	222.49	0.32	218.97	222.49
11M057	217.21	221.68	220.97	0.70	217.21	220.97
11M058	216.92	219.95	219.41	0.54	216.92	219.41
11M060	216.53	220.35	219.36	0.98	216.53	219.36
11M061	215.14	219.54	218.91	0.63	215.14	218.91
11M062	213.50	218.89	217.73	1.16	213.5	217.73
11M063	212.88	218.89	218.13	0.76	212.88	218.13
11M064	212.42	216.88	216.03	0.85	212.42	216.03
11M065	211.97	215.19	214.86	0.33	211.97	214.86
11M066	232.93	235.40	234.69	0.71	232.93	234.69
11M067	232.80	235.52	234.56	0.96	232.8	234.56
11M068	232.70	235.62	234.83	0.79	232.7	234.83
11M069	233.43	236.47	235.54	0.93	233.43	235.54
11M070	233.04	235.87	235.35	0.52	233.04	235.35
11M071	232.22	235.42	234.76	0.66	232.22	234.76
11M072	226.44	229.91	229.09	0.82	226.44	229.09
11M073	220.70	224.53	223.95	0.58	220.7	223.95
11M074	214.97	218.10	218.07	0.03	214.97	218.07
11M075	211.95	215.03	214.62	0.41	211.95	214.62

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M076	211.63	215.00	213.79	1.21	211.63	213.79
11M077	209.96	213.64	212.56	1.08	209.96	212.56
11M078	209.20	213.07	212.37	0.70	209.2	212.37
11M080	207.58	211.63	210.69	0.94	207.58	210.69
11M082	233.10	235.81	235.28	0.53	233.104	235.28
11M083	224.28	231.79	226.99	4.80	224.282	226.99
11M084	218.55	222.87	220.88	1.99	218.552	220.88
11M085	212.42	215.78	215.34	0.44	212.42	215.34
11M086	212.05	215.63	214.82	0.81	212.05	214.82
11M087	228.15	230.69	229.12	1.57	228.15	229.12
11M089	228.59	232.09	228.83	3.25	228.59	228.83
11M090	221.55	225.62	223.95	1.67	221.55	223.95
11M091	217.37	220.96	219.75	1.21	217.37	219.75
11M092	212.59	215.93	214.76	1.17	212.59	214.76
11M093	211.68	214.70	214.01	0.69	211.68	214.01
11M094	210.41	212.28	211.93	0.35	210.41	211.93
11M095SF	207.14	211.53	210.72	0.81	207.14	210.72
11M096	207.67	209.08	208.60	0.48	207.67	208.6
11M097	207.30	209.00	209.14	-0.14	207.3	209.14
11M098	207.00	209.30	209.04	0.26	207	209.04
11M099	207.95	210.00	209.20	0.80	207.95	209.2
11M100	205.89	209.17	208.98	0.19	205.89	208.98
11M101	233.91	237.24	236.16	1.08	233.91	236.16
11M106	212.10	217.33	216.86	0.47	212.1	216.86
11M107	211.85	214.79	214.46	0.33	211.85	214.46
11M108	211.69	214.43	213.26	1.17	211.69	213.26
11M109	211.43	213.90	213.59	0.31	211.43	213.59
11M110	237.36	241.00	239.71	1.29	237.36	239.71
11M111	237.13	239.47	239.39	0.08	237.13	239.39
11M112	236.96	240.00	239.15	0.85	236.96	239.15
11M113	236.93	240.00	239.31	0.69	236.93	239.31
11M114	236.70	240.00	239.20	0.80	236.698	239.2
11M115	237.74	240.78	240.04	0.74	237.74	240.04
11M116	237.29	240.43	239.69	0.73	237.29	239.69
11M117	236.39	239.78	239.22	0.56	236.388	239.22
11M118	236.39	239.59	238.71	0.88	236.39	238.71
11M119	235.44	238.85	238.21	0.64	235.44	238.21
11M120	235.15	238.82	238.33	0.49	235.15	238.33

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M121	234.84	238.11	237.56	0.55	234.84	237.56
11M122	233.90	235.79	235.60	0.19	233.9	235.6
11M123	233.64	236.85	235.82	1.03	233.64	235.82
11M124	233.40	236.65	236.42	0.23	233.4	236.42
11M125	236.34	239.11	238.42	0.69	236.34	238.42
11M126	233.19	237.77	237.16	0.61	233.19	237.16
11M127	232.98	237.05	236.32	0.73	232.98	236.32
11M128	226.89	234.65	233.72	0.93	226.89	233.72
11M129	224.17	226.05	224.82	1.23	224.17	224.82
11M130	216.76	217.39	216.82	0.57	216.76	216.82
11M131	233.36	236.68	236.25	0.43	233.36	236.25
11M132	228.80	231.78	231.20	0.58	228.8	231.2
11M133	221.61	226.97	226.15	0.82	221.61	226.15
11M134	215.56	218.17	217.51	0.66	215.56	217.51
11M135	210.97	214.50	213.62	0.88	210.97	213.62
11M136	210.70	213.37	212.86	0.51	210.7	212.86
11M137	209.37	212.00	210.36	1.64	209.37	210.36
11M138	208.66	211.00	210.05	0.95	208.66	210.05
11M139	207.50	209.52	208.89	0.63	207.5	208.89
11M140	207.00	209.71	209.17	0.54	207	209.17
11M141	207.39	209.00	208.34	0.66	207.39	208.34
11M142	209.35	212.27	211.23	1.04	209.35	211.23
11M143	208.35	210.73	209.93	0.80	208.35	209.93
11M144	207.68	209.82	209.25	0.57	207.68	209.25
11M145	207.40	209.59	208.59	1.00	207.4	208.59
11M146	207.30	209.08	208.54	0.54	207.3	208.54
11M147	205.50	208.97	208.50	0.47	205.5	208.5
11M148	205.32	209.00	208.56	0.44	205.32	208.56
11M149	207.17	209.00	208.02	0.98	207.17	208.02
11M150	205.02	209.00	207.81	1.19	205.02	207.81
11M151	206.41	209.00	207.65	1.35	206.41	207.65
11M152	206.38	208.82	207.34	1.48	206.38	207.34
11M153	206.14	208.27	207.35	0.92	206.14	207.35
11M154	206.11	208.39	207.25	1.14	206.11	207.25
11M155	206.30	207.98	207.31	0.67	206.3	207.31
11M156	204.45	208.26	207.15	1.11	204.45	207.15
11M157	203.92	213.59	214.25	-0.66	203.92	214.25
11M158	203.62	208.57	208.15	0.42	203.62	208.15

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M159	229.20	234.63	234.20	0.43	229.2	234.2
11M160	224.06	231.88	230.85	1.03	224.06	230.85
11M161	218.94	227.97	227.35	0.62	218.94	227.35
11M162	216.27	223.63	223.47	0.16	216.266	223.47
11M163	212.20	217.86	215.67	2.19	212.2	215.67
11M164	209.56	215.03	214.24	0.79	209.56	214.24
11M165	207.93	211.37	210.17	1.20	207.93	210.17
11M167	207.66	210.05	209.56	0.49	207.66	209.56
11M168	212.18	215.84	215.34	0.50	212.18	215.34
11M169	210.84	214.19	213.19	1.00	210.84	213.19
11M170	208.75	211.94	210.99	0.95	208.75	210.99
11M171	208.01	211.97	209.88	2.09	208.01	209.88
11M172	207.92	211.66	209.59	2.07	207.92	209.59
11M173	207.58	210.00	209.46	0.54	207.58	209.46
11M174	207.57	210.00	209.41	0.59	207.57	209.41
11M175	207.62	210.00	209.36	0.64	207.62	209.36
11M176	207.89	210.63	209.27	1.36	207.89	209.27
11M184	205.50	208.00	205.96	2.04	205.5	205.96
11M186	204.60	207.00	206.26	0.74	204.6	206.26
11M187	204.51	207.00	205.93	1.07	204.508	205.93
11M188	204.44	207.05	206.17	0.88	204.435	206.17
11M189	204.37	206.97	206.31	0.66	204.374	206.31
11M190	205.39	207.81	206.32	1.49	205.39	206.32
11M191	205.20	207.85	206.61	1.24	205.2	206.61
11M192	205.09	207.57	206.79	0.78	205.09	206.79
11M193	204.80	213.00	209.07	3.93	204.8	209.07
11M194	204.75	208.24	209.48	-1.24	204.75	209.48
11M195	206.61	209.00	208.61	0.39	206.61	208.61
11M196	206.58	208.73	208.19	0.54	206.58	208.19
11M197	206.44	207.50	206.65	0.85	206.44	206.65
11M198	205.83	208.03	206.16	1.87	205.83	206.16
11M199	205.52	207.88	214.11	-6.23	205.52	214.11
11M200	205.08	207.98	211.42	-3.44	205.08	211.42
11M201	204.45	207.37	209.77	-2.40	204.45	209.77
11M202	204.33	208.39	207.22	1.17	204.33	207.22
11M203	203.50	206.80	207.61	-0.81	203.5	207.61
11M204	203.38	207.00	213.60	-6.60	203.38	213.6
11M205	203.30	207.00	205.72	1.28	203.303	205.72

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M206SF	229.25	235.00	226.23	8.77	220.478	226.23
11M207	222.25	224.85	224.38	0.47	222.25	224.38
11M208	220.33	223.55	222.76	0.79	220.33	222.76
11M209	218.20	221.23	220.69	0.54	218.2	220.69
11M210	216.13	218.73	218.12	0.61	216.13	218.12
11M211	214.12	216.86	215.89	0.97	214.12	215.89
11M212	213.92	216.69	215.56	1.13	213.92	215.56
11M213	213.49	216.43	215.42	1.01	213.49	215.42
11M214	213.26	215.82	215.09	0.73	213.26	215.09
11M215	219.15	221.93	221.30	0.63	219.15	221.3
11M216	216.38	219.35	218.73	0.62	216.38	218.73
11M218	215.61	218.50	217.73	0.77	215.61	217.73
11M219	213.00	215.00	214.89	0.11	213	214.89
11M220	209.04	214.71	214.58	0.13	209.04	214.58
11M221	211.99	217.57	217.13	0.44	211.99	217.13
11M222	212.50	222.00	217.10	4.90	212.5	217.1
11M223	214.24	219.00	217.67	1.33	214.24	217.67
11M224	212.77	215.50	215.29	0.21	212.77	215.29
11M225	207.67	213.68	214.33	-0.65	207.67	214.33
11M226	207.44	212.71	212.92	-0.21	207.44	212.92
11M227	212.08	214.95	213.87	1.08	212.08	213.87
11M228	211.95	214.61	213.60	1.01	211.95	213.6
11M229	211.82	214.20	213.34	0.86	211.82	213.34
11M230	211.61	213.96	213.28	0.68	211.61	213.28
11M231	211.47	213.90	213.49	0.41	211.47	213.49
11M234	211.01	213.49	213.16	0.33	211.01	213.16
11M236	207.01	212.92	212.80	0.12	207.01	212.8
11M239	212.55	214.82	213.80	1.01	212.55	213.8
11M242	211.77	213.35	213.03	0.32	211.77	213.03
11M243	211.56	213.57	213.20	0.37	211.56	213.2
11M246	206.72	209.00	208.61	0.39	206.72	208.61
11M247	206.19	208.00	207.63	0.36	206.19	207.63
11M248	205.88	208.00	211.58	-3.58	205.88	211.58
11M249	204.95	207.60	206.98	0.62	204.95	206.98
11M250	204.41	207.00	206.16	0.84	204.41	206.16
11M251	212.60	214.85	214.13	0.72	212.6	214.13
11M252	212.40	214.78	214.09	0.69	212.4	214.09
11M253	212.14	214.00	213.44	0.56	212.14	213.44

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M254	212.07	214.00	213.83	0.17	212.07	213.83
11M258	212.11	214.00	213.66	0.34	212.114	213.66
11M260	212.11	214.82	214.31	0.51	212.11	214.31
11M261	212.08	214.99	214.16	0.83	212.08	214.16
11M262	212.10	215.00	214.57	0.43	212.1	214.57
11M263	212.08	214.85	214.30	0.55	212.08	214.3
11M264	212.07	214.27	213.90	0.37	212.07	213.9
11M267	211.59	214.07	214.05	0.01	211.59	214.05
11M268	211.38	213.35	212.96	0.39	211.38	212.96
11M269	212.24	214.60	213.76	0.84	212.24	213.76
11M270	211.82	214.00	213.31	0.69	211.82	213.31
11M271	211.30	213.28	213.03	0.25	211.3	213.03
11M272	210.40	212.85	212.71	0.14	210.4	212.71
11M273	206.76	212.97	212.55	0.42	206.76	212.55
11M274	206.52	211.17	210.71	0.46	206.52	210.71
11M276	204.89	207.60	206.98	0.62	204.89	206.98
11M278	204.05	207.00	206.35	0.65	204.05	206.35
11M279SF	203.10	207.00	206.13	0.87	203.1	206.13
11M280	204.75	207.00	206.17	0.83	204.746	206.17
11M281	204.57	207.00	205.81	1.19	204.573	205.81
11M282	204.36	207.00	205.52	1.48	204.362	205.52
11M284	213.00	218.00	216.62	1.38	213	216.62
11M290	204.22	207.00	205.31	1.69	204.22	205.31
11M292	204.94	207.76	206.24	1.52	204.94	206.24
11M293	204.78	207.48	206.27	1.21	204.78	206.27
11M294	204.63	207.01	206.33	0.67	204.63	206.33
11M295	204.49	206.84	206.06	0.78	204.49	206.06
11M296	204.17	206.55	205.78	0.77	204.17	205.78
11M297	204.12	206.00	205.17	0.83	204.12	205.17
11M298	203.64	206.00	205.03	0.97	203.64	205.03
11M299	205.31	207.64	207.15	0.49	205.31	207.15
11M300	204.02	206.00	205.43	0.57	204.02	205.43
11M301	202.63	206.00	205.40	0.60	202.63	205.4
11M302	202.57	206.00	205.29	0.71	202.57	205.29
11M303	204.19	207.33	206.38	0.95	204.19	206.38
11M304	203.71	205.26	204.85	0.41	203.71	204.85
11M305	202.11	205.25	204.85	0.39	202.11	204.85
11M310	204.28	207.00	206.28	0.72	204.28	206.28

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M311	203.75	207.00	206.30	0.70	203.75	206.3
11M312	203.15	205.63	205.04	0.59	203.15	205.04
11M313	202.01	205.76	204.88	0.88	202.01	204.88
11M314	205.52	208.00	206.85	1.15	205.52	206.85
11M315	205.33	207.00	205.78	1.22	205.33	205.78
11M316	205.27	207.00	206.57	0.43	205.27	206.57
11M317	205.14	207.00	206.39	0.61	205.14	206.39
11M318	205.06	207.58	206.26	1.32	205.056	206.26
11M319	205.01	207.81	206.10	1.71	205.008	206.1
11M320	204.70	207.00	206.28	0.72	204.7	206.28
11M321	210.49	212.86	212.40	0.46	210.49	212.4
11M322	212.60	214.46	213.78	0.68	212.6	213.78
11M323	210.10	213.04	212.57	0.47	210.1	212.57
11M324	209.10	211.83	210.96	0.87	209.1	210.96
11M325	211.29	214.62	213.64	0.98	211.29	213.64
11M326	211.03	213.63	213.00	0.63	211.03	213
11M328	210.30	213.30	212.65	0.65	210.3	212.65
11M329	208.45	210.52	210.22	0.30	208.45	210.22
11M330	205.15	208.28	207.46	0.82	205.15	207.46
11M340	203.80	206.66	205.86	0.80	203.8	205.86
11M341	201.74	205.43	204.91	0.52	201.74	204.91
11M342	201.57	205.59	204.98	0.61	201.57	204.98
11M343	201.50	205.19	204.57	0.62	201.5	204.57
11M344	209.45	212.68	211.80	0.88	209.45	211.8
11M345	203.57	206.70	205.56	1.14	203.57	205.56
11M346	203.14	205.29	204.66	0.63	203.14	204.66
11M347	206.62	207.00	206.60	0.40	206.22	206.6
11M349	203.58	206.48	205.76	0.72	203.58	205.76
11M350	201.36	205.42	204.84	0.58	201.36	204.84
11M351	202.77	208.03	205.66	2.37	202.77	205.66
11M352	202.63	206.75	204.89	1.86	202.63	204.89
11M353	202.58	204.59	204.06	0.53	202.58	204.06
11M354	205.42	208.01	207.18	0.83	205.42	207.18
11M356	204.88	207.39	206.79	0.60	204.88	206.79
11M357	200.96	205.24	204.14	1.10	200.96	204.14
11M358	210.65	214.19	212.94	1.25	210.65	212.94
11M360	209.93	213.35	212.57	0.78	209.93	212.57
11M362	209.32	211.60	211.07	0.53	209.319	211.07

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M365	203.88	207.46	205.17	2.29	203.88	205.17
11M366	202.48	205.27	204.34	0.93	202.48	204.34
11M367	202.02	203.81	203.63	0.18	202.02	203.63
11M369	205.42	208.95	207.52	1.43	205.42	207.52
11M370	202.31	205.84	204.98	0.86	202.31	204.98
11M371	200.74	205.27	204.13	1.14	200.74	204.13
11M372	210.07	214.28	212.89	1.39	210.07	212.89
11M373	209.76	214.00	212.97	1.03	209.76	212.97
11M374	209.10	213.41	211.68	1.73	209.1	211.68
11M379	202.20	205.00	204.11	0.89	202.196	204.11
11M380	201.97	204.44	203.92	0.52	201.974	203.92
11M381	209.95	212.00	210.78	1.22	209.954	210.78
11M382	204.93	209.00	207.93	1.07	204.934	207.93
11M383	202.50	205.23	204.30	0.93	202.496	204.3
11M384	200.41	204.91	204.09	0.82	200.41	204.09
11M385	202.95	206.51	206.03	0.48	202.95	206.03
11M386	202.75	205.81	204.79	1.02	202.75	204.79
11M387	202.20	205.27	203.89	1.38	202.2	203.89
11M388	201.68	205.00	204.00	1.00	201.68	204
11M389	200.56	205.00	204.01	0.99	200.56	204.01
11M390	201.52	205.02	204.15	0.87	201.52	204.15
11M392	210.25	212.76	212.19	0.57	210.25	212.19
11M394	210.08	212.01	211.31	0.70	210.08	211.31
11M395	209.39	212.00	211.24	0.76	209.39	211.24
11M396	209.10	212.00	211.34	0.66	209.1	211.34
11M399	207.12	209.75	209.38	0.37	207.12	209.38
11M400	203.89	208.23	207.48	0.75	203.89	207.48
11M401	200.10	207.12	206.21	0.91	200.1	206.21
11M402	210.90	213.84	213.19	0.65	210.9	213.19
11M403	210.50	213.65	212.61	1.04	210.5	212.61
11M404	210.35	213.89	212.52	1.37	210.35	212.52
11M405	211.00	214.00	212.62	1.38	211	212.62
11M407	210.30	213.74	212.46	1.28	210.3	212.46
11M408	211.35	214.00	213.33	0.67	211.35	213.33
11M409	210.10	214.00	212.97	1.03	210.1	212.97
11M410	209.97	214.00	212.95	1.05	209.97	212.95
11M411	211.11	214.00	212.67	1.33	211.11	212.67
11M412	210.99	214.00	212.75	1.25	210.99	212.75

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M413	210.97	214.00	212.72	1.28	210.97	212.72
11M414	211.50	214.28	213.57	0.71	211.5	213.57
11M415	210.98	214.96	213.51	1.45	210.98	213.51
11M416	210.95	214.81	213.14	1.67	210.95	213.14
11M417	211.68	213.97	213.21	0.76	211.68	213.21
11M418	210.92	214.00	212.82	1.18	210.92	212.82
11M419	210.75	214.00	213.02	0.98	210.75	213.02
11M420	210.64	214.00	213.07	0.93	210.64	213.07
11M421	210.58	214.82	212.85	1.97	210.58	212.85
11M422	209.96	214.00	212.89	1.11	209.96	212.89
11M423	209.94	214.17	212.62	1.55	209.94	212.62
11M424	209.64	213.76	212.24	1.52	209.64	212.24
11M425	211.44	214.00	213.38	0.62	211.44	213.38
11M426	210.94	213.94	212.76	1.18	210.94	212.76
11M427	210.17	213.59	212.27	1.31	210.17	212.27
11M428	209.50	213.59	212.22	1.36	209.5	212.22
11M429	208.98	213.12	212.43	0.69	208.98	212.43
11M430	212.00	214.00	214.09	-0.09	212	214.09
11M431	212.00	214.00	213.71	0.29	212	213.71
11M432	211.68	214.00	213.26	0.74	211.68	213.26
11M433	211.37	214.00	213.76	0.24	211.37	213.76
11M434	210.81	214.00	213.25	0.75	210.81	213.25
11M435	210.57	213.45	213.00	0.45	210.57	213
11M436	205.55	212.30	211.28	1.02	205.55	211.28
11M437	205.10	208.80	208.43	0.37	205.1	208.43
11M438	203.77	206.79	206.43	0.36	203.77	206.43
11M439	205.12	208.28	207.38	0.90	205.12	207.38
11M440	203.88	206.03	206.05	-0.02	203.88	206.05
11M441	202.05	205.01	204.65	0.36	202.05	204.65
11M442	201.87	204.05	203.65	0.40	201.87	203.65
11M443	201.69	203.91	203.62	0.29	201.69	203.62
11M445	210.53	214.00	212.90	1.10	210.53	212.9
11M446	209.82	213.28	212.26	1.02	209.82	212.26
11M448	207.54	212.15	211.39	0.76	207.54	211.39
11M449	207.46	210.63	209.56	1.07	207.46	209.56
11M450	207.35	211.00	209.94	1.06	207.35	209.94
11M451	207.25	211.03	210.45	0.58	207.25	210.45
11M452	207.14	211.61	211.00	0.61	207.14	211

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M453	207.14	211.28	211.03	0.25	207.14	211.03
11M454	210.47	214.00	212.57	1.43	210.47	212.57
11M455	210.68	214.00	212.41	1.59	210.68	212.41
11M456	208.97	211.78	211.32	0.46	208.97	211.32
11M457	205.80	208.53	207.68	0.85	205.8	207.68
11M460	210.95	214.00	212.95	1.05	210.95	212.95
11M462	203.10	208.00	206.30	1.70	203.1	206.3
11M463	207.06	212.25	211.80	0.45	207.062	211.8
11M464	206.83	211.12	210.26	0.86	206.834	210.26
11M465	206.45	209.38	208.92	0.46	206.45	208.92
11M466	206.76	209.20	208.63	0.57	206.761	208.63
11M467	208.43	212.98	212.52	0.46	208.43	212.52
11M468	205.47	210.00	207.96	2.04	205.47	207.96
11M469	209.34	212.72	212.01	0.71	209.34	212.01
11M470	208.02	209.93	209.51	0.42	208.02	209.51
11M471	236.00	239.00	238.39	0.61	236	238.39
11M472	234.20	239.00	236.63	2.37	234.2	236.63
11M473	233.20	237.00	234.78	2.22	233.198	234.78
11M474	232.74	237.00	234.92	2.08	232.736	234.92
11M475	235.00	238.00	236.05	1.95	235	236.05
11M476	236.00	238.00	237.10	0.90	236	237.1
11M477	231.80	237.00	236.38	0.62	231.8	236.38
11M478	231.80	234.04	233.68	0.36	231.8	233.68
11M479	228.74	232.89	230.11	2.78	228.74	230.11
11M481SF	215.00	225.00	218.95	6.05	215	218.95
11M482	201.66	203.78	203.30	0.48	201.66	203.3
11M483	234.82	238.00	237.32	0.68	234.82	237.32
11M484	199.86	203.86	203.94	-0.08	199.858	203.94
11M485	234.31	238.00	236.84	1.16	234.31	236.84
11M486	233.76	238.00	236.98	1.02	233.76	236.98
11M487	233.43	237.08	236.70	0.38	233.43	236.7
11M488	214.64	216.79	215.86	0.93	214.644	215.86
11M492	204.87	206.67	206.15	0.52	204.868	206.15
11M496	200.48	205.12	203.68	1.44	200.48	203.68
11M498	212.77	214.99	214.73	0.26	212.774	214.73
11M499	212.47	214.46	214.38	0.07	212.467	214.38
11M500	212.29	214.40	213.85	0.55	212.29	213.85
11M501	212.16	214.00	213.69	0.31	212.164	213.69

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M502	211.98	214.00	213.78	0.22	211.983	213.78
11M503	211.89	214.00	213.58	0.42	211.89	213.58
11M505	233.68	238.76	237.86	0.89	233.68	237.86
11M508SF	204.15	207.00	205.66	1.34	204.15	205.66
11M509	238.63	242.00	240.24	1.76	238.628	240.24
11M510	212.01	214.00	213.73	0.27	212.012	213.73
11M511	212.22	214.00	213.30	0.70	212.221	213.3
11M512	208.29	215.17	215.12	0.05	208.289	215.12
11M513	207.91	214.87	215.18	-0.31	207.908	215.18
11M514	211.39	215.27	213.42	1.85	211.386	213.42
11M515	239.00	244.00	240.17	3.83	239	240.17
11M516	205.38	208.73	207.47	1.26	205.38	207.47
11M517	208.51	210.97	210.62	0.35	208.505	210.62
11M518	207.09	209.81	208.82	0.99	207.085	208.82
11M519	227.71	230.48	230.38	0.10	227.71	230.38
11M521	211.60	214.00	213.57	0.43	211.602	213.57
11M522	211.59	214.00	214.04	-0.04	211.59	214.04
11M523	235.10	237.43	236.68	0.75	235.1	236.68
11M524	234.59	237.00	235.82	1.18	234.59	235.82
11M525	234.14	238.00	236.77	1.23	234.139	236.77
11M526	234.11	238.00	236.90	1.10	234.11	236.9
11M527	234.42	238.00	236.98	1.02	234.42	236.98
11M528	208.71	212.90	211.51	1.39	208.713	211.51
11M529	208.61	212.96	211.39	1.57	208.61	211.39
11M530	208.35	212.60	211.29	1.31	208.35	211.29
11M531	207.14	210.28	209.66	0.62	207.139	209.66
11M532	203.93	206.41	205.57	0.84	203.927	205.57
11M533	202.92	205.00	204.09	0.91	202.922	204.09
11M534	202.42	205.00	203.96	1.04	202.415	203.96
11M535	202.36	205.00	203.99	1.01	202.362	203.99
11M536	203.83	206.18	205.34	0.84	203.833	205.34
11M537	209.50	214.00	211.56	2.44	209.5	211.56
11M538	209.50	214.00	212.41	1.59	209.5	212.41
11M539SF	233.96	238.00	236.90	1.10	233.96	236.9
11M540	204.40	207.00	206.50	0.50	204.4	206.5
11M541	204.62	206.87	206.46	0.41	204.62	206.46
11M542	205.66	208.00	206.76	1.24	205.655	206.76
11M543	211.26	213.81	213.39	0.42	211.255	213.39

