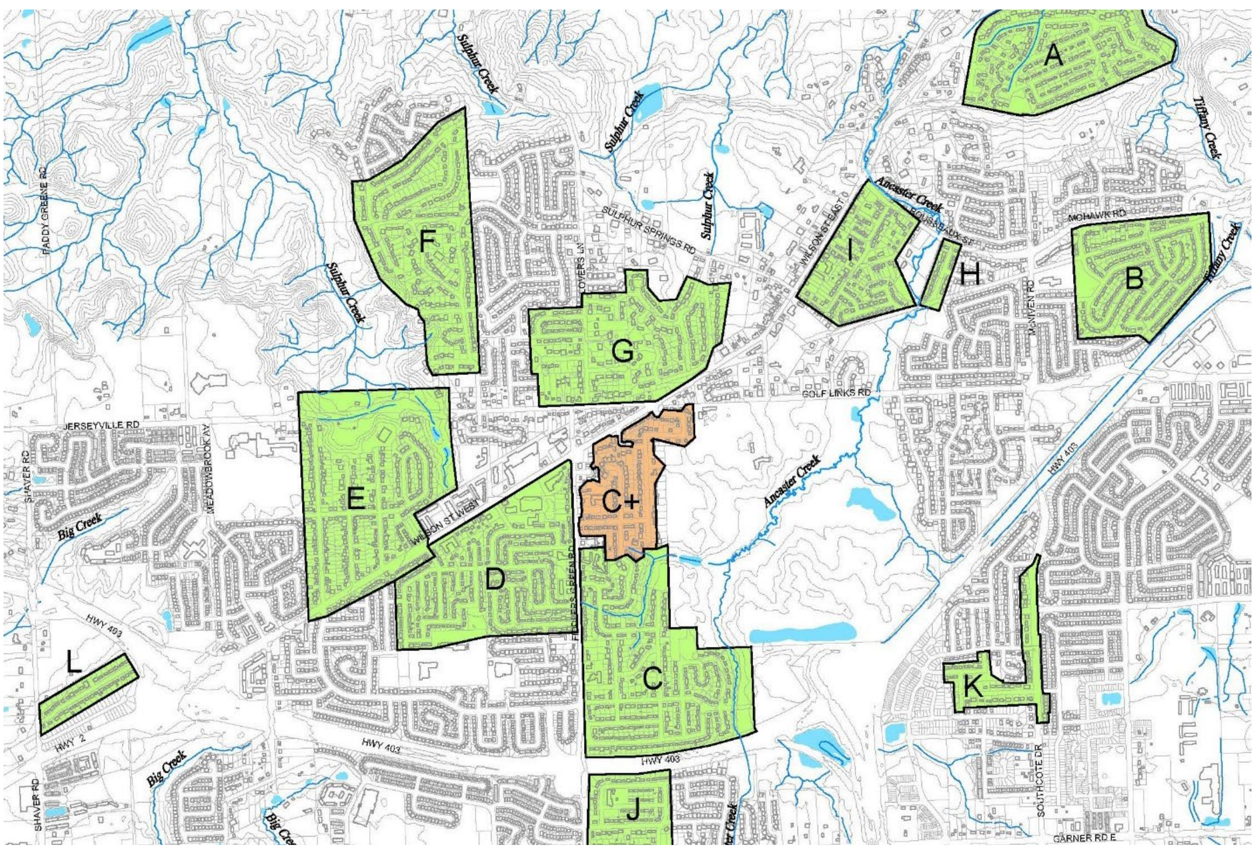
COMMUNITY OF ANCASTER, CITY OF HAMILTON

SUMMARY REPORT (FINAL)

DETAILED DRAINAGE ASSESSMENT STUDY (PHASE 2) OF RURALLY-SERVICED EXISTING RESIDENTIAL NEIGHBOURHOODS

APRIL 06, 2023



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DETAILED DRAINAGE ASSESSMENT STUDY (PHASE 2) OF RURALLY-SERVICED EXISTING RESIDENTIAL NEIGHBOURHOODS

COMMUNITY OF ANCASTER, CITY OF HAMILTON

PROJECT NO.: TPB178165
DATE: APRIL 06, 2023

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SIGNATURES

APPROVED[1] BY

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EXECUTIVE SUMMARY

Problem Statement and Purpose

WSP E&I Canada Limited (WSP; formerly Wood Environment & Infrastructure Solutions Canada Limited) prepared the (Phase 1) "Pilot Study Assessment of Increase in Lot Coverage in Rurally Serviced Roadway Neighbourhoods, Community of Ancaster" (August 2016), which involved an assessment of a Pilot area within the Community of Ancaster, with the objective to analyze and assess the potential for impacts on flooding, and to a lesser extent erosion and water quality. The premise of that study related to the development trends in various high value 'desirable' neighbourhoods across Hamilton, whereby severances and the redevelopment of lots has been leading to increased lot coverage, thereby affecting the performance of existing drainage systems, particularly in those areas serviced by ditches (rural or semi-urban drainage systems). Lands within these areas have seen building coverage shift to the maximum allowable by planning policy (35 %), however notably, this only accounts for the portion of land occupied by the buildings and primary accessories / structures and does not include any other impervious areas, such as driveways, walkways, and patios, which have also seen a trend to significantly increase and thereby further cover lot areas with hard surfaces.

Based upon the assessment of the Pilot Study Area and the analytical modelling conducted, significant potential increases in both peak flows and runoff volumes would be anticipated, depending on the extent of coverage, location within the development area and intensity of the storm.

The current (Phase 2) study constitutes an extension of the Phase 1 study area limits to include all of the Existing Residential (ER) neighbourhoods in the Community of Ancaster with rural drainage servicing (i.e. roadside ditching), related to the Level of Service (LOS) associated with these drainage systems and the expected impacts of re-development/intensification to maximum "as of right" limits. The study has assessed the impacts of re-development and developed a mitigation plan to mitigate these potential impacts, and an associated implementation strategy.

Methodology and Base Findings

A resolute hydrologic-hydraulic model has been developed to represent existing land use conditions and calibrated/validated based on available local flow monitoring data. Under existing conditions, the simulated results indicate that the majority of the existing ditch systems would be capable of conveying the 100-year storm event within the public roadway right-of-way. A baseline with respect to erosion potential and water budget has been established for existing land use conditions. The potential impacts of more formative storm events, both with respect to climate change adjusted rainfall, and recent local extreme storm events, have been assessed accordingly.

Under an assumed build out to the currently permissible limits of development (houses built out to 35% of the available lot area – "as–of right" conditions), impervious surfaces within the study area would be increased, due to increased home areas and associated amenity areas (driveways, patios, etcetera). The overall expected impervious coverage would increase from approximately 41% to 57%, representing 51.0 hectares of additional impervious area in the Ancaster Community study area. As would be expected, the simulated results indicate that this change would result in an increase in peak flows, resulting in decreased ditch conveyance performance, increased peak flows to downstream receivers, increased erosion potential, and an altered water budget for the overall area. As such, a stormwater management strategy was determined to be necessary to mitigate drainage system impacts.

Mitigation Strategy

Based on a review of potential alternatives, the preferred alternative is considered to be the application of source controls on private property. This alternative places the onus for control on the developing property, while allowing the works to be designed and constructed in conjunction with the overall development. The City of Hamilton should however determine a preferred approach to ensure source controls are either implemented on the property title (or on a defined easement) or defined through another legal instrument (such as the Drainage Act). This is necessary to ensure that the City of Hamilton is able to continue to verify that the controls remain in place and are suitably maintained.

Source controls are expected to provide not only primary flood/quantity control benefits, but also ensure adequate control with respect to erosion, water budget, and water quality. The integrated hydrologic-hydraulic modelling has been applied to determine required capture targets for source controls. Based on these analyses, capture depths of 55 – 70 mm of rainfall per impervious hectare (550 – 700 m^3 of runoff per per impervious hectare) are considered necessary to provide control up to, and including, the 100-year storm event. Required targets vary by primary drainage network, reflecting the variability in surficial soils and topography. The simulated results indicate that the preceding source controls would be sufficient to mitigate the expected impacts of full “as of right” development.

In addition to the preceding, the hydrologic-hydraulic modelling has been used to determine the additional potential requirements associated with climate change impacts. An estimated additional 30 – 45 mm of rainfall capture would be required (based on the most formative of the three (3) assessed climate change scenarios) for a total capture target of 90 – 115 mm of rainfall per impervious hectare (900 – 1150 m^3 of runoff per impervious hectare).

In addition to the preceding primary mitigation measures, recommendations for municipal hydraulic structure (culvert) upgrades to address existing drainage system deficiencies has also been undertaken. The analysis has considered minimum depth of cover requirements, to ensure that the proposed culvert upgrades are reasonable and realistic. Based on the completed assessment, a total of five (5) such locations have been identified where upsizing or twinning would be beneficial. A further two (2) locations have been identified where mitigation measures would be beneficial in addressing drainage system deficiencies through private property.

In conjunction with the preceding recommended conveyance improvements, the culvert inventory (completed by others) noted a number of locations where culverts are damaged or obstructed, and require replacement, repair, or clean-out/maintenance. These locations have been identified and summarized as part of the current report.

Implementation

An implementation plan for the preferred solution (private property side source controls) has been developed. In general, site measures should be designed and planned in accordance with the City of Hamilton’s “Comprehensive Development Guidelines and Financial Policies Manual” (2019 or latest revision). In general, preferred measures are considered to include:

- Permeable Pavement (Paving Stones and/or Permeable Surfaces - Driveway Areas)
- Bioretention Areas
- Enhanced Grassed Swales and Bioswales
- Sub-surface infiltration areas (open-bottom chambers, soakaway pits, etcetera)

Notwithstanding the preceding, the City of Hamilton supports the implementation of innovative solutions as required to address specific site conditions and site constraints. The City and Provincial principle of a “treatment train” is also recommended where feasible, which would involve the implementation of more than a single source control measure.

Approvals for developments under this enhanced approach would be generally consistent with the current approach, which involves the submission of a Stormwater Management (SWM) Report, along with other supporting studies (specifically a geotechnical/hydro-geological assessment to confirm specific on-site conditions).

A fundamental consideration associated with implementation will be ensuring that some form of legal instrument is in place to ensure that the source controls remain in place as per the approved plan. As noted previously, this may involve placement on title or an easement, or may involve the application of the Drainage Act. The City of Hamilton should determine the preferred approach and implement any associated policy changes accordingly. Overall, controls located in the front yard areas would generally be preferred for ease of access for inspection and future maintenance works.

A separate review of implementation policies and procedures has been completed as part of this study and included in Appendix F of this document.

Recommendations for improvements/upsizing to existing roadway culverts and locations where culverts would be expected (but not been located) to address identified hydraulic capacity deficiencies have also been made. It is expected that the City of Hamilton will incorporate these proposed works into its long-term capital planning efforts. Where the proposed measures correlate with reported instances of flooding (through the City's Hot Spot Flooding or otherwise), a higher priority should be applied. Notwithstanding, it is expected that culvert replacement works would likely be correlated with overall roadway reconstruction works, depending on the age and condition of the local roadway.

A number of structural culvert deficiencies have also been identified. Where feasible, repairs to address these deficiencies should be implemented by the City's Roads Group should be implemented as soon as possible, particularly if the works can be implemented relatively easily (i.e. flushing). Notwithstanding, where more substantial repairs or replacement are warranted, these works may necessarily be deferred and included as part of capital works (i.e. roadway reconstruction).

Future Study

In addition to the current study, there are a number of potential additional future studies which may be considered by the City of Hamilton, as well as its partners (such as the Hamilton Conservation Authority) associated with the outcomes of this study. Potential additional studies for the study area may include:

— Additional assesssment of potential mitigation measures to address existing drainage system deficiencies, including ditch conveyance improvements (not assessed as part of the current scope), and measures around identified private property drainage features. It is expected that such a study would be connected to future roadway reconstructions.

— In conjunction with the preceding, a review of potential opportunities to implement conveyance controls (i.e. LID BMPs) within the municipal roadway right-of-way to provide quantity, quality and erosion control to downstream receivers.

— Further study of downstream erosion issues, and a strategy with respect to reconstruction/remediation.

— A future Climate Change mitigation/adaptation strategy, including specific recommendations on stormwater management design requirements. A subsequent climate change vulnerability and adaptation strategy could also be considered. It is understood that the City has commenced a climate change study in 2020.

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1 INTRODUCTION

WSP E&I Canada Limited (WSP; formerly Wood Environment & Infrastructure Solutions Canada Limited) prepared the "Pilot Study Assessment of Increase in Lot Coverage in Rurally Serviced Roadway Neighbourhoods, Community of Ancaster" (August 2016), which involved an assessment of a Pilot area within the Community of Ancaster, with the objective to analyze and assess the potential for impacts on flooding, and to a lesser extent erosion and water quality. The premise of that study related to the development trends in various high-value 'desirable' neighbourhoods across Hamilton, whereby severances and the redevelopment of lots has been leading to increased lot coverage, thereby affecting the performance of existing drainage systems, particularly in those areas serviced by ditches (rural or semi-urban drainage systems). Lands within these areas have seen building coverage shift to the maximum allowable by planning policy (35 %), however notably, this only accounts for the portion of land occupied by the buildings and primary accessories / structures and does not include any other impervious areas, such as driveways, walkways, and patios, which have also seen a trend to significantly increase and thereby further cover lot areas with hard surfaces.

Based upon the assessment of the Pilot Study Area and the analytical modelling conducted, significant potential increases in both peak flows and runoff volumes would be anticipated, depending on the extent of coverage, location within the development area and intensity of the storm.

In terms of mitigation, the Pilot Study (Phase 1) examined a number of alternatives, including source controls through Low Impact Development Best Management Practices (LID BMPs) which could be implemented on the individual lots proposing to redevelop or sever. Notwithstanding, other more holistic neighbourhood-based alternatives were also cited, which could be considered at a broader study scale (i.e. upsizing conveyance infrastructure with neighbourhood scale stormwater management).

The study concluded with a number of recommendations which included additional management criteria and exploration of on-lot BMPs, and neighbourhood-based drainage assessments, inspection and maintenance of driveway culverts and the provision of sub-drains for rurally-serviced roadway ditches.

The current (Phase 2) study is intended as an extension of the Phase 1 study area limits to include all of the Existing Residential (ER) neighbourhoods in the Community of Ancaster with rural drainage servicing, related to the Level of Service (LOS) associated with these drainage systems (Refer to Drawing 1 [attached] for an overview of the study area limits) and the expected impacts of re-development to maximum "as of right" limits. The study is intended to similarly assess the impacts of re-development, and develop a mitigation plan to mitigate these potential impacts, and an associated implementation strategy.

2 BACKGROUND INFORMATION REVIEW

The following data have been obtained and reviewed for the purposes of this assessment.

2.1 DRAWINGS

Various engineering drawings have been obtained through the City of Hamilton's online records management platform '*SPIDER*'. Available drawings include plan and profiles for roadway reconstructions, watermain replacement, and stormwater and sanitary as-built drawings within the study area, as well as other supporting drawings for site developments. These drawings have been used to confirm overall drainage pathways or areas where drainage is uncertain. Storm sewer data such as pipe material, geometry, and invert and rim elevations have been obtained from the drawings for input into the PCSWMM model. Drawing information related to roadway, ditch and culvert elevations has generally not been used for detailed analyses, as it is considered that this information is superseded by information from field surveys and available topographic data.

2.2 COUNCIL/CITY DOCUMENTS

City of Hamilton By-Law No. 15-176 (July 10, 2015): The City of Hamilton Council enacted a Site Plan Control Area by-law to restrict development in several areas not included within the current drainage assessment study area. This by-law provides the City the ability to regulate infill developments and the redevelopments within designated areas to mitigate their impact to city owned infrastructure. While this by-law does not prevent developments and re-developments from being constructed in the study area, it does place restrictions on the types of developments permitted and requires City approval prior to commencing activities to ensure developments meet the by-law requirements.

City of Hamilton By-Law No. 18-104 (April 25, 2018): The City of Hamilton Council amended the Site Plan Control Areas, By-Law 15-176, to include thirteen (13) new areas for Site Plan Control pertaining to existing residential (ER) zoned lands. They have been identified as Schedules C1 to C13. The By-Law applies to any single detached, duplex, or semi-detached dwelling as well as accessory buildings, structures, decks, and additions in Schedules 1-13. This indicates that the properties within these schedules are subject to the development restrictions which are effective as of April 26, 2018. However, properties which had submitted building permits prior to this date are not subject to the By-Law.

City of Hamilton By-Law No. 19-026 (December 19, 2018): The City of Hamilton Council amended By-Law 18-104 to add clarifications regarding buildings and structures affected by the by-law, including new buildings, alterations or additions, accessory buildings, and lot coverage (i.e. where coverage exceeds 35%).

Hot Spot Flooding (October 11, 2018): Spreadsheet documenting the service calls received by City staff to respond to incidences of flooding throughout the City of Hamilton. Pertinent information includes ditch and culvert flooding within Ward 12 which incorporates the study area. Each call is logged with a date, time, and property initiating the call. The corresponding geospatial information (mapping) has also been received from the City and is used in the assessment.

Ward 12 History of New Construction, Demolition, and Additions (June 2018): Spreadsheets containing the properties within Ward 12 which have obtained permits for structural demolition, new construction, or adding a structural addition to their property. The records provided by the City of Hamilton range in date from 2001 to 2018, however WSP has been advised by City staff that these records may not be complete. The properties subject to demolition, new construction, or additions are identified by their property address and several City property and project identification numbers, and has been linked to a geospatial mapping data layer.

City of Hamilton 2018 – Capital Works Forecast: The City of Hamilton's 2018 budget identifies various capital works/projects forecasted for 2019 to 2027. The forecast for Ward 12 has been reviewed to determine if any of the forecasted works overlap with this project's study area; thus, presenting opportunities for greater synergy if remedial measures or drainage system improvements are recommended for areas where reconstruction works are already planned. Based on this review, it has been identified that in 2021 works are forecasted for Mohawk Road between Highway 403 and McNiven Avenue. This section of Mohawk Road borders study area 'B' (refer to Drawing 1). The forecasted works on Mohawk Road may present an opportunity to incorporate works recommended by this assessment for study area 'B'. No other planned reconstruction projects within the study area limits have been identified at this time.