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
11M544	210.75	213.53	213.46	0.07	210.75	213.46
11M545	202.33	204.98	204.46	0.52	202.33	204.46
11M546	202.70	207.58	205.09	2.49	202.7	205.09
11M547	202.58	206.21	204.45	1.76	202.58	204.45
11M548	202.43	204.69	203.93	0.76	202.43	203.93
11M549SF	201.06	205.34	204.09	1.25	201.06	204.09
11M550	211.35	214.27	213.41	0.86	211.351	213.41
11M551	202.53	205.11	204.74	0.37	202.53	204.74
11M552	201.81	204.42	203.73	0.69	201.81	203.73
11M552SF	203.08	207.00	206.37	0.63	203.084	206.37
11M556	215.96	218.66	217.98	0.68	215.96	217.98
11M558	204.32	206.96	206.11	0.85	204.32	206.11
11M559	206.25	208.78	207.98	0.80	206.252	207.98
11M560	205.82	207.63	207.31	0.32	205.821	207.31
11M561	205.63	208.06	207.19	0.87	205.633	207.19
11M562	204.73	207.84	206.46	1.38	204.734	206.46
11M563-1	211.08	214.04	213.04	1.00	211.08	213.04
11M565	206.40	209.00	207.60	1.40	206.4	207.6
11M566	214.05	217.22	216.40	0.82	214.05	216.4
11M567	216.18	219.26	218.35	0.91	216.18	218.35
11M568	226.10	228.71	228.26	0.45	226.1	228.26
11M569	203.68	206.00	205.06	0.94	203.68	205.06
11M570	215.52	217.73	217.01	0.72	215.524	217.01
11MC001	234.41	239.00	237.78	1.22	234.41	237.78
11MC002	234.99	238.00	237.27	0.73	234.99	237.27
11MC003	234.32	239.00	237.17	1.83	234.32	237.17
11MC006	211.00	214.00	212.94	1.06	211	212.94
11MC007	210.00	212.00	211.21	0.79	210	211.21
11MC008	209.00	212.00	209.78	2.22	209	209.78
11MC010	215.50	226.00	214.66	11.34	204.161	214.66
11MC012	208.36	210.00	209.34	0.66	208.356	209.34
11MC017	234.61	238.00	237.35	0.65	234.61	237.35
11MC018	234.08	239.00	237.64	1.36	234.08	237.64
14G013	202.49	204.74	204.12	0.62	202.49	204.12
14G014	202.29	205.00	204.20	0.80	202.29	204.2
14G015	202.15	205.00	204.11	0.89	202.15	204.11
14G018	201.52	205.06	204.68	0.38	201.52	204.68
14G070	201.84	205.49	204.05	1.44	201.84	204.05

Table A1: Comparison of Rim elevation of minor system against 2X2 DEM Mosaic						
Conduit ID	Original Invert Elevation (m)	Original Rim Elevation (m)	Rim Elevation per 2x2 DEM Mosaic (m)	Difference in rim elevation (m)	Updated Invert Elevation (m)	Updated Rim Elevation (m)
14G071	202.11	204.72	203.73	0.99	202.11	203.73
18G031	212.65	214.00	213.83	0.17	212.65	213.83
18G032	212.46	214.00	213.86	0.14	212.46	213.86
18G034	211.68	214.00	213.73	0.27	211.68	213.73
21G002	237.70	239.00	238.47	0.53	237.7	238.47
21G003	236.85	238.70	238.74	-0.04	236.85	238.74
21G245	213.05	215.00	215.15	-0.15	213.053	215.15
21G256SF	237.68	239.00	238.58	0.42	237.68	238.58
21G302	237.88	239.00	238.57	0.43	237.884	238.57
47364	224.00	226.50	225.72	0.78	224	225.72
47365	216.55	219.40	218.64	0.76	216.55	218.64
47367	230.60	233.66	233.16	0.49	230.6	233.16
BP-JC-200	211.90	217.00	215.34	1.66	211.899	215.34
BP-JC-205	213.20	217.00	217.38	-0.38	213.204	217.38
J12	194.79	198.35	198.89	-0.54	194.792	198.89
J15	197.45	202.50	200.21	2.29	197.446	200.21
J27	205.11	210.49	209.30	1.18	205.112	209.3
J38	222.17	225.32	224.86	0.46	222.174	224.86
J4	193.75	197.22	197.38	-0.16	193.748	197.38
J45	215.83	217.69	216.46	1.23	215.827	216.46
J5	193.91	197.40	197.64	-0.24	193.909	197.64
J60	200.17	202.34	201.76	0.58	200.172	201.76
J76	208.72	214.90	214.84	0.06	208.722	214.84
J8	194.35	197.87	198.17	-0.30	194.347	198.17
JCT-192	198.47	202.53	199.47	3.06	198.466	199.47
JCT-194	192.09	198.61	191.79	6.82	185.263	191.79
JCT-200	196.57	202.53	198.96	3.57	196.574	198.96
JCT-58	196.63	201.86	199.14	2.72	196.633	199.14
JCT-60	200.63	202.97	202.47	0.50	200.627	202.47
JCT-62	192.51	201.62	200.57	1.05	192.506	200.57
JCT-64	199.73	202.45	200.39	2.06	199.731	200.39
JCT-66	214.78	216.50	216.50	0.00	214.781	216.5
JCT-68	199.66	201.64	201.08	0.56	199.661	201.08
JCT-70	203.50	209.12	202.20	6.92	196.582	202.2
JCT-72	215.13	220.45	218.84	1.61	215.125	218.84
JCT-76	198.97	202.82	196.78	6.04	192.93	196.78
JCT-78	208.58	210.00	201.72	8.28	200.297	201.72

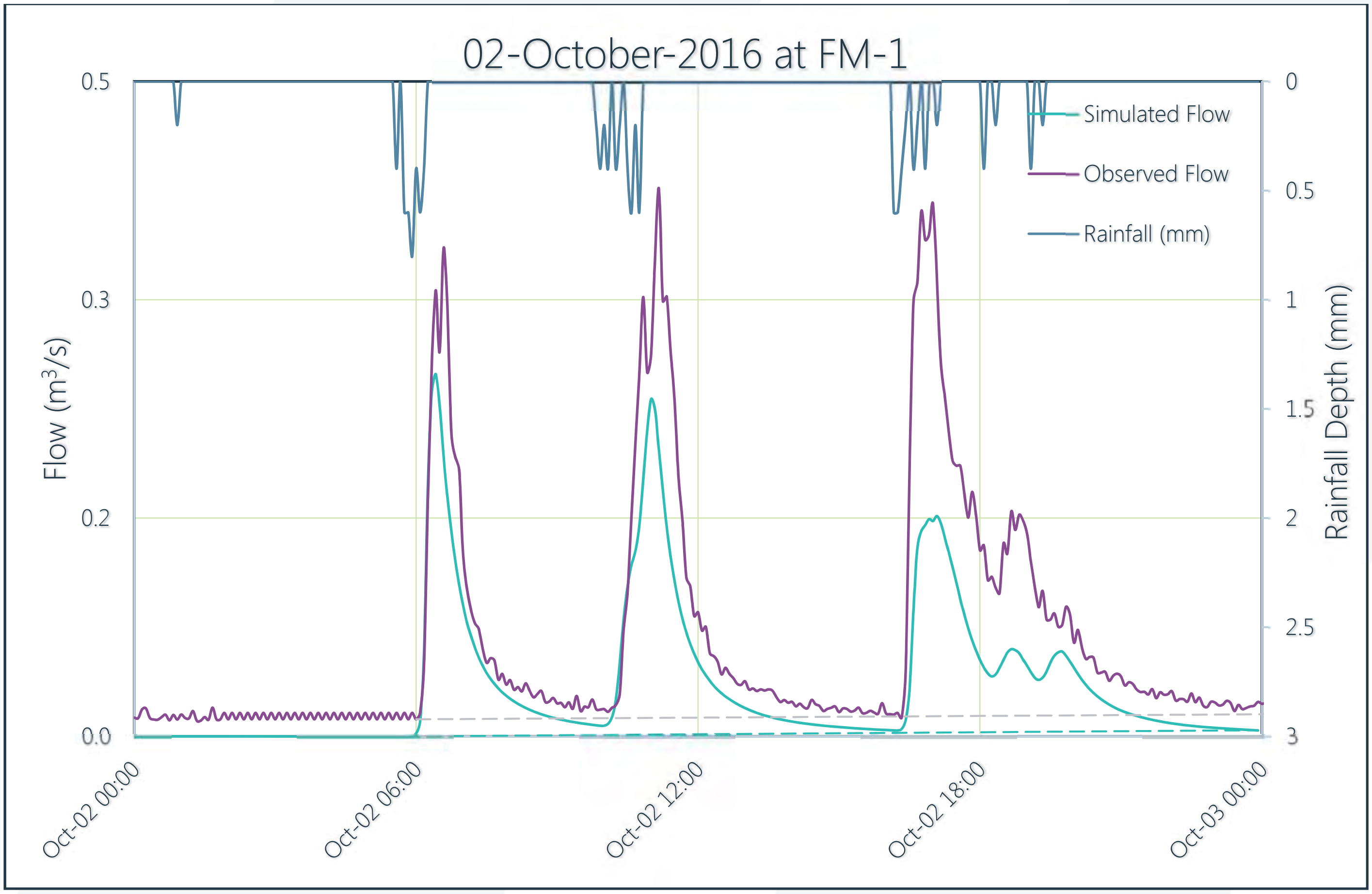
Table A2: Comparison of Minor system parameters from the hydraulic model against "as-built" drawings.

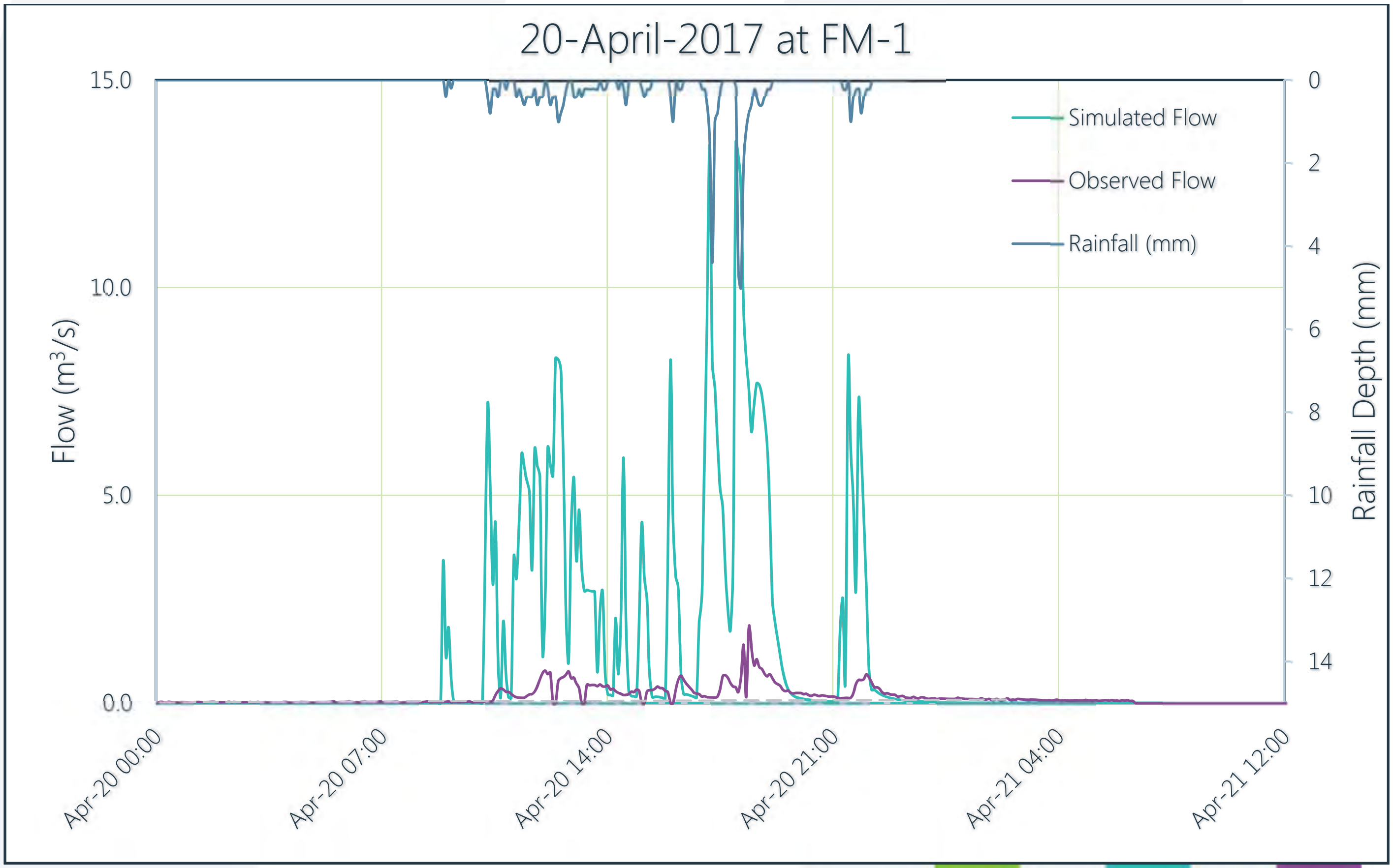
Street Name / Segment Name	Description	Model ID	Model		Drawing		Model		Drawing		Sheet ID and Date of Plot
			U/S Invert	D/S Invert	U/S Invert	D/S Invert	Pipe Length (m)	Pipe Size (mm)	Pipe Length (m)	Pipe Size (mm)	
Arthur Street and Drummond Street	From West to East	07M130-07M222	207.17	202.54	-	203.19	123.42	300	82	300	2-2211-2-AB 20/04/2018
	From West to East	07M130-07M222A	207.17	202.512			123.42	1200	Not Present	Not Present	
	From West to East	Not Present	-	-	203.15	203.17	-	-	10.4	450	
	From West to East	Not Present	-	-	-	202.6	-	-	8	450	
	from North to South	07M220-07M222	203.33	202.512		202.59	102.89	375	-	375	
Arthur Street From Drumroad St to Rawdon St	From West to East	Not Present	-	-	202.56	-	-	-	12	525	
	From West to East	Not Present	-	-	202.51	201.97	-	-	10.8	525	
	From West to East	07M222-07M137	202.53	201.32	201.95	200.87	59.91	450	77	450	
	From West to East	07M137-07M248SF	200.925	199.08			63.72	450			
	From West to East	07M222-07M248SF	202.512	199.08	-	-	123.63	1425	Not Present	Not Present	
	From West to East	Not Present	-	-	200.85	200.7	-	-	12	450	
	From West to East	Not Present	-	-	200.68	-	-	-	12.4	450	
Arthur Street and Rawdon Street	from North to South	07M272SF-07M210	199.28	199.08		199.1	99.33	1500		1500	
	from North to South	07M210-07M248SF	199.08	199.08	199.1		0.91	1650		1650	
		07M248SF-07M211	199.08	198.76			99.21	1650			
Stanley Street and darling Street	From East to West	07M092-07M197	205.18	204.64			35.56	300		300	2-2135-2 31/07/2007
stanley Street from Darling St to wellington St	From North to South	06M166-06M183	200.08	199.71	200.032	-	112.59	1500	-	1500	
	From North to South	06M279-06M166	200.27	200.08	200.51	200.042	99.05	1500	98.5	1500	
	From North to South	06M165-06M279	200.493	200.467	200.493	200.467	13.7	1200	12.5	1200	
	From North to South	06M157-06M165	200.84	200.52		200.503	111.99	1200		1200	
Stanley Street and Wellington Street	From West to East	07M080-06M279	202.48	202.13			46.17	900		900	
	From East to West	06M280-06M165	203.4	202.692		202.176	6.63	450	3.4	450	
		06M164-06M280	204.7	203.46			87.94	450		450	

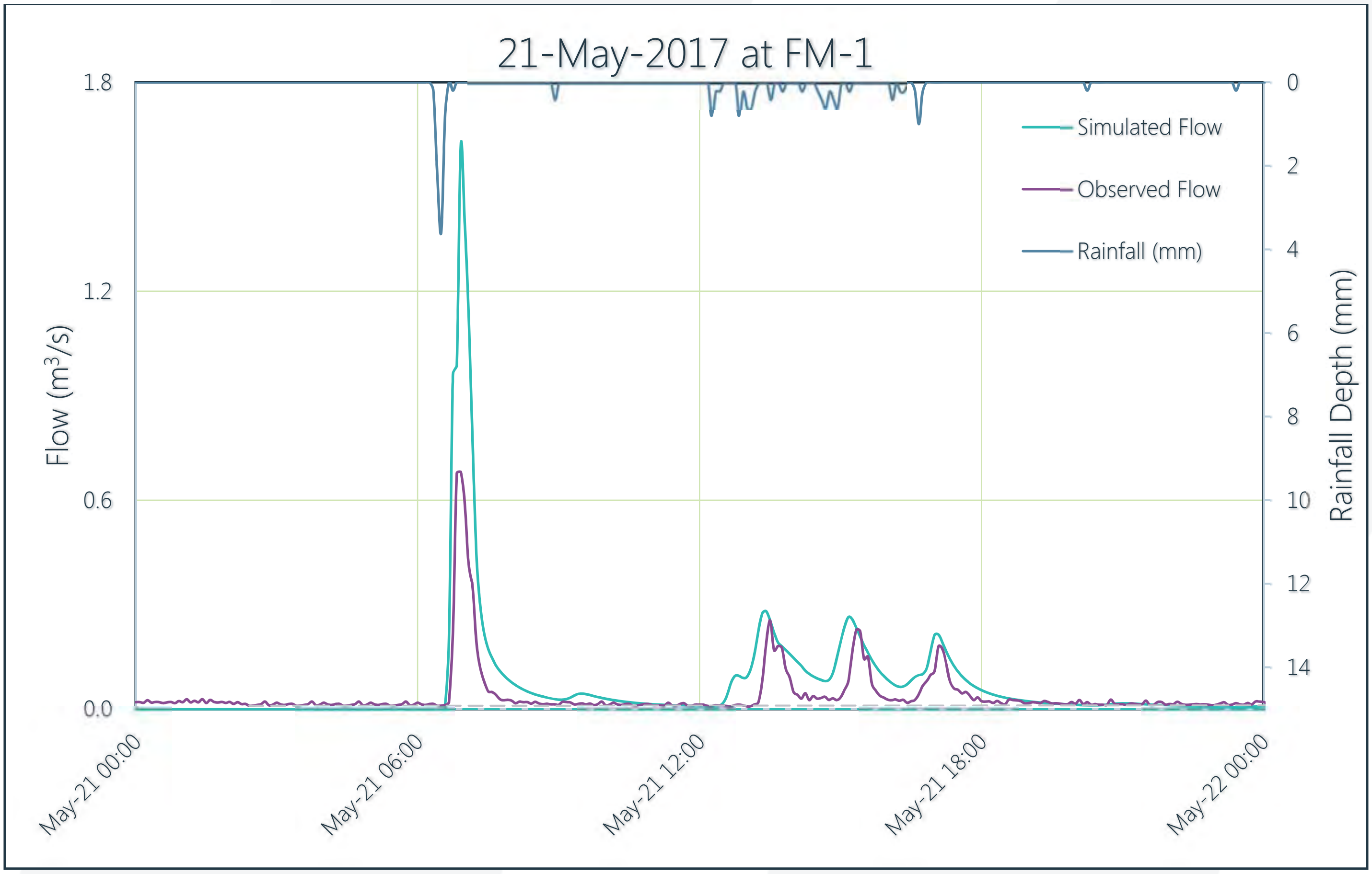
Table A2: Comparison of Minor system parameters from the hydraulic model against "as-built" drawings.

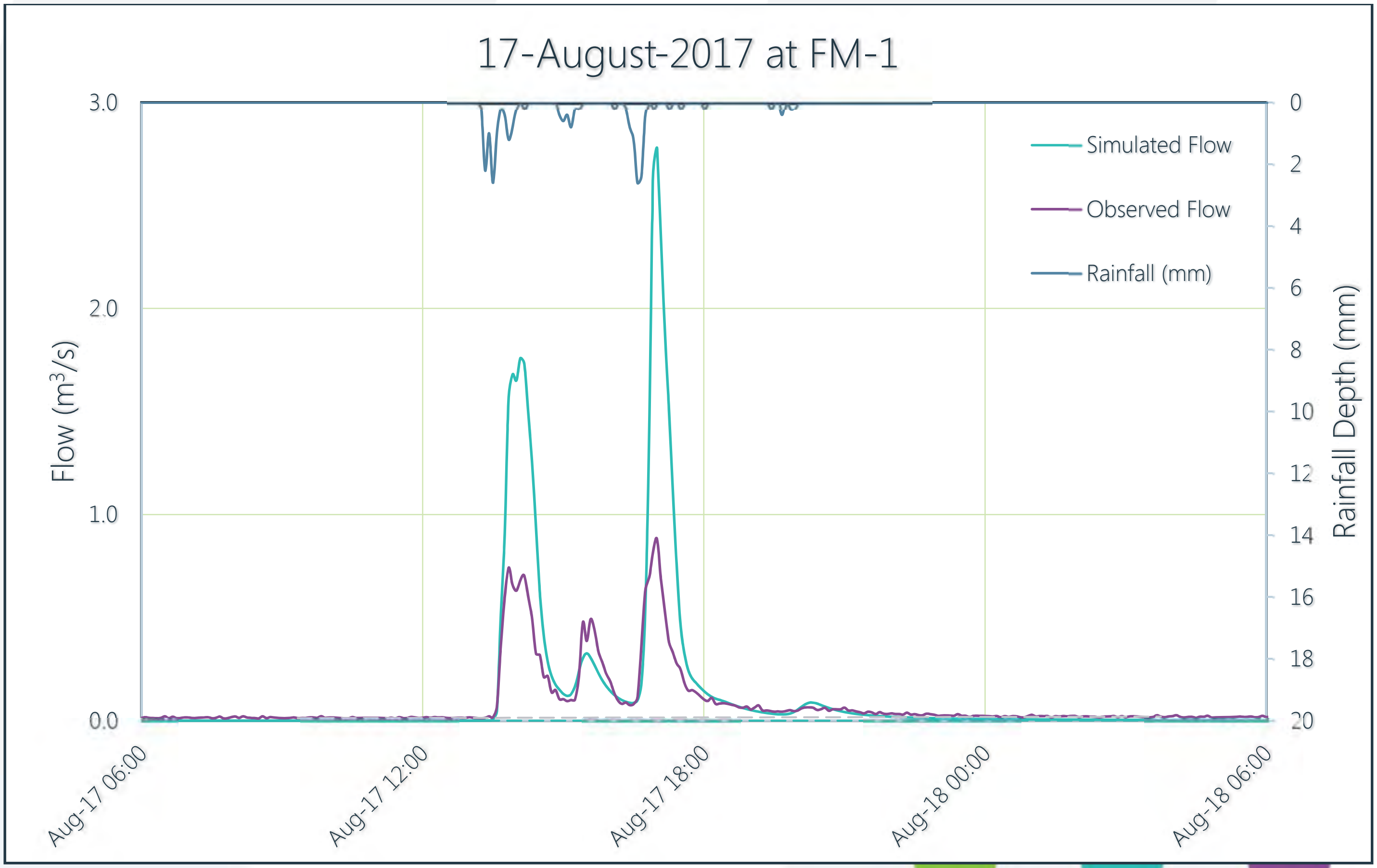
Street Name / Segment Name	Description	Model ID	Model		Drawing		Model		Drawing		Sheet ID and Date of Plot
			U/S Invert	D/S Invert	U/S Invert	D/S Invert	Pipe Length (m)	Pipe Size (mm)	Pipe Length (m)	Pipe Size (mm)	
Stanley Street and Nelson St	From East to West	06M156-06M157	204.39	200.64			63.63	450		375	2-1777-2 04/09/1990
stanley Street from Nelson St to Chatham St	From North to South	06M157-06M165	200.84	200.52			111.99	1200	105	1200	
	From North to South	06M234-06M157	204.489	200.84			99.81	1200	113	1200	
	From North to South	Not Present				201.2			4.7	1200	
	From North to South	07M033-06M234	205.089	204.489			120.01	1200		1200	
Stanley Street and Chatham St	From West to East	06M233-06M234	201.147	201.107			10.78	1200	Not Present	Not Present	
	From East to West	06M150-06M234	205.54	204.489			20.86	450	~15	450	
	From East to West	06M149-06M150	206.39	205.54			70.88	450		300	
Stanley Street and Colborne St	From West to East	07M119-06M185	202.72	199.44		202.155	84.74	450		525	2-2135-1 16/08/2007
stanley Street from Colborne St to Dalhousie St	From North to South	06M185-06M205	199.44	198.8	199.415		26.12	1500		1500	
	From North to South	06M184-06M185	199.49	199.45	199.455	199.435	18.18	1500		1500	
	From North to South	06M183-06M184	199.71	199.49	199.674	199.485	85.4	1500	89.5	1500	
	From North to South	06M166-06M183	200.08	199.71		199.966	112.59	1500		1500	
Stanley Street and Dalhousie St	From East to West	06M182-06M183	201.67	201.5		200.666	62.09	750		750	
	From East to West	06M183-07M100	201.44	201.32	201.054		73.36	450		375	