2.3 REPORTS

Master Drainage Plan, Town of Ancaster (Philips Planning and Engineering Limited, November 1987): Philips Planning and Engineering Limited was retained by the Town of Ancaster and the Hamilton Region Conservation Authority to address existing and future SWM concerns and co-ordinate future development from a drainage perspective within the Municipality. A hydrologic model (OTTHYMO) and hydraulic model (HEC-2) were created for the Ancaster and Tiffany Creeks which were used to assess the drainage impacts of urbanization and to develop SWM recommendations.

Ancaster/Sulphur Creek Floodline Mapping Study (R.V. Anderson Associates Limited, March 1990): R.V. Anderson Associates Ltd was retained by the Town of Ancaster to review and develop floodline mapping for portions of Ancaster and Sulphur Creeks. Two (2) reports were prepared for the study; a Technical Report discussed the hydraulic analysis, production of the topographic mapping and described the Regulatory Flood Plain, while the General Report discusses the Study results and the extent of the Regulatory Flood Plain. A HEC-2 hydraulic model was developed for the study which used existing and future conditions peak flow rates from the Spencer Creek Watershed Hydrology Study by MacLaren Plansearch (Lavalin), 1990. The study concludes that for the study area, 45 buildings would be inundated during the Regulatory event while 27 buildings would be flooded during the 100-year storm event.

Tiffany Creek Subwatershed Plan (Hamilton Region Conservation Authority, July 2000): The subwatershed study was undertaken by the Hamilton Region Conservation Authority to develop multiple management strategies, including those for natural areas, water quality and quantity, and management of proposed development. Multiple recommendations were made to protect the natural environment in the watershed.

Garner Neighbourhood Master Drainage Plan Class Environmental Assessment (Philips Engineering Ltd, October 2006): The MDP was originally completed in 1996, and subsequently updated in September 2005 and finalized in October 2006. The report determines the preferred solution of stormwater management for the area to mitigate the impacts for planned future development, including considerations of flooding, erosion, and water quality.

Crestview Avenue Drainage Review: Final Report, City of Hamilton (Dillon Consulting Limited, Nov 2006): Dillon Consulting Ltd. was retained by the City of Hamilton to conduct a review of the existing drainage pattern in the area of Crestview Avenue and Colleen Street, Ancaster. The review was initiated in response to erosion concerns identified in the rear yard of 200 Crestview Ave. The report assessed several alternatives aimed at mitigating the erosion concerns. Alternative 3 (Re-route Drainage) was the alternative recommended by the assessment. This alternative proposed the re-construction of an existing storm sewer with limited capacity (1:2 year) and the construction of a new overland flow route on the City's lands.

Ancaster Creek Su***bwatershed – Stewardship Action Plan (Hamilton Conservation Authority, Apr 2008):*** The HCA produced this document to outline the status of the natural features in the watershed and provide recommendations to mitigate and restore the natural environment to a healthy state.

Crestview Avenue Drainage Study: Memo, City of Hamilton (Dillon Consulting Limited, Sept 2017): This memo built upon the previous study (ref. Crestview Avenue Drainage Review: Final Report, Dillon Consulting Ltd. Nov 2006), documented the examination of additional alternatives and expanded the study to a broader area. The memo identified next steps and summarized discussions between the owners of 200 Crestview Ave. and the City. The memo also included an analysis of rainfall data for the study area.

Geotechnical Reports: Various Areas and Dates (LandTek, Terraprobe, etc.): Various geotechnical reports have been provided by the City of Hamilton for the various rurally serviced areas. These reports have been selectively verified against overall surficial soils mapping; this is discussed further within this report.

Planning and Economic Development SWM/Subwatershed Reports: Numerous technical reports, such as functional servicing reports and SWM briefs, have been provided by the City of Hamilton for various private developments or redevelopments in the study area. These technical reports outline the SWM criteria for each site and typically provide the mitigation strategy and the post to pre-development flow rates for the sites. A directory spreadsheet of SWM reports has also been provided by the City which indicates forty-nine (49) SWM reports for the study area, of which eighteen (18) have been provided to WSP, while the remainder have been identified as either not found or not submitted.

Ecology Information: HCA provided ecological information pertaining to the study area which partially or wholly falls into five (5) Natural Areas Inventory regions. All of the contributing drainage areas convey flow to cool water streams which support salmonids as identified on a plan provided by the HCA as well as listed in an ExcelTM spreadsheet.

Mineral Springs Dam Assessment and Remediation Reports: Four (4) reports have been provided pertaining to the Mineral Springs Dam assessment and remediation; Mineral Springs Dam Natural Heritage and Ecology Report (HCA, November 2010), Sulphur Creek Fluvial Geomorphological Assessment Final Report (Parish Geomorphic, December 2010), Mineral Springs Dam Structural Assessment (Hatch, December 2010), Mineral Springs Dam Remediation, Design and Hydrologic Modelling Report (Water's Edge Environmental Solutions, February 2015). The Natural Heritage and Ecology Report, Structural Assessment, and the Fluvial Geomorphological Assessment Report were completed in support of the remediation report to mitigate the potential for flow blockage and repair damage from previous overtopping. Ultimately, a 1 m riser was recommended at the inlet to the culvert in the dam and the downstream embankment was to be protected with riprap.

2.4 GIS AND MAPPING DATA

The City of Hamilton, Grand River Conservation Authority (GRCA), Hamilton Conservation Authority (HCA), and the Ministry of Natural Resources and Forestry (MNRF), have provided GIS data for use in this study area. The following summarizes the data received, which has been reviewed accordingly:

- Existing elevation contour data (1.0 metre intervals), which is understood was interpreted from a 2010 DTM, cropped to the study area (provided by: City of Hamilton, October 2017)

- Grand River Conservation Authority Mapping, inclusive of: Regulation limits, groundwater discharge areas, Regulatory Floodplain, vulnerable aquifers, significant groundwater recharge areas, well head protection areas, watershed boundaries, wetland mapping, river mapping and water body mapping (GRCA, September 2017)
- Ministry of Natural Resources and Forestry Mapping, inclusive of: Areas of Natural and Scientific Interest, Wetlands, Southern Ontario Land Classification System mapping, Natural Resources and Values Information System mapping (provided by: MNRF, October 2017)
- Hamilton Conservation Authority Mapping, inclusive of: Regulation limits, regulatory floodplain mapping, river mapping and water body mapping (HCA, October 2017)
- Polygons containing surficial soils data for the City of Hamilton, cropped to the study area (City of Hamilton, October 2017)
- Polygon Areas representing tree canopy coverage, cropped to the study area (City of Hamilton, October 2017)
- Property Parcel Mapping, cropped to the study area (City of Hamilton, October 2017)
- Building Footprints Mapping, cropped to the study area (City of Hamilton, provided for the Phase 1 - Pilot Study [2010])
- Roadway Mapping, cropped to the study area (provided by: City of Hamilton, October 2017)
- Existing, and Official Plan Land Use Mapping, cropped to the study area (provided by: City of Hamilton, October 2017)
- Culvert Mapping, cropped to the study area (provided by: City of Hamilton, October 2017)
- Storm sewer, maintenance hole and catch basin mapping, cropped to the study area (provided by: City of Hamilton, October 2017)
- SWM Facility Mapping (provided by the City of Hamilton, October 2017)
- Aerial Photography for the City of Hamilton (provided by: City of Hamilton, December 2017)
- Hamilton Public Works capital projects line shapefile, cropped to the study area (provided by: City of Hamilton, June 2018)
- Hamilton Public Works capital projects point shapefile, cropped to the study area (provided by: City of Hamilton, June 2018)
- Severance and Building Permit Data extracted from the City's AMANDA database, cropped to the study area and also provided as Excel spreadsheets for properties applying for additions, demolitions, and new construction (provided by: City of Hamilton, June 2018)
- Floodline mapping shapefile for portions of Ancaster Creek and Tiffany Creek (provided by HCA)

A topographic survey of City culverts and other significant culverts (those in critical locations or where a significant upstream storage area results) was undertaken by MCHKTH Surveying Ltd (subsidiary of J.D. Barnes Limited). A total of 155 culverts were surveyed as part of this effort. These data have been provided to WSP to support the development of the hydraulic routing portion of the proposed modelling. A review of the data, and implications to hydraulic modelling, is discussed further in subsequent sections.

As noted above, the City of Hamilton has provided 1 m contour data (ref. City of Hamilton 2010). In addition, the City subsequently provided higher resolution LiDAR data (July 11, 2018) obtained from the Hamilton Conservation Authority. It is understood that these data are the raw (unprocessed) data from the Southwestern Ontario Orthophotography Project (SWOOP) via Land Information Ontario (LIO). In addition to this, WSP obtained the processed DEM data (2 m horizontal resolution) from the SWOOP program. This DEM used a "steam rolling" algorithm to reduce the raised surface features from the Raw LAS dataset. These datasets have been applied for the current study.

3 BASE HYDROLOGIC AND HYDRAULIC MODEL SETUP

3.1 AREA OVERVIEW

3.1.1 STUDY AREA LIMITS

The general rurally serviced drainage neighbourhood areas identified for this study have been depicted in Drawing 1. Actual catchment areas differ slightly from the general neighbourhood limits, and are presented in Drawing 2. The focus of the current study is on areas zoned "Existing Residential" (ER) by the City of Hamilton (refer to Location Map included in Appendix C), specifically those with rural drainage servicing (i.e. roadside ditching). The Phase 1 Pilot (August 2016) previously identified a total of eight (8) different distinct rurally serviced areas (A through G and area C+). Ultimately, Area C+ was selected as the candidate area for the previous assessment. Based on a subsequent review for the current study, additional rurally serviced areas have been identified.

A summary of the rurally serviced areas and their approximate extents is provided in Table 3.1. Thirteen (13) separate rurally serviced areas (A to L) have been delineated, totalling an area of 326.30 ha (this summation excludes the Pilot Study Area, C+). This includes five (5) previously unidentified areas (Areas H, I, J, K, and L) totalling an additional 44.36 ha. All the identified areas include "hybrid" servicing with the exception of areas J, and L, namely areas with rurally serviced (ditched) roadways which include some storm sewer collection systems. The storm sewers have not been found throughout each identified area, but rather in isolated locations, often in areas where there is not a suitable outlet for the stormwater runoff or where standing water would likely occur without the storm sewer. To distinguish between a storm sewer and a culvert for establishing hybrid networks, a culvert has been defined as a single run pipe, typically without bends or multiple catch basins. While a storm sewer has been defined as a series of consecutive pipes or confluences with subsurface bends or multiple catch basins.

Although included in Table 3.1, it is noted that Area C+ was previously evaluated by the Precursor / Pilot Study (August 2016), as such the area will not be re-evaluated in the current study.

The existing residential rurally serviced area at Holstein Drive and Elm Hill Boulevard, south of Golf Links Road, between the Hamilton Golf and Country Club and Southcote Road (Pinecrest Neighbourhood), has been excluded from this study. The 16.9 ha (+/-) hybrid area is serviced with storm sewers throughout and therefore did not meet the criteria for the study, given the areas selected for the study only have limited storm sewers. Other smaller areas were also excluded for similar reasons, including the area west of Southcote Road and south of Highway 403, north of John Frederick Drive (Harmony Hall II Neighbourhood), which contains an extensive network of storm sewers, beyond the preceding criteria for inclusion in the current study.

Table 3.1. Ancaster Rurally Serviced Areas Summary

AREA ID	AREA SIZE (ha)
A	50.02
B	29.67
C	35.99
C+	19.91
D	38.89
E	31.45
F	46.05
G	49.87
H	4.05
I	13.42
J	10.84
K	13.52
L	2.53
Total	326.30[1]

[1] This summation of the area (326.30 ha) excludes the C+ Pilot Study area (19.91 ha)

3.1.2 OVERALL DRAINAGE AREAS

A review of the rurally serviced areas' drainage features has been advanced, in order to develop overall subcatchment boundary plans (ref. Drawing 2). The subcatchment boundaries have been derived through a review of the topographic data provided by the City of Hamilton (1 m interval contours), as well as a review of record drawings, reports, aerial imagery, GoogleTM Maps (Street View), as well as additional field reconnaissance (as described in Section 3.3.1). A total of fifty-four (54) drainage basins have been identified within the twelve (12) rurally serviced areas being assessed for this study. The size of the sub-basins, as well as a short description of each basin's outlet is provided in Table 3.2. An overall plan of the identified drainage basins has been prepared (ref. Drawing 2, attached).

Another consultant (AECOM) has been retained by the City to develop a hydrologic/hydraulic model of the urban storm sewer serviced areas of Ancaster. The modelling is being completed using a more resolute "all pipes" model, similar to previously completed studies for the communities of Dundas and Stoney Creek. The drainage boundaries for the two studies have been reviewed and edited by both parties to limit the study overlap. Based on discussions with City staff, it is understood that the most recent revision/iteration (comments/comparisons from AECOM of September 17, 2018 in response to WSP's supplied boundaries of August 17, 2018) is considered to be acceptable, with negligible differences between the two.

Table 3.2. Ancaster Rurally Serviced Areas Summary

AREA ID	SUB AREA ID	DRAINAGE AREA (ha)	OUTLET DESCRIPTION
A	A1	8.35	Flows to a 600-mm dia. sewer on Eleanor Pl. which discharges to ditching on the south side of Wilson St. E, contributes to Ancaster Creek.
	A2	21.35	Flows overland toward ditching on the south side of Wilson St. E., contributes to Ancaster Creek.
	A3	0.22	Flows overland toward ditching on the south side of Wilson St. E., contributes to Tiffany Creek.

AREA ID	SUB AREA ID	DRAINAGE AREA (ha)	OUTLET DESCRIPTION
	A4	14.20	Flows overland toward ditching on the south side of Wilson St. E., contributes to Tiffany Creek.
	A5[1]	2.57	Flows overland toward ditching on the south side of Wilson St. E., contributes to Ancaster Creek.
	A6	3.34	Discharges to a 375 mm dia. sewer north of Stonegate Dr., major and minor outlets to ditching on Eleanor Dr., flows northerly to Ancaster Creek.
B	B1	2.24	Discharges to a 525 mm dia. sewer on Tuscarora Dr. contributes to Ancaster Creek.
	B2	9.96	Discharges to ditching on the north side of Highway 403, contributes to Tiffany Creek
	B3	1.51	Discharges through private property to a 525 mm dia. sewer east of McNiven Rd, south of Mohawk Rd. Contributes to Ancaster Creek.
	B4	2.83	Discharges to 675 mm dia. sewer on Mohawk Rd., flows north toward Ancaster Heights, contributes to Tiffany Creek.
	B5	9.71	Discharges to 450 mm dia. sewer, flows north toward catchment B4 prior to entering the 975 mm dia. sewer, contributes to Tiffany Creek
	B6[2]	3.01	Major-minor split. Discharges to a 450 mm dia. sewer and stormwater management facility east of Oneida Boulevard, south of Seneca Drive, and contributes to Tiffany Creek. The major system is conveyed overland to the Oneida Boulevard east ditch, north of Seneca Drive, sub-area B2.
	B7	0.41	Discharges to ditching on the north side of Highway 403, contributes to Tiffany Creek.
C	C1	10.52	Flows overland toward Ancaster Creek.
	C2[3]	11.75	Discharges to a 600 mm dia. storm sewer on Hatton Drive and contributes to Ancaster Creek. Major system flows overland to Ancaster Creek. Overland flow during less frequent storm events conveyed between houses on Hatton Drive to ditching on the north side of Highway 403, to Ancaster Creek.
	C3	3.62	Flows overland and through a 450 mm dia. storm sewer toward Ancaster Creek.
	C4[4]	4.34	Flows overland toward Ancaster Creek.
	C5[5]	2.13	Flows overland toward Ancaster Creek.
	C6	3.63	Flows overland toward Ancaster Creek.
D	D1	15.56	Discharges to a 750 mm dia. sewer on Seminole Rd. and flows northerly toward Sulphur Creek. This catchment is included within the GRCA boundary; however, the runoff is conveyed to HCA jurisdiction.
	D2	22.00	Crosses via culvert under Fiddler's Green Rd. and flows overland toward Ancaster Creek.
	D3	1.33	Discharges to a 675 mm dia. storm sewer on Todd Street toward Sulphur Creek
E	E1	0.95	Flows overland toward Sulphur Creek.
	E2	3.72	Flows overland toward Sulphur Creek.
	E3	0.89	Flows overland toward Sulphur Creek.
	E4	2.39	Flows overland toward Sulphur Creek.

AREA ID	SUB AREA ID	DRAINAGE AREA (ha)	OUTLET DESCRIPTION
	E5	1.09	Flows overland toward Sulphur Creek.
	E6	1.05	Flows overland toward Sulphur Creek.
	E7	21.35	Discharges to a 525 mm dia. sewer east side of Wilson St. W. which outlets to ditching on the north side of Highway 403 before contributing to a tributary of Big Creek (GRCA).
F	F1[7]	9.96	Flows overland toward Sulphur Creek. Minor system near the intersection of Brookview Court and Summerdale Place is conveyed to sub-area F5
	F2	11.28	Flows overland toward Sulphur Creek.
	F3	1.64	Flows overland toward Sulphur Creek.
	F4	18.08	Flows overland toward Sulphur Creek.
	F5	5.10	Minor/Major Split, the major system is conveyed to Sub area F1, while the minor system is conveyed to a SWM facility west of Sulphur Springs Road and Woodview Crescent. Both systems flow toward Sulphur Creek
G	G1	3.26	Discharges to 375 mm dia. sewer on McGregor Crescent. Flows northerly toward Sulphur Creek.
	G2	0.24	Discharges to ditch conveyed into Postlawn Park. Flows southerly toward Sulphur Creek.
	G3	13.27	Discharges to 375 mm dia. sewer on Lover's Ln. Flows northerly toward Sulphur Creek.
	G4	19.89	A catch basin on the west side of Mansfield Drive conveys flow to the 900 mm dia. pipe/culvert on the east side of the road, while excess flow not captured by the culvert is conveyed to a 525 mm dia. culvert which is also conveyed under Sulphur Springs Rd. Both the 525 mm dia. culvert and the 900 mm dia. culvert convey flow to Sulphur Creek.
	G5	7.26	Discharges to 600 mm dia. sewer on Mansfield Dr. flows northerly toward Sulphur Creek.
	G6	5.96	Discharges to two (2) catch basins at a sag in the road on Judith Crescent, south of Maureen Avenue. Outlet of the storm sewer has been assumed to be to the ditch on the west side of Mansfield Drive, north of Judith Crescent, in sub-area G4. The major system outlet would spill north toward Harrington Place if sufficient ponding were to occur at the sag in the road on Judith Crescent. There is no formal/appropriate major overland outlet as confirmed during site inspection.
H	H1	5.74	Discharges to 600 mm dia. sewer on Lowden Ave. Flows westerly toward Ancaster Creek.
I	I1	1.31	Flows overland toward Ancaster Creek.
	I2	1.70	Flows overland toward Ancaster Creek.
	I3	4.13	Discharges to 300 mm dia. sewer on Lodor St. Flows northerly toward Ancaster Creek.
	I4	6.27	Discharges to 300 mm dia. sewer on Rousseaux St. Flows northerly to Ancaster Creek.
J	J1	3.86	Discharges to sub-area J2. Flows easterly toward Ancaster Creek.
	J2	6.14	Discharges to 600 mm dia. sewer on Garden Ave. Flows easterly toward Ancaster Creek.