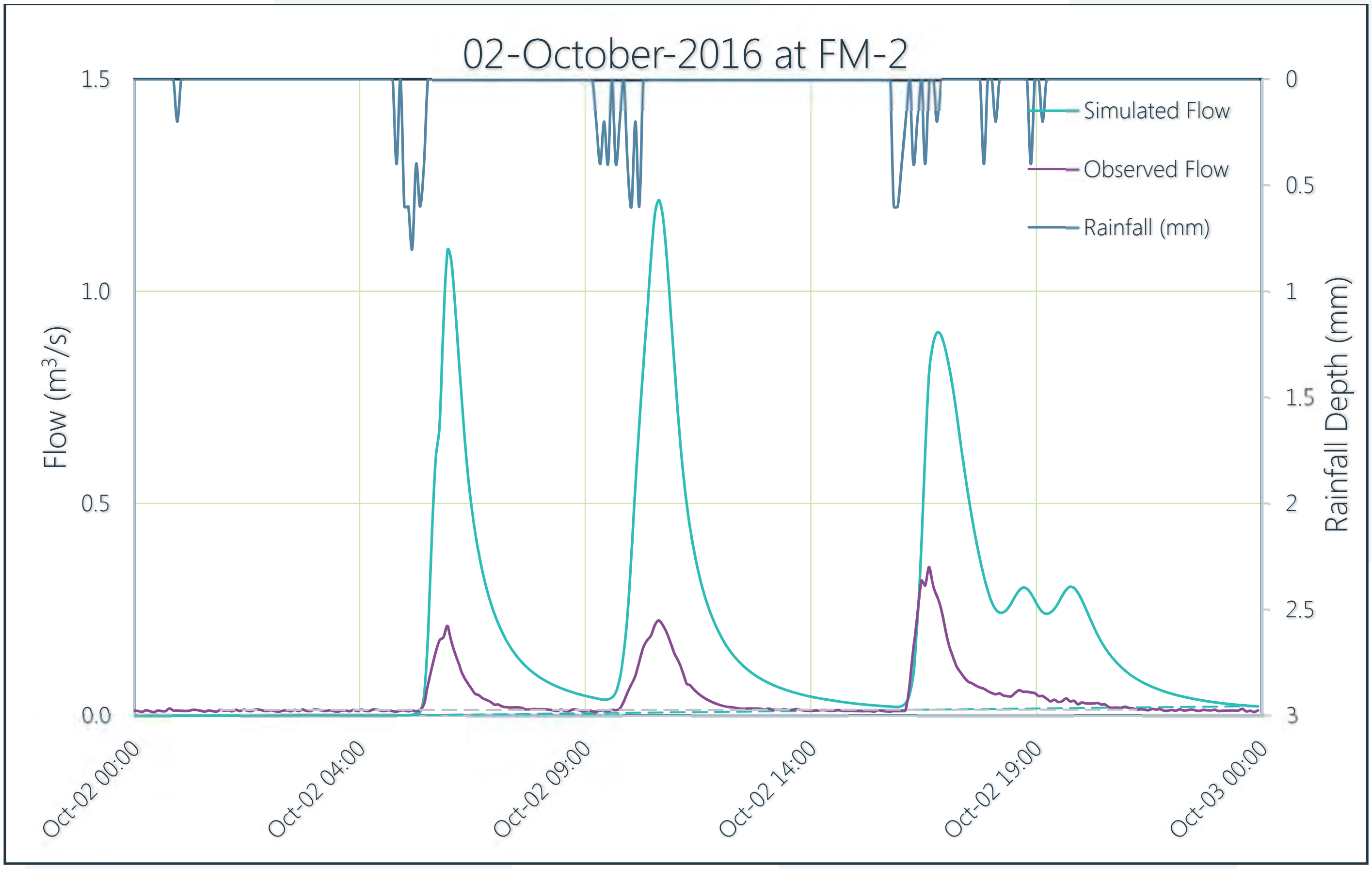
Appendix B: Uncalibrated Model Results

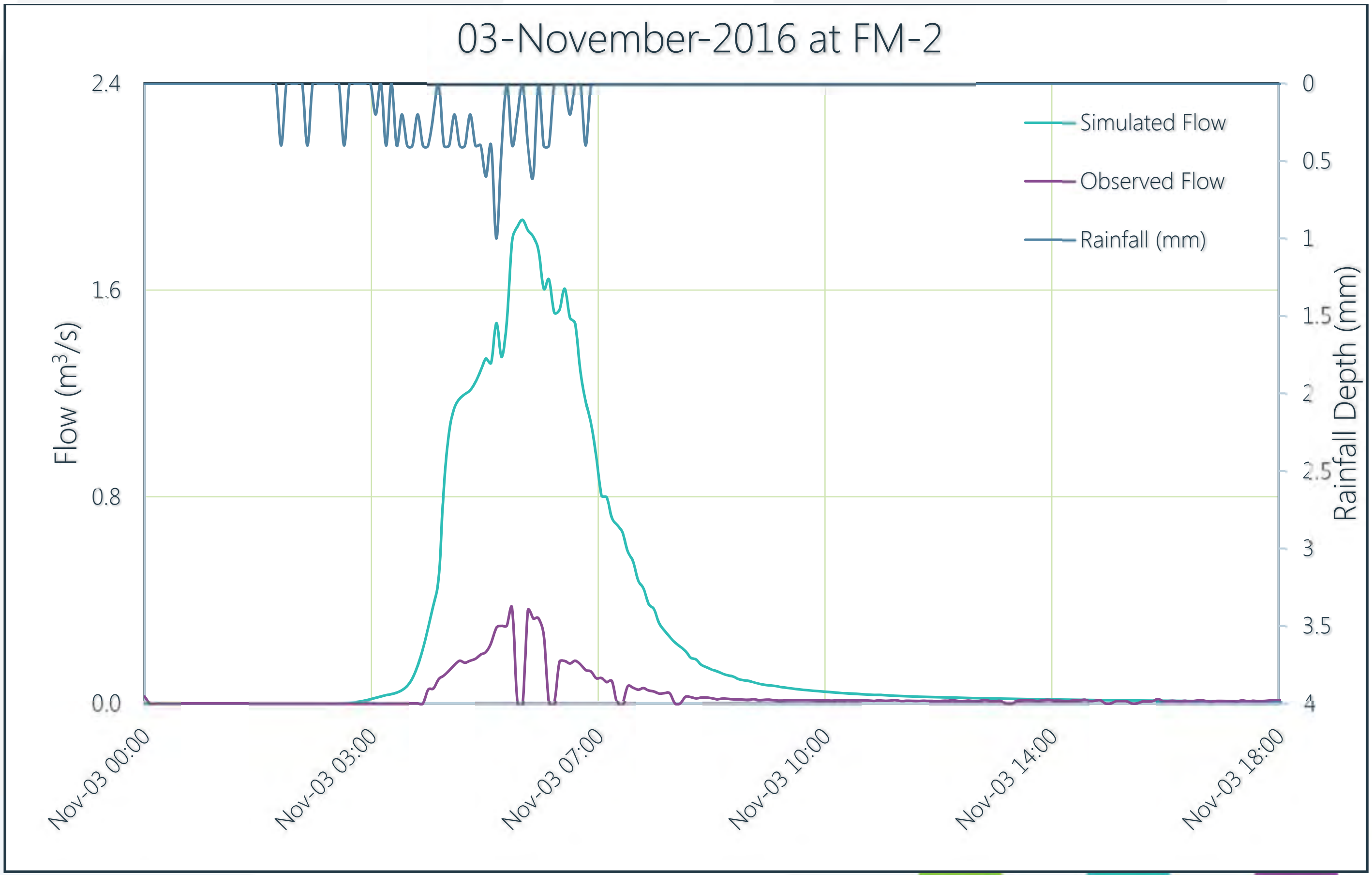

02-October-2016 at FM-1
Flow (m3/s)
0.5
0.3
0.2
0.0
Rainfall Depth (mm)
0
0.5
1
1.5
2
2.5
3
Simulated Flow
Observed Flow
Rainfall (mm)
Oct-02 00:00
Oct-02 06:00
Oct-02 12:00
Oct-02 18:00
Oct-03 00:00

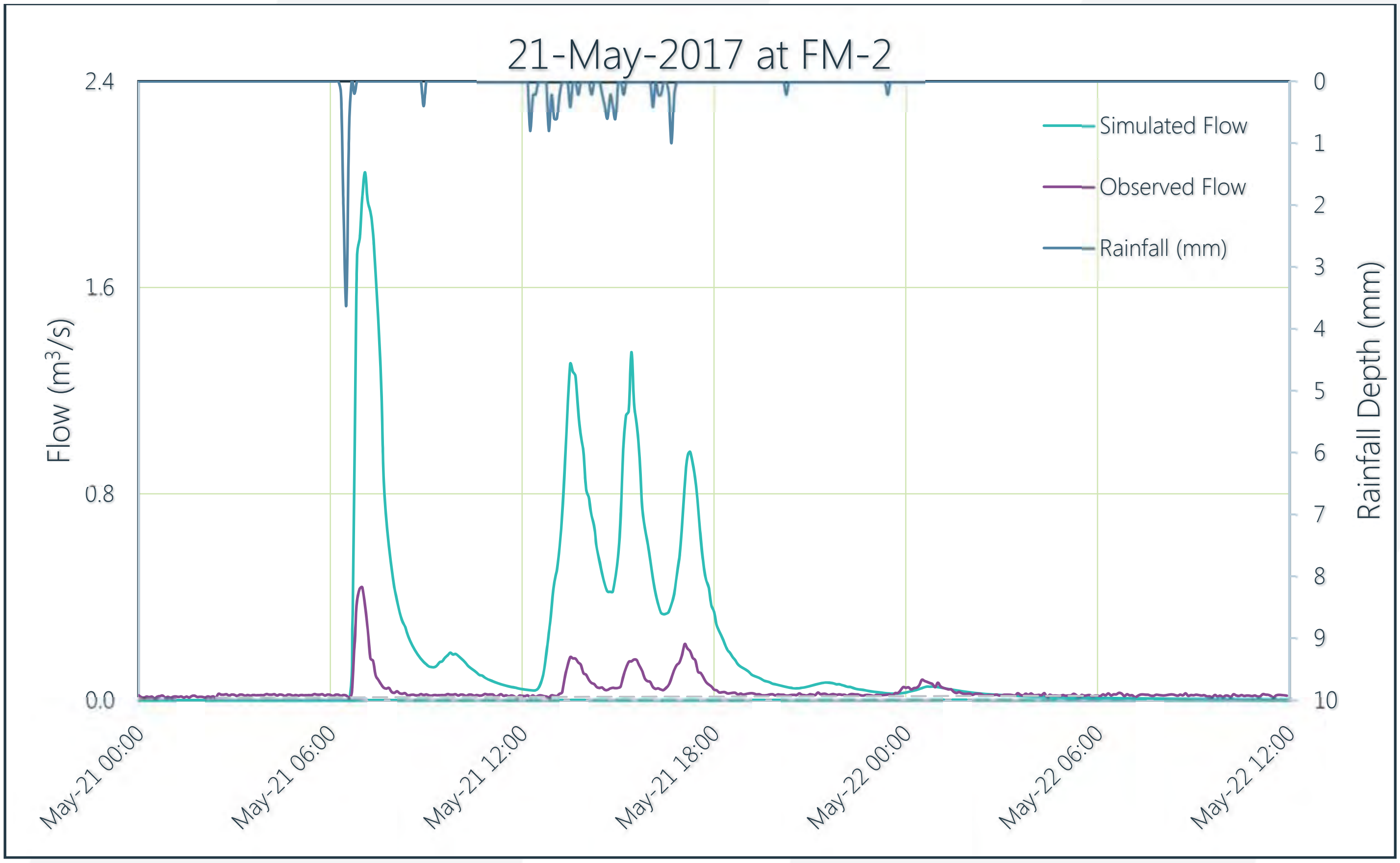

20-April-2017 at FM-1
Flow (m3/s)
15.0
10.0
5.0
0.0
Rainfall Depth (mm)
0
2
4
6
8
10
12
14
Simulated Flow
Observed Flow
Rainfall (mm)
Apr-20 00:00
Apr-20 07:00
Apr-20 14:00
Apr-20 21:00
Apr-21 04:00
Apr-21 12:00

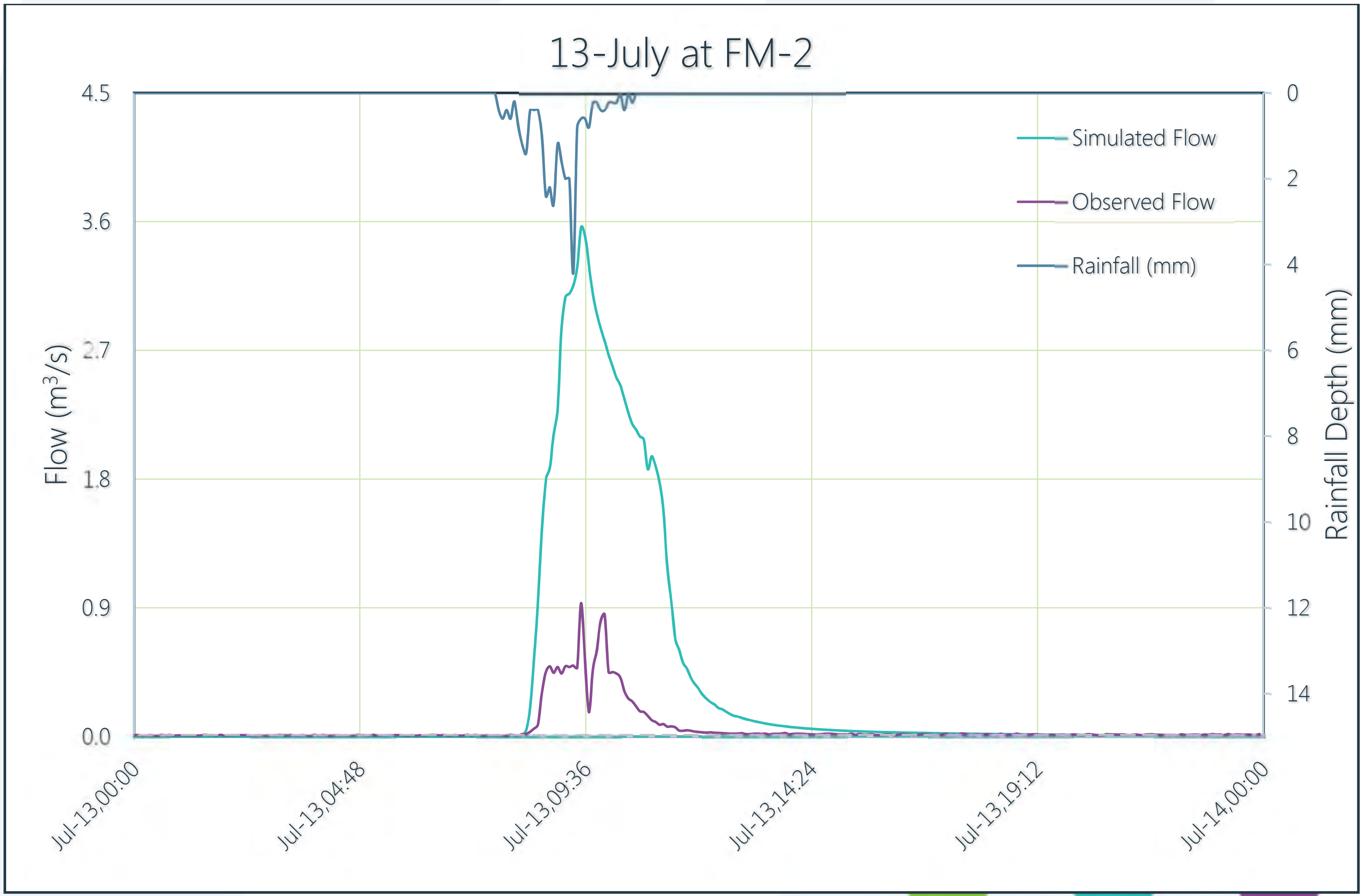

21-May-2017 at FM-1
Flow (m3/s)
Rainfall Depth (mm)
1.8
1.2
0.6
0.0
0
2
4
6
8
10
12
14
Simulated Flow
Observed Flow
Rainfall (mm)
May-21 00:00
May-21 06:00
May-21 12:00
May-21 18:00
May-22 00:00

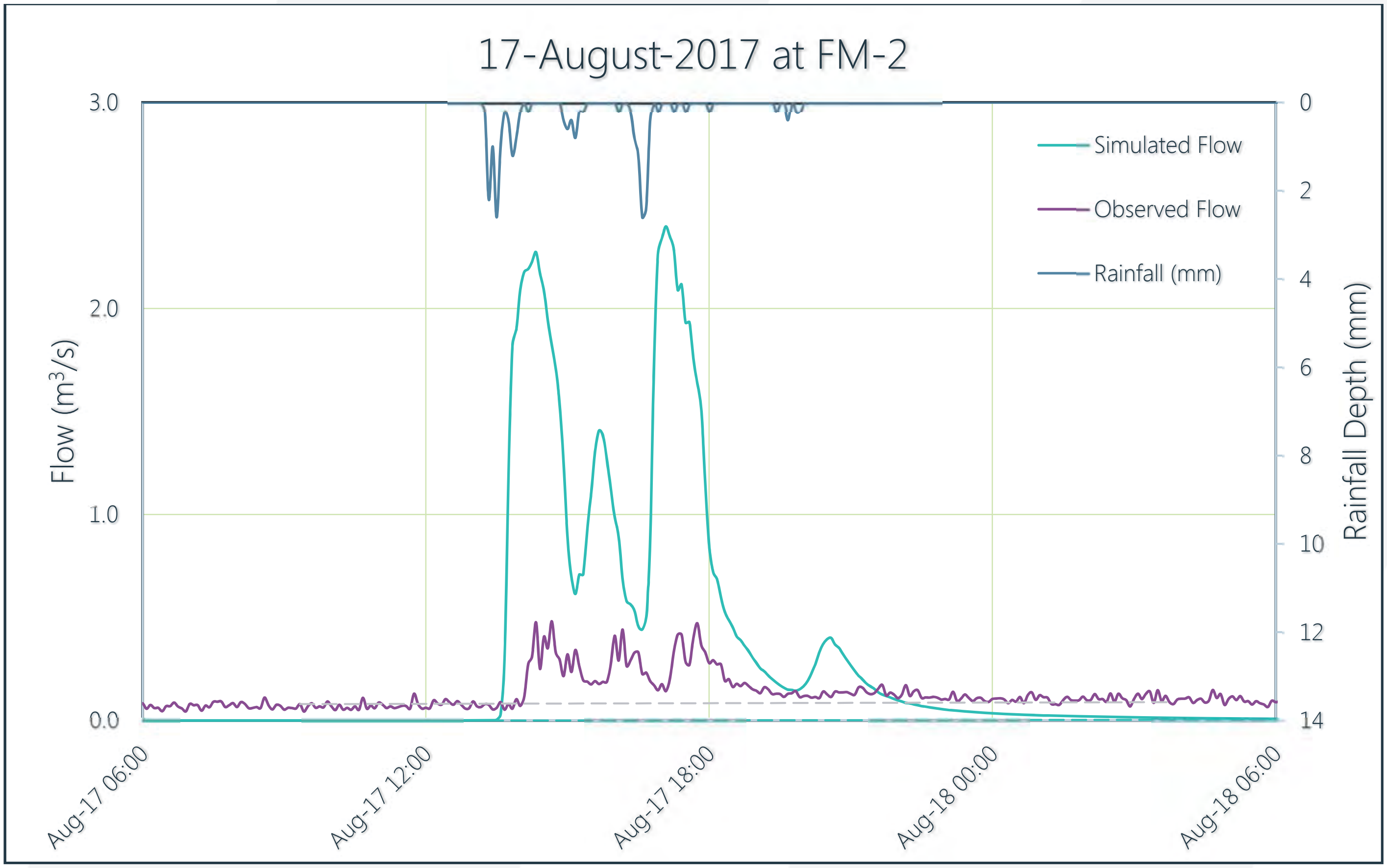

17-August-2017 at FM-1
Flow (m3/s)
Rainfall Depth (mm)
3.0
2.0
1.0
0.0
0
2
4
6
8
10
12
14
16
18
20
Simulated Flow
Observed Flow
Rainfall (mm)
Aug-17 06:00
Aug-17 12:00
Aug-17 18:00
Aug-18 00:00
Aug-18 06:00

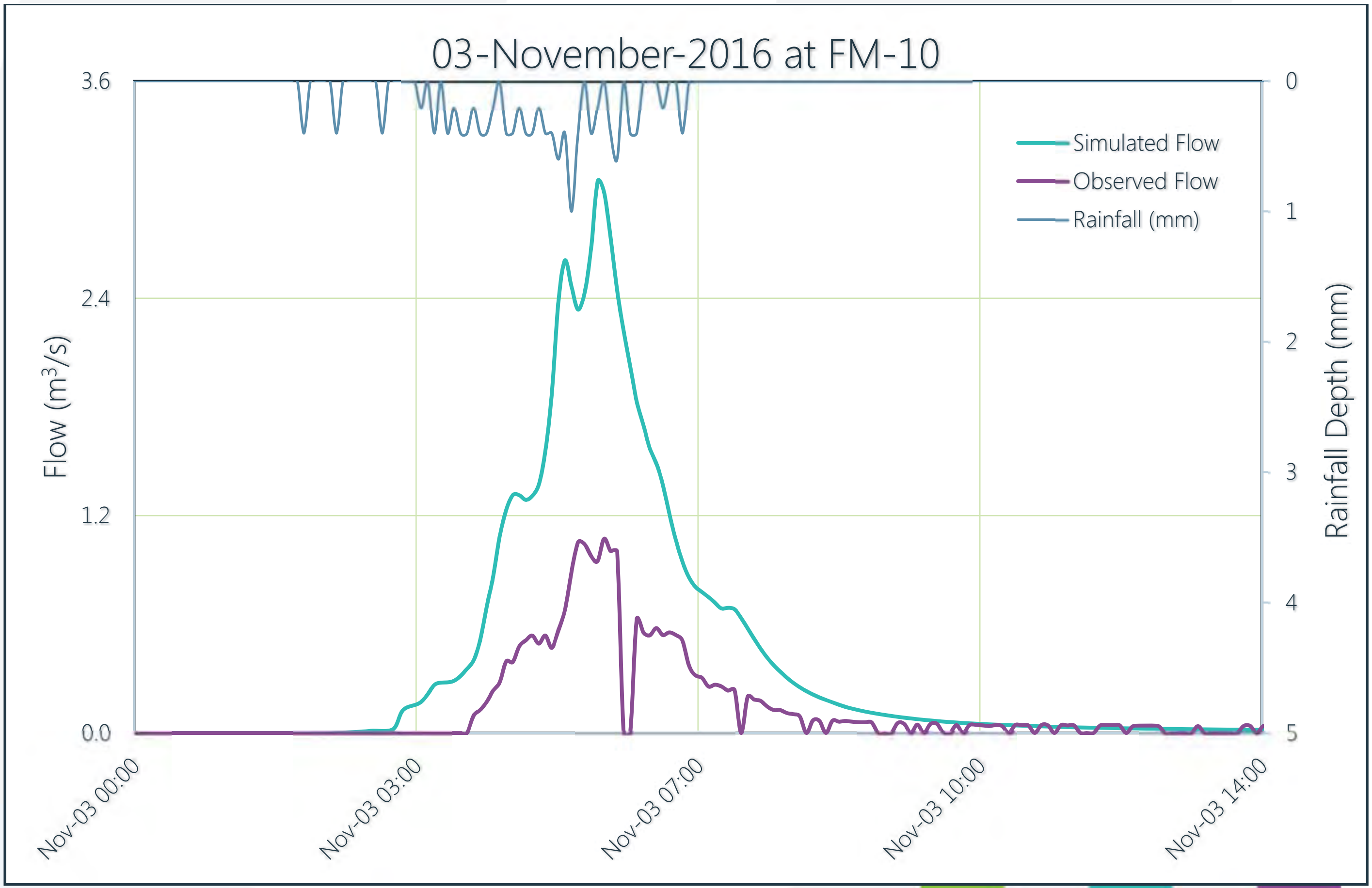

02-October-2016 at FM-2
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
1.5
1.0
0.5
0.0
0
0.5
1
1.5
2
2.5
3
Oct-02 00:00
Oct-02 04:00
Oct-02 09:00
Oct-02 14:00
Oct-02 19:00
Oct-03 00:00

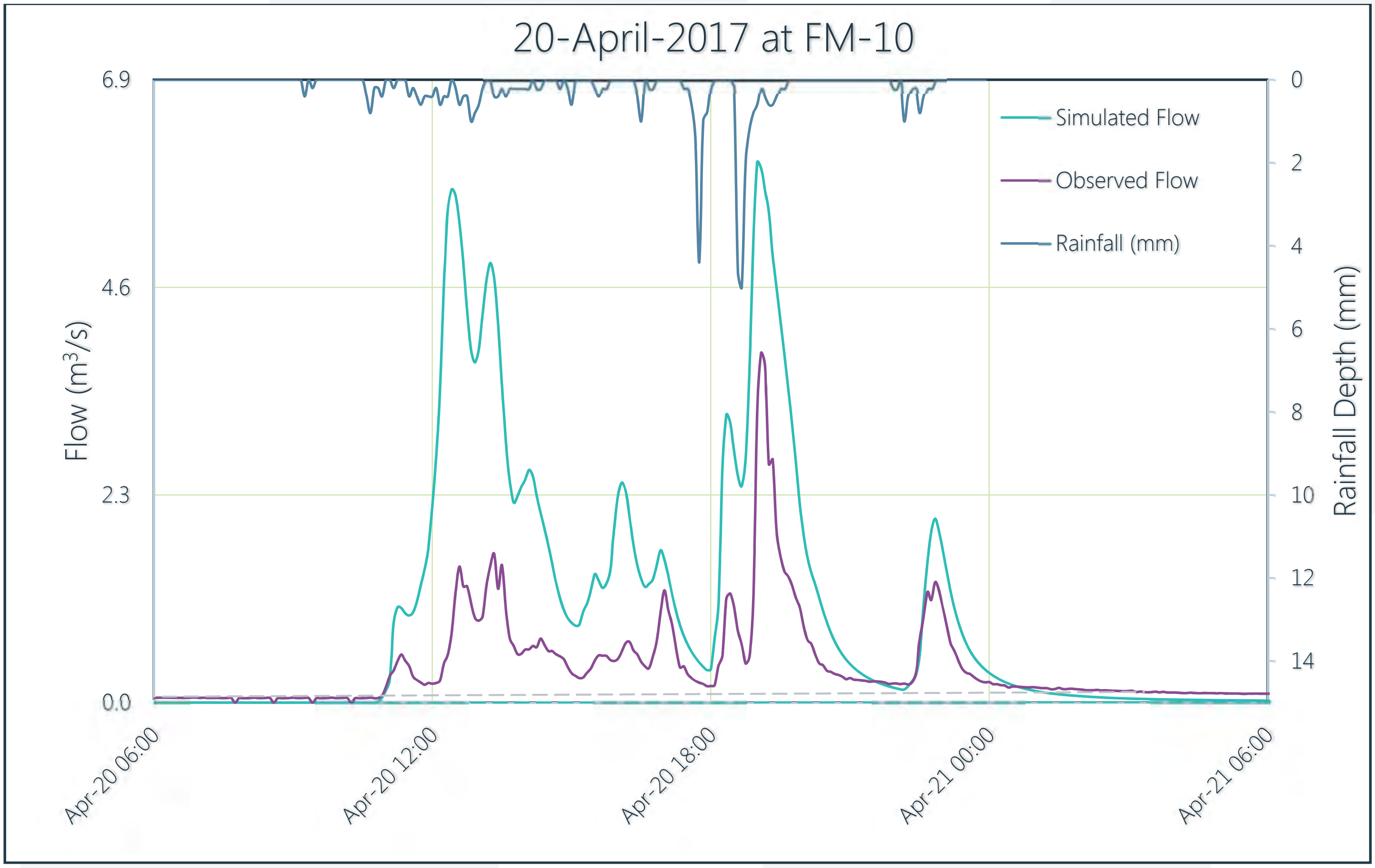

03-November-2016 at FM-2
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
2.4
1.6
0.8
0.0
0
0.5
1
1.5
2
2.5
3
3.5
4
Nov-03 00:00
Nov-03 03:00
Nov-03 07:00
Nov-03 10:00
Nov-03 14:00
Nov-03 18:00


21-May-2017 at FM-2
Flow (m³/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
2.4
1.6
0.8
0.0
0
1
2
3
4
5
6
7
8
9
10
May-21 00:00
May-21 06:00
May-21 12:00
May-21 18:00
May-22 00:00
May-22 06:00
May-22 12:00

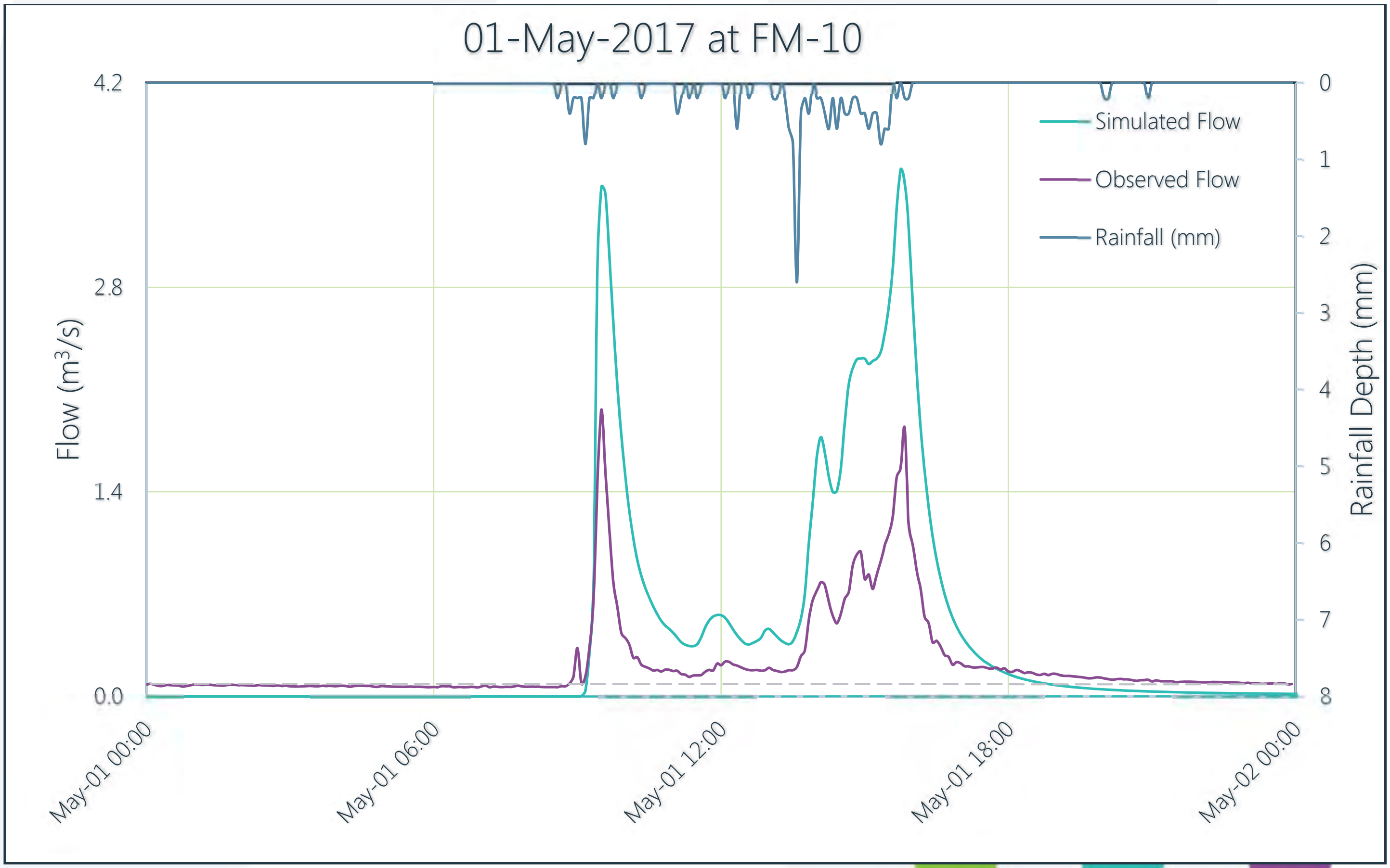

13-July at FM-2
Flow (m³/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
4.5
3.6
2.7
1.8
0.9
0.0
0
2
4
6
8
10
12
14
Jul-13,00:00
Jul-13,04:48
Jul-13,09:36
Jul-13,14:24
Jul-13,19:12
Jul-14,00:00


17-August-2017 at FM-2
3.0
2.0
1.0
0.0
Flow (m3/s)
0
2
4
6
8
10
12
14
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Aug-17 06:00
Aug-17 12:00
Aug-17 18:00
Aug-18 00:00
Aug-18 06:00

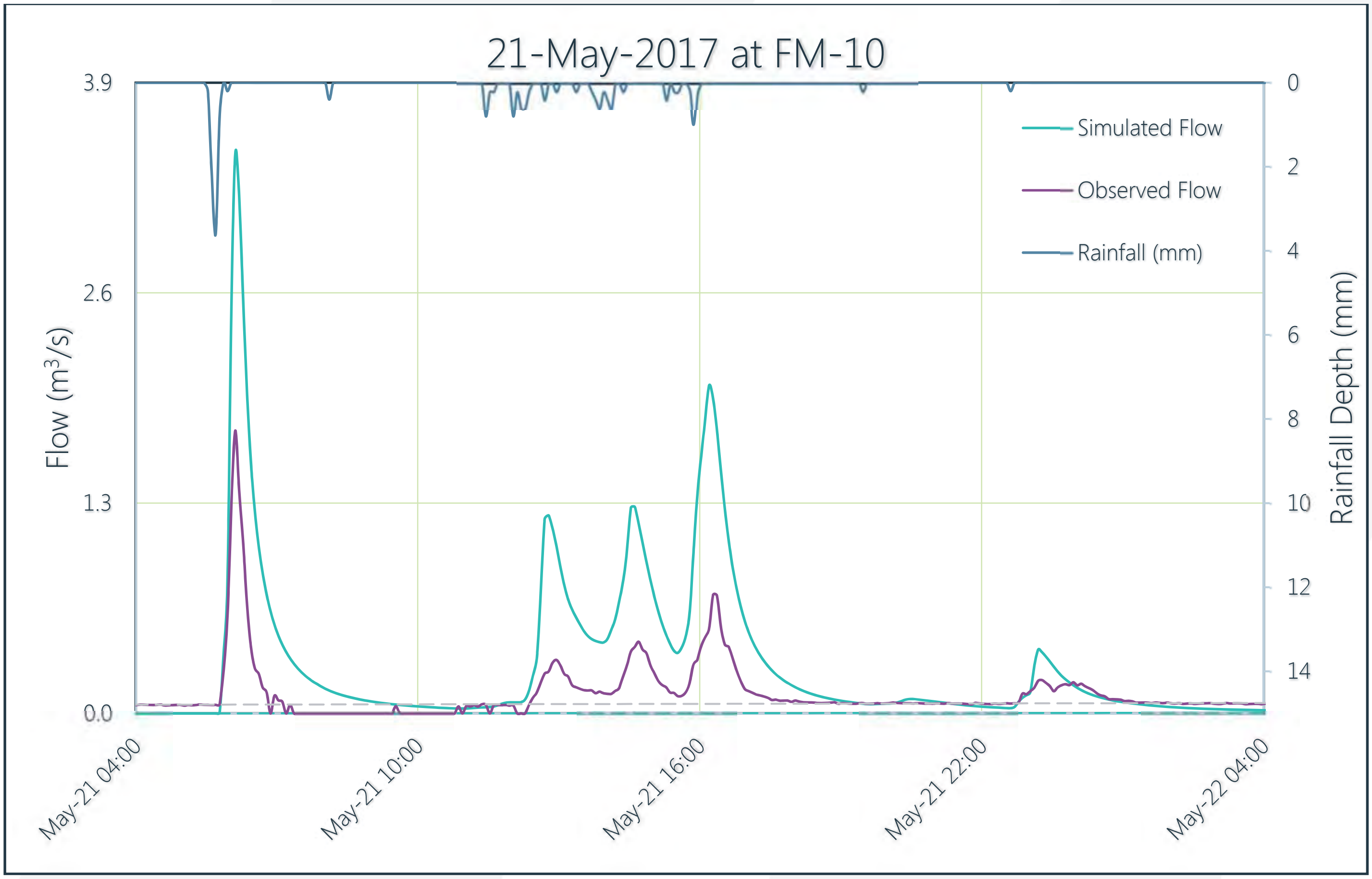

03-November-2016 at FM-10
3.6
2.4
1.2
0.0
Flow (m3/s)
0
1
2
3
4
5
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Nov-03 00:00
Nov-03 03:00
Nov-03 07:00
Nov-03 10:00
Nov-03 14:00

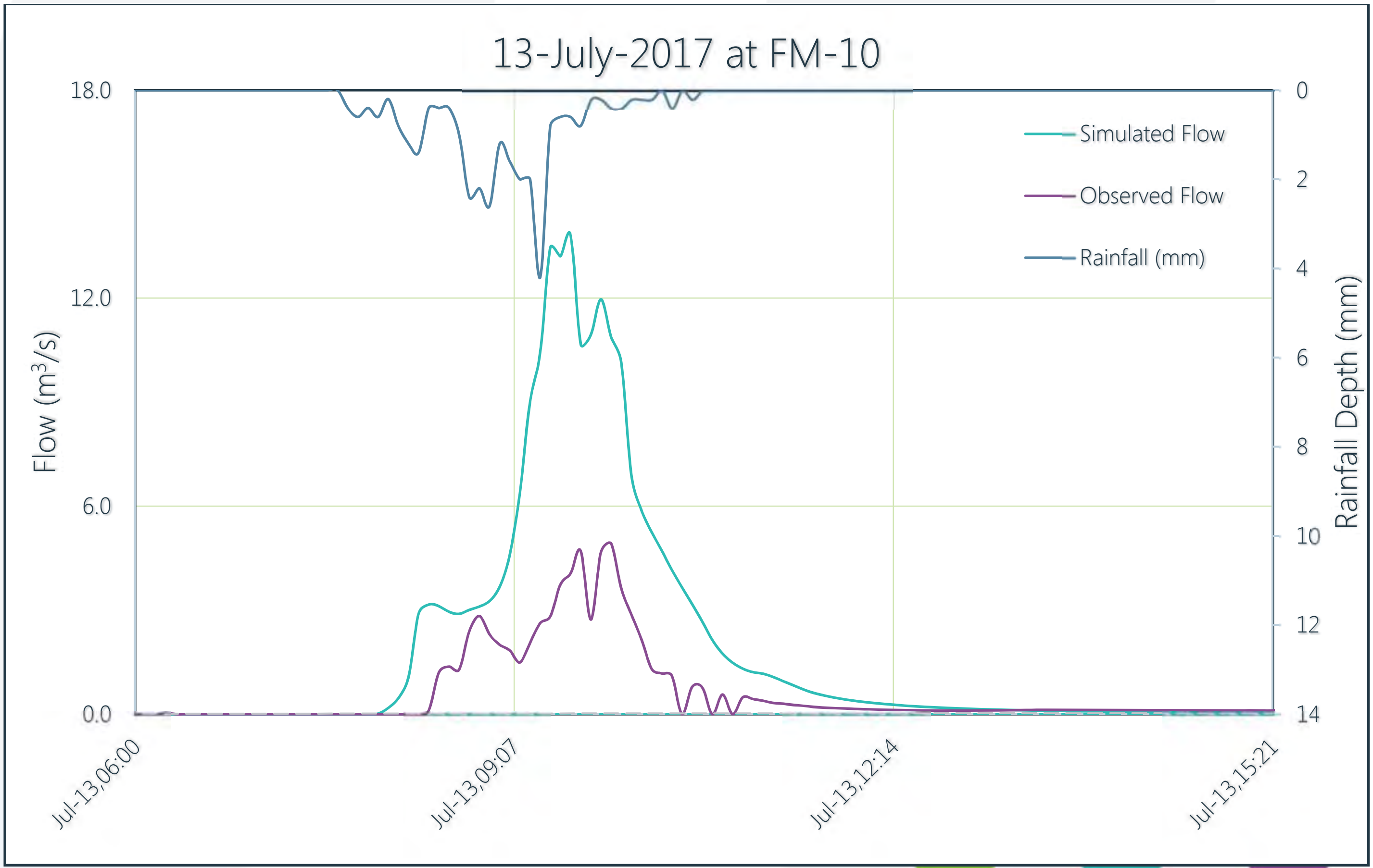


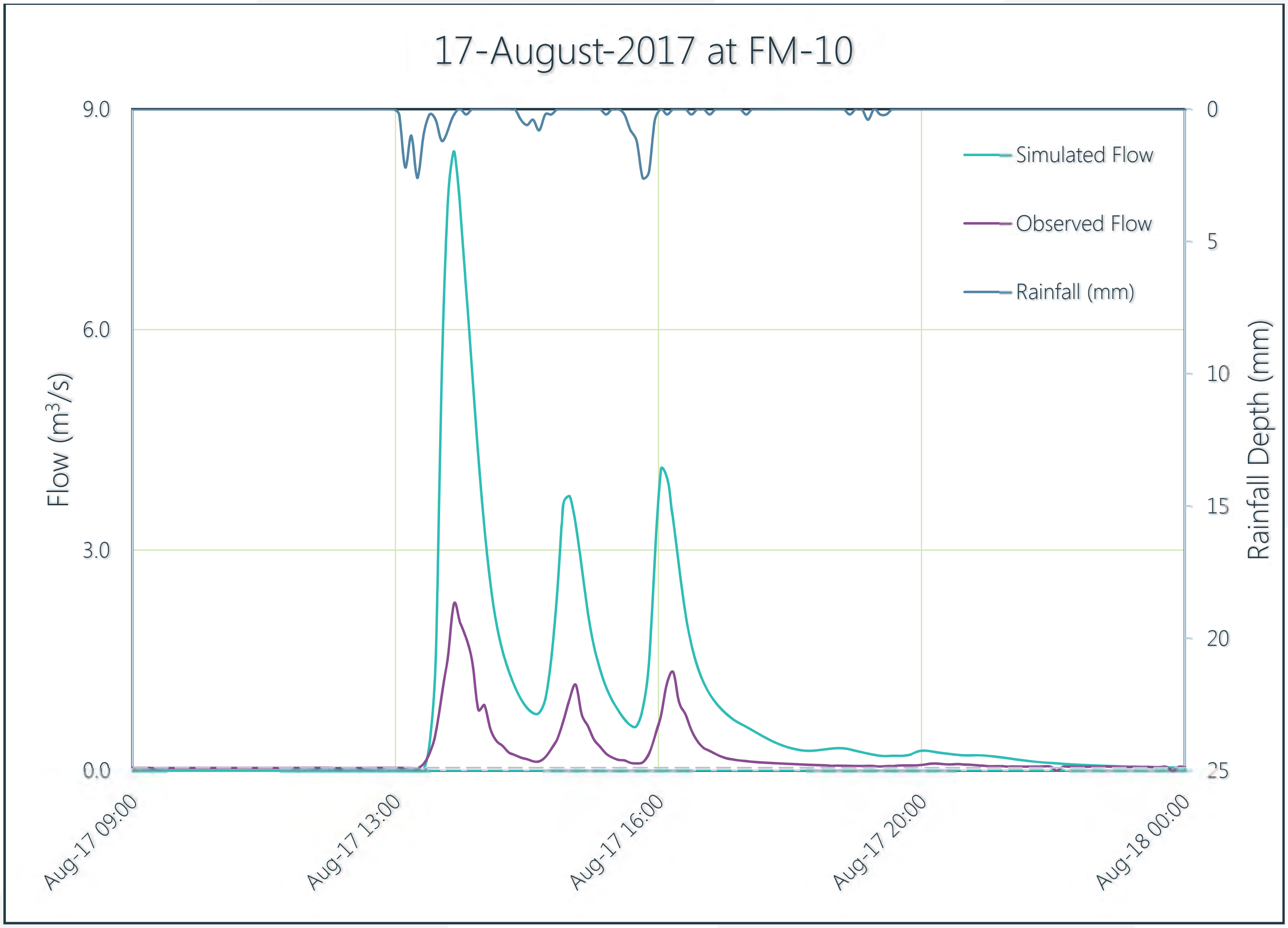
20-April-2017 at FM-10
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
6.9
4.6
2.3
0.0
0
2
4
6
8
10
12
14
Apr-20 06:00
Apr-20 12:00
Apr-20 18:00
Apr-21 00:00
Apr-21 06:00



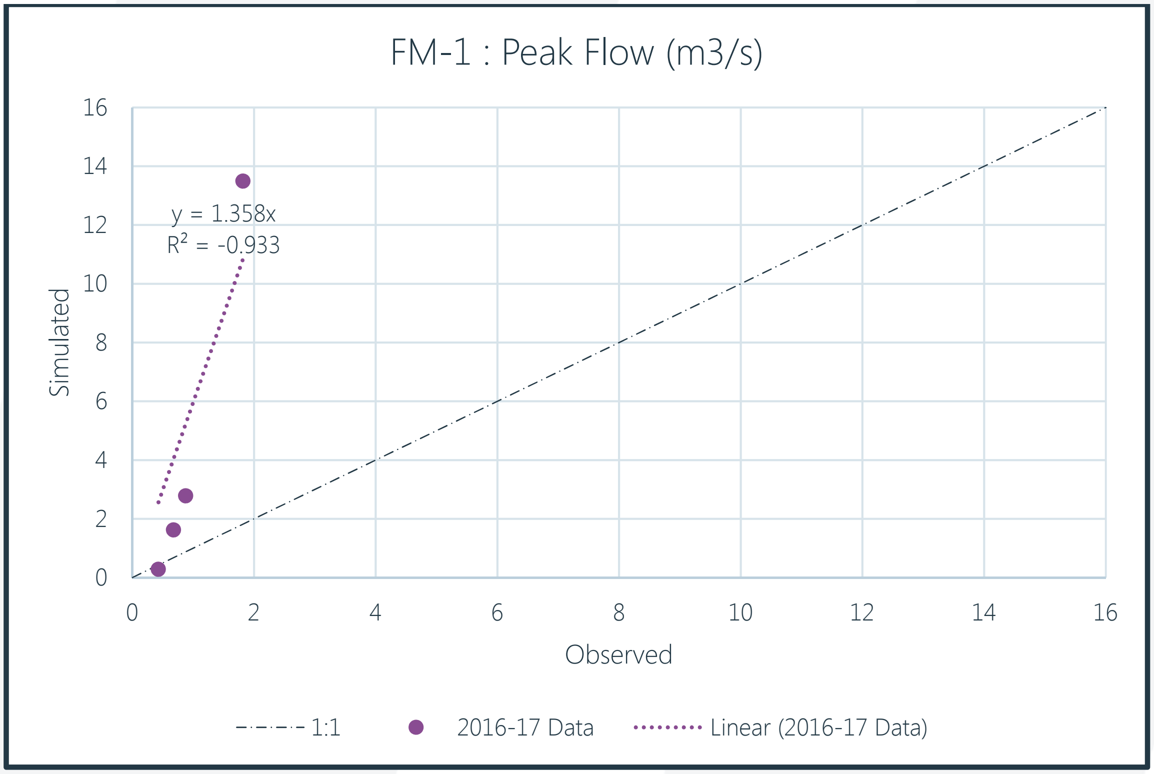
01-May-2017 at FM-10
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
4.2
2.8
1.4
0.0
0
1
2
3
4
5
6
7
8
May-01 00:00
May-01 06:00
May-01 12:00
May-01 18:00
May-02 00:00

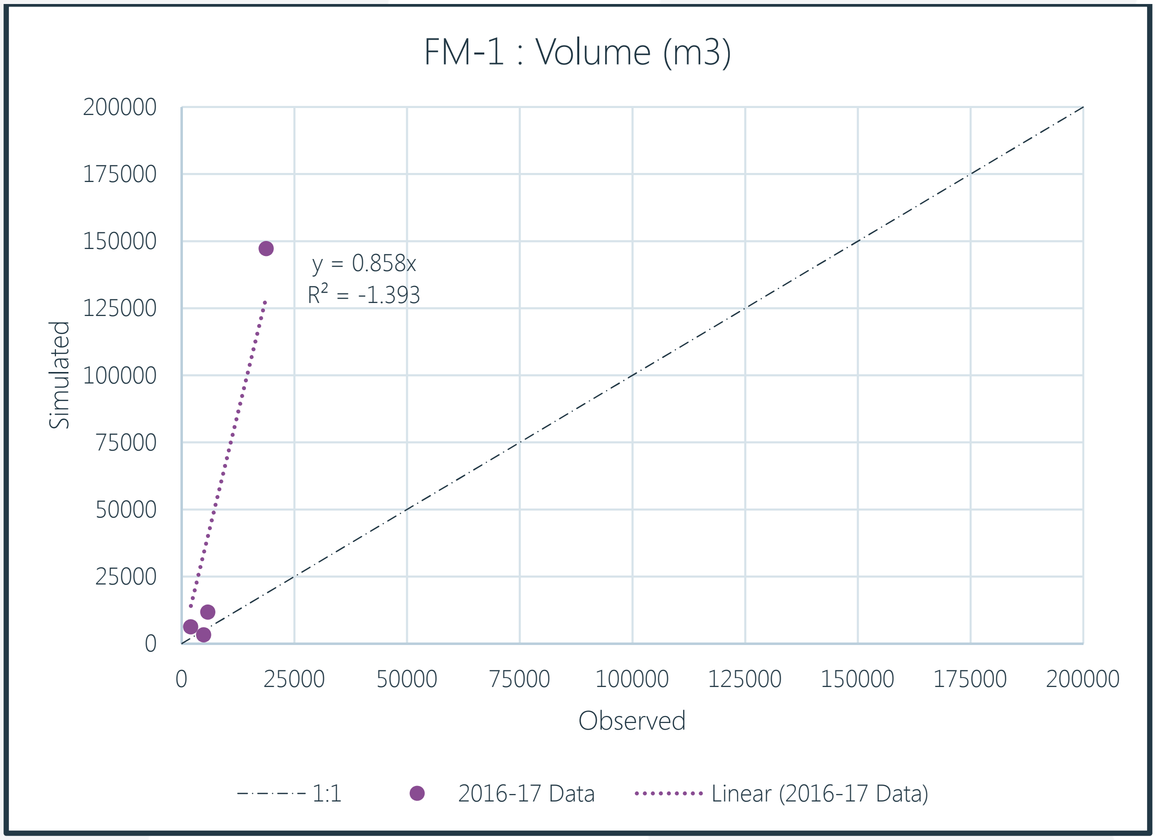

21-May-2017 at FM-10
3.9
2.6
1.3
0.0
Flow (m3/s)
0
2
4
6
8
10
12
14
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
May-21 04:00
May-21 10:00
May-21 16:00
May-21 22:00
May-22 04:00

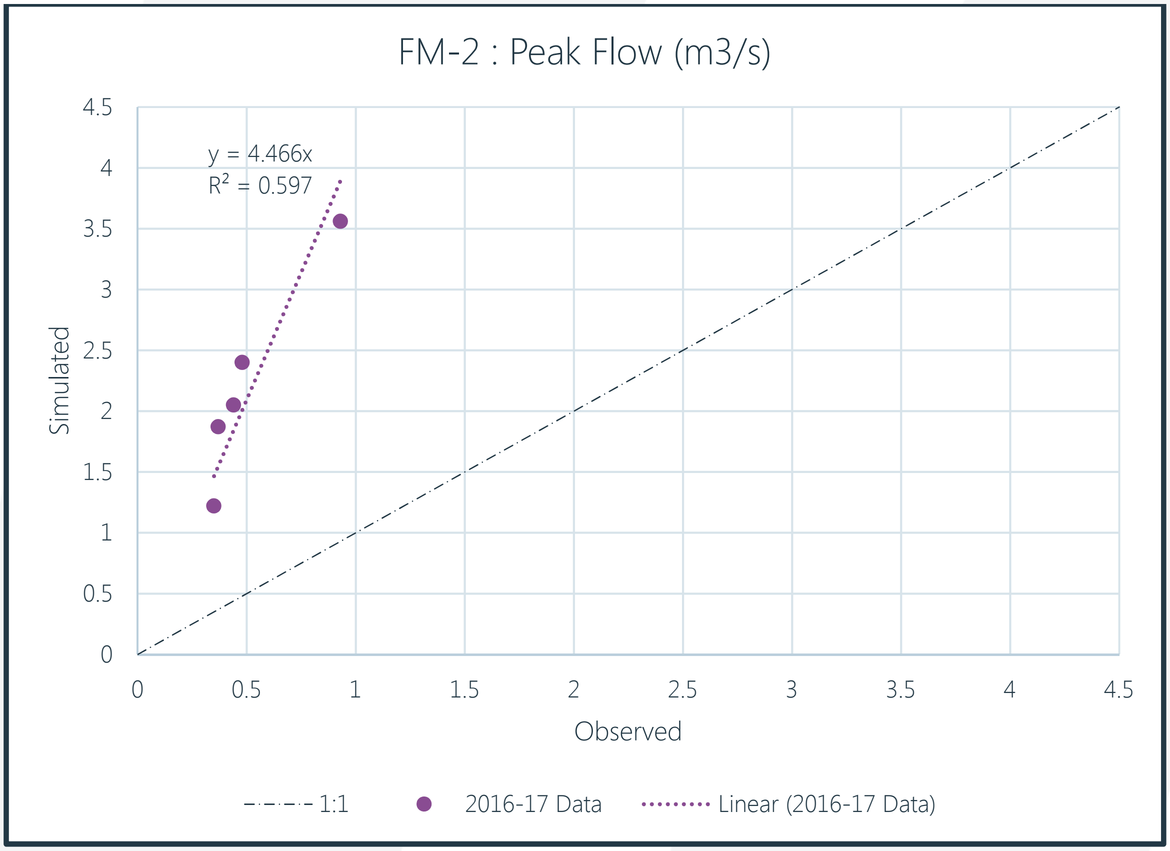

13-July-2017 at FM-10
18.0
12.0
6.0
0.0
Flow (m3/s)
0
2
4
6
8
10
12
14
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Jul-13,06:00
Jul-13,09:07
Jul-13,12:14
Jul-13,15:21

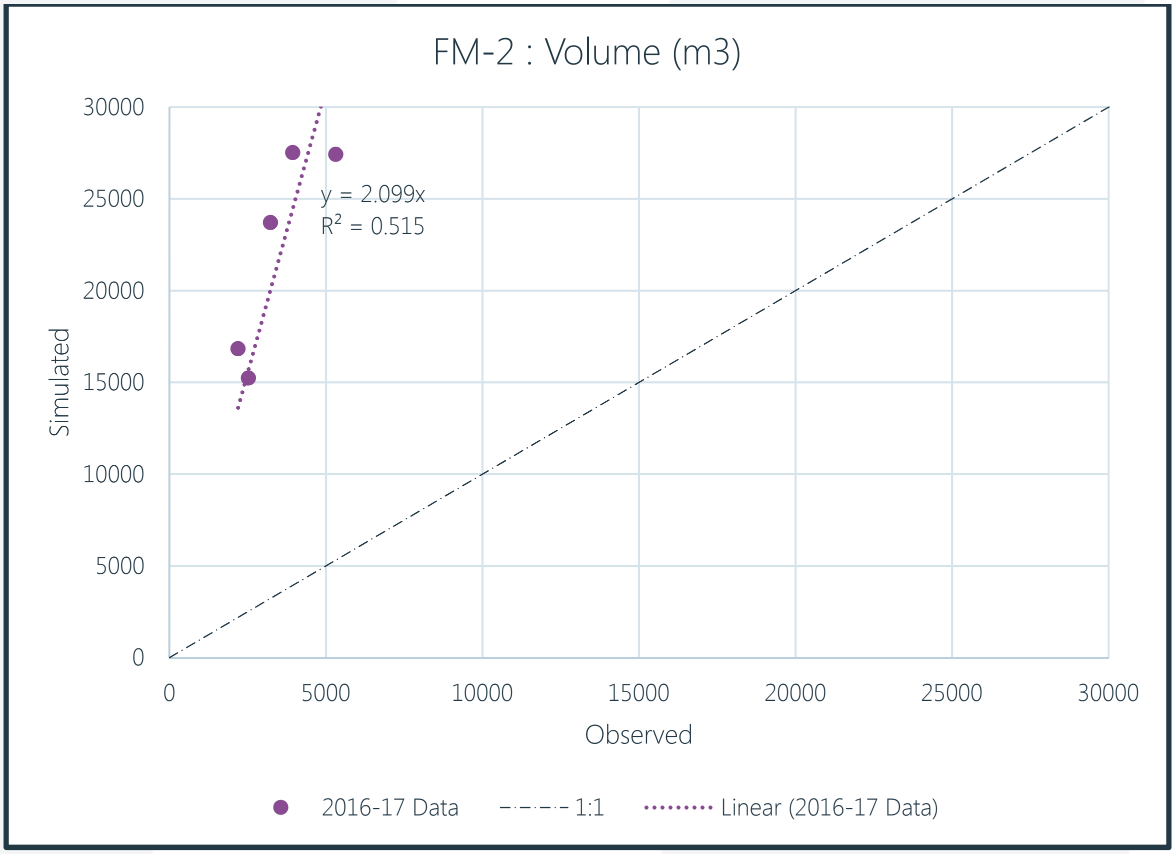

17-August-2017 at FM-10
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
9.0
6.0
3.0
0.0
0
5
10
15
20
25
Aug-17 09:00
Aug-17 13:00
Aug-17 16:00
Aug-17 20:00
Aug-18 00:00