AREA ID	SUB AREA ID	DRAINAGE AREA (ha)	OUTLET DESCRIPTION
	J3	0.85	Flows to ditching on the east side of Fiddler's Green Rd. Flows conveyed southerly toward a tributary of Big Creek.
K	K1	0.56	Discharges to 300 mm dia. sewer on Southcote Rd. flows easterly to SWM pond west of John Frederick Dr. and outlets to a tributary of Ancaster Creek. Major-minor split (subcatchment S2_K1) from private property.
	K2	3.95	Discharges to 300 mm dia. sewer at Calder St. flows northerly toward Tiffany Creek.
	K3	6.03	Discharges to a 750 mm diam. sewer north of Gregorio Ave., flows southerly towards SWM pond west of John Frederick Dr. and outlets to a tributary of Ancaster Creek.
	K4	1.50	Discharges to 750 mm dia. sewer on Southcote Rd., flows northerly to Tiffany Creek. Major-minor split (subcatchments S3_K4 and S4_K4) from private property.
	K5	1.48	Discharges to 525 mm dia. sewer on Anna Lee Dr. flows southerly to SWM pond west of John Frederick Dr. and outlets to a tributary of Ancaster Creek.
L	L1	2.53	Discharges to rurally serviced Shaver Rd. Also discharges via overland flow through easement; both outlets conveyed to northerly to Big Creek.

Notes:
[1] A sub-area had been identified as A5 in Technical Memorandum 1 (TM1) on the east side of the intersection of Montgomery Drive and Bishop Place. However, during detailed analysis, it has been found the drainage from sub-area A5 is conveyed to sub-area A4 and is not a separate sub-area.
[2] A sub-area had been identified as B6 in TM1 on Cayuga Avenue, on the south side of Hiawatha Boulevard. However, during site reconnaissance, it was noticed the overland flow is conveyed to sub-area B3 and is not a separate sub-area.
[3] Sub-area C2 has been created from sub-areas C2 and C4 identified in TM1.
[4] Sub-area C4 has been created from a portion of subarea C1 and all sub-area C5 identified in TM1.
[5] Sub-area C5 had not been previously identified in TM1.
[6] Sub-area D3 at Fiddler's Green Road and Amberly Boulevard has been removed from the PCSWMM model and subsequent drawings as per City of Hamilton comments (ref. Seradj-Senior, October 26, 2018).
[7] Sub-area F1 has been created from sub-areas F1 and F6 identified in TM1.

To summarize, twenty-seven (27) of the rurally serviced areas drain to an open channel or open watercourse feature, twenty-four (24) rurally serviced areas are conveyed to a storm sewer system, and six (6) have major/minor splits. These six (6) major-minor splits do not include the previously identified sub area D3, located at Fiddler's Green Road and Amberly Boulevard. Based on a review of the information provided, no urban/sewer serviced areas have been identified as contributing directly to the rural drainage systems assessed for this study, with the exception of sub-areas A6 and G6. A number of major/minor split areas have been identified, where overland flow during formative storm events may enter the rurally-serviced drainage area. Consideration of these areas is required as part of the hydrologic modelling.

3.2 HYDROLOGIC MODELLING

As noted, the current (Phase 2) study is intended as an expansion of the Phase 1 pilot study area limits to include all of the Existing Residential (ER) neighbourhoods in the Community of Ancaster with rural drainage servicing. As noted in Section 3.1.1, this excludes two (2) primary areas with rural drainage servicing (ditching), as these areas also have extensive or near complete storm sewer networks rather than localized storm sewers, which was considered still suitable for inclusion in the current study. The excluded areas include the Pinecrest Neighbourhood (Holstein Drive area) and the Harmony Hall II Neighbourhood (north of John Frederick Drive).

In general, the modelling methodology applied for the Phase 1 component of this study has been applied for the Phase 2 assessment to maintain overall consistency. The integrated hydrologic/hydraulic modelling program PCSWMM has been used for this assessment, consistent with the approach applied for Phase 1. PCSWMM provides a graphical user interface (GUI) and decision support system in conjunction with the EPA-approved SWMM engine which integrates both hydrology and hydraulics. PCSWMM can be used to effectively consider aspects such as infiltration, impervious coverage, roadside ditch conveyance/storage, and also support the evaluation of potential Low Impact Development/Source Control BMPs.

A review of hydrologic modelling considerations and parameters is outlined further within the sub-sections which follows.

3.2.1 SUBCATCHMENT DELINEATION (PRIMARY STUDY AREA)

WSP had initially considered the application of a higher resolution LiDAR data set for subcatchment delineation, which was provided by the City of Hamilton through the Hamilton Conservation Authority. These datasets are understood to be the raw LiDAR data from the 2015 SWOOP program. Notwithstanding, this raw data are not classified, meaning the elevations within the data set are not separated according to the surface elevation type (tree canopy, ground, roof of building). Therefore, the data would not have been reliable to use for delineating the subcatchments, as the data set would have produced inaccurate results. Based on the preceding, the processed 2 m resolution Digital Elevation Model (DEM) from the same 2015 SWOOP program has been applied for the delineation of refined subcatchment boundaries.

PCSWMM’s automated watershed delineation tool has been applied for initial boundary determination based on the preceding DEM. The boundaries have been reviewed and refined based on aerial imagery, field reconnaissance, and Google Street ViewTM to ensure the boundaries are reasonable. Additional information has also been applied for boundary verifications, including record drawings and field reconnaissance, as well as dialogue with other consultants involved with parallel studies within the area (AECOM, who is completing an “all pipes” storm sewer model of the urban serviced area of the Community of Ancaster).

The initial coarse subcatchment boundaries (refer to Drawing 2 and Section 3.1.2) have been further refined to those presented in Drawings S4-S11, which presents the detailed sub-catchment boundaries for each of the sub-areas. Drawing 3 presents an overall index of the sub-areas. The developed subcatchment boundaries are more discrete than previously anticipated, with an average area of 0.43 ha (+/-) for a total of 764 subcatchments; in TM1 WSP had estimated an average area of 0.64 ha (+/-) to be consistent with the Phase 1 pilot study, which would have resulted in a total of 500 subcatchments.

Based on subsequent discussions with City staff (November 1, 2018), separate subcatchments are required for external areas in order to quantify overall impacts to downstream receivers (not presented in Drawings S4-S11). The delineation of these external areas is described further in Section 3.2.5.

3.2.2 RAINFALL ABSTRACTIONS

Consistent with the approach applied for the Phase 1 Study (August 2016) and as discussed with City staff (November 1, 2018), the SCS Curve Number infiltration methodology has been used for the simulation of infiltration for pervious areas. Impervious areas are represented separately.

Surficial soils mapping has been provided by the City of Hamilton, in conjunction with a large number of past geotechnical investigations from the study area. The soils mapping provided by the City has been compared to the Ontario Base Soils Mapping (OBSM) (ref. Soil Survey Report 32 – Soils of Hamilton-Wentworth to verify that the datasets are consistent. In order to further validate the surficial soils mapping, the data have been compared to selected borehole log data from several geotechnical reports; the results of this comparison are presented in Table 3.3 and Drawing 15 (attached).

Table 3.3. Comparison of Geotechnical Reports to City of Hamilton Soils Mapping

GEOTECHNICAL REPORTS DATA				CITY OF HAMILTON SOILS MAPPING (2010)
AUTHOR / REPORT - DESCRIPTION	BOREHOLE ID.	DEPTH (mbg)	SOIL DESCRIPTION	
Sutton & Associates Montgomery Drive Borehole 1, May 25, 2004.	A1	0.4 - 2.3	Silt, trace clay, trace weathered shale, trace gravel, moist (Possible Fill)	ACE – Ancaster Silt (Hyd. Grp. C)
Sutton & Associates Montgomery Drive Borehole 3, May 25, 2004.	A2	0.5 - 1.5	Silt, trace clay, trace weathered shale, trace gravel, wet (Possible Fill)	ACE - Ancaster Silt (Hyd. Grp. C)
Landtek Limited Algonquin Avenue Borehole 1, February 29, 2000.	B1	2.0 - 3.5 [1]	Silt with fine sand, very moist to wet below 2.7 m.	ACE – Ancaster Silt (Hyd. Grp. C)
Soil-Mat Fiddlers Greed Rd (285-293) Borehole 2, May 31, 2013.	C1	0.75 – 6.75	Sand, with traces of to some Silt, traces of Clay. Silty Sand deposit at the 3.0 m depth.	SRI – Springvale Sandy Loam (Hyd. Grp. B)
Peto MacCallum Ltd. Jerseyville Road Borehole 2, Aug 15, 1979	E1	1.3’ – 10’	Fine Sandy Silt: Brown, Compact, damp.	BRT – Brant Silt (Hyd. Grp. B)
Terraprobe (993024) Terrence Park Dr. Borehole 13, April 22, 1999	F1	0.45 – 2.2	Silt: trace sand trace gravel.	SRI – Springvale Sandy Loam (Hyd. Grp. B)

Note: [1] The soil stratum above 2.0 m below ground was identified as a layer of fill, and hence has not been used as a reference for this comparison.

Based on the initial comparison, it is considered that the surficial soils mapping is reasonably consistent with the more resolute geotechnical borehole data. As such, it is suggested that these data can reasonably be applied to establish SCS Soil Classification and associated SCS Curve Numbers, in combination with land use coverage information.

The soil composition within the study area varies, including various series of silt, sandy loams, silty clays, and loams. The soil types within the Study Area, as well as their reference soil type and hydrologic soil group (as per MTO Chart BA-1) are summarized in Table 3.4. As evident, SCS Soil classifications vary notably over the study area, from more permeable A class soils to low permeability D class soils.

Table 3.4. Study Area Soil Types per City of Hamilton OMAFRA Soils Mapping Data

SOIL TYPE	REF. SOIL TYPE	PARENT MATERIAL[1]	SOIL MOISTURE	REF. HYDRO. SOIL GROUP
URBAN	-	-	-	C[3]
ALBERTON - SICL	Silty Clay loam, over clay	Silt clay loam over clay	Variable	D[1]
ALBERTON - SIL	Silt loam	Silt loam over clay	Variable	C[1]
ANCASTER	Silt clay loam	Silt clay loam till	Well Drained	C
BEVERLY	Silt loam	Lacustrine silty clay loam and silty clay	Imperfectly Drained	C
BRANT	Silt loam	Water deposited silt loam and fine sandy loam	Well Drained	B
BRANTFORD	Silt loam	Lacustrine silty clay loam and silty clay	Well Drained	C
COLWOOD	Silt loam	Water deposited silt loam and fine sandy loam	Poorly Drained	C
ESCARPMENT	-	-	-	C[1]
FLAMBORO	Sandy Loam	Water deposited medium and fine sand	Poorly Drained	C
GRIMSBY	Sandy Loam	Water deposited medium and fine sand	Well Drained	AB
MUCK	Organic	-	Poorly Drained	D[1]
ONEIDA	Loam	Clay loam till	Well Drained	C
RAVINE	-	-	-	C[1]
SPRINGVALE	Sandy Loam	Sand over outwash gravel	Well Drained	AB
STREAM COURSE	-	-	-	D[1]
TOLEDO - SICL	Silty Clay loam	Lacustrine silty clay loam and silty clay	Poorly Drained	D
TOLEDO - SIL	Silt Loam	Lacustrine silty clay loam and silty clay	Poorly Drained	D
TUSCOLA	Silt Loam	Water deposited silt loam and fine sandy loam	Imperfectly Drained	B
VINELAND	Sandy Loam	Water deposited find and medium sand	Imperfectly Drained	B

Notes: [1] The soil stratum above 2.0 m below ground was identified as a layer of fill, thus only the native soils below this layer have been applied.
[2] Parent Material is per the Ontario Base Soils Mapping (OBSM) (ref. Soil Survey Report 32 – Soils of Hamilton-Wentworth)
[3] The SCS soil group for these soil types has been assumed, as no data were provided. Assumptions are based upon the USCS soil classification and are considered conservative.

Following the development of the refined subcatchment boundaries (Section 3.2.1), the surficial soil mapping has been reviewed to confirm coverage. Based on this review, eleven (11) of the twenty (20) soil types identified within the study area were not found within the drainage boundaries; the remaining nine (9) soil types used for the subcatchment soil classification have been highlighted in Table 2.3. An area weighting approach has been used to determine the proportion of each SCS Soil Type within the subcatchment. A summary of the estimated soil composition by primary drainage network is presented in Table 3.5, which demonstrates that 58 % of the study area has been identified as a more permeable AB type soil, while 41 % of the study area is indicated as a less permeable C type soil. Areas with Type B and Type D soils represent a minor portion of the overall study area.

Table 3.5. Soil Composition by Network (ha)

NETWORK	AB	B	C	D	TOTAL AREA (ha)
A			50.02		50.02
B			29.67		29.67
C	34.64		1.35		35.99
D	38.79	0.1			38.89
E	31.45				31.45
F	23.72		22.33		46.05
G	37.05		12.82		49.87
H			2.23	1.82	4.05
I			13.42		13.42
J	10.85				10.85
K	9.3	3.68	0.54		13.52
L	2.53				2.53
Total	188.33	3.78	132.38	1.82	326.31
Total (%)	57.72	1.16	40.57	0.56	100.00

Representative SCS Curve Numbers (CNs) for pervious areas have been determined based on the hydrologic soil group of each identified soil type and associated surface cover. Two ground cover classes have been applied based on a review of available aerial imagery for the study area. Given the predominantly residential zoning of the study area, the *good condition grass cover* has been primarily applied given the prevalence of well-maintained or mowed residential lawns. Wooded areas have also been identified in Networks A and G at the escarpment brow and near the intersection of Sulphur Springs Road and Mansfield Drive respectively, which necessitated a separate category for *good condition woods*. Assumed SCS CN values for the various pervious ground cover and hydrologic soil groupings are presented in Table 3.6. Values are consistent with those provided in the US SCS "Urban Hydrology for Small Watersheds" (Technical Release 55, 2nd Edition, June 1986).

Table 3.6. Hydrologic SCS Soil Group Curve Numbers

HYDROLOGIC SOIL GROUP	GOOD CONDITION GRASS COVER	GOOD CONDITION WOODS
AB	50	42.5
B	61	55
C	74	70
D	80	77

3.2.3 LAND USE COVER

Given the number of modelled subcatchments for the study area (764, as per Section 3.2.1), manual determination of total and directly connected imperviousness for each subcatchment is considered inefficient. As discussed with City staff (August 15, 2018 conference call), WSP's preferred approach is to develop a representative GIS-based layer of land use, which can in turn be used to calculate and update associated values of subcatchment imperviousness based on area-weighting tools.

The land use mapping layer developed for this study has been developed based on the City provided zoning, building, road parcel, and property parcel GIS layers, and aerial imagery. A number of existing features have been extracted from available GIS data as part of this effort, with a primary focus on the core existing residential land use area. In these areas, building envelopes (roofs) have been specified based on mapping from the City of Hamilton, using aerial photography to identify any required updates. In addition, the roadway right-of-way has been classified separately based on property limits data. The balance of the area for the primary existing rurally-serviced residential areas represents greenspace (lawns), and amenity areas (driveways, patios, etcetera). Other, separate land uses have also been accounted for (i.e. parks, commercial/industrial or high-density residential areas).

Based on the aerial photography and the property parcel GIS layer, a minimum of five (5) representative residential properties have been identified for each network (A-L) and a total of 109 properties for measurement of the amenity areas within the private property boundaries of the Existing Residential (ER) zone. Features measured included driveways, patios, walkways, sheds, and pools. The measurement values have been summed and divided by the total private lot area of the measured properties, not including the buildings, which have been accounted for separately. This resulted in an average amenity imperviousness of 23.8%. The buildings in the ER zone have not been measured but rather extracted from the City provided GIS layer as noted, and assigned an imperviousness of 100%. Only the buildings within the ER zone have been extracted in this manner; buildings in other land use areas have been incorporated into the overall imperviousness value. This alternative approach for the ER zone has been applied in order to simplify the calculations for the subsequent as-of-right scenario. It should be noted that some sheds or minor external structures have been observed within the ER zone in the building GIS layer, however the majority are not accounted in the GIS layer and therefore the amenity area measurements have not been revised to exclude these features.

One (1) representative road right-of-way (ROW) section of 50 m in length has been measured in each primary drainage network using aerial imagery and the property limit data. The measurements therefore include not only the roadway surface, but driveway entrances located within the ROW. Based on these measurements, an average imperviousness of 52.9 % has been determined for the ROW.

Less common areas, such as institutional, commercial, and parks and open spaces have applied more typical values (based on WSP's previous experience with respect to drainage plans and subwatershed studies) as these areas constitute less than 10% of the overall study area.

A summary of assumed and measured imperviousness values for the different land use types/zones applied in the current study is presented in Table 3.7 while the land use types/zones within the study area are presented in Drawing 17.

As a precaution to ensure the accuracy of the calibration process and the modelling results, selected zones have been reviewed for a more representative imperviousness based on available aerial imagery such as the Deferred Development zones, Institutional zones, and the Public zones. These zones are not common throughout the study area and it has been considered unrealistic to apply a higher imperviousness value to a zone located in one area that was not reflective of a similar zone in an alternate location.

Table 3.7. Assumed Land Use Types and Imperviousness Values Used for the Study Area

LAND USE TYPE/ZONE	IMPERVIOUSNESS (%)	TOTAL AREA (ha)	PROPORTION OF STUDY AREA (%)	SOURCE
Commercial	100.00	1.06	0.32	Assumed
Conservation Hazard	5.00	13.73	4.21	Assumed
Deferred Development	33.77	4.10	1.26	Measured
Deferred Development (Commercial)	50	0.10	0.03	Assumed
Deferred Development (Open Space)	20	3.02	0.93	Assumed
Existing Residential - Amenity Areas	23.79	144.81	44.39	Measured
Existing Residential – Houses/Rooftops	100.00	36.79	11.28	Assumed
Institutional (Cemetery)	10.00	0.03	0.01	Assumed
Institutional (High Impervious)	75.00	2.17	0.67	Assumed
Institutional (Open Space)	10.00	1.29	0.40	Assumed
Open Space	5.00	0.55	0.17	Assumed
Park	10.00	5.16	1.58	Assumed
Public (Parking Lot)	75.00	0.11	0.03	Assumed
Public (Open Space)	10.00	0.19	0.06	Assumed
Residential 1	34.31	4.40	1.35	Measured
Residential 2	40.83	11.24	3.45	Measured
Residential 3	51.20	14.27	4.37	Measured
Residential 4	65.84	3.04	0.93	Measured
Residential Multiple 1	42.73	0.10	0.03	Measured
Residential Multiple 3	57.67	1.08	0.33	Measured
Residential Multiple 4	75.00	0.15	0.05	Assumed
Residential Multiple 6	80.00	0.35	0.11	Assumed
Roadway Right-of-Way (ROW)	52.89	77.62	23.79	Measured
Village Area	100.00	0.87	0.27	Assumed

The additional residential zones presented in Table 3.7 are located within the study area and are described as follows (ref. By-law No. 87-57 The Zoning By-Law of the Town of Ancaster):

— Residential 1, 2, 3, and 4 zones are single detached homes, with variation in the lot size amongst other set back and yard by-law specifications.

— Residential Multiple 1 zones are semi-detached homes

— Residential Multiple 3 and 4 zones are townhouses with variation in density

— Residential Multiple 6 zones are apartment buildings

Using an area-weighting approach, the assigned impervious values presented in Table 3.7 and the associated land use mapping layer developed by WSP have been applied to calculate the resulting imperviousness value under existing conditions for each subcatchment. Detailed subcatchment parameterization tables are included in Appendix B, C, and D.

It has been noted that given the rurally-serviced nature of the study area's drainage system, there theoretically is no directly connected imperviousness (i.e. no continuous impervious pathway to the outlet). However, due to sediment deposition and long-term compaction in ditches and other factors, it is expected that there is a degree of directly connected imperviousness. PCSWMM provides the option to route some percentage of the impervious land segment across the pervious land segment (rather than directly to an outlet) to account for this. This mechanism has been reviewed further as part of the hydrologic model calibration, described further in Section 4.

3.2.4 OTHER HYDROLOGIC PARAMETERS

Other parameters relevant to the integrated hydrologic modelling include overland flow length, watershed slope, Manning's Roughness Coefficients for overland flow, and depression storage.

In the PCSWMM (and EPA-SWMM) methodology, overland flow length is applied represent internal routing within the subcatchment which affects the time of concentration. Based on WSP's previous experience, for resolute subcatchment sizes (average drainage area of 0.43 ha +/- for the current study), simulated peak flow is much less sensitive to variations in this parameter as compared to other model parameters. Given the small subcatchment areas, the overland flow length has been directly measured as the sheet flow length (i.e. back of the property line to the roadway) consistent with the approach applied in the Phase 1 Pilot study. The overland flow length has been rounded to the nearest 5 m interval. In addition, subcatchments of a similar size and shape have applied the same flow length.

A typically constructed lot slope for residential subcatchments of 2% has been applied for subcatchments within the study area as a default value. Slopes have been revised however in identified steep drainage areas primarily in the vicinity of the Niagara Escarpment. This includes areas in Network A, and areas near the Dundas Valley Conservation Area (Networks F and G). Slope measurements have been obtained and applied to the subcatchments in these areas as necessary.

From WSP's experience, simulated peak flow and runoff are generally insensitive to changes in the other noted hydrologic parameters (Manning's Roughness Coefficients and Depression Storage). For the purposes of base model development typical parameters (as applied by WSP for other hydrologic models within the City of Hamilton) have been applied. The initial parameter values are shown in Table 3.8.

Table 3.8. PCSWMM Subcatchment Hydrologic Parameters

SUBCATCHMENT PARAMETER	INITIAL VALUE
Flow Length (m)	As Measured
Slope (%)	2% or As Measured (steep areas)
Manning's Roughness - Impervious	0.013
Manning's Roughness - Pervious	0.25
Depression Storage - Impervious (mm)	1
Depression Storage - Pervious (mm)	5
Subarea Routing (%)	40

Sub-area routing defines the percentage of the modelled impervious land segment which is routed across the pervious land segment, as noted in Section 3.2.3. An initial estimated value of 40% has been assumed in this case based on WSP's experience with other modelling studies.

3.2.5 EXTERNAL AREAS AND WATERSHED IMPACT ASSESSMENT

As part of the current study, the potential peak flow rate and erosions threshold impacts to downstream receivers from changes in land use is to be assessed. Based upon a review of the study area limits (ref. Drawing 1 and 2), the primary areas of concern are those areas draining to the Ancaster Creek system (Hamilton Conservation Authority) watershed, given that the majority of the study area falls within HCA jurisdiction, and impacts would be expected to be greatest to these receivers. There is a much more limited contributing drainage area to the Big Creek watershed within the Grand River Conservation Authority's (GRCA's) jurisdiction. Further, based on discussions with Grand River Conservation Authority (GRCA) staff, there are limited hydrologic and hydraulic modelling files available for the receivers in that case (Big Creek). As such, the focus of the impact assessment is upon those areas draining to the HCA's jurisdiction.

The hydrologic impact assessment will review the change in peak flow rate from existing conditions to as-of-right land use conditions as well as the change in the duration of flows exceeding the erosion threshold at selected locations of interest on Sulphur Creek, Ancaster Creek, and Tiffany Creek. In order to estimate the potential hydrologic impacts to receivers and downstream areas, a reasonable representation of these features is required to account for timing and flow addition. Several options to account for these external areas in the Ancaster Creek system have been considered:

— Discount external areas, and focus on impacts directly at modelled outlets
— Assess hydrologic impacts for major storm events only, and utilize a pro-rating or scaled approach to the previously simulated hydrographs from existing modelling
— Integrate lumped catchment areas for additional watershed areas into the PCSWMM modelling to assess impacts in a more integrated manner

The third option of integrating the lumped catchments in the PCSWMM model has been identified as the preferred approach, given the associated benefits to modelling efficiency. Based on discussions with City staff (November 1, 2018) this approach has been confirmed as the preferred alternative. It should be clearly understood that this is a "relative modelling" approach, given that the current study is essentially combining two (2) separate models for the purposes of the current assessment. Given the scope and purpose of the current study, this approach is considered the most reasonable of the potential approaches. Notwithstanding, this limitation should be clearly understood when interpreting subsequent modelling results and analyses.

The development of the external area subcatchments has been based upon the QUALHYMO modelling developed as part of "Spencer Creek Watershed Hydrology Study" (MacLaren Plansearch, 1990). This study completed a continuous simulation and frequency analysis under both Existing and Future Land Use conditions for the Spencer Creek and Cootes Paradise Watershed, which includes the Ancaster Creek subwatershed. In addition to the continuous simulation modelling, the Regional Storm event was also simulated. For simplicity in comparing the original QUALHYMO modelling results to the re-created PCSWMM modelling, the Regional Storm event has been applied as the point of comparison.

The subcatchments contributing to Tiffany, Ancaster and Sulphur Creeks in relation to the study area have been digitized from the subcatchment boundary plan provided in the Spencer Creek Hydrology Study report. The external downstream location to which the pertinent rurally serviced study areas contribute is Node 167 from the Spencer Creek Hydrology Study, which has been renamed as AC-22 on Drawing 16. This location is the most downstream confluence of the contributing rurally serviced areas conveyed to Spencer Creek. As such, all the contributing catchments to this location from the Spencer Creek Hydrology study have been included. The routing elements (channel cross-sections and length) have been extracted from the QUALHYMO modelling files in addition to the subcatchments.

Imperviousness has been directly obtained from the QUALHYMO model based on the reported values under the "Future Land Use" assessment, as this condition better represents the current level of urban development within the contributing areas, as opposed to the Existing Conditions assessment, given the vintage of the report (1990). Overall however, the intent of the current study is to assess the specific impacts from land uses changes within the study area, with the external areas held constant in all subsequent scenarios. Thus, the exact land use values for external areas are likely less critical in this case; however, it is again considered that the "Future Land Use" values are likely more representative of current conditions for external areas than (then) "Existing Land Use" values, and have been applied accordingly.

The impervious values for the catchments have been assigned as reported in the Spencer Creek Hydrology study and have not been altered. Additional required subcatchment parameters for PCSWMM, such as Manning's roughness coefficient and depression storage, have applied typical default parameters as per study area subcatchments (refer to Table 3.8). The average slope for each subcatchment has been estimated from available contour data.

The original QUALHYMO modelling employed the US SCS Curve Number methodology for infiltration, consistent with the proposed approach for the study area (ref. Section 3.2.2). Notwithstanding, the US SCS Curve Number methodology is only intended for single rainfall event simulations. Although EPA-SWMM (and PCSWMM) include a "drying time" parameter to allow for the recovery of infiltration capacity when using the SCS CN methodology, this is an approximate method only. Further, there is a known limitation to incorporating the SCS Curve Number methodology in SWMM for continuous simulations where larger values of depression storage are incorporated, as is expected to be the case for the analysis of potential mitigation measures in the Ancaster Community study area. Applying a larger depression storage for a subcatchment in EPA-SWMM where the SCS CN infiltration methodology is employed during a continuous simulation causes that component of the subcatchment element to eventually not infiltrate.

[NOTE: It is understood that the computational issue in question occurred due to a change in version 5.0.022 of the EPA-SWMM computational engine (and thus all subsequent versions). The Curve Number infiltration calculation was modified to include only direct precipitation, and not run-on flow (i.e. routed flow from other subcatchments) or internally routed flow (i.e. routed flow from the impervious component of the subcatchment to the pervious component). Given the nature of the study area (rurally-serviced, or ditched areas), and the need to assess LID BMP elements in future scenarios, both of these conditions would be expected to occur. Within the EPA-SWMM engine calculations, as depression storage is increased, the effective infiltration rate (calculated as a modified Curve Number based on direct precipitation only) more quickly trends towards zero. The infiltration rate at the end of the previous precipitation event is used for subsequent precipitation events. The infiltration rate remains at zero and does not reset to the full infiltration potential during subsequent precipitation events in the continuous simulation. Ultimately, infiltration ceases, and all the precipitation becomes runoff for the remainder of the continuous simulation. The application of the drying time and evaporation data for the continuous simulation do not mitigate this calculation issue.]

The preceding issue is unique to the SCS Curve Number infiltration methodology; it does not occur for other available infiltration routines within EPA-SWMM (i.e. Horton's Equation and Green & Ampt). Given the noted limitation with the SCS Curve Number approach, specifically for continuous simulation (water budget and erosion analyses), a secondary version of the base modelling, which uses an alternative infiltration methodology has been considered necessary. The Green & Ampt infiltration methodology has thus been selected accordingly, as this methodology is considered more appropriate for continuous simulation than the other potential methodologies available in EPA-SWMM (Horton's equation, which only recovers infiltrative capacity through an approximate "drying time" parameter similar to the SCS CN approach).

The Green & Ampt infiltration methodology employs three (3) user input parameters (ref. Table 3.9) to simulate the infiltrative capacity of the surficial soil.

Table 3.9. Green & Ampt Infiltration Parameter Summary

PARAMETER	DESCRIPTION	UNITS
Suction Head	Soil capillary suction at the wetting front	mm
Hydraulic Conductivity	The rate of movement in which a fluid (water) can be conveyed through the pore spaces in a soil	mm/hr
Initial Moisture Deficit	The fraction of soil that is initially dry	Unitless

The base values used for each of these parameters have been selected based on the soil classification as identified from available surficial soils mapping (ref. Drawing 15). The corresponding Green & Ampt soil parameters sourced from Handbook of Hydrology (D.R. Maidment, 1993) provided in Table 3.10 have been applied to the soils within the study area. Area weighting has been used for each parameter where multiple soil classification types were located within one subcatchment. These values have also been further validated as part of the model calibration/validation effort; this is discussed further in Section 4.4.

Table 3.10. Green & Ampt Infiltration Parameters

USDA SOIL TEXTURE CLASSIFICATION	SOIL TYPE NAME	SUCTION HEAD (mm)	HYDRAULIC CONDUCTIVITY (mm/hr)	INITIAL MOISTURE DEFICIT (-)
Sandy Loam	Grimsby and Springvale	110.1	21.8	0.358
Loam	Oneida	88.9	13.2	0.346
Silt Loam	Alberton-Sil, Brant, Colwood, Ravine, and Toledo-Sil	166.8	6.8	0.368
Silty Clay Loam	Ancaster	273.0	2.0	0.263

The most critical parameter with respect to replicating the originally reported QUALHYMO peak flow results in PCSWMM is the subcatchment flow length. Given the large area of the external area subcatchments, the overland flow length parameter cannot be directly measured as it becomes an empirical value, which must represent other internal subcatchment flow routing processes. As an initial estimate, subcatchment flow lengths in PCSWMM have been estimated as the total watershed (channel) length, with values ranging between 1.0 km and 3.4 km. In order to ensure reasonable results, these base subcatchment flow lengths have been adjusted through an iterative process to produce close agreement in the generated peak flows for the Regional Storm Event. Beginning with the most upstream reporting nodes, the flow length of the subcatchments contributing to that flow node have been adjusted uniformly by a set factor until the resulting Regional Storm Event flow reasonably matches the reported value from the original QUALHYMO modelling. This process has been completed for each reporting node within the Tiffany, Ancaster and Sulphur Creek drainage areas. Simulated peak flow results are presented in Table 3.11.

Table 3.11. Comparison of Simulated Regional Storm Flows for Nodes of Interest

REPORTING NODE[1] (2019)	CREEK SYSTEM	ORIGINALLY REPORTED FLOW – QUALHYMO[1] (m^3/s)	UNADJUSTED PCSWMM[2] FLOW (m^3/s)	DIFFERENCE TO ORIGINAL (%)	ADJUSTED PCSWMM[2] FLOW (m^3/s)	DIFFERENCE (%)
149 (SC-08)	Sulphur Creek	78.6	62.25	-21	77.3	-2
162 (TC-03)	Tiffany Creek	47.9	33.28	-31	47.45	-1
163 (TC-05)	Tiffany Creek	60.4	40.18	-33	55.84	-8
155 (AC-08)	Ancaster Creek	27.4	8.59	-69	27.37	0
158 (AC-10)	Ancaster Creek	46.3	16.84	-64	45.44	-2
159 (AC-15)	Ancaster Creek	52.6	21.63	-59	51.35	-2
167 (AC-22)	Ancaster Creek	257.3	174.4	-32	257.4	0

Note: [1] As per Spencer Creek Watershed Hydrology Study" (MacLaren Plansearch, 1990) – SCS CN
[2] Updated modelling using Green & Ampt methodology for infiltration

As evident from the results presented in Table 3.11, through iterative adjustments to the subcatchment flow length parameter, the simulated peak flow results more closely replicate the previously reported values, with adjusted peak flows differences of 8% or less. Subcatchment flow lengths have been reduced in order to increase peak flows; adjusted values are between 9 and 46% of the original high-level estimated values.

The use of the Green & Ampt infiltration methodology may impact the results generated for more frequent storm events in comparison to the SCS CN methodology due to the limited validation to the Spencer Creek Study; the Regional Storm peak flow rates at the identified locations are the only means of model validation for the external drainage area model. Ideally peak flow rates generated for more frequent storm events would be applied for further validation, however no such detailed results are available.

Following the generation of a base replicated hydrologic model for Ancaster Creek in PCSWMM, the large-scale subcatchment boundaries have been adjusted in order to incorporate the more resolute study area models (Area A – L). The subcatchment flow lengths have been reduced proportionally to the reduction in drainage area. Further edits to the external subcatchment parameters have not been made, other than drainage area. Overall network peak flows using the primary SCS Curve Number infiltration methodology and those using Green & Ampt (for continuous simulation modelling assessment of water budget and erosion) has been undertaken as part of the model calibration/validation effort, as described in Section 4.4.

3.2.6 STORMWATER MANAGEMENT FACILITIES

Upon further discussion with the City and review of the study area, four (4) stormwater management facilities (SWMFs) have been included in the model development. One (1) SWMF, servicing Network H, has been included in the primary modelling (i.e. for primary study area), as the SWMF contributes to the storm sewer along Cedar Grove Court which has the potential to impact the ditch performance within this network. The remaining three (3) SWMFs have only been included in the External Areas model (i.e. to assess resulting impacts to downstream areas beyond the study area), as these are outlets of a portion of the Rurally Serviced areas; hence these will influence the impact assessment of downstream features in these areas.

The sources of the contributing drainage areas, storage capacities and discharge relationships for each of the SWMFs have been taken from the original SWM reports, as available from the City, or have been supplemented by information found in the "Physical Inventory of Stormwater Management Ponds", completed by Aquafor Beech in July 2005, as part of the Stormwater Master Plan for the City of Hamilton.

Details regarding the SWMFs included in the models have been summarized in Table 3.12 below.