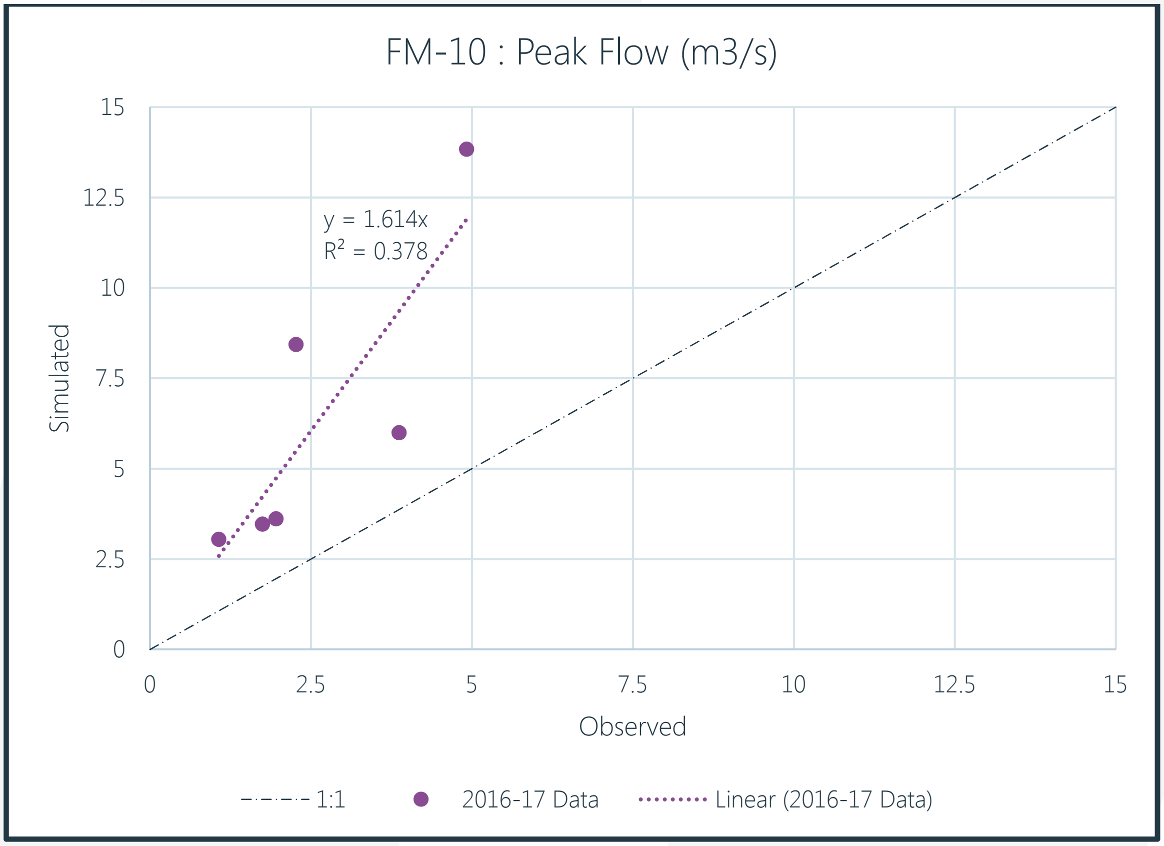
SCATTER PLOTS : Uncalibrated Model

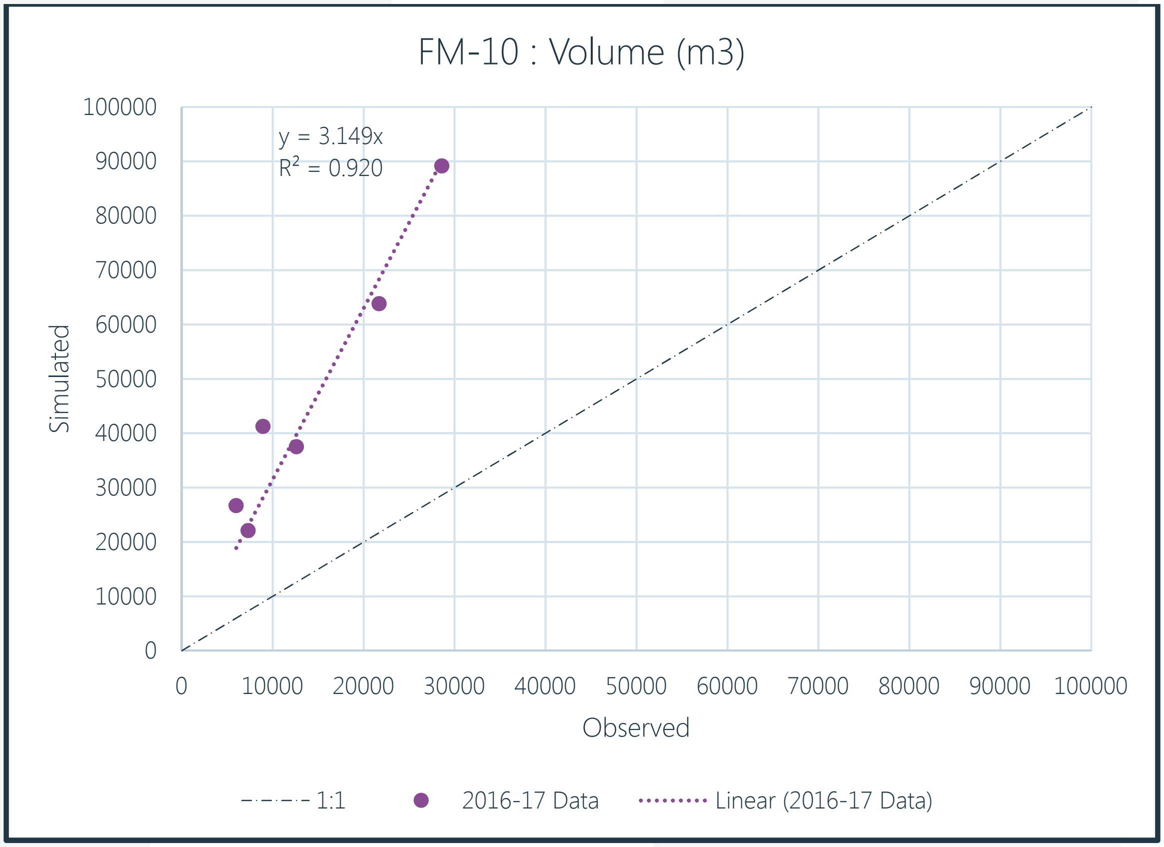


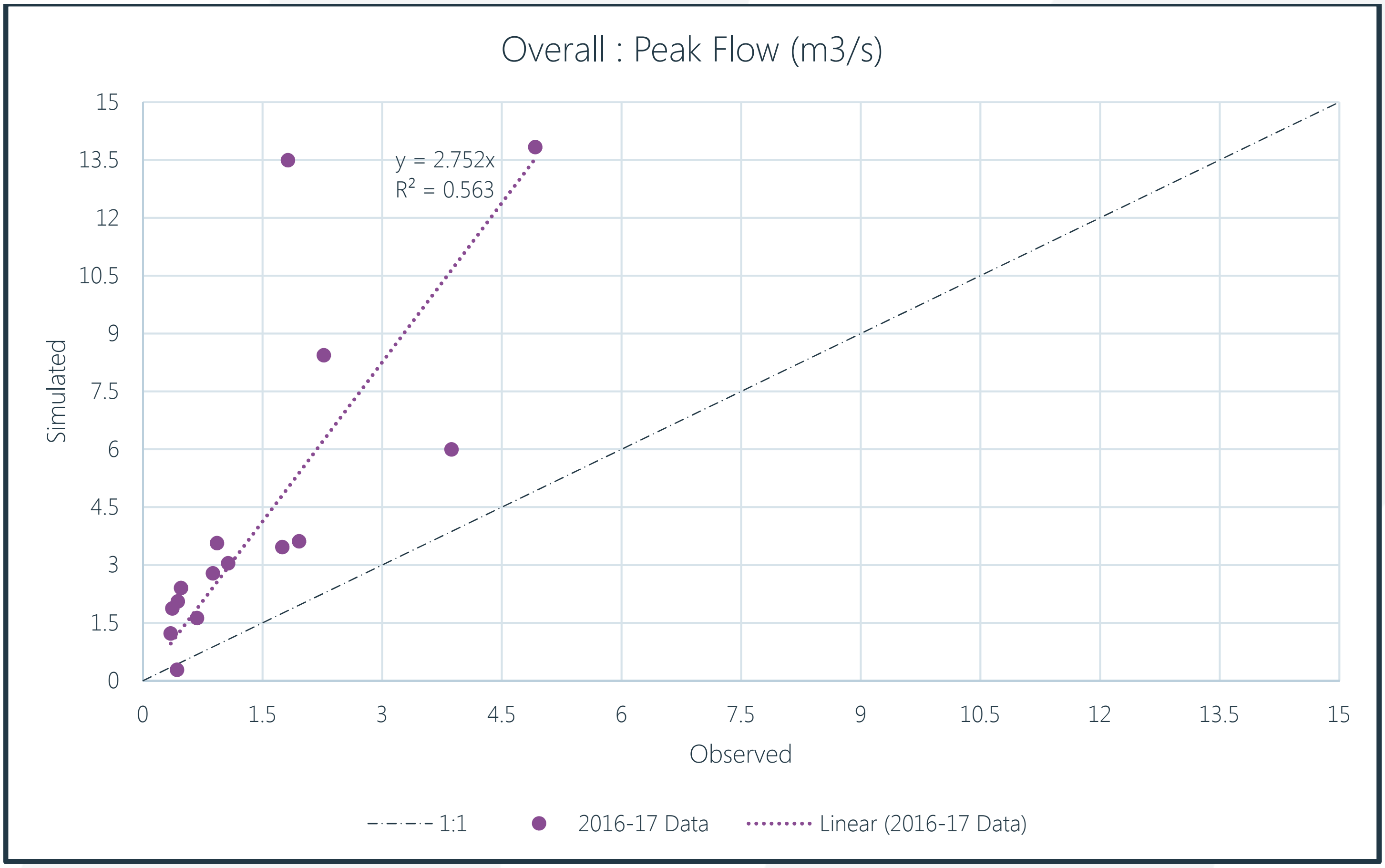


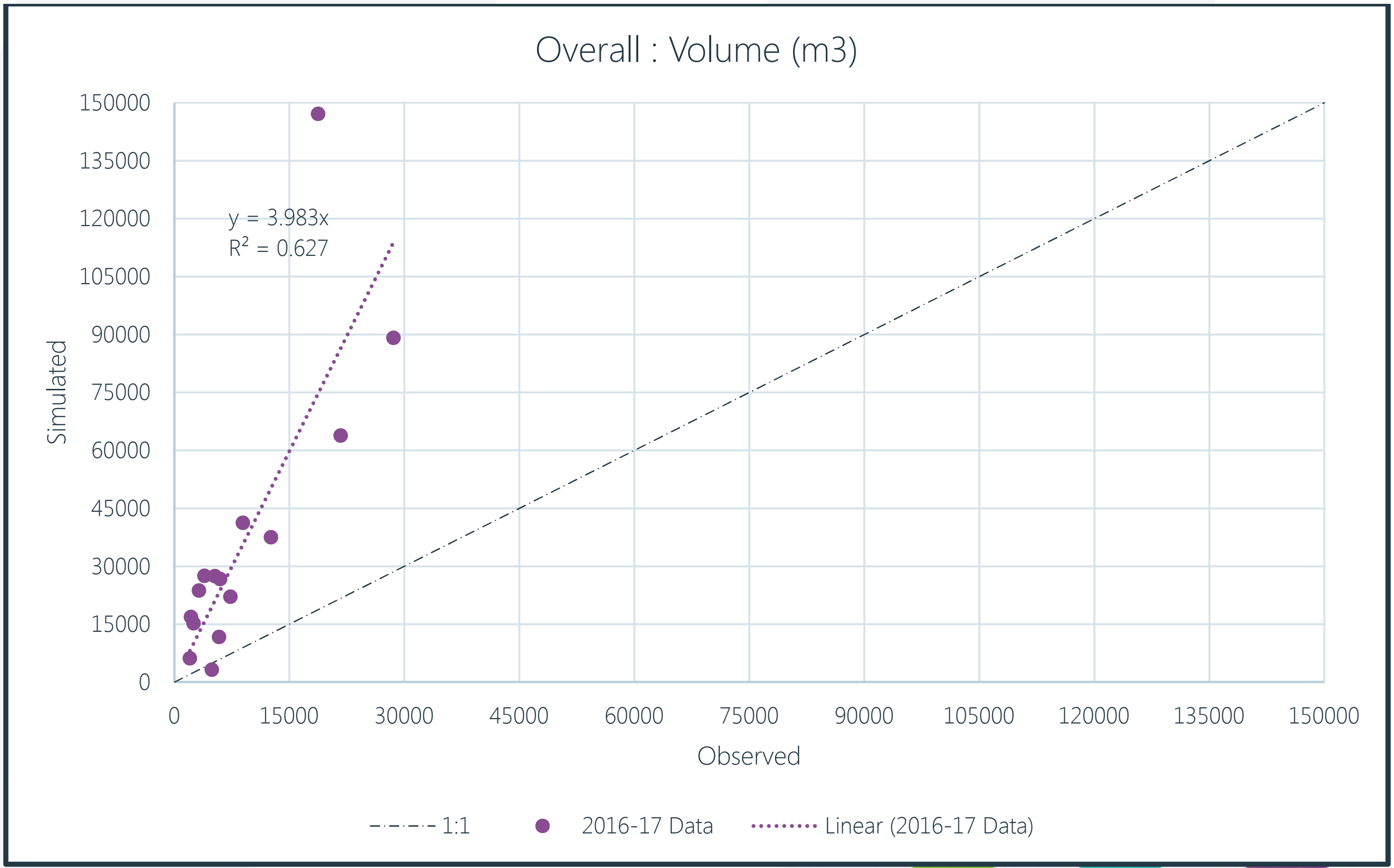

FM-2 : Peak Flow (m3/s)
y = 4.466x
R² = 0.597
Simulated
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Observed
1:1
2016-17 Data
Linear (2016-17 Data)


FM-2 : Volume (m3)
y = 2.099x
R² = 0.515
Simulated
0
5000
10000
15000
20000
25000
30000
Observed
2016-17 Data
1:1
Linear (2016-17 Data)

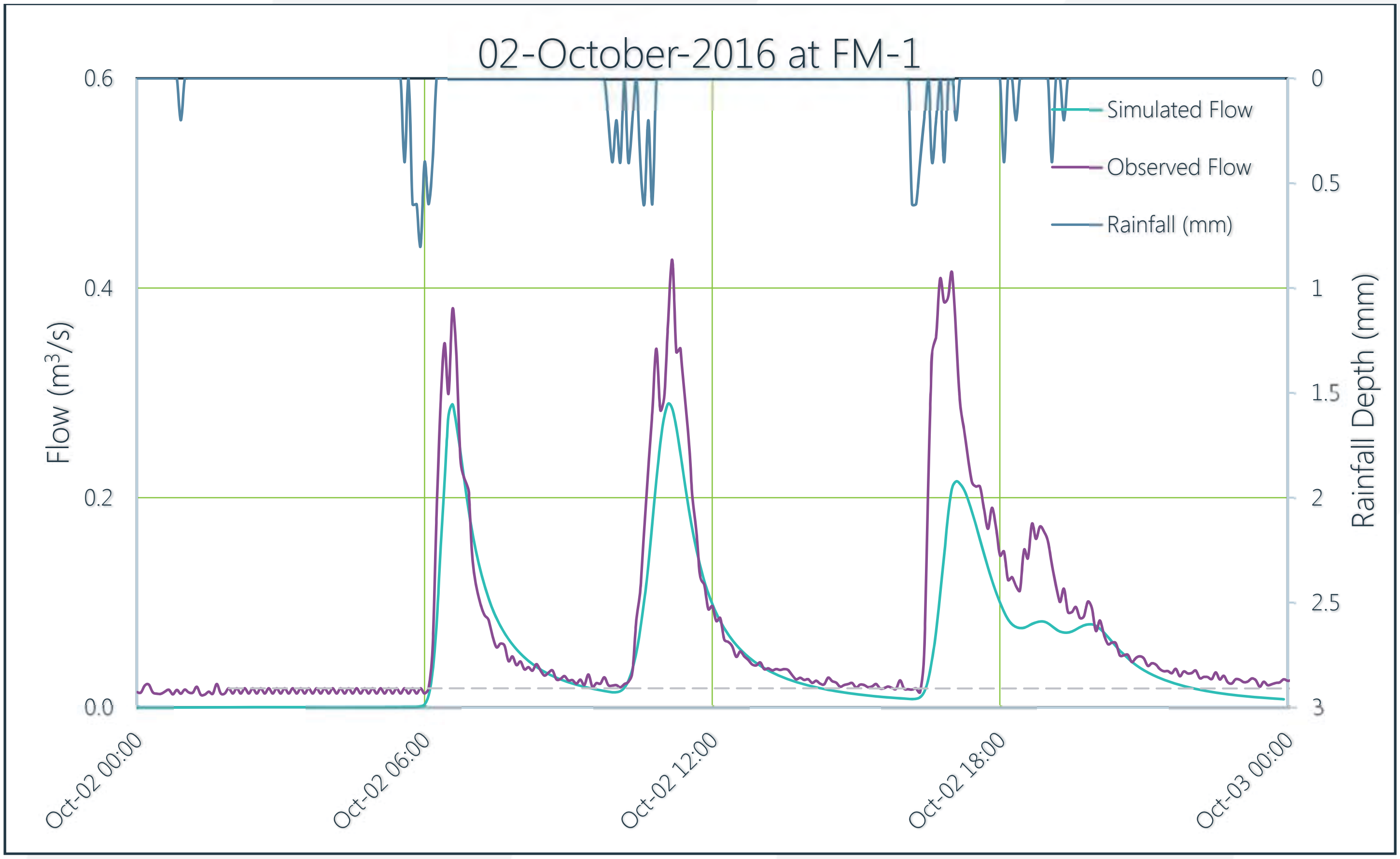

FM-10 : Peak Flow (m3/s)
y = 1.614x
R² = 0.378
Simulated
Observed
1:1
2016-17 Data
Linear (2016-17 Data)

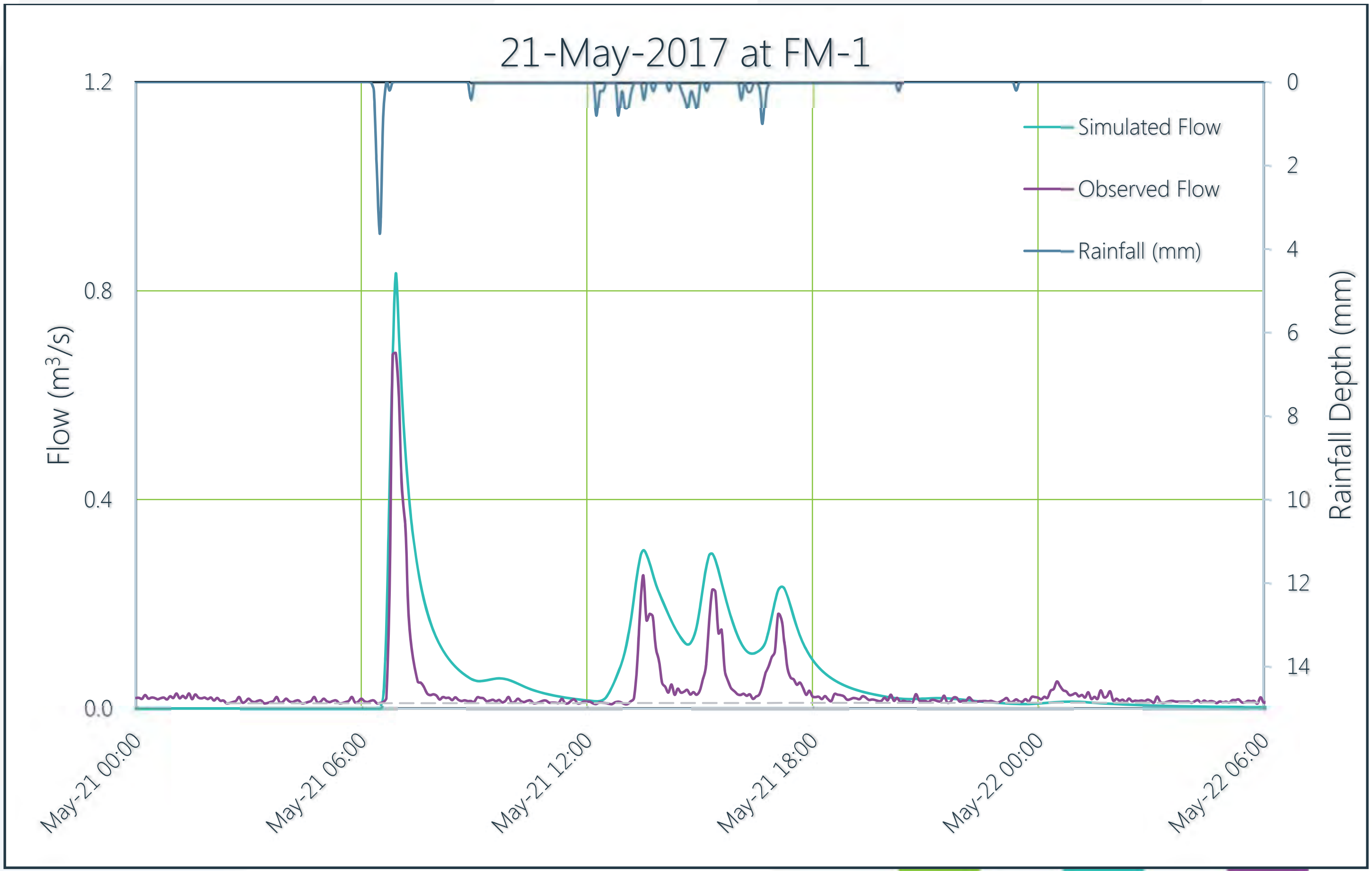

FM-10 : Volume (m3)
y = 3.149x
R² = 0.920
Simulated
Observed
1:1
2016-17 Data
Linear (2016-17 Data)

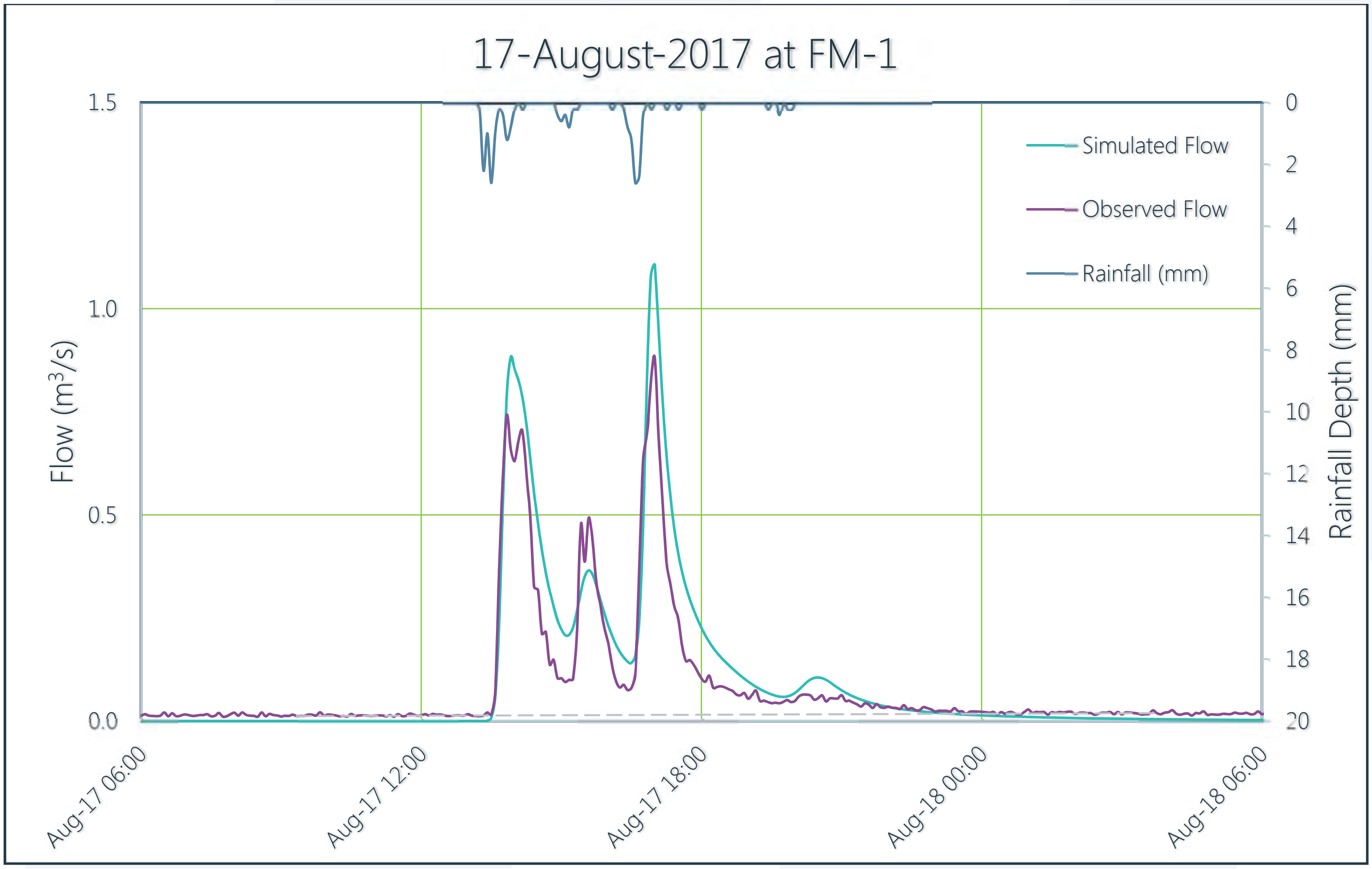

Overall : Peak Flow (m3/s)
y = 2.752x
R² = 0.563
Simulated
Observed
0
1.5
3
4.5
6
7.5
9
10.5
12
13.5
15
1:1
2016-17 Data
Linear (2016-17 Data)