Table 3.12. City of Hamilton Stormwater Management Facilities Input into the PCSWMM Model

CITY POND ID	NETWORK AREA	INFORMATION SOURCE	MODEL	ADDITIONAL NOTES
Pond #7	H	Physical Inventory of Stormwater Management Ponds – Aquafor Beech (July 2005)	Rurally Serviced & External Areas	Located south of Cedar Grove Court. Receives external and rear yard drainage and outlets to the 525 mm storm on Cedar Grove Court. Contributes to Ancaster Creek.
Pond #18	B	SWM Report – Mohawk Meadows Addition – A.J. Clarke and Associates Ltd. (June 1987)	External Areas	Located south of Oneida Blvd. Receives minor system flows from area B6. Contributes to Tiffany Creek.
Pond #22	G	SWM Report – The Enclave – A.J. Clarke and Associates Ltd. (April 1997)	External Areas	Located north of Harrington Place. Receives spill flows from G6 (Judith Crescent). Contributes to Sulphur Creek.
Pond #23W	F/G	SWM Report – Ward Estates – A.J. Clarke and Associates Ltd. (August 2000)	External Areas	Located on Woodview Crescent, receives major/minor system flows from F1, F2, F5, G1, and G3. Contributes to Sulphur Creek.

3.3 HYDRAULIC MODELLING

3.3.1 OPEN CHANNEL ELEMENTS

A detailed field reconnaissance has been conducted to identify and classify the study area's drainage features. The field reconnaissance has included field truthing the drainage pathways identified by topographic mapping and record drawings. The field reconnaissance has also been used to review and categorize approximate drainage features sizes, and to verify the presence and size of certain culverts and sewers. A number of the drainage features have been field-measured, with the data used to develop a typical drainage feature section classification system. In addition to the field-measured classification system, scoped survey data (J.D. Barnes Limited, August and September 2018) have been provided by the City of Hamilton for twelve (12) cross sections within the study area (ref. Drawing 12; cross-section locations are indicated on Drawings D4 to D11).

The preceding data have been used to categorize drainage features into the following five (5) section types. The five categories have been described as:

Type 'A' - Poorly Defined

Type 'B' - Shallow Swale

Type 'C' - Medium Swale

Type 'D' - Large Swale

Type 'E' - Large Ditch

Typical sections assigned to each drainage feature type are depicted in Drawing 13 (attached). Photographs of example drainage features which correspond to each type, are also included in Drawing 14 (attached). Assigned ditch classifications for the study area are presented in Drawings D4 to D11.

An analysis of the surveyed ditch cross sections (ref. Drawing 12) has been undertaken to estimate a standard ROW geometry (ref. Table 3.13) for local roadways, as measured from the surveyed centreline of the ditch to the adjacent private property line, using the City's property parcel GIS data. The roadway width for these types of roadways has been assumed to be relatively consistent, thus the focus has been upon the areas beyond the primary roadway width. Wider roadway sections have been assessed separately.

Table 3.13. Measured Distance from Property Line to Centre Line of Ditch (m)

SURVEY SECTION	ROAD	LEFT SIDE OF SURVEY SECTION	RIGHT SIDE OF SURVEY SECTION
A-A	Central Drive	5.33	5.23
B-B	Seminole Road	4.85	5.22
C-C	Fallingbrook Drive	3.57	4.00
D-D	Lloyminn Avenue	4.13	N/A
E-E	Lovers Lane	4.21	3.79
F-F	Mansfield Drive	7.97	N/A
G-G	Cumin Court	4.71	5.13
H-H	Fiddler's Green Road	4.28	6.36
I-I	Robina Road	5.45	4.93
J-J	Massey Drive	10.14	2.69
K-K	Algonquin Avenue	5.00	4.93
L-L	Miller Drive	3.56	1.26
Average		4.85	

The surveyed centerline of the ditch has been assumed to be the lowest surveyed elevation on each side of the road. The average distance of all the measurements is 4.85 m (+/-). However, a reduced standard right-of-way (ROW) ditch distance of 4.0 m from the centreline of the ditch to the property line has been applied for the typical ditch sections in order to conservatively account for sections with lower values. This distance has been applied as a conservative approach to represent the geometry of the ditches within the standard ROW width given the variation of the property lines throughout the study area.

Two (2) survey sections indicate values notably greater than the average; the left side of Mansfield Drive (Section F-F) and the left side of Massey Drive (Section J-J). These larger values on one side are balanced by reduced values on the other side (unbalanced roadways), thus the previously noted average value is considered reasonable.

The majority of the roads within the study area have a standard 20 m (+/-) ROW as measured from property line to property line on either side of the roads in the City of Hamilton's property fabric mapping data. However, four (4) streets have been identified within the study area where the 20 m (+/-) ROW is not applicable (ref. Table 3.14) and the standard 4.0 m distance from the centerline of the ditch to the property line is also not likely applicable.

Table 3.14. Summary of Roads with a Non-Standard Right-of-Way Width within the Study Area

NETWORK	STREET NAME	RIGHT-OF-WAY WIDTH (m)
A	Massey Drive	26
D	Fiddler's Green Road	32
E	Wilson Street	26
K	Southcote Road	32

The Massey Drive ROW is 26 m (+/-) wide however it is not evenly distributed on either side of the road as demonstrated from surveyed cross section J-J in Table 3.13. The west side of the road has a greater distance from the centerline of the ditch to the property line than the east side of the road. While Fiddler's Green Road has a 32 m ROW width, the paved road surface is actually wider than a standard two-lane ROW road surface which makes this ROW wider. The measured distances from the centerline of the ditch to the property lines for Fiddler's Green Road, provided in Table 3.13 (ref. Section H-H), are similar to the average measurement. The Wilson Street ROW does not have ditches that have been modelled for this assessment; portions of networks D and E outlet to the Wilson Street major and minor systems. Southcote Road in Network K is similar to Massey Drive in that the ROW is not evenly distributed on either side of the road; the distance from the centerline of the ditch on the east side of Southcote Road to the property line is greater than the distance on the west side of the road.

Overall, it is considered that there are very few locations (as per Table 3.14) with larger ROW widths, and of those locations, not all would impact modelling results (i.e. Wilson Street, which does not include roadside ditches within the study limits). Based on the preceding, and to maintain consistency within the modelling, the previously noted typical ditch section width has been maintained throughout.

Ditch invert elevations have been determined based on a hierarchy of best available information. Where data are available from the topographic survey (either culvert invert information on ditch cross-section), this information is considered to be the most accurate. Where this information is not available, DEM data (as described in previous sections) have been employed. Ditch profiles have necessarily been reviewed for reasonableness in the profile; where issues have been noted (potentially due to the differing data sources), information from the as-built drawings (from SPIDER) has been used to validate and confirm grades.

Ditch sections on either side of the road have been modelled separately, to the connection point at the roadway centreline. The separate ditch sections have been linked in order to account for spills across the roadway centreline using weirs or rectangular spill conduits.

A typical urban street (curb and gutter) cross section has been used throughout the PCSWMM model where existing urban streets have been identified to contribute major system flow conveyance to the rurally serviced areas. The typical cross section has been input into the model based on aerial imagery and property parcel measurements of Stonegate Drive (ref. Table 3.15). This typical urban cross section has been applied to similar urban streets such as Brookview Court, Woodland Drive, and Oneida Boulevard amongst others, as these streets have similar cross-sectional dimensions. Standard assumptions have been made regarding the curb height, road cross fall, and the ROW bank slope; these values are commonly used in standard urban road design. It is understood that not all urban roads have the same dimensions; the application of these sections is to provide major system flow conveyance to, or from, the rurally serviced areas and their performance will not be explicitly assessed as part of this study.

Table 3.15. Summary of Typical Urban Street Dimensions and Roughness

URBAN STREET PARAMETER	DIMENSION	MANNING'S ROUGHNESS
Street Width Between Curbs (m)	8.5	-
Curb Height (m)	0.15	-
Road Cross Slope (%)	2.0	0.014
Right-of-Way Width (m)	23.5	-
Right-of-Way Bank Slope (%)	2.0	0.04

3.3.2 CULVERT DATA AND MODELLING APPROACH

As per the approved scope of work, individual driveway culverts have not been included in the modelling. Municipal (City) culvert crossings and key culverts (those in critical locations or where a significant upstream storage area results) have been included based on the received survey data.

It is noted that the impact of storage behind driveway culverts can potentially be incorporated into the modelling, based on an assessment of the influence of existing cross-sections, and the ponding depth (and associated storage volume) associated with the hydraulic capacity (depth-discharge) of a typical driveway culvert. This information would then be used to develop a hydraulically “equivalent” ditch section for each different ditch classification. Notwithstanding, for the purposes of the current assessment, it has been proposed to implement open channel sections based on the classifications previously noted, and to not directly reflect the impacts of driveway culverts. This proposed approach has been confirmed based on subsequent discussions with City staff (November 1, 2018).

The focus of the current modelling effort has therefore been on municipal (City-owned) culverts. The municipal culverts have been classified into three (3) categories pertaining to the condition assessment:

- Blocked
- Crushed
- Functional

The three (3) classification categories have been assigned to simplify the categorization of culverts based on the completed field reconnaissance. A blocked culvert refers to sediment (buried or partially sedimented) or debris which was found to be impeding stormwater flow conveyance at either end of the culvert and could be causing a partial or complete blockage of the culvert. A crushed culvert refers to damage at either end of the culvert which would prevent complete or partial stormwater flow conveyance through the culvert. A good or functional culvert implies that the condition of the culvert is not impeding hydraulic flow conveyance through the culvert. Similar to the culvert condition, the condition of storm sewer inlet pipes has also been assessed. Storm sewer inlets are pipes that resemble culverts in that their upstream end is an open pipe that collects and conveys ditched storm water, however in these cases the downstream end is enclosed (connected to a storm sewer).

Culvert classifications based on the preceding classification system are presented in Drawings C4 to C11 (attached). A summary of assessed culvert condition is presented in Table 3.16.

Table 3.16. Culvert and Storm Inlet Condition Summary

NETWORK	CULVERT				STORM - INLET PIPE			
	BLOCKED	CRUSHED	FUNCTIONAL	TOTAL	BLOCKED	CRUSHED	FUNCTIONAL	TOTAL
A	1	4	15	20	0	0	10	10
B	0	1	12	13	0	1	3	4
C	0	4	14	18	0	0	1	1
D	1	10	14	25	1	0	0	1
E	5	2	6	13	0	0	0	0
F	0	2	10	12	0	0	3	3
G	2	3	6	11	0	0	2	2
H	0	0	0	0	0	0	1	1
I	1	3	3	7	0	0	1	1
J	0	4	1	5	0	1	0	1
K	0	2	4	6	0	2	1	3
L	1	1	0	2	0	0	0	0
Total	11	36	85	132	1	4	22	27

During the hydrologic/hydraulic model development process, several culverts (which were not previously identified or included in the original survey of 155 culverts) have been identified using various sources, including aerial imagery, GoogleTM Street View, and subsequent site reconnaissance. Additionally, several culverts have been reclassified as storm sewers (ref. Section 3.3.3) as these pipes meet the definition of a storm sewer; series of consecutive pipes or confluences with bends or multiple catch basins. The summary presented in Table 3.16 and in Drawings C4 to C11 reflect these additional identified culverts. An appropriate overland flow conveyance element (spill over the road) has been included in the modelling to account for the expected roadway overtopping, based upon the findings of this subsequent field assessment. Culverts that have been identified following the completion of the survey field work have been assigned an elevation obtained from the available DEM GIS data or from drawings obtained from the SPIDER Database.

For culverts which have been noted as “blocked” or “crushed” in Table 3.16 (i.e. “buried”, “partially sedimented”, or “damaged” from survey), for the simulation of the primary modelling scenarios (Existing Conditions and Future “as of right”), the culverts have been modelled assuming the culverts are in a functional, unimpeded condition (i.e. culverts are modelled as having the full conveyance area available). However as discussed with City Staff (November 1, 2018), it has been agreed that such culverts in the vicinity to the monitoring locations should be modelled as per their field observed condition for the calibration/validation process to more accurately represent conveyance constraints and associated storage/attenuation impacts.

3.3.3 STORM SEWERS AND URBAN DRAINAGE

Although the current study area is primarily comprised of rural drainage systems (roadside ditches), several catchments are considered “hybrid” areas, due to the presence of localized storm sewers and catch basins. These features, where present, have been included in the PCSWMM modelling.

Furthermore, certain rurally-serviced areas also receive major system flows from adjacent areas with urban drainage systems (curb/gutter and storm sewer). Where present, these areas have also been incorporated into the model to account for major system flows. Where storm sewer systems are required but were not included in the previously completed topographic survey, available record drawings provided by the City (SPIDER Database) have been employed to provide the necessary model parameters (pipe size, material, elevations, etcetera). Where necessary, other data have been estimated using other sources, including DEM data and field reconnaissance. Approximately 7,500 m (+/-) of storm sewer in such areas has been included in the models accordingly. All storm sewer locations included in the PCSWMM model have been identified in Table 3.17 (ref. drawings C4-C11), including modelled storm sewers that commence at the study area limits and are part of a larger storm sewer network. The total length of storm sewers and storm inlet pipes in each network has been provided in Table 3.18.

Table 3.17. Summary of Storm Sewers Located within the Study Area

NETWORK	STORM SEWER LOCATION	TOTAL SYSTEM LENGTH (m)	TOTAL NETWORK LENGTH (m)
A	Massey Drive from Alexander Road to Montgomery Drive	501	1,367
	Bailey Avenue from Alexander Road to Montgomery Drive	372	
	Stonegate Drive down the escarpment to English Place	373	
	Intersection of Eleanor Place and Montgomery Drive to the outlet at Wilson Street	121	
B	Oneida Boulevard from the west end of Seneca Drive to Oneida Boulevard	106	974
	Oneida Boulevard from Onondaga Drive to a SWM facility	418	
	Iroquois Avenue and Algonquin Avenue to Hiawatha Boulevard through private property to Mohawk Road and to Highvalley Road	450	
C	Hatton Drive from Enmore Avenue to the south end of Woodworth Drive	460	497
	Woodworth Drive to the outlet at Ancaster Creek	37	
D	Seminole Road from Nakoma Road to Wilson Street (commencement of larger storm sewer system)	143	232
	Todd Street to Wilson Street (commencement of larger storm sewer system)	88	
E	Outlets at Wilson Street storm sewer (commencement of larger storm sewer system)	370	380
	Orchard Drive, north of Taylor Road	10	
F	Brookview Court to Woodland Drive and to the SWM facility at Woodview Crescent and Sulphur Springs Road	925	1,244
	Blair Lane to the outlet at Sulphur Creek	42	
	Crestview Avenue from Fallingbrook Drive to the outlet at Sulphur Creek	243	
	Lloymin Avenue, south of Somerset Park (commencement of larger storm sewer system)	34	
G	Judith Crescent from the urbanized are on Maureen Avenue to Mansfield Drive	550	1443
	Reding Road from Dalley Drive to the intersection at Mansfield Drive and Sulphur Springs Road	569	
	West side of Mansfield Drive to Sulphur Springs Road	120	
	Lover's Lane from Joanne Court northward (commencement of larger storm sewer system)	96	
	McGregor Crescent northward (commencement of larger storm sewer system)	107	
H	Cedar Grove Court to the channel west of Lowden Avenue	298	298
I	Lodor Street from Church Street to Brookdale Drive, outlets to the west ditch	173	383

NETWORK	STORM SEWER LOCATION	TOTAL SYSTEM LENGTH (m)	TOTAL NETWORK LENGTH (m)
	Lodor Street from Academy Street to Lorne Avenue, outlets to the east ditch	169	
	Lodor Street at Rousseaux Street to the outlet at Ancaster Creek (this section is part of a larger storm sewer system on Rousseaux Street)	41	
J	Outlet to Garden Avenue storm sewer (commencement of larger storm sewer system)	141	141
K	Anna Lee Drive (commencement of larger storm sewer system)	39	584
	Gregorio Avenue (commencement of larger storm sewer system)	20	
	Southcote Road at Calder Street northward (commencement of larger storm sewer system)	206	
	Three (3) private storm sewer systems which provide major-minor splits on the east side of Southcote Road	32	
	Southcote Road at Stonehenge Drive eastward (commencement of larger storm sewer system)	162	
	Southcote Road at Bookjans Drive, southward (commencement of larger storm sewer system)	126	
L	None found	N/A	N/A

Table 3.18. Storm System Length by Network (m)

NETWORK	STORM SEWER	STORM - INLET PIPE	TOTAL
A	1,204	164	1,367
B	853	121	973
C	484	13	497
D	143	88	232
E	380	0	380
F	1,223	21	1,244
G	1,387	56	1,443
H	295	3	298
I	376	7	383
J	129	12	141
K	534	50	584
L	0	0	0
Total	7,008	533	7,542

The storm sewers, identified at Maureen Avenue and Judith Crescent using drawings obtained from the SPIDER Database, were field inspected by City of Hamilton staff. City staff confirmed the location of the storm sewers; however, staff was unable to locate the outlet. Based on the available data, it has been assumed that the storm sewer originating on Judith Crescent, outlets to the ditch on the west side of Mansfield Drive, north of Judith Crescent. This assumption is based on the storm sewer invert elevation data at the intersection of Maureen Drive and Judith Crescent, from available drawings and the DEM elevation data at the suspected outlet. The length between these two points has been measured and a slope of 2 % (+/-) has been calculated.

Following the City staff site visit, further site reconnaissance by WSP staff was not viable during the development of the PCSWMM model in this area due to poor weather conditions and snow/ice cover at the time. A review of Google Street ViewTM at the suspected outlet identified two (2) parallel driveway culverts at 110 Mansfield Drive exiting on the north side of the driveway, while only one (1) driveway culvert was shown on the south side of the driveway. It has been assumed that the second driveway culvert is the outlet for the Maureen/Judith storm sewer. The Maureen/Judith storm sewer has been modelled accordingly, based on the assumption that the storm sewer outlets on the west ditch on the north side of the driveway at 110 Mansfield Drive.