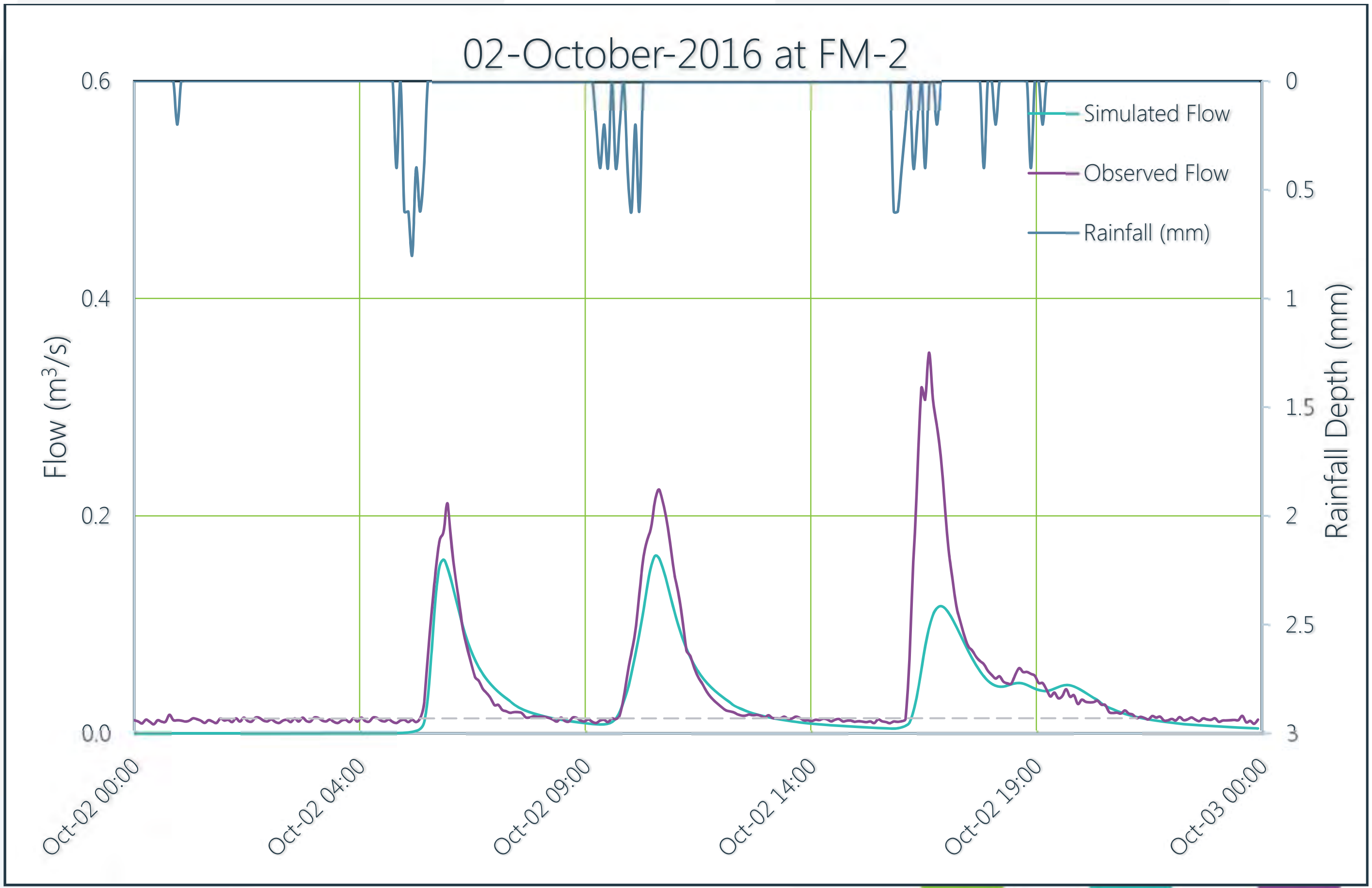

Overall : Volume (m3)
y = 3.983x
R² = 0.627
Simulated
Observed
0
15000
30000
45000
60000
75000
90000
105000
120000
135000
150000
1:1
2016-17 Data
Linear (2016-17 Data)

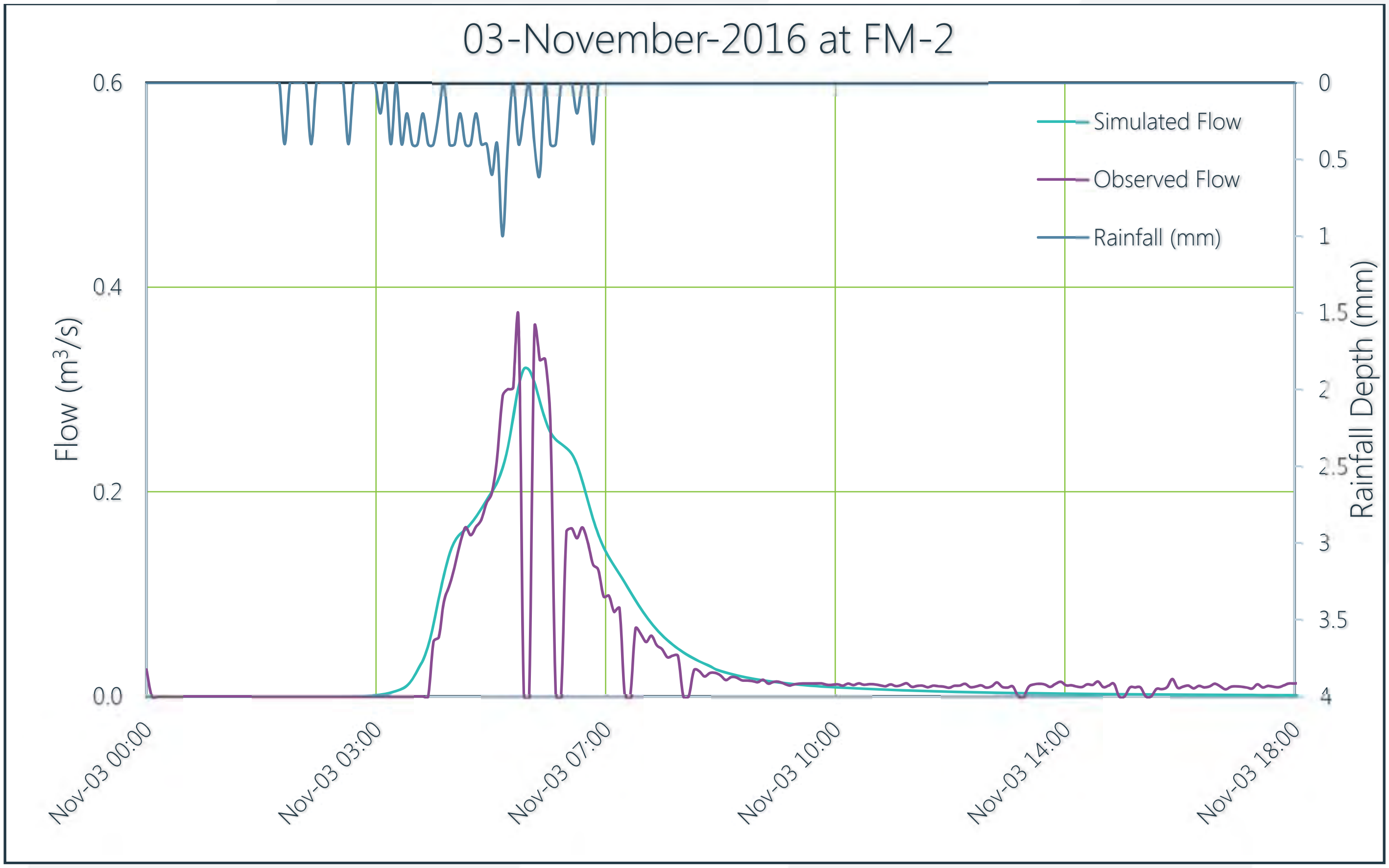
Appendix C: Calibrated Model Results


02-October-2016 at FM-1
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
0.6
0.4
0.2
0.0
0
0.5
1
1.5
2
2.5
3
Oct-02 00:00
Oct-02 06:00
Oct-02 12:00
Oct-02 18:00
Oct-03 00:00

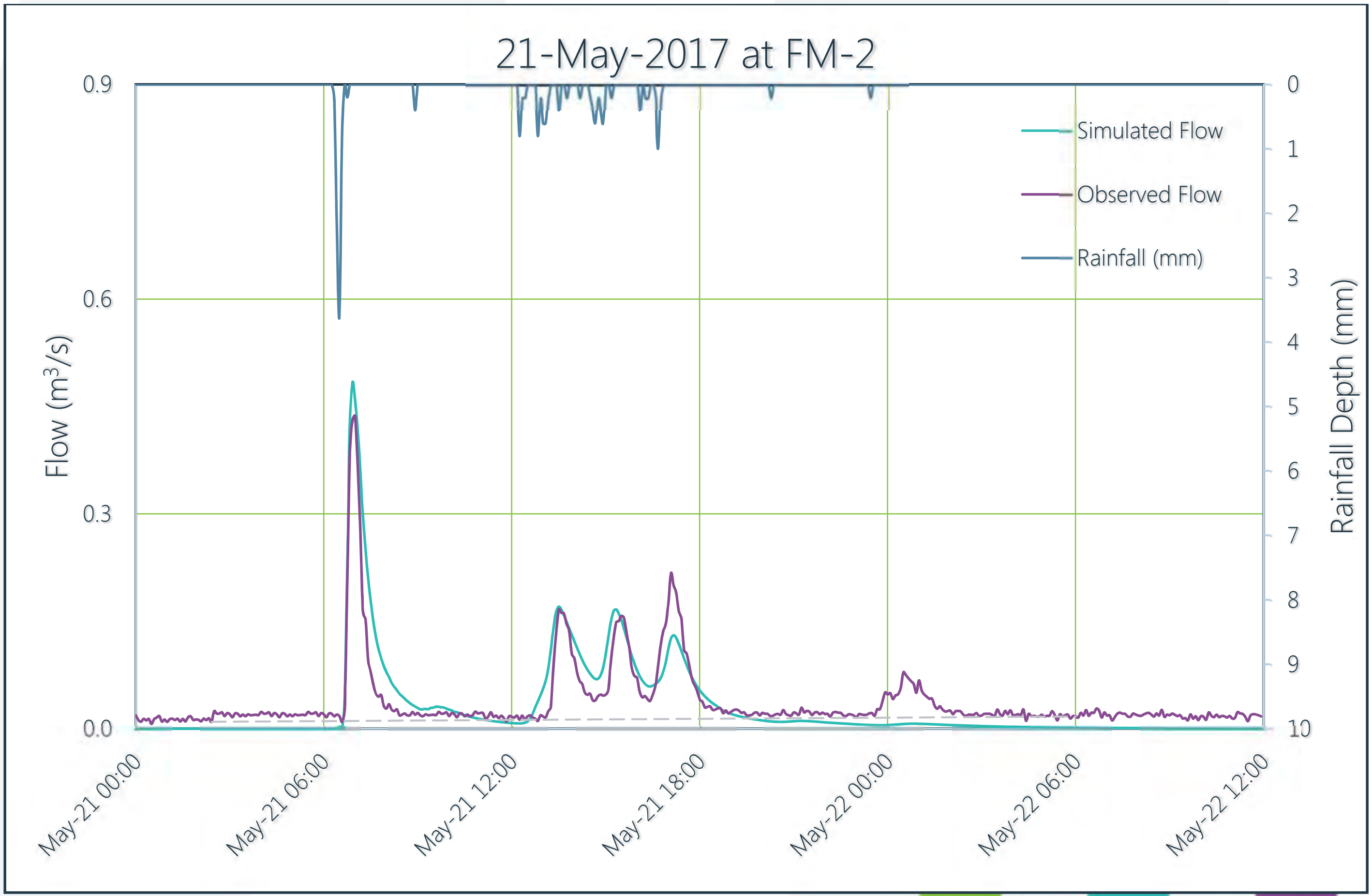

21-May-2017 at FM-1
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
1.2
0.8
0.4
0.0
0
2
4
6
8
10
12
14
May-21 00:00
May-21 06:00
May-21 12:00
May-21 18:00
May-22 00:00
May-22 06:00


17-August-2017 at FM-1
Flow (m3/s)
1.5
1.0
0.5
0.0
Rainfall Depth (mm)
0
2
4
6
8
10
12
14
16
18
20
Simulated Flow
Observed Flow
Rainfall (mm)
Aug-17 06:00
Aug-17 12:00
Aug-17 18:00
Aug-18 00:00
Aug-18 06:00

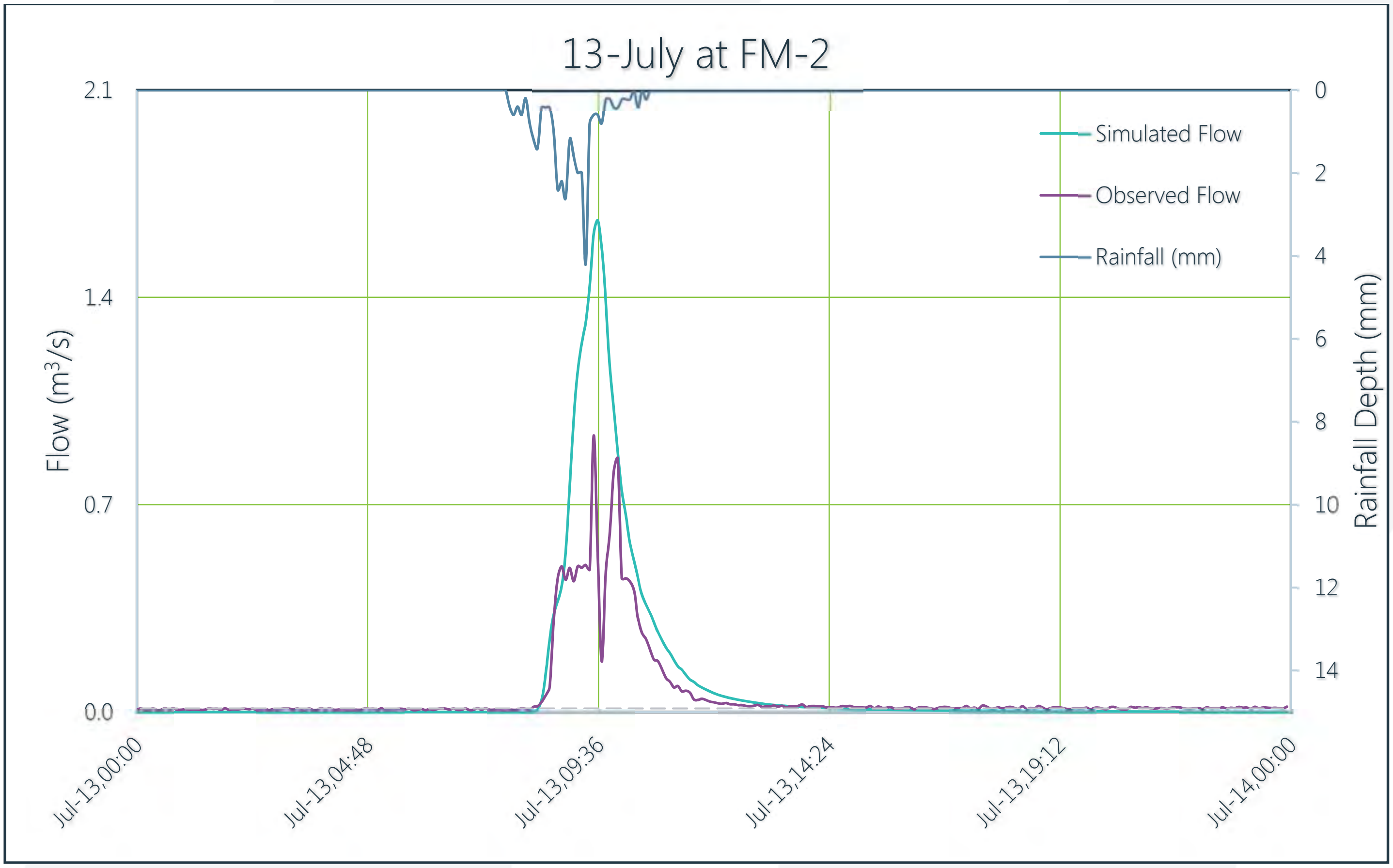

02-October-2016 at FM-2
Flow (m3/s)
0.6
0.4
0.2
0.0
Rainfall Depth (mm)
0
0.5
1
1.5
2
2.5
3
Simulated Flow
Observed Flow
Rainfall (mm)
Oct-02 00:00
Oct-02 04:00
Oct-02 09:00
Oct-02 14:00
Oct-02 19:00
Oct-03 00:00

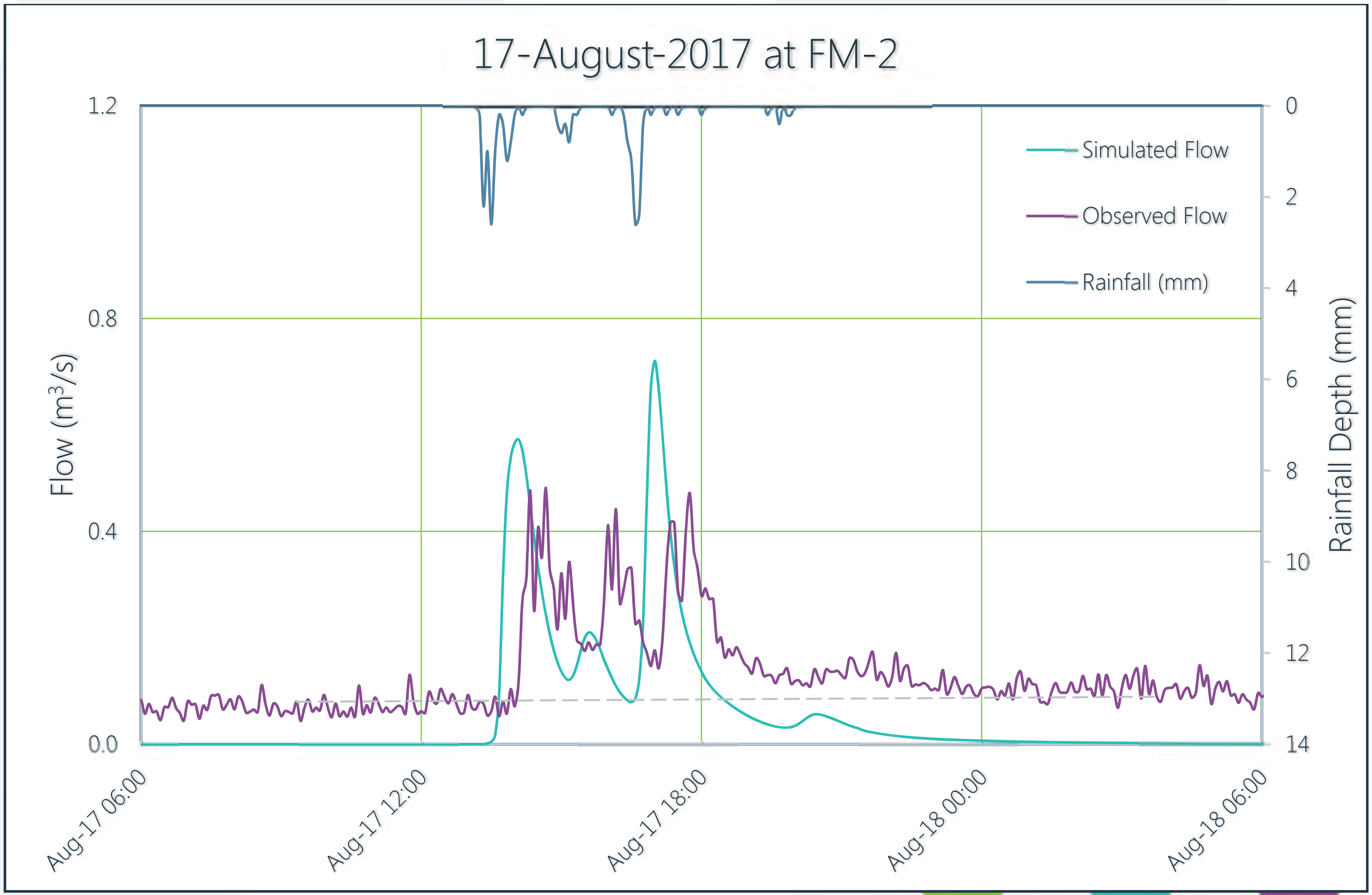


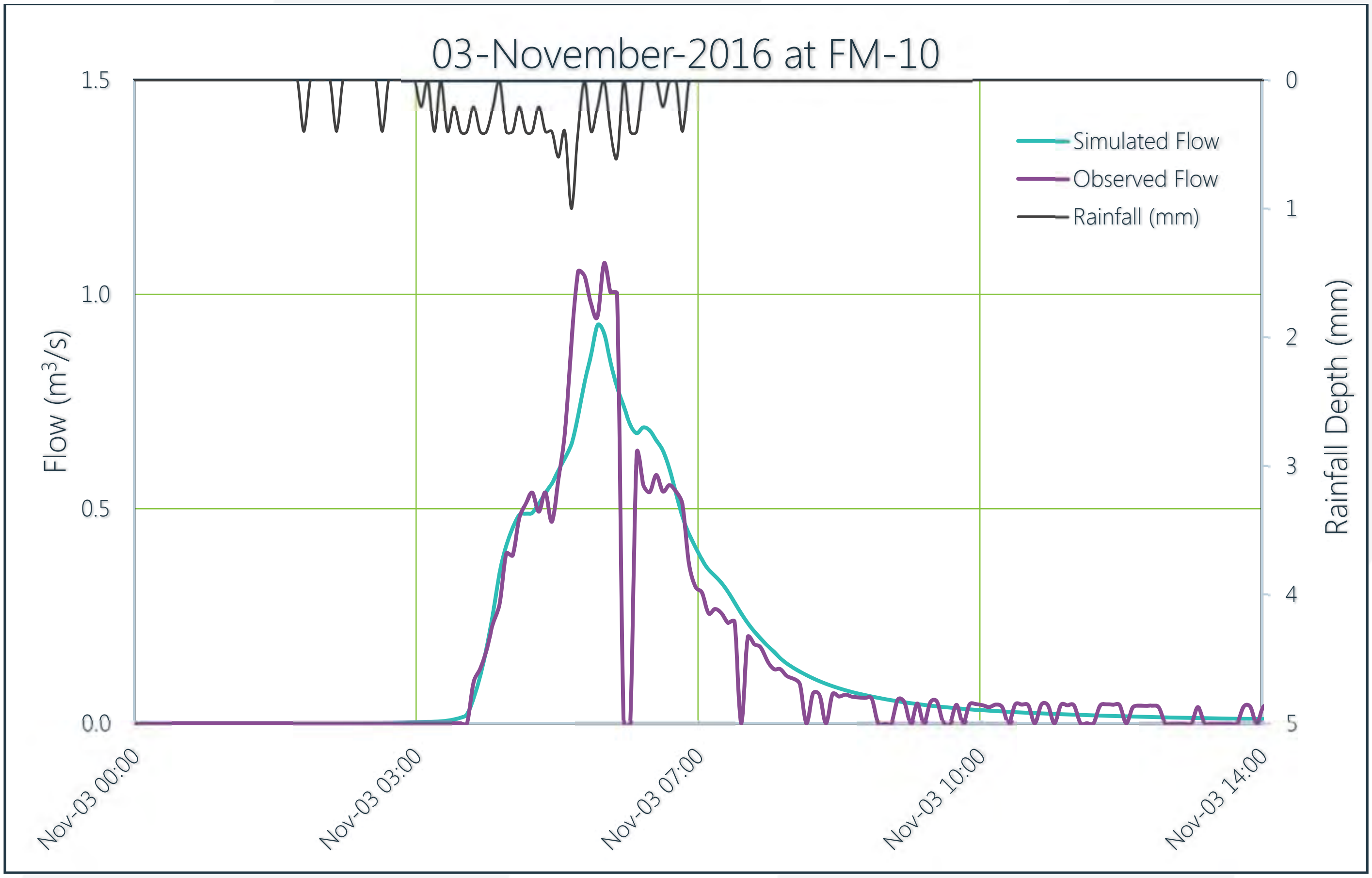
03-November-2016 at FM-2
Flow (m³/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
0.6
0.4
0.2
0.0
0
0.5
1
1.5
2
2.5
3
3.5
4
Nov-03 00:00
Nov-03 03:00
Nov-03 07:00
Nov-03 10:00
Nov-03 14:00
Nov-03 18:00