Following substantial model development, WSP staff completed a site reconnaissance of the Maureen/Judith area for verification of modelling assumptions cited earlier. Based on this reconnaissance, only one (1) driveway culvert was observed on the north side of 110 Mansfield Drive, rather than two (2) driveway culverts assumed. Two (2) catch basins that have not been incorporated into the PCSWMM model were observed in the Mansfield Drive west ditch providing stormwater conveyance in a northly direction. A subsequent catch basin in the series was incorporated in the PCSWMM model in the ditch at 138 Mansfield Drive; this catch basin had a pipe entering from the direction of the previously unidentified catch basins.

Based on the observed conditions, it is assumed that the Maureen/Judith storm sewer is conveyed to the storm sewer system in the Mansfield Drive west ditch to the outlet at Sulphur Springs Road. While this differs from the PCSWMM model in that the Maureen/Judith storm sewer outlets into the west ditch, the conveyance direction is the same and is not anticipated to impact the overall model results.

Another storm sewer system was also identified following substantial model development on Orchard Drive. A drawing obtained from the SPIDER Database indicated an east-west 450 mm (+/-) diameter 10 m (+/-) long culvert in the ROW at 86 Orchard Drive. During WSP’s site reconnaissance, two (2) catch basins were observed at either end of the CSP culvert; the east ditch catch basin conveys stormwater to the west catch basins adjacent to the driveway at 86 Orchard Drive. The west catch basin had standing water partially submerging the inlet and outlet pipes below the CSP outlet pipe. The ultimate flow direction of the conveyance through the deeper inlet outlet pipes was not determined due to the standing water. Another catch basin was observed in the west ditch on the north west corner of the intersection of Orchard Drive and Taylor Road. A pipe was observed entering from the south with an unknown origin, while a pipe was observed entering from the north, assumed to be connected to the catch basin at 86 Orchard Drive.

Further catch basins were not observed on Orchard Drive or Taylor Road and the ultimate origin or outlet could not be verified. This system could potentially provide beneficial stormwater conveyance to alleviate the local ditch system conveyance issues during frequent storm events, however it is unlikely that this stormwater system would provide meaningful benefit during less frequent, more formative storm events. Furthermore, the standing water observed in the catch basin at 86 Orchard Drive is indictive of some type of flow impediment, which would likely prevent the designed conveyance through the system. As a conservative approach, this storm sewer system has not been included within the PCSWMM model due to the limited information and the unconfirmed conveyance direction of the system.

3.3.4 CONVEYANCE THROUGH PRIVATE PROPERTY

Areas where storm water flow conveyance potentially commences or crosses private property have been identified within the study area and are documented in Table 3.19. Flow conveyance through private property has been identified based on the associated major and minor systems. Major system or overland flow conveyance through private property would consist of spills from the ROW, remnant channels, and verified or unverified ditches. Minor system conveyance through private property would consist of culverts or storm sewers.

Nine (9) locations have been identified where both the minor and major systems are conveyed through the same section of private property. Locations that lack a defined major system outlet, such as a spill from the ROW through private property, have also been identified. An example of this would be the spill identified in Network G near the intersection of Judith Crescent and Maureen Avenue; a major/minor split has been identified at this location without a defined outlet for the major system during less frequent storm events and the spill is depicted to be conveyed through private property to Harrington Place. Major systems that commence on private property have not been field verified and have been assumed/estimated based on the available topographic data. The locations listed in Table 3.19 are presented in Drawings 4 to 11.

Table 3.19. Summary of Drainage Systems Conveyed through Private Property

NETWORK	ID NUMBER	DRAINAGE AREA (ha)	SYSTEM TYPE (MAJOR, MINOR, BOTH)	DEFINED MAJOR SYSTEM	EASEMENT
A	P1	11.7	Minor	No	No
	P2	2.00	Minor	No	No
	P3	21.35	Both	No	No
	P4	0.22	Major	Yes	No
	P5	4.41	Both	Yes	Yes
	P6	14.08	Both	Yes	Yes
	P7	0.84	Major	Yes	No
	P8	0.91	Major	No	No
	P9	4.04	Both	Yes	No
	P37	0.04	Minor	No	No
	P38	0.27	Minor	No	No
B	P10	12.97	Both	No	Yes
	P11	1.51	Major	No	No
	P12	9.71	Both	No	No
	P13	3.23	Minor	No	No
C	P14	3.41	Major	No	No
	P15	5.33	Minor	No	No
	P16	12.94	Major	Yes	No
	P17	0.68	Minor	No	No
	P18	1.43	Major	No	No
E	P19	3.72	Major	No	No
	P20	0.89	Both	No	Yes
	P21	5.44	Major	No	No
F	P22	1.80	Major	Yes	No
	P23	2.20	Major	Yes	No
	P24	3.34	Major	No	No
	P25	1.76	Major	No	No
	P26	1.64	Both	Yes	Yes
	P27	1.37	Major	No	No
	P28	1.18	Major	Yes	No
	P29	12.07	Major	Yes	No

NETWORK	ID NUMBER	DRAINAGE AREA (ha)	SYSTEM TYPE (MAJOR, MINOR, BOTH)	DEFINED MAJOR SYSTEM	EASEMENT
G	P30	3.68	Major	Yes	No
	P31	2.33	Major	Yes	Yes
	P32	1.67	Major	No	Yes
	P33	2.47	Major	Yes	No
	P34	5.96	Major	No	No
I	P35	1.31	Major	Yes	Yes
K	P36	6.03	Both	Yes	Yes

City of Hamilton mapping of easements has been reviewed and nine (9) properties with easements have been identified. Six (6) of the easements are at locations with coincident minor systems while the remaining three (3) easements are located at coincident major systems. Easements have not been identified at nine (9) minor systems.

The potential impacts of spills or flows to the preceding private properties is assessed in subsequent sections of this report.

3.3.5 CONNECTIVITY TO EXTERNAL AREAS

The routing elements (cross-sections and lengths) representing the Tiffany, Ancaster and Sulphur Creeks have been maintained from the Spencer Creek Hydrology Study QUALHYMO model, and incorporated into the PCSWMM modelling accordingly as open channel sections with the cross-section data from the QUALHYMO modelling applied for the transects. Upstream and downstream junction node elevations have been estimated based on available DEM data. Original routing sections have been split as required to include flow inputs from the more resolute study areas. Additional routing elements have also been incorporated to connect drainage from the more resolute study areas to the primary watercourse receivers. New transects for these channels have been developed based on the available DEM data, along with associated upstream and downstream invert elevations. Lengths of all conduits have been directly determined from the GIS engine within PCSWMM.

4 DATA COLLECTION AND MODEL CALIBRATION

4.1 EROSION ASSESSMENT

An erosion threshold analysis of downstream receivers within the Hamilton Conservation Authority (HCA) jurisdiction, namely tributaries of Tiffany Creek, Ancaster Creek, and Sulphur Creek was undertaken as part of the current study by AquaLogic Consulting. A complete copy of the report has been included in Appendix A. As discussed in Section 3.2.5, the majority of the study area falls within HCA jurisdiction, and impacts would be expected to be greatest to these receivers. Based on discussions with Grand River Conservation Authority (GRCA) staff, there is limited hydrologic or hydraulic modelling files available for the receivers in that case (Big Creek), thus an erosion analysis of those tributaries was considered a lesser priority as compared to those within the HCA's jurisdiction.

A total of five (5) different locations were assessed through field verification and numerical analyses; two (2) locations on tributaries of Ancaster Creek, and three (3) locations on various tributaries of Sulphur Creek. The sites were assessed using Rapid Assessment Analysis, and an Erosion Threshold Analysis to determine the estimated stable flow values, above which erosion causing flows would be expected to occur. These values have been subsequently applied for the calculation of off-site impacts and erosion sensitivity through continuous simulation modelling, as described in subsequent sections.

Of the five (5) sites assessed, three (3) were deemed to be stable, while two (2) were noted to be experiencing signs of incision and instability. The stability flows and overall findings determined by AquaLogic for each site are proposed to be used as part of the continuous simulation hydrologic modelling and associated duration analysis, described further in subsequent sections. These flows and findings have been summarized in Table 4.1.

Table 4.1. Critical Erosion Threshold Analysis – Flow Results

WATERCOURSE SITE	CONTRIBUTING STUDY DRAINAGE AREAS	STABILITY FLOW (M^3/S)	STABILITY NOTES
Ancaster Creek Tributary	Area A	0.41	Stable
Ancaster Creek Tributary	Area C and D	0.12	Stable
Sulphur Creek Tributary	Area D and E	0.23	Moderately Unstable
Sulphur Creek Tributary	Area F	0.33	Moderately Unstable
Sulphur Creek Tributary	Area G	0.53	Stable

The erosion assessment completed by AquaLogic found that two (2) of the sites within the Sulphur Creek Tributaries (Area D/E and F) are moderately unstable and exhibit evidence of channel adjustment due to incision and widening processes viewed during the infield assessment. It was recommended that the duration exceedance analysis be completed at these two (2) sites by using flow stages between the stability flows outlined in Table 5.4 and the 25 year event, as a reasonable upper level for entrenchment.

4.2 FLOW MONITORING DATA

Flow monitoring in support of the current study was undertaken by others (Cole Engineering Group Ltd) at three (3) locations within the study area, which are listed in Table 4.2. Reference is made to the monitoring summary report ("Stream Flow Monitoring in Ancaster – 2018, AMEC Sites – Final Report" Cole Engineering Group Ltd., January 2019).

Three (3) gauges were initially installed at two sites on May 30/31, 2018 (two (2) gauges at Site 1 and one (1) gauge at Site 2), and a fourth gauge was installed on July 10/11, 2018 (Site 3). The gauges were all removed on November 9, 2018. Rainfall data were obtained both from the Hamilton Conservation Authority (HCA) Workshop gauge, as well as the City of Hamilton's Daffodil gauge. While the HCA Workshop gauge is closer to gauges 1 and 2, the Daffodil Rain Gauge is closer to Site 3.

Table 4.2. 2018 Flow Monitoring Locations

SITE ID	CULVERT DIAMETER (mm)	LOCATION	INSTALLATION DATE	CONTRIBUTING DRAINAGE AREAS
Site 1A	900	Sulphur Springs Road at Mansfield Drive	May 30, 2018	G4, G5, G6 (33.10 ha +/-)
Site 1B	525	Sulphur Springs Road at Mansfield Drive	May 30, 2018	G4, G6 (25.85 ha +/-)
Site 2	450	117 Woodview Crescent	May 31, 2018	F1, F5 (14.74 ha +/-)
Site 3	750	795 Montgomery Drive	July 10-11, 2018	A2 (21.97 ha +/-)

Table 4.3 summarizes the seventeen (17) observed rainfall events during the monitoring period with depths approximately greater than 10 mm, which is a commonly applied threshold for distinguishing between minor and more formative storm events. Observed rainfall events with a high peak intensity and a short event duration, such as the July 26, 2018 rain event, are considered ideal for the PCSWMM model calibration/validation, as these events tend to generate a higher flow response that can be more readily simulated in the modelling.

The flow monitoring data collected at the four (4) flow monitoring gauges for the seventeen (17) identified rain events have been reviewed based on the flow response (ref. Table 4.4); a flow response of greater than 50 L/s was observed during eleven (11) monitoring occurrences, with the majority (10/11) occurring for Monitoring Gauge 1A. Sixteen (16) monitoring occurrences demonstrated a flow response between 10 and 50 L/s, with a more event distribution between gauges (5 for Gauge 1A, 1 for Gauge 1B, 6 for Gauge 2, and 3 for Gauge 3. Eleven (11) monitoring occurrences produced a flow response between 1 and 10 L/s, while twenty-five (25) monitoring occurrences demonstrated a flow response of less than 1 L/s.

Many of these monitoring events are not considered suitable for the calibration/validation process due to the muted flow response. These muted responses may reflect higher rates of infiltration or depression storage, or the effects of flow blockages (crushed or damaged driveway and roadway culverts). The long list of potential calibration events has been reviewed based on the observed rainfall presented in Table 4.3, and associated flow response presented in Table 4.4. Based on this review, candidate events have been identified. A total of twenty-six (26) flow responses, fifteen (15) from Site 1A, one (1) from Site 1B, seven (7) from Site 2, and three (3) from Site 3, from the four (4) sites have been identified. The selected events are highlighted in Table 4.4.

Table 4.3. Significant Observed Rainfall Events for Monitoring Period (>10 mm)

DATE	RAIN GAUGE SOURCE	TOTAL RAINFALL DEPTH (mm)	EVENT DURATION (HOURS)	PEAK RAINFALL INTENSITY (mm/hr)[1]
June 3, 2018	HCA_Workshop	10.8	1.0	26.8
June 18, 2018	HCA_Workshop	9.7	4.0	26.8
June 22-23, 2018	HCA_Workshop	19.5	18.0	12.8
June 24, 2018	HCA_Workshop	36.2	6.5	24.8
July 21-22, 2018	HCA_Workshop	18.8	11.8	6.0
	DaffodilRG	19.6	21.3	9.6
July 26, 2018	HCA_Workshop	24.0	4.5	40.8
	DaffodilRG	19.4	8.0	74.4
August 6-7, 2018	HCA_Workshop	10.8	16.6	28.8
	DaffodilRG	12.5	16.0	10.0
August 8, 2018	HCA_Workshop	14.0	9.4	14.4
	DaffodilRG	15.3	9.3	13.2
August 16-18, 2018	HCA_Workshop	8.0	29.7	4.8
	DaffodilRG	33.7	38.5	80.0
August 21-22, 2018	HCA_Workshop	20.0	28.6	26.4
	DaffodilRG	21.3	28.8	24.0
September 10-11, 2018	HCA_Workshop	22.0	26.5	7.2
	DaffodilRG	20.0	26.5	9.6
September 24-26, 2018	HCA_Workshop	20.5	34.0	14.0
	DaffodilRG	16.4	28.2	16.8
September 30 - October 2, 2018	HCA_Workshop	39.0	35.2	19.2
	DaffodilRG	34.2	35.2	33.6
October 6-7, 2018	HCA_Workshop	10.3	26	6.8
	DaffodilRG	8.4	32.3	7.2
October 27-29, 2018	HCA_Workshop	27.8	54.2	5.2
	DaffodilRG	21.6	47.8	4.8
October 30-31, 2018	HCA_Workshop	18.2	15.7	4.8
	DaffodilRG	16.0	16.2	12.0
November 1-2, 2018	HCA_Workshop	40.5	37.7	12.0
	DaffodilRG	33.8	33.2	14.4

Note: [1.] Peak intensities from the HCA rainfall data are recorded in 15 minute intervals whereas the City's rainfall data are recorded in 5 minute intervals.

Table 4.4. Peak Flow Response Observed During 2018 Monitoring Period (L/s)

DATE	TOTAL RAINFALL DEPTH (mm)	TOTAL RAINFALL DEPTH IN THE PREVIOUS 5 DAYS (mm)	SITE 1A	SITE 1B	SITE 2	SITE 3
June 3	10.8	0	2.9	0	0	N/A
June 18	9.7	0.5	81	0	0	N/A
June 22-23	19.5	10	33.7	0	0.9	N/A
June 24	36.2	19.8	172.8	0.1	46.7	N/A
July 21-22	18.8	0.2	26	0	0	0
	19.6	1.8				
July 26	24.0	20	206.1	45.6	76.9	46.7
	19.4	21.2				
August 6-7	10.8	0.7	94.5	0	1.6	2.8
	12.5	0				
August 8	14.0	12.5	108.8	0.1	26.1	6.4
	15.3	10.8				
August 16-18	8.0	0	40.5	0	19.7	0
	33.7	0				
August 21-22	20.0	33.7	68.4	0	8.1	11.5
	21.3	8				
September 10-11	20.0.	1.5	32.3	0	1.2	4.1
	22.0	1				
September 24-26	16.4	0	94.7	0	1.7	17.4
	20.5	0				
September 30 - October 2	39.0	15	74.0	0	22.8	2.4
	34.2	11.8				
October 6-7	10.3	33.7	272.8	0.3	0	0
	8.4	27.6				
October 27-29	27.8	2.2	31.7	0	6.3	0
	21.6	1.6				
October 30-31	18.2	27.8	30.3	0	16.0	0
	16.0	21.8				
November 1-2	40.5	33.0	61.2	0	22.2	1.3
	33.8	26.4				

As evident from Table 4.4, the largest number of identified calibration flow responses are sourced from Site 1A (15/26). This reflects the more urbanized nature of the upstream drainage area in this location. Based on investigations by City staff in the contributing upstream drainage area, portions of both Judith Crescent/Mansfield Drive and Reding Road were found to have partially urban drainage systems (i.e. storm sewers). These systems would tend to reduce the potential for infiltration as compared to ditched systems, and would also tend to convey flows towards the outlet more rapidly, which could result in quicker flow responses and higher peak flows.

The soil composition of the monitoring locations (ref. Table 4.5) demonstrates that the Sites 1A and 1B are predominately composed of more permeable type "AB" soils with greater infiltration potential than monitoring Sites 2 and 3 which are primarily composed of a type "C" soils with a lower infiltration potential. This would suggest that Sites 2 and 3 should produce greater runoff values than Sites 1A and 1B due to the lower expected infiltration potential of the soils. However, the monitoring results provided have indicated otherwise as demonstrated from the number of observed responses at Sites 1A and 1B in comparison to those at Sites 2 and 3 (ref. Table 4.4). This may reflect the more rapid conveyance and decreased opportunity for infiltration associated with the localized storm sewers upstream of Site 1.

Table 4.5. Soil Composition of the Monitoring/Calibration Location Drainage Areas (ha)

CALIBRATION LOCATION	NETWORK	SOIL COMPOSITION				
		AB	B	C	D	TOTAL
Site 1A	G4, G5, G6	20.28	0.00	12.82	0.00	33.10
Site 1B	G4, G6	18.97	0.00	6.88	0.00	25.85
Site 2	F1, F5	0.16	0.00	14.58	0.00	14.74
Site 3	A2	0.00	0.00	20.97	0.00	20.97
Total		20.44	0.00	48.37	0.00	68.81

4.3 HYDROLOGIC SENSITIVITY ANALYSIS

A sensitivity analysis has been conducted to determine the sensitivity of the hydrologic model output (peak flow and runoff volume) to changes in input parameters, and thus which parameters are critical for adjustment to calibrate the PCSWMM model to better match the observed flow responses. The sensitivity of model output to hydraulic modelling parameters (i.e. channel roughness and channel seepage rate in particular) has not been assessed, as these parameters have not been proposed to be applied for subsequent model calibration.

Typically, the percent imperviousness for a subcatchment is the most sensitive parameter with respect to resulting changes to both peak flows and runoff volume. Notwithstanding, the estimated imperviousness values for the hydrologic modelling for this study have been measured based on actual information, and thus are considered reasonably accurate and representative of existing coverage within the study area. Given this, and the need to reasonably quantify expected changes in imperviousness between existing and "as of right" land use conditions, imperviousness has not been included as part of the sensitivity analysis, nor the subsequent model calibration (Section 4.4). As an alternative approach, the "percent routed" parameter, also known as subarea routing, which defines the percentage of impervious area which is routed across the pervious area (and thus provides an opportunity for infiltration) has been assessed as part of the sensitivity analysis. Other parameters selected for the hydrologic sensitivity analysis include:

- Slope
- Overland Flow Length
- Manning's Roughness Coefficients (Impervious and Pervious Land Segments)
- Depression Storage (Pervious Land Segment Only)
- SCS Curve Number
- Drying Time

The June 18, 2018, precipitation event has been selected for the model sensitivity analysis due to the short duration of the event of 4 hours and the high rainfall intensity of 26.8 mm/hr. Furthermore, in review of the monitored hydrographs, this event resulted in a sharp increase in flow at Monitoring Site 1A.

The range of the subcatchment parameter adjustments has been selected based on the source of the initial parameters, and their expected sensitivity based on WSP's experience with previous hydrologic models. The identified adjustment ranges are presented in Table 4.6, along with the simulated impacts to both peak flow and runoff volume.

Table 4.6. Sensitivity Analysis – June 18, 2018 Storm Event at Monitoring Site

SUBCATCHMENT PARAMETERS	BASE PARAMETER VALUE	PARAMETER ADJUSTMENT RANGE (%)	PERCENT CHANGE IN PARAMETER OF INTEREST (%)			
			PEAK FLOW		RUNOFF VOLUME	
			LOW	HIGH	LOW	HIGH
Subarea Routing (%)	40	40	-26%	+9%	-26%	+18%
Slope (%)	2 % or As Measured	20	0%	0%	-0.2%	0%
Flow Length (m)	As Measured	20	-1%	+1%	-0.4%	0%
Manning's Roughness - Pervious	0.25	50	-3%	+3%	-1%	+2%
Manning's Roughness - Impervious	0.013	50	-3%	+3%	-1%	+2%
Depression Storage - Pervious (mm)	5	50	0%	0%	-0.1%	+2%
SCS Curve Number	Calculated	50	0%	+3%	0%	+44%

As shown in Table 4.6, the majority of the assessed hydrologic parameters indicate limited sensitivity to adjustment, including SCS Curve Number, which is typically a more sensitive hydrologic modelling parameter. The observed lack of sensitivity may reflect the more permeable area soils for Site 1A (Springvale Sandy Loam – SCS Soil Type AB), which would potentially require a greater relative adjustment to affect runoff, particularly given the relatively lower overall rainfall intensities associated with available monitoring events (relative to larger design storm events).

The greatest sensitivity is indicated for the subarea routing parameter, which as noted previously determines what portion of the impervious land segment is routed across the pervious land segment and would therefore be expected to impact both peak flow and volume as observed.

The results of the sensitivity analysis suggest that the slope, flow length, Manning's Roughness, depression storage, and SCS Curve Number are largely insensitive to variation in the Ancaster study area setting, at least for the selected storm event and monitoring location. The results suggest that if these parameters are included in model calibration, a greater level of adjustment may be necessary to have an impact on the resulting simulated flows. Subarea routing indicates the greatest degree of sensitivity and thus will be a primary parameter to be modified as part of the hydrologic model calibration, as described in Section 4.4.

As noted in Section 3.2.5, due to issues with the EPA-SWMM computational routine, the SCS Curve Number Infiltration Routine cannot be reasonably applied for continuous simulation parameters. A separate version of the hydrologic modelling, which uses the Green & Ampt infiltration routine for both external areas and the primary site area, has been generated accordingly. Given the preceding, a further assessment of the sensitivity of the "drying time" parameter is not considered necessary or informative, as this parameter is only applicable to the recovery of infiltrative capacity between storm events when the SCS Curve Number routine is applied for continuous simulation purposes.

4.4 HYDROLOGIC MODEL CALIBRATION

4.4.1 PRIMARY MODEL CALIBRATION

The hydrologic model calibration process has examined three (3) aspects of the monitored data:

— A comparison of the observed and simulated runoff volumes;

— A comparison of the observed and simulated peak flow rates; and

— A visual inspection of the observed and simulated hydrographs with respect to overall shape/fit and timing.

As per the screening of potential monitoring data described in Section 4.2, a total of twenty-six (26) individual flow monitoring calibration events have been selected, which reflects a combination of fifteen (15) different storm events and four (4) monitoring gauge locations. A high proportion of the selected events are represented by Site 1A, which has been applied for the sensitivity analysis described in Section 4.3.

Initial comparisons of uncalibrated model results to observed data have been presented in Figure 4.5; the results indicate that the simulated runoff volume is approximately five (5) times greater than the observed data. Simulated peak flow rates from the uncalibrated modelling were also approximately two (2) times greater than the observed data, as shown in Figure 4.6. Notwithstanding, the timing of the simulated hydrographs in comparison to the observed hydrographs demonstrated a reasonable fit of the data, with coinciding peaks. Based on the preceding, the focus of the calibration process has been to reduce the simulated runoff volume through the adjustment of the most sensitive subcatchment parameters. As per typical calibration processes, an iterative approach has been necessary to determine the optimal adjustments to key parameters. The parameter modifications resulting from the fifteen (15) monitoring rainfall events and the twenty-six (26) flow monitoring events are presented in Table 4.7.

Table 4.7. PCSWMM Subcatchment Hydrologic Parameters

SUBCATCHMENT PARAMETER	INITIAL VALUE	FINAL VALUE
Subarea Routing (%)	40	90
Slope (%)	2 % or Measured	Reduced by 40 %
Flow Length (m)	As Measured	Increased by 20 %
Depression Storage - Pervious (mm)	5	10

Ultimately, the parameter modifications presented in Table 4.7 have resulted in a reduction in simulated peak flow rates to values more consistent with observed responses; and, to a lesser extent a reduction in simulated runoff volumes. The greatest reduction in simulated runoff volume resulted from an increase in the sub area routing (to 90 % conveyance to the pervious area), which is consistent with the findings of the sensitivity analysis (Section 4.3). The increase in this parameter is considered reasonable, given that there are limited directly connected impervious areas, and the majority of the impervious areas (driveway, roadways, and roof tops) would be conveyed overland towards ditches where the runoff could potentially infiltrate. Adjustments have also been made to the overland flow length and slope, in order to further reduce the runoff volume by increasing the time in which the runoff could potentially infiltrate over the pervious land segment. The ultimately proposed adjustments of 20 % and 40 % for the flow length and slope respectively are considered reasonable given the expected variation in typical residential lot slopes and sizes. Further, given the abundance of gardens, mature trees, and manicured lawns within the existing residential area (as well as more pervious surficial soils in many areas), the pervious depression storage has been increased to 10 mm which further reduced simulated runoff volumes, but had a minimal impact on peak flows.

The SCS Curve Number values have not been adjusted from their initial parameters, as a review of the infiltration results within several of the subcatchments indicated that the soils were not infiltrating runoff to their capacity. This would suggest a reduction in the SCS Curve Number values to increase the infiltration ability of the soils would have limited impact on the runoff volume and peak flow rate, and is consistent with the findings of the sensitivity analysis (Section 4.3).

Four (4) sample hydrograph comparisons of the observed data, simulated uncalibrated data, and the simulated calibrated data have been provided (ref. Figures 4.1 – 4.4). These hydrographs demonstrate the improvement of the simulated uncalibrated data versus the simulated calibrated data.