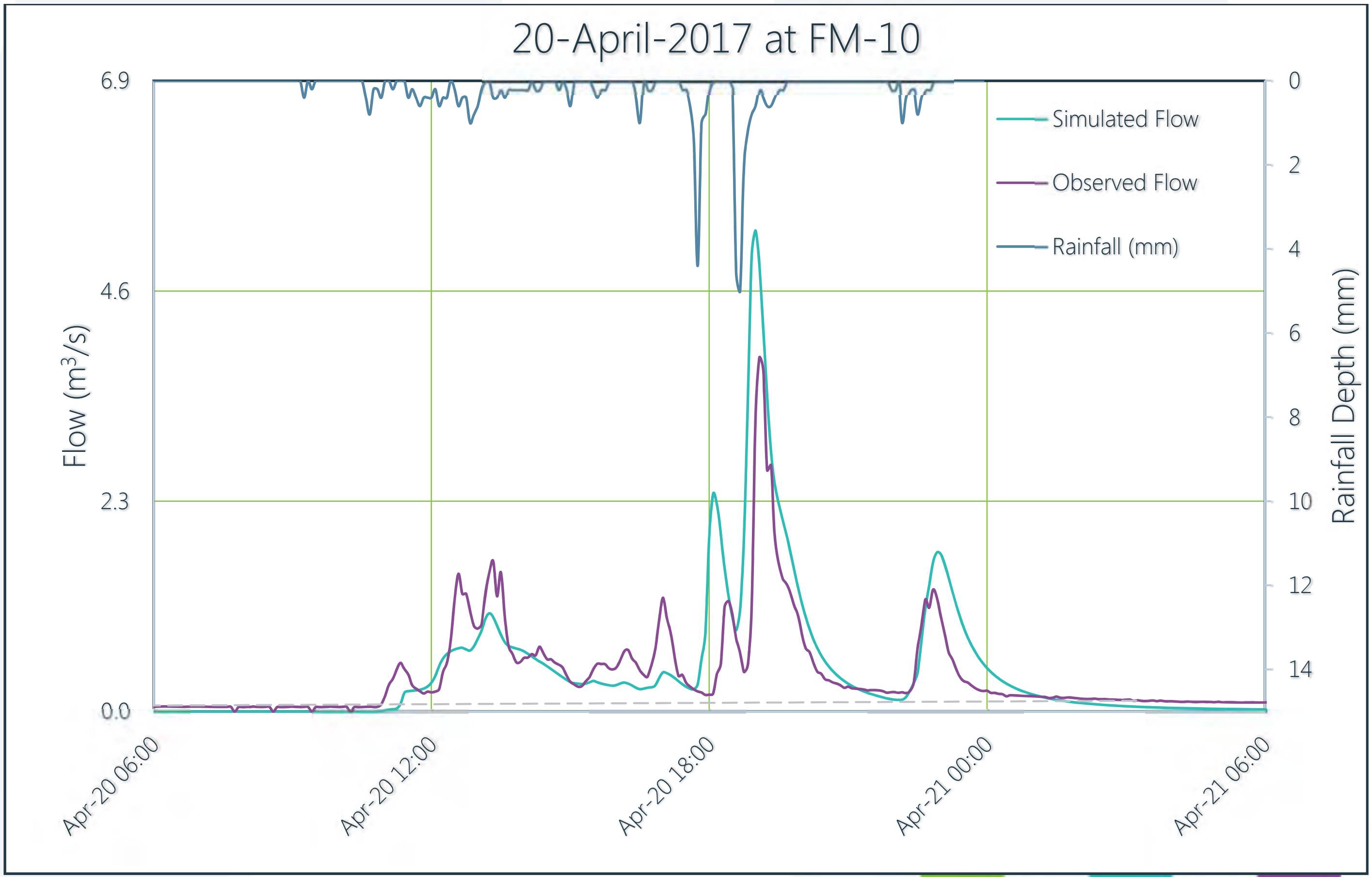


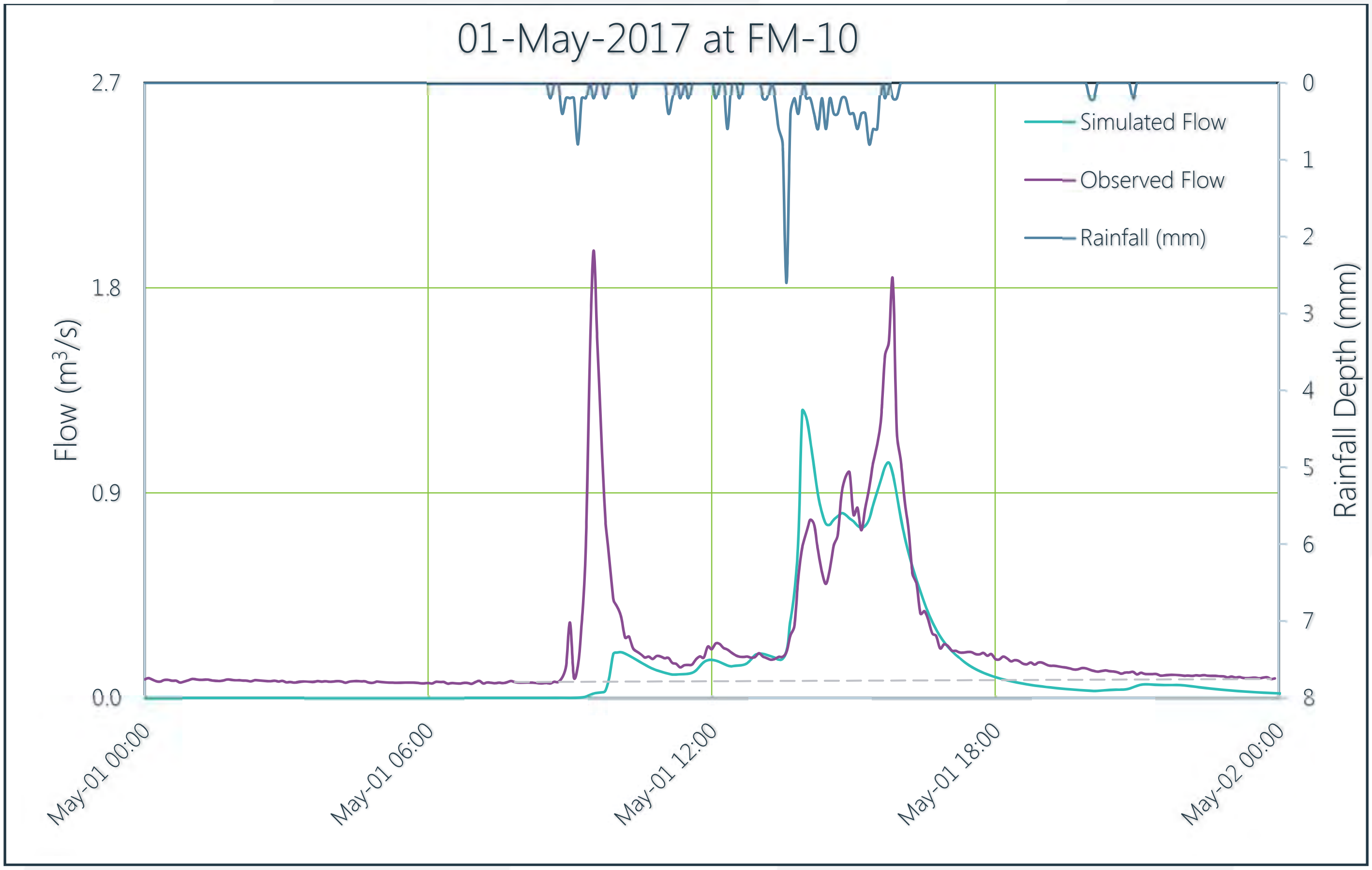
21-May-2017 at FM-2
Flow (m³/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
0.9
0.6
0.3
0.0
0
1
2
3
4
5
6
7
8
9
10
May-21 00:00
May-21 06:00
May-21 12:00
May-21 18:00
May-22 00:00
May-22 06:00
May-22 12:00

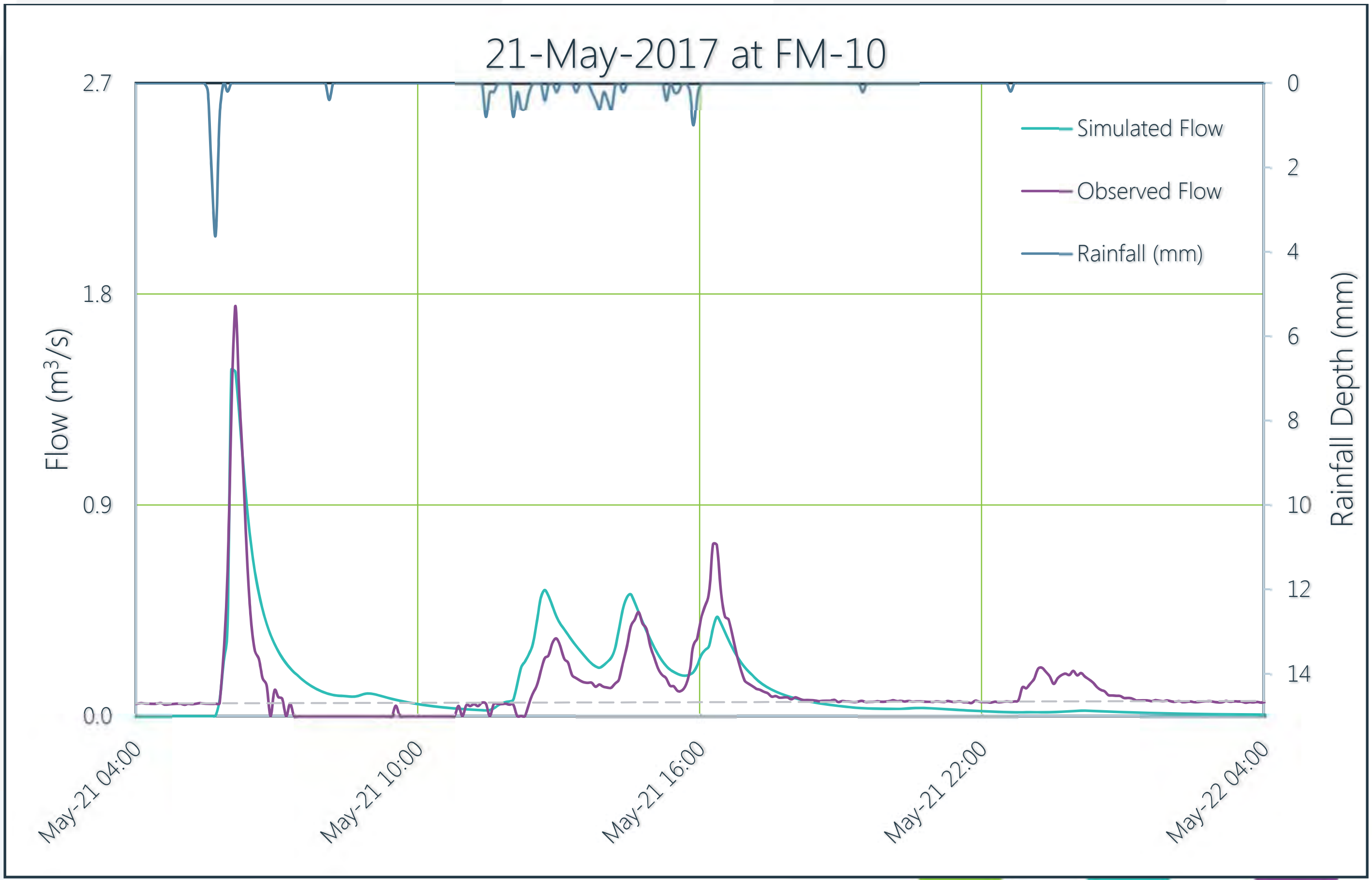

13-July at FM-2
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
2.1
1.4
0.7
0.0
0
2
4
6
8
10
12
14
Jul-13,00:00
Jul-13,04:48
Jul-13,09:36
Jul-13,14:24
Jul-13,19:12
Jul-14,00:00

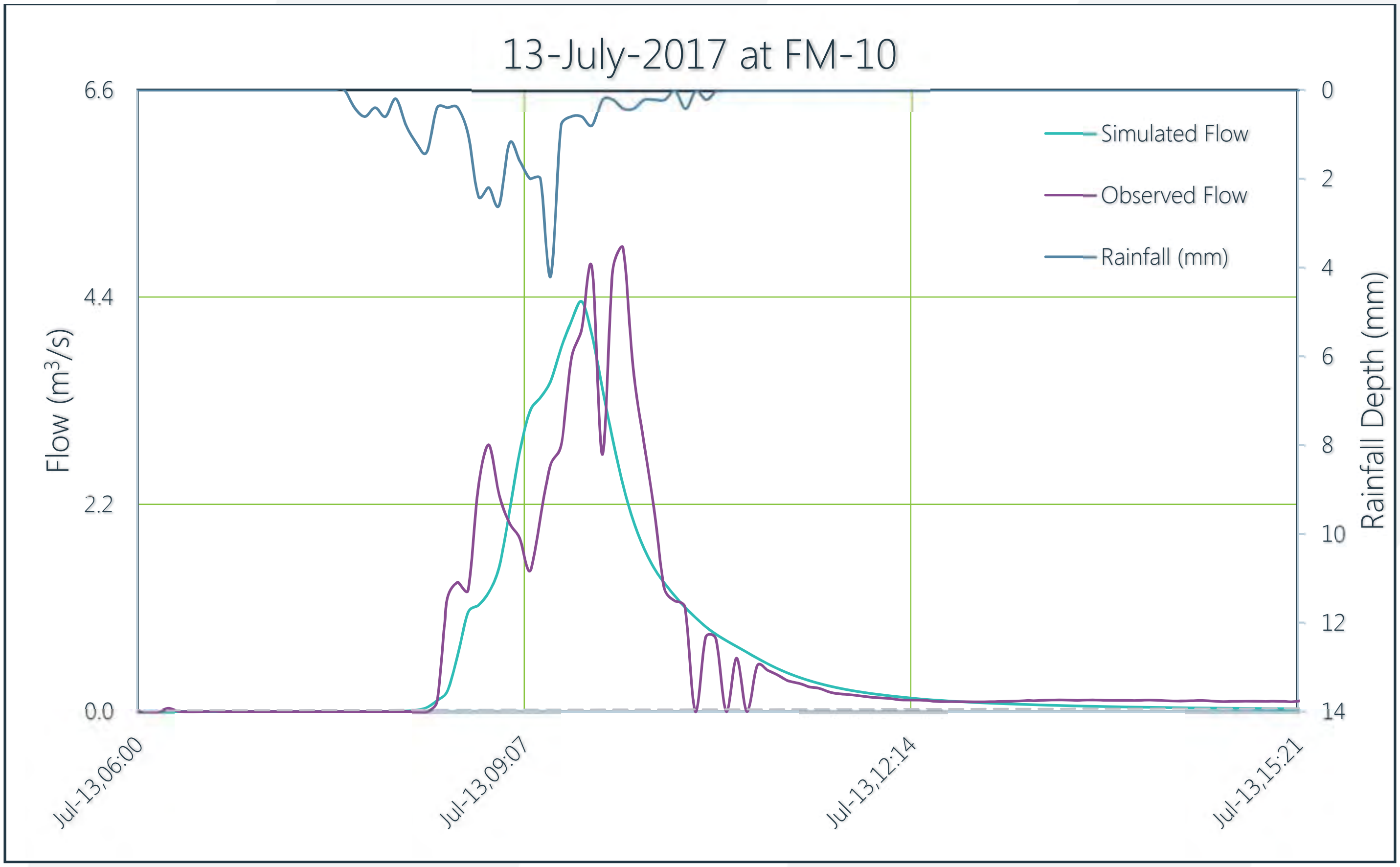

17-August-2017 at FM-2
Simulated Flow
Observed Flow
Rainfall (mm)
Flow (m3/s)
Rainfall Depth (mm)
1.2
0.8
0.4
0.0
0
2
4
6
8
10
12
14
Aug-17 06:00
Aug-17 12:00
Aug-17 18:00
Aug-18 00:00
Aug-18 06:00

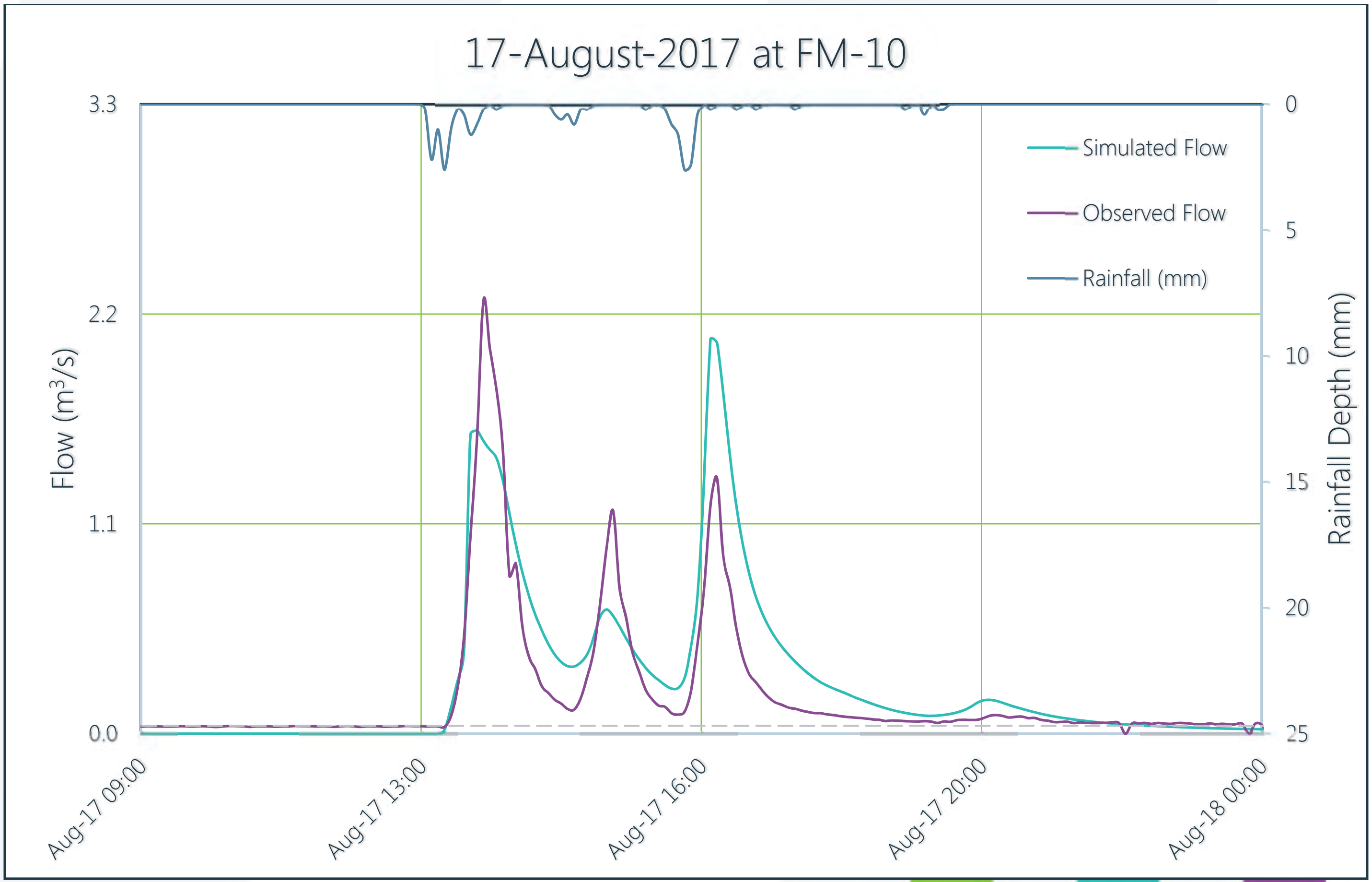

03-November-2016 at FM-10
1.5
1.0
0.5
0.0
Flow (m³/s)
0
1
2
3
4
5
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Nov-03 00:00
Nov-03 03:00
Nov-03 07:00
Nov-03 10:00
Nov-03 14:00


20-April-2017 at FM-10
6.9
4.6
2.3
0.0
Flow (m³/s)
0
2
4
6
8
10
12
14
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Apr-20 06:00
Apr-20 12:00
Apr-20 18:00
Apr-21 00:00
Apr-21 06:00

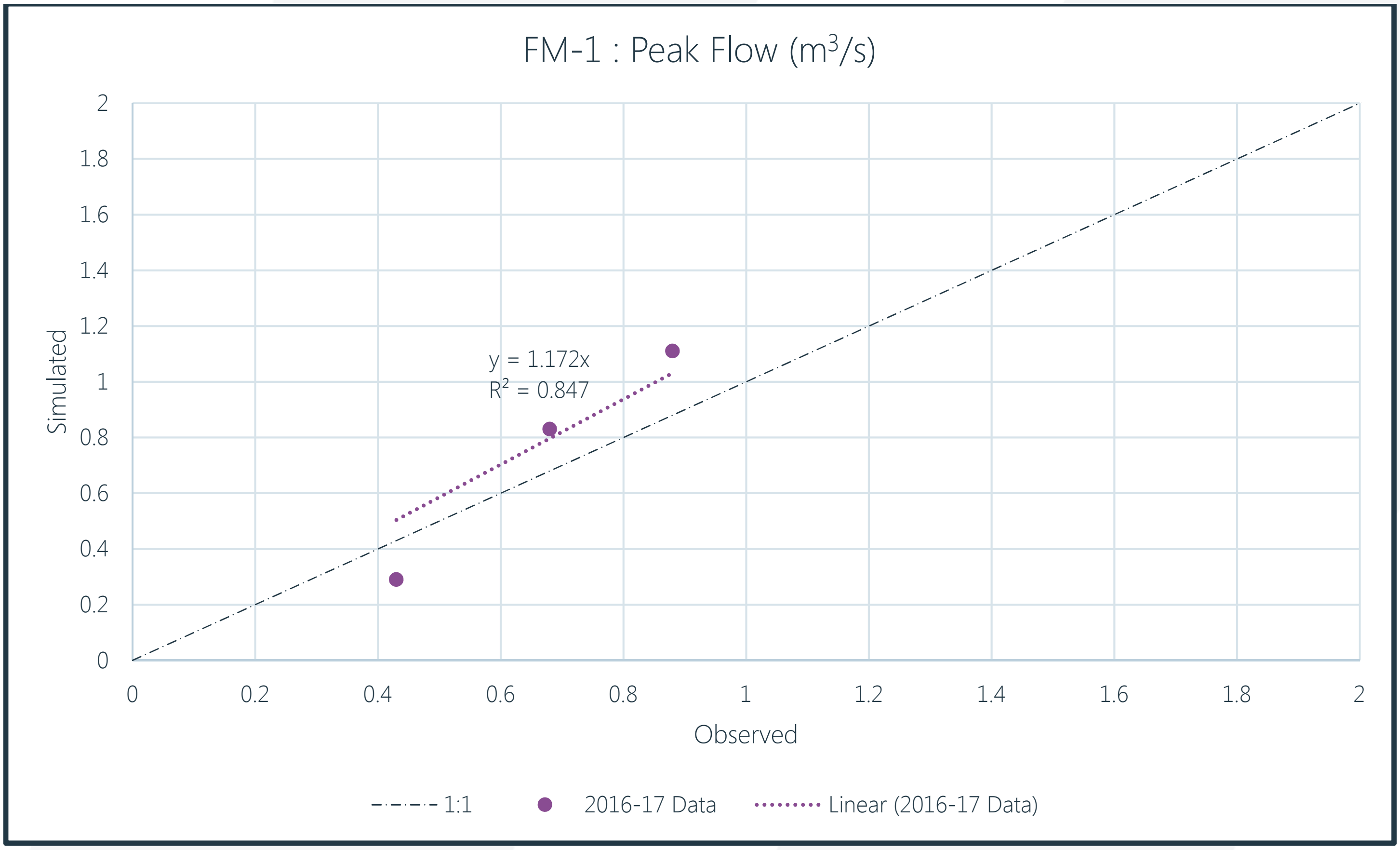

01-May-2017 at FM-10
Flow (m3/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
2.7
1.8
0.9
0.0
0
1
2
3
4
5
6
7
8
May-01 00:00
May-01 06:00
May-01 12:00
May-01 18:00
May-02 00:00

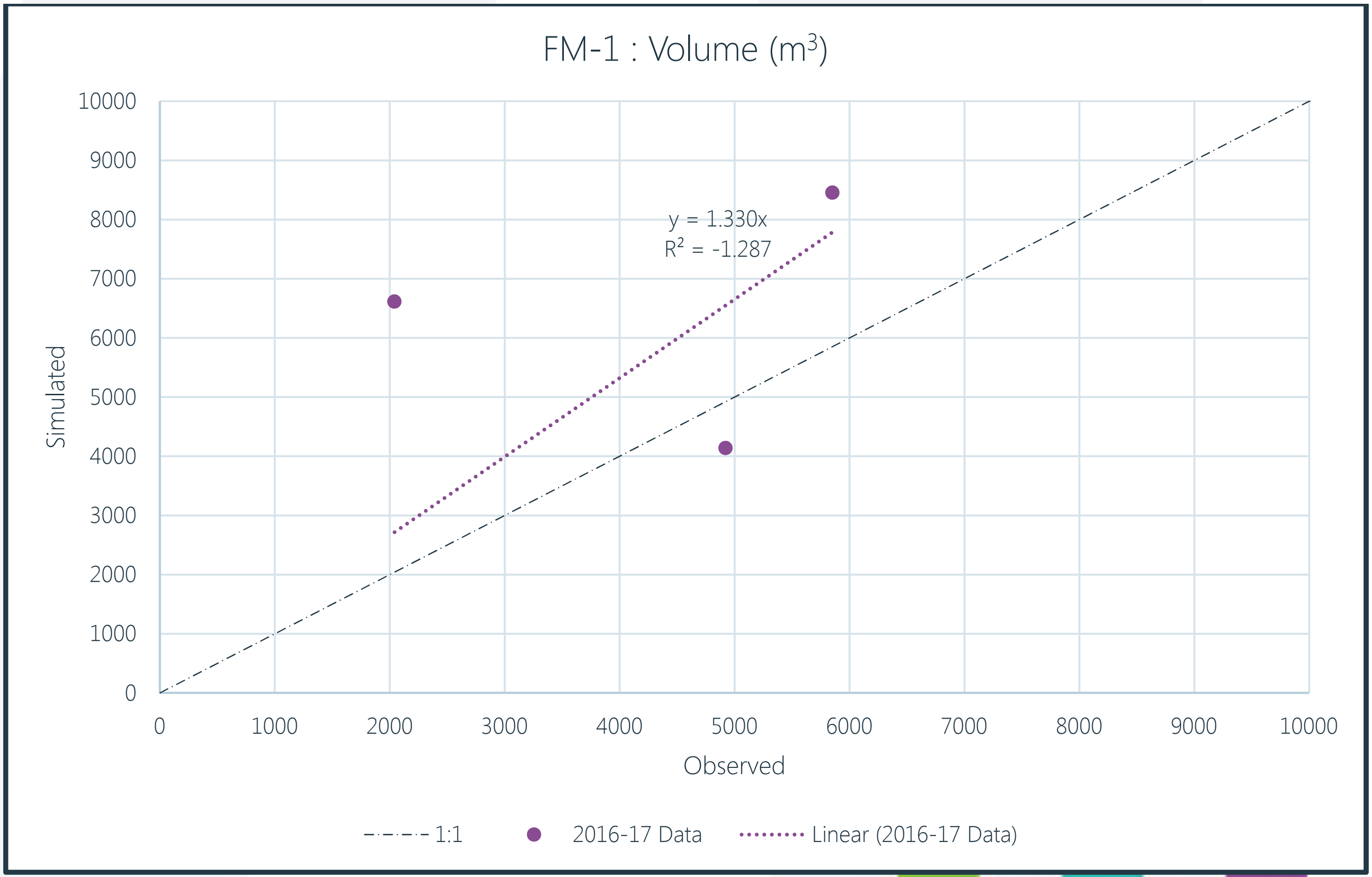

21-May-2017 at FM-10
Flow (m3/s)
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
2.7
1.8
0.9
0.0
0
2
4
6
8
10
12
14
May-21 04:00
May-21 10:00
May-21 16:00
May-21 22:00
May-22 04:00

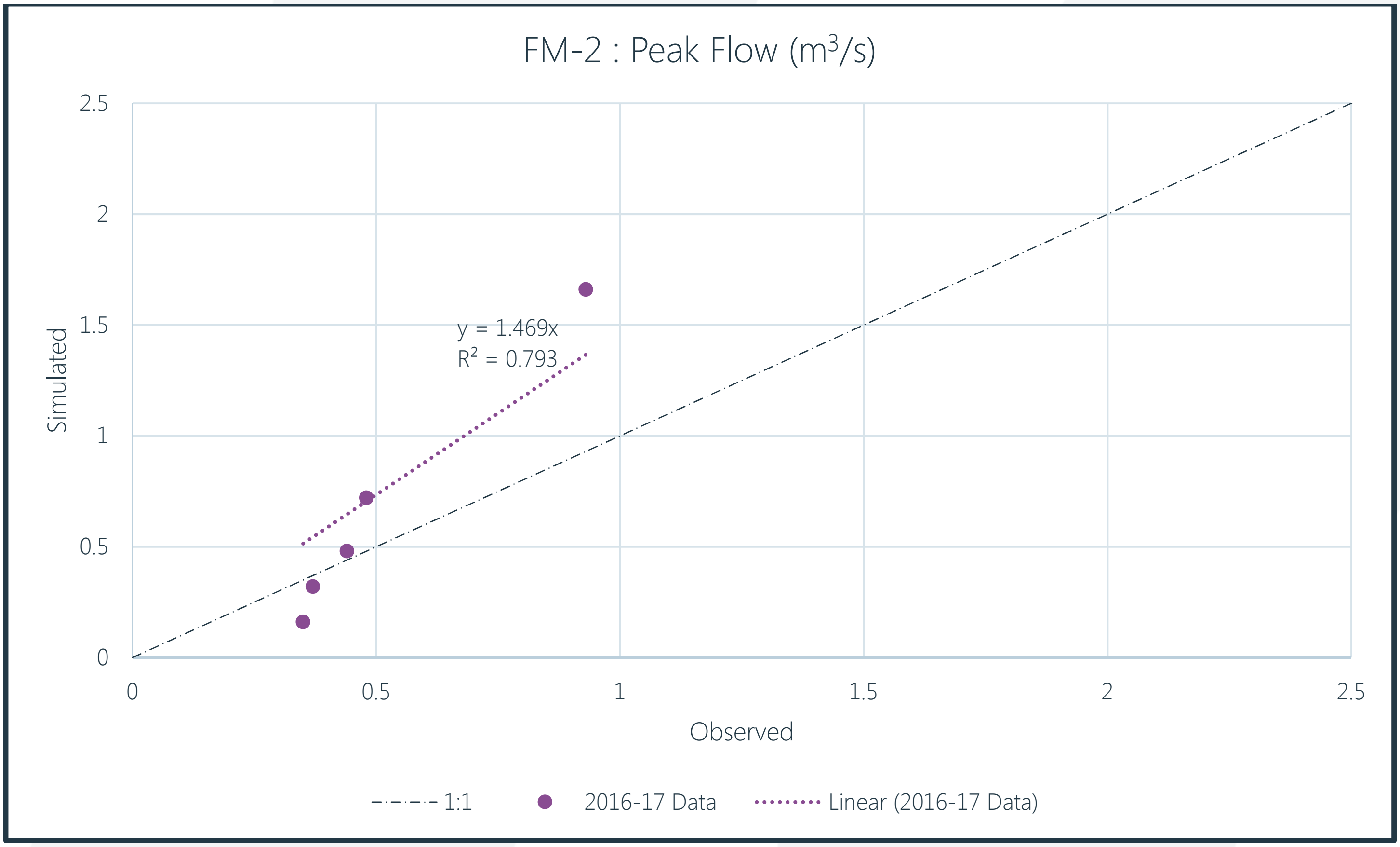

13-July-2017 at FM-10
6.6
4.4
2.2
0.0
Flow (m3/s)
0
2
4
6
8
10
12
14
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Jul-13,06:00
Jul-13,09:07
Jul-13,12:14
Jul-13,15:21

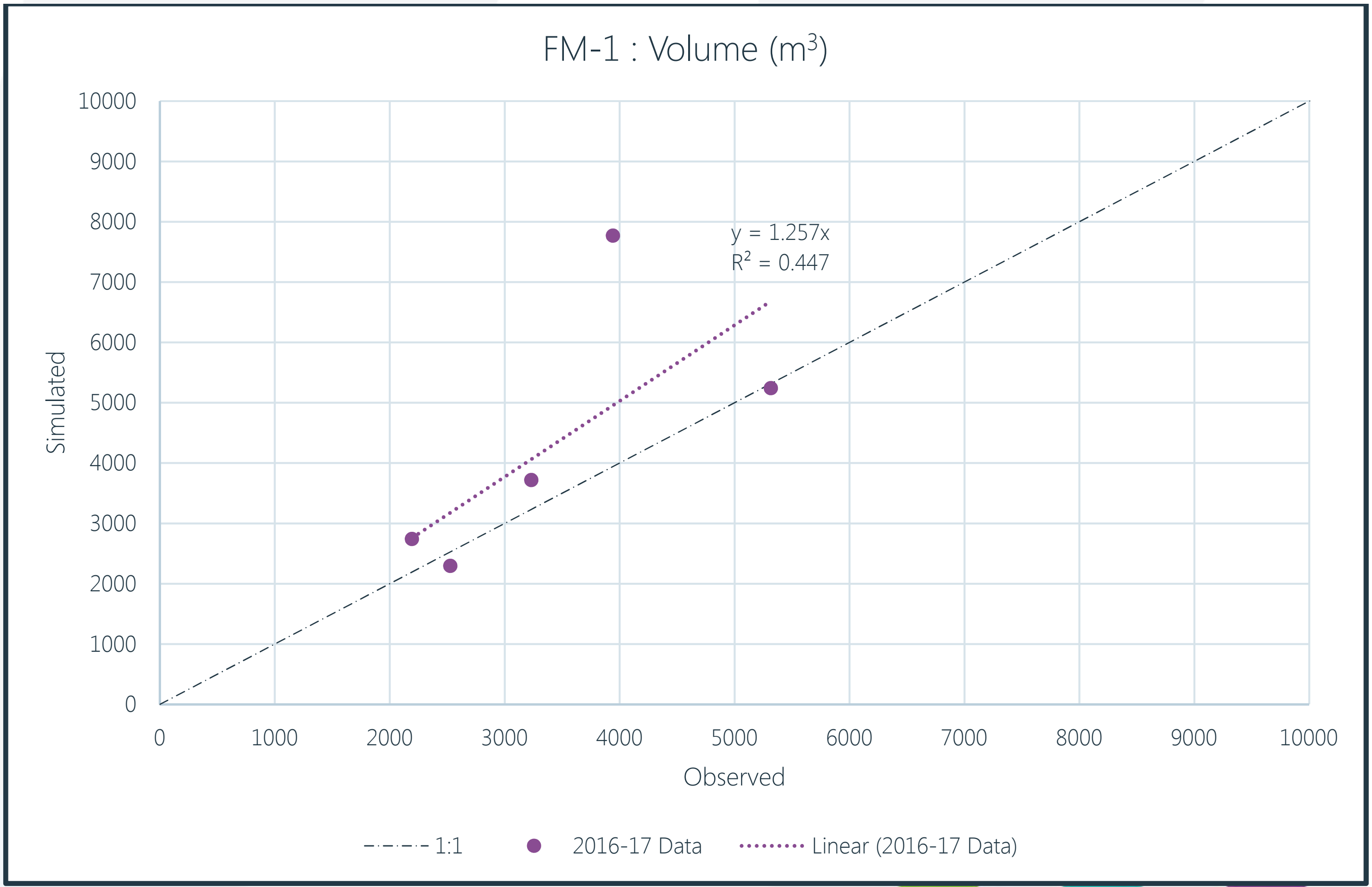

17-August-2017 at FM-10
3.3
2.2
1.1
0.0
Flow (m3/s)
0
5
10
15
20
25
Rainfall Depth (mm)
Simulated Flow
Observed Flow
Rainfall (mm)
Aug-17 09:00
Aug-17 13:00
Aug-17 16:00
Aug-17 20:00
Aug-18 00:00

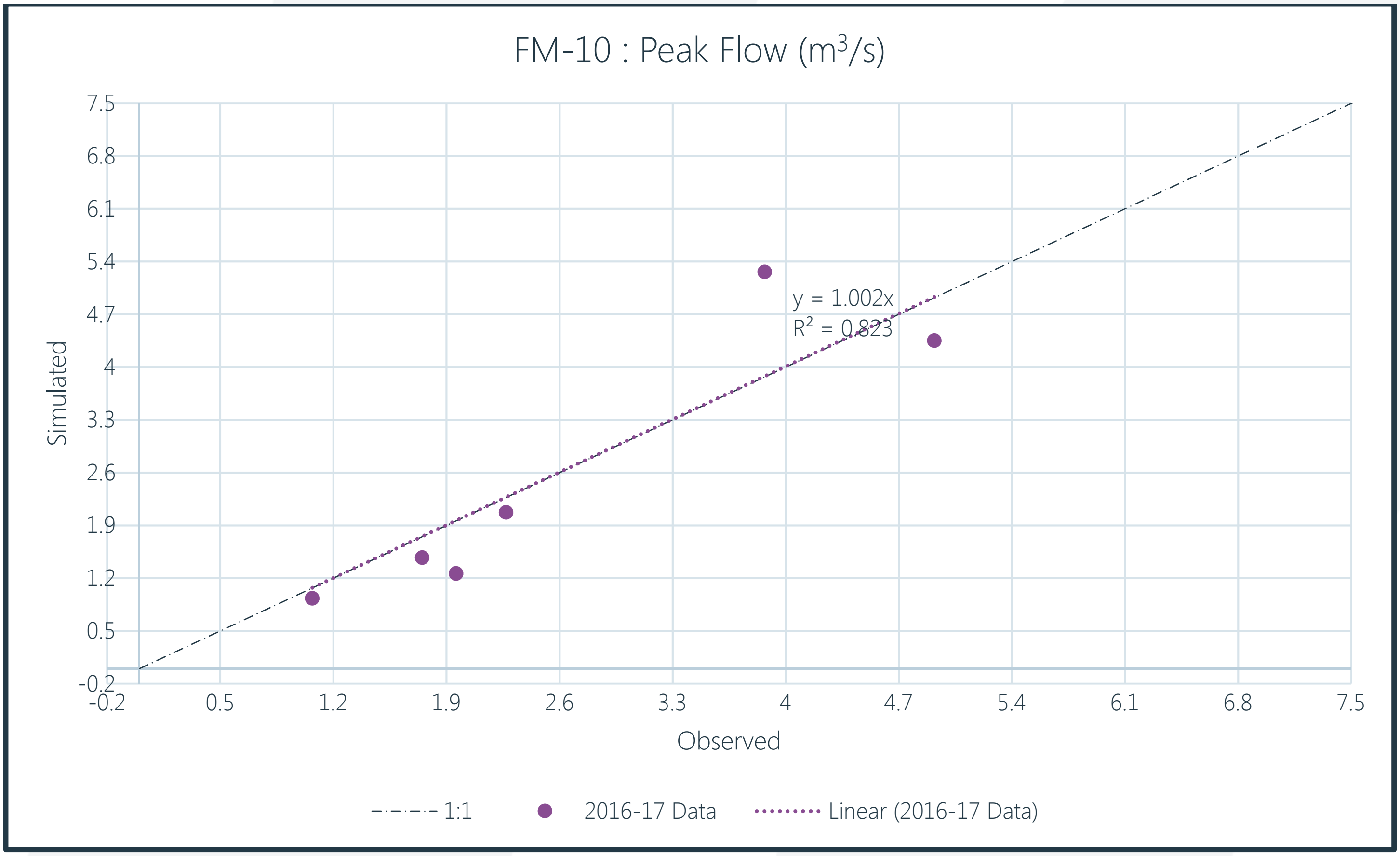
Appendix D: Model Simulation Results

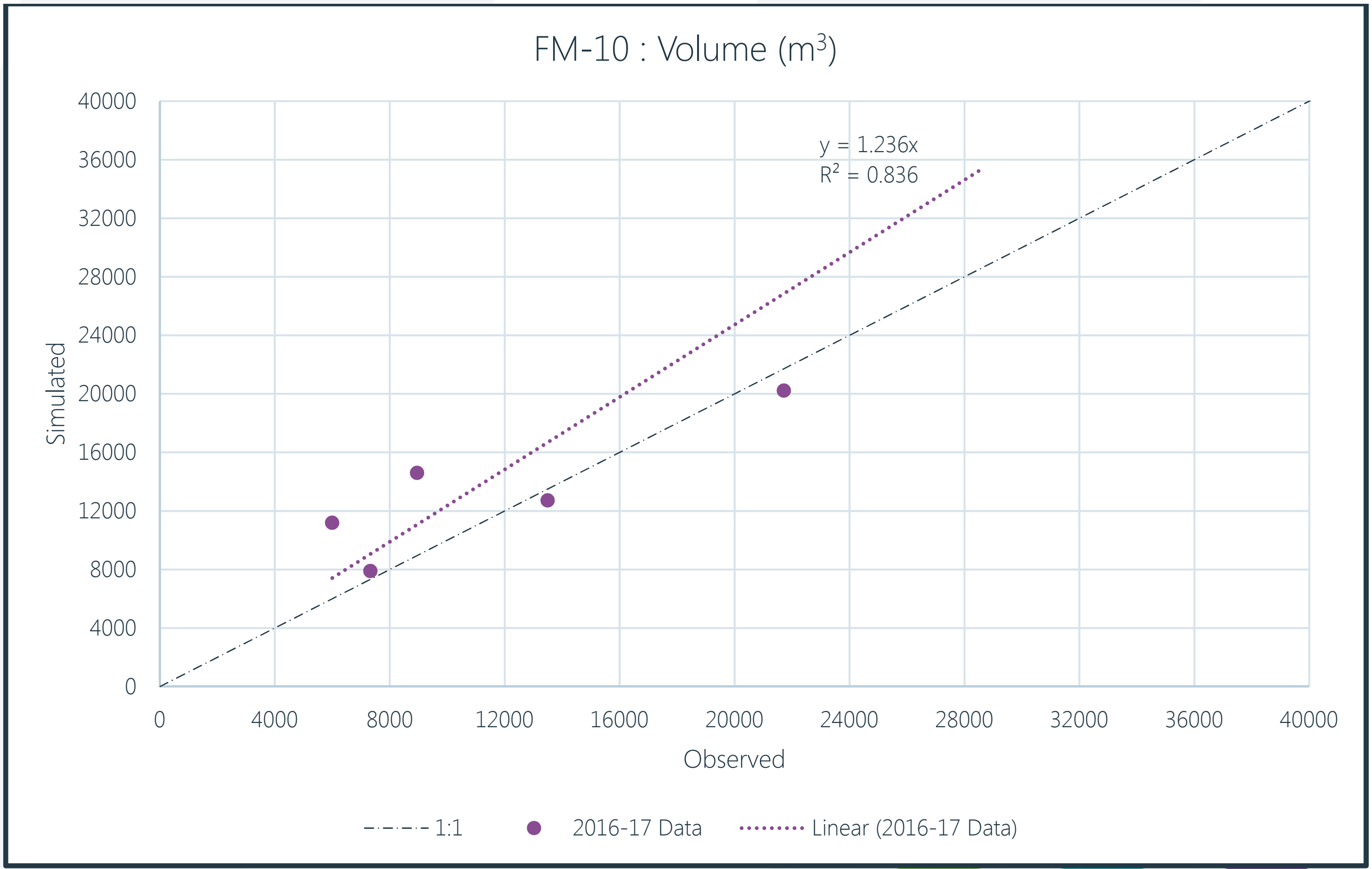

FM-1 : Peak Flow (m3/s)
Simulated
Observed
y = 1.172x
R2 = 0.847
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
1:1
2016-17 Data
Linear (2016-17 Data)

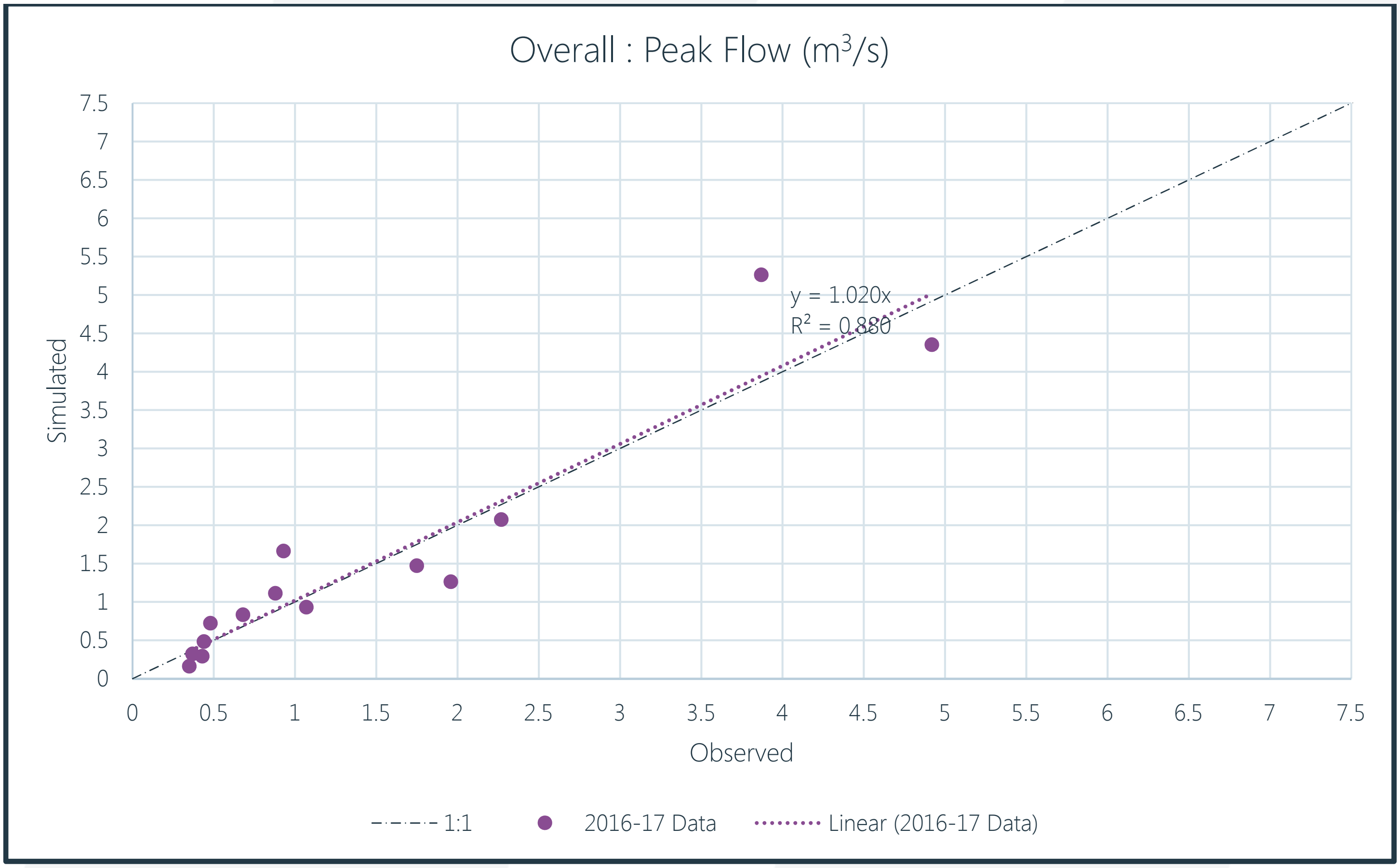

FM-1 : Volume (m3)
Simulated
Observed
y = 1.330x
R2 = -1.287
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1:1
2016-17 Data
Linear (2016-17 Data)

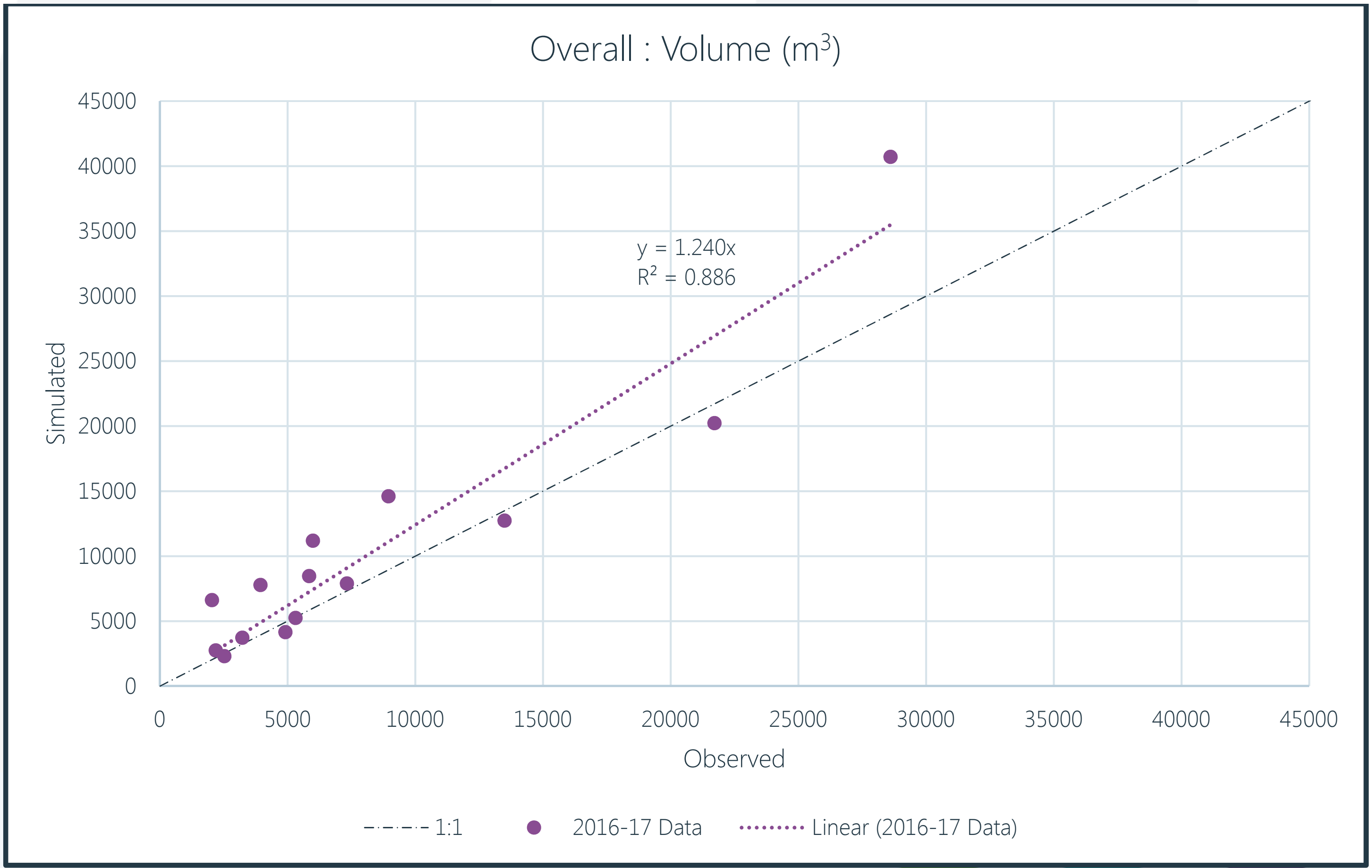

FM-2 : Peak Flow (m3/s)
y = 1.469x
R² = 0.793
Simulated
Observed
0
0.5
1
1.5
2
2.5
1:1
2016-17 Data
Linear (2016-17 Data)


FM-1 : Volume (m3)
y = 1.257x
R² = 0.447
Simulated
Observed
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1:1
2016-17 Data
Linear (2016-17 Data)


FM-10 : Peak Flow (m3/s)
Simulated
Observed
y = 1.002x
R² = 0.823
7.5
6.8
6.1
5.4
4.7
4
3.3
2.6
1.9
1.2
0.5
-0.2
-0.2
0.5
1.2
1.9
2.6
3.3
4
4.7
5.4
6.1
6.8
7.5
1:1
2016-17 Data
Linear (2016-17 Data)


FM-10 : Volume (m3)
Simulated
Observed
y = 1.236x
R² = 0.836
40000
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
0
4000
8000
12000
16000
20000
24000
28000
32000
36000
40000
1:1
2016-17 Data
Linear (2016-17 Data)


Overall : Peak Flow (m³/s)
Simulated
Observed
y = 1.020x
R² = 0.880
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
1:1
2016-17 Data
Linear (2016-17 Data)


Overall : Volume (m³)
Simulated
Observed
y = 1.240x
R² = 0.886
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
1:1
2016-17 Data
Linear (2016-17 Data)

Appendix E: Cost Estimates

MOHAWK LAKE AND CANAL FUNCTIONAL MASTER DRAINAGE AND RESTORATION STUDY

SUBWATERSHED STORMWATER PLAN

APPENDIX E
LID BMP/SOURCE CONTROL AND END OF PIPE COSTING FOR ROADWAY RECONSTRUCTIONS

For potential conveyance controls (i.e. LID BMPs), it should be understood that construction costs will vary greatly depending on the approach selected. In addition, as noted previously, the form of the conveyance control will need to consider project budget and design status, including potential constraints within the respective roadway right-of-way, particularly for surface-based features such as bioretention planters or grassed swales/bioswales. As such, costs for these measures have been provided as a range, from simple measures such as exfiltration pipes to more costly measures such as tree planter cells and permeable pavement. Costs could also be further adjusted if LID BMPs are proposed for only a portion of the roadway, rather than the entire section.

Construction costs for LID BMPs have been sourced from "Assessment of Life Cycle Costs for Low Impact Development Stormwater Management Practices" (STEP, April 2013); assumptions are presented in Table E1.

Table E1 Low Impact Development Construction Cost Estimates (from STEP, 2013)

LID BMP Measure	High-Level Construction Cost Per Area Treated ($/m^2)	Note
Enhanced Grass Swales	$10	Less costly due to minimal excavation and infrastructure (piping), however necessitates space in the ROW which may not be available
Infiltration Chambers	$25	Assume more costly unit rate from STEP that assumes pre-treatment
Infiltration Trenches	$25	Apply more costly unit rate from STEP that assumes pre-treatment
Bioretention	$30	Increase base STEP cost to include assumed pre-treatment via catchbasin inserts
Tree Planter Cells	$50	Additional aesthetic benefit for street, additional cost to modify catchbasin inlets to re-direct stormwater flows into system
Permeable Pavement	$100	Typically the most costly LID BMP measure; cost based on full roadway only, when ROW included cost would be less ($50/m^2)

Based on the high-level cost estimates provided in Table E1, it is evident that LID BMP costs can vary significantly based on the option chosen. Assuming a mid-range cost of $30/m^2, LID BMP measures would likely only be more cost effective for smaller roadway sections (i.e. less than 0.5 ha), which would represent a typical installation cost for a mid-range oil/grit separator ($150,000). As such, in many cases end-of-pipe measures (oil/grit separators) are typically the lowest cost option, given their limited spatial extents and their form as pre-fabricated units. Thus a typical cost of $150,000 has been estimated for incorporation of water quality measures into roadway reconstruction jobs (< 5 ha). Where larger drainage areas are involved (i.e. > 5 ha), more substantial and costly OGS units would be required, and it is suggested a correspondingly higher price ($300,000) be applied accordingly.

As discussed previously, LID BMP costs can vary substantially depending on the approach employed, and the contributing drainage area/area treated. Options would need to be reviewed for each site as part of the design process, given potential constraints with respect to available space, surficial soils and groundwater, sub-surface utilities, and the construction budget. Construction costs could be further reduced from the estimates provided in Table E1 by scoping the LID BMPs to a portion of the contributing area, or by combining LID BMP measures with other engineered or end-of-pipe measures. The "treatment train" approach is generally a preferred approach to include redundancy and resiliency and also increase water quality treatment effectiveness.

PROJECT #1 - SHALLOW CREEK PRELIMINARY COST ESTIMATE (EXCLUDES PED BRIDGE REPLACEMENT)

Item #	Description	Unit	Quantity	Unit Cost	Cost assumption	Total
1	General requirements	LS	1	$300,000	Bonding, mobilization, removals, ESC, dewatering	$300,000
2	Enclosure (3.0 x 2.4 m box)	m	100	$10,000	Double supply, conservative size assumption	$1,000,000
3	Earth Removal	m^3	18,000	$150	Assume non-contaminated material (non-landfill disposal) - additional cost if contaminated	$2,700,000
4	Piping and control structure	LS	1	$100,000	Rough estimate for piping, structures, spillway	$100,000
5	Channel restoration	m	130	$2,000	Higher cost based on grading, landscaping	$260,000
6	Landscaping	LS	1	$100,000	Seeding and plantings	$100,000
					Rounded Sub-Total	**$4,500,000**

Cost estimate is preliminary only - CCA Class D or lower (within 20 to 30% +\-)
Does not include any contingencies or construction observation/contract administration services.
Construction cost estimates will be further refined at detailed design stage.

PROJECT #2 - RAWDON POND RETROFIT PRELIMINARY COST ESTIMATE

Item #	Description	Unit	Quantity	Unit Cost	Cost assumption	Total
1	General requirements	LS	1	$300,000	Bonding, mobilization, removals, ESC, dewatering	$300,000
2	Flow splitter MH	LS	1	$50,000	Assume large diameter with custom splitter	$50,000
3	Diversion sewer	m	200	$1,600	Assume 1200 mm diameter pipe to match existing, 2x supply	$320,000
4	Earth Removal	m^3	23,000	$150	Assume non-contaminated material (non-landfill disposal) - additional cost if contaminated	$3,450,000
5	Retaining wall	m	300	$1,000	Assume some type of engineered system requried	$300,000
6	Outlet control structure	LS	1	$100,000	New connection to Mohawk Canal	$100,000
7	Landscaping	LS	1	$100,000	Seeding and plantings	$100,000
					Rounded Sub-Total	**$4,700,000**

Cost estimate is preliminary only - CCA Class D or lower (within 20 to 30% +\-)
Does not include any contingencies or construction observation/contract administration services.
Construction cost estimates will be further refined at detailed design stage.