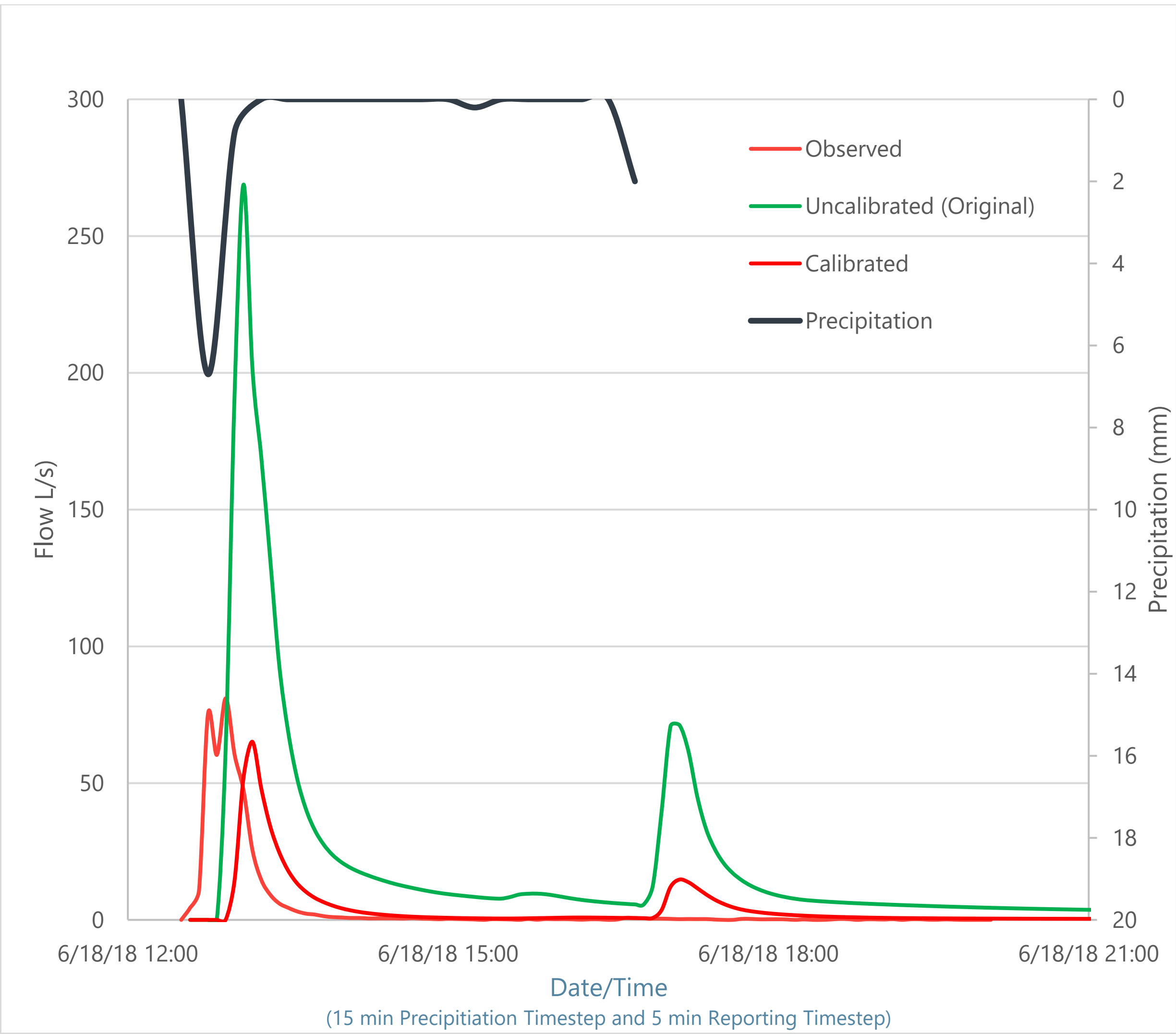


Figure 4.1. Site 1A, June 18, 2018, Hydrograph

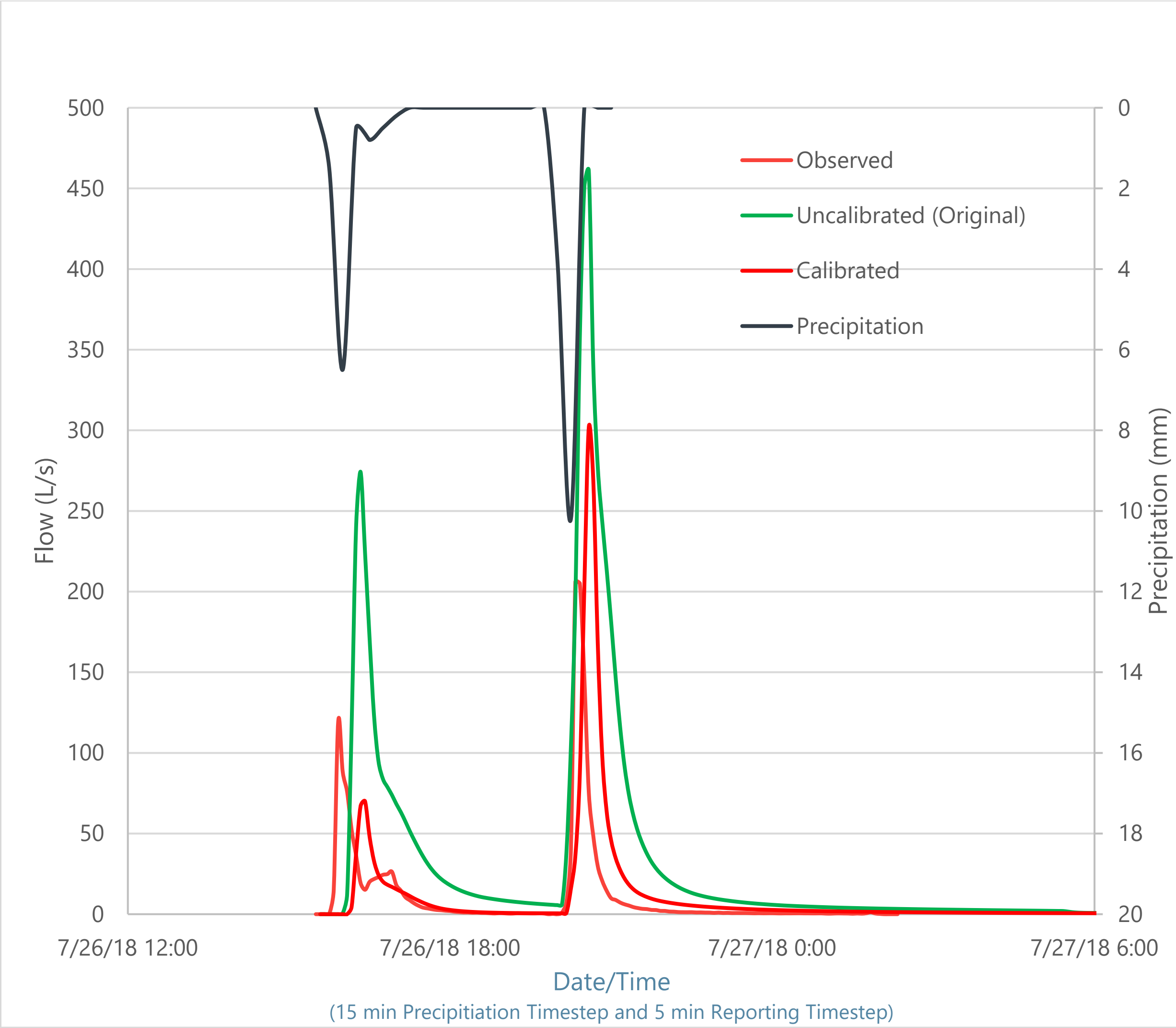


Figure 4.2. Site 1A, July 26, 2018, Hydrograph

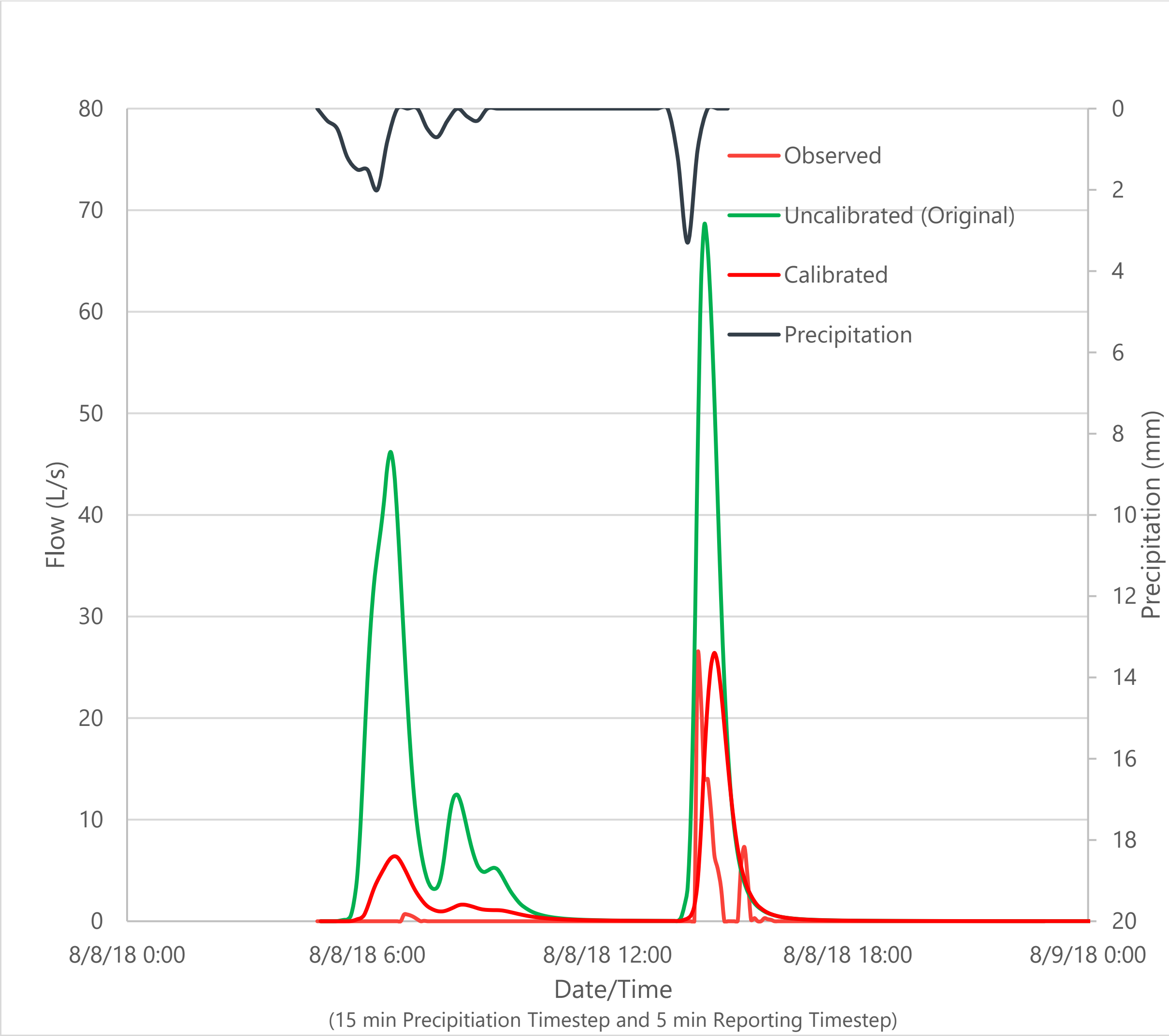


Figure 4.3. Site 2, August 8, 2018, Hydrograph

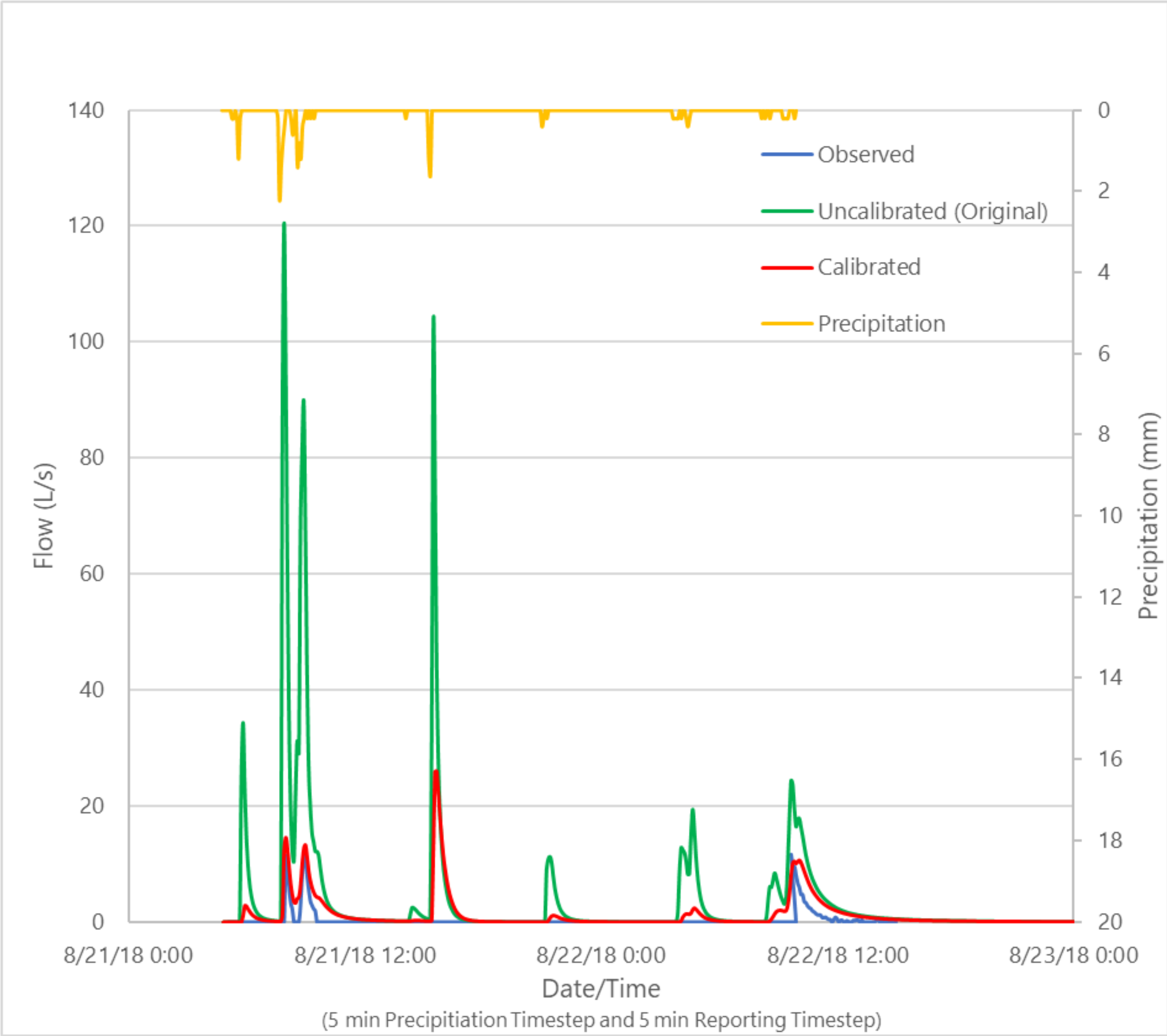


Figure 4.4. Site 3, August 21-22, 2018, Hydrograph

Calibration scatter plots for runoff volume and peak flows are presented in Figures 4.5 and 4.6 respectively. These results are based on a discrete, event-based analysis. A continuous simulation of the monitored precipitation data has also been conducted for the finalized calibration parameters; the results demonstrated similar trends as the event-based simulation (ref. Table 4.8. The calibrated runoff volume for all the identified events using continuous simulation are indicated as 5.5 (+/-) times greater than the observed runoff volumes while the peak flow rates were 1.1 (+/-) times greater than the observed peak flow rates. However, the distribution of the peak flow rate data (coefficient of determination) at -0.42 was notably poorer than the runoff volume distribution at 0.69. The continuous simulation screened events (based on the exclusion of storm events with a very low observed runoff response and those relatively insensitive to modelling changes) calibration plot results demonstrate improvement similar to those of the event-based calibration plots.

Table 4.8. Simulation Scatter Plot Trend Line Results for Calibrated Modelling

CALIBRATION FEATURE	SCENARIO	ALL EVENTS		SCREENED EVENTS	
		y	R^2	y	R^2
Total Runoff Volume	Event	3.75	0.56	1.23	0.53
	Continuous	5.46	0.69	1.40	0.49
Peak Flow Rate	Event	1.09	-0.38	1.17	0.64
	Continuous	1.11	-0.42	0.99	0.58

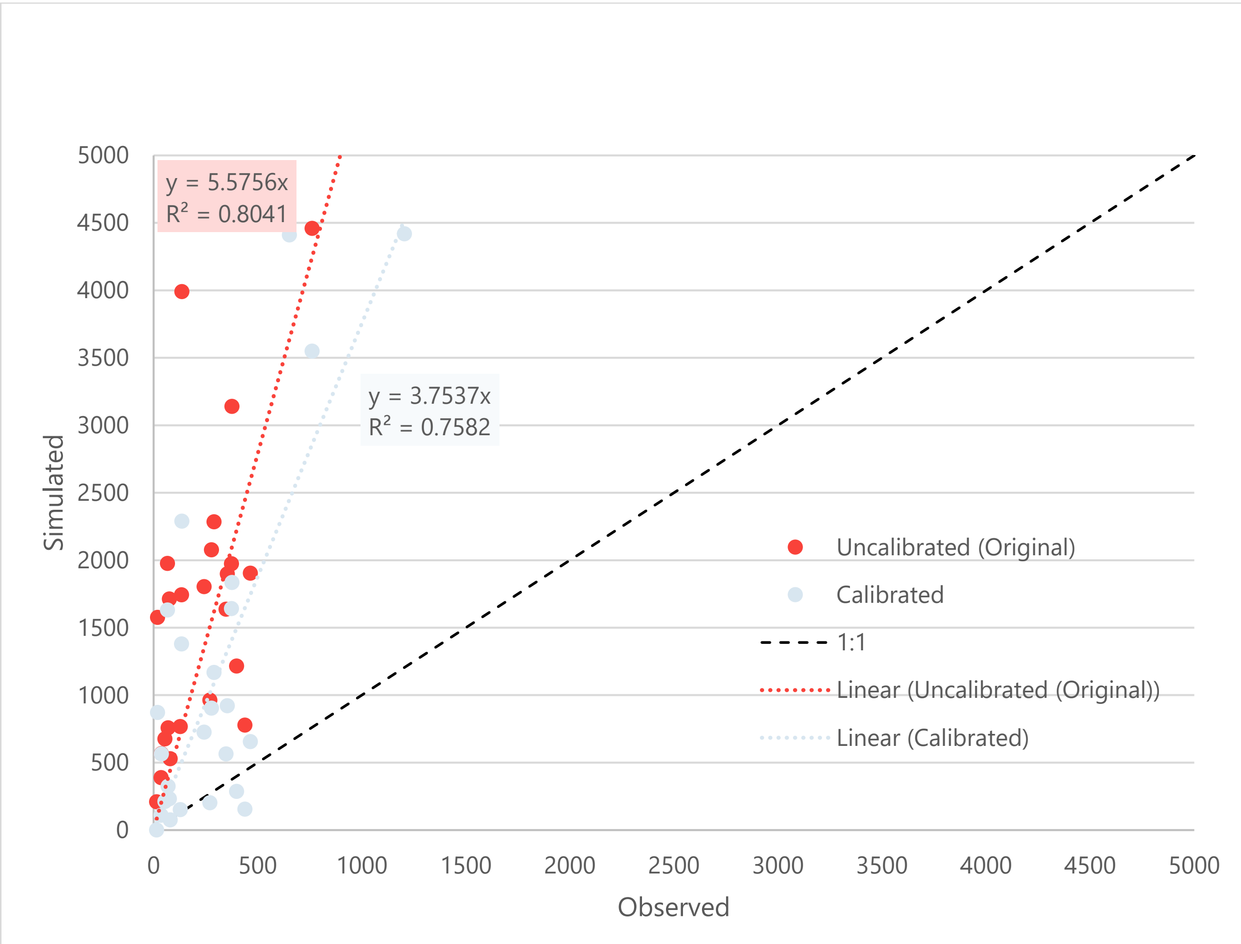


Figure 4.5. Final Calibration Parameters – All monitored Events – Event Based Volume (m³)

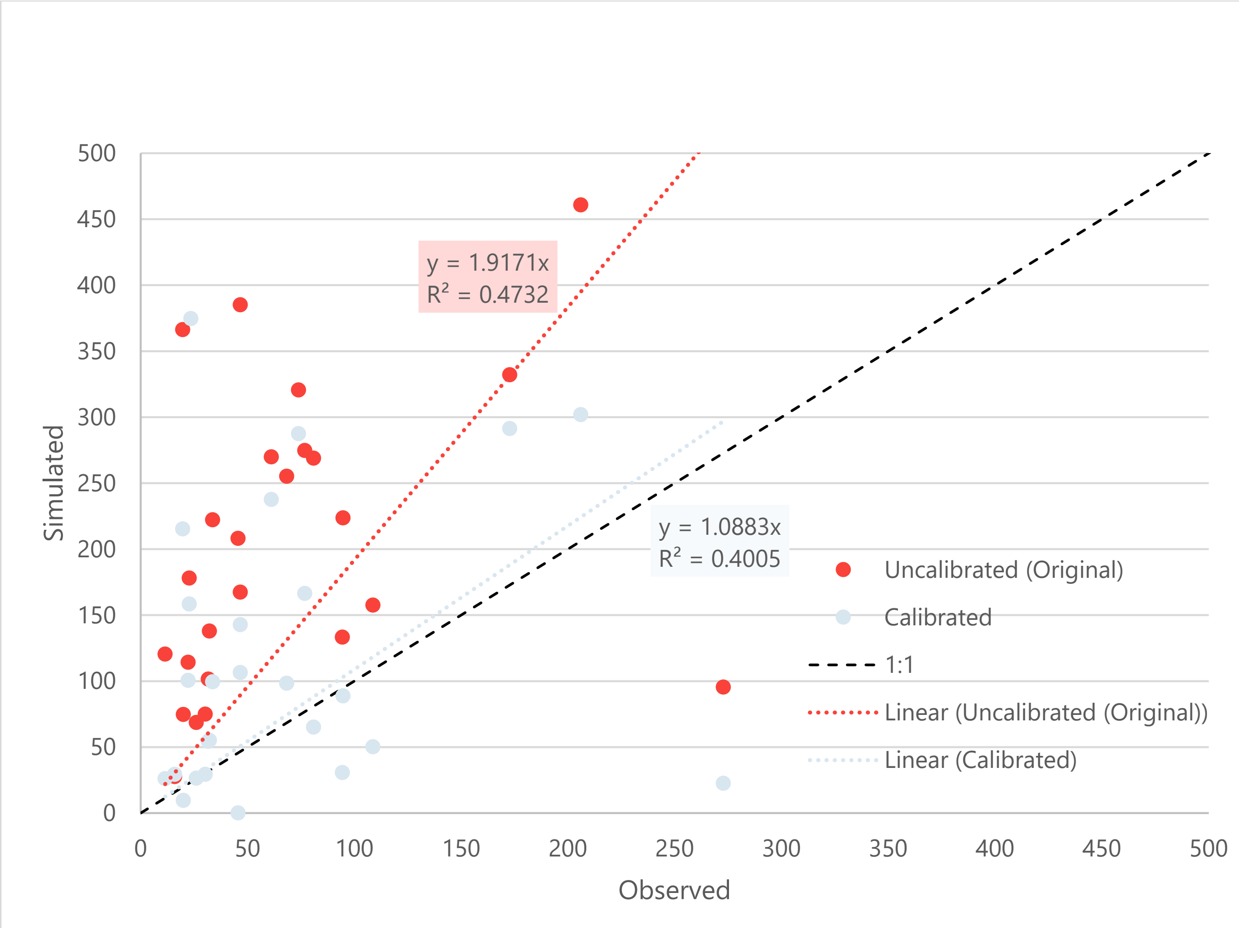


Figure 4.6. Final Calibration Parameters – All Monitored Events – Event Based Flow (L/s)

The results presented in Figure 4.5 indicate that while the simulated over-estimation of runoff volume is somewhat reduced by the proposed calibration, the trendline slope is still much greater than the 1:1 line of perfect fit. By contrast, the trendline slope for peak flows (Figure 4.6) indicates a much better fit with the proposed calibration parameters in place, although the scatter of the data remains relatively high.

In general, the presented results indicate that there are a number of low volume/low peak flow events which remain over-estimated by the calibrated modelling. These events (typically longer duration, lower intensity type storms) indicate a general insensitivity to further parameter adjustment. A data screening process has been undertaken to remove these types of events, which approximately halved the originally generated calibration dataset to a total of eleven (11) flow monitoring events obtained from seven (7) precipitation events which indicated a reasonable response to parameter adjustment. The screened storm events used for calibration have been listed below; associated rainfall characteristics are presented in Table 4.9.June 18, 2018

- July 26, 2018
- August 6-7, 2018
- August 8, 2018
- August 21-22, 2018
- September 24-26, 2018
- October 30-31, 2018

Rainfall depths for the selected storm events range from 9.7 mm to 24.0 mm; peak rainfall intensities ranged from 4.8 to 74.4 mm/hr. For comparison purposes, based on the City of Hamilton's current IDF parameters, a 2-year return period has a 15 minute intensity of 58.4 mm/hr. Only one (1) storm event (August 6-7, 2018) exceeded this value; all others were well below this, typically approximately half (30 mm/hr or less; 40.8 mm/hr for the July 26, 2018 storm event).

The total precipitation in the five (5) days prior to the observed events has been summarized in Table 4.9 to demonstrate the antecedent precipitation conditions during each of the screened monitoring events. The precipitation has been summed over the previous five (5) days from the commencement of the identified monitored event. The results indicate that three (3) precipitation events had less than 1 mm of precipitation in the previous five (5) days while the remaining four (4) precipitation events had greater than 10 mm of precipitation in the previous five (5) days. The antecedent rainfall may have affected the soil moisture conditions during the monitoring period, providing less infiltration potential and greater runoff when compared to ideal conditions (no antecedent rainfall in the previous 5 days). Notwithstanding, in areas with relatively rapidly draining soils (i.e. Site 1A/1B – type "AB" soils), this would be expected to have a more limited impact unless the antecedent rainfall occurred directly prior to the primary storm event of interest. Given that none of the antecedent rainfall periods were identified as candidate calibration events themselves, this suggests that while notable, the antecedent rainfall was of a lower intensity, and therefore potentially of a lower influence with respect to the simulation of calibration events.

The scatter plot results for the screened calibration events are presented in Figure 4.7. and 4.8.

Table 4.9. Screened Precipitation Events Used for the Calibration of the Simulated Monitored Events

DATE	MONITORING STATION	RAIN GAUGE SOURCE	TOTAL RAINFALL DEPTH IN THE PREVIOUS 5 DAYS (mm)	TOTAL RAINFALL DEPTH (mm)	EVENT DURATION (HOURS)	PEAK RAINFALL INTENSITY (mm/hr)[1]
June 18, 2018	Site 1A	HCA_Workshop	0.5	9.7	4.0	26.8
July 26, 2018	Sites 1A, 1B, and 2	HCA_Workshop	21.2	24.0	4.5	40.8
	Site 3	DaffodilRG	20	19.4	8.0	74.4
August 6-7, 2018	Site 1A	HCA_Workshop	0	10.8	16.6	28.8
August 8, 2018	Sites 1A and 2	HCA_Workshop	10.8	14.0	9.4	14.4
August 21-22, 2018	Site 3	DaffodilRG	33.7	21.3	28.8	24.0
September 24-26, 2018	Site 3	DaffodilRG	0	16.4	28.2	16.8
October 30-31, 2018	Site 1A	HCA_Workshop	27.8	18.2	15.7	4.8

Note: [1] Peak intensities from the HCA rainfall data are recorded in 15 minute intervals whereas the City's rainfall data are recorded in 5 minute intervals.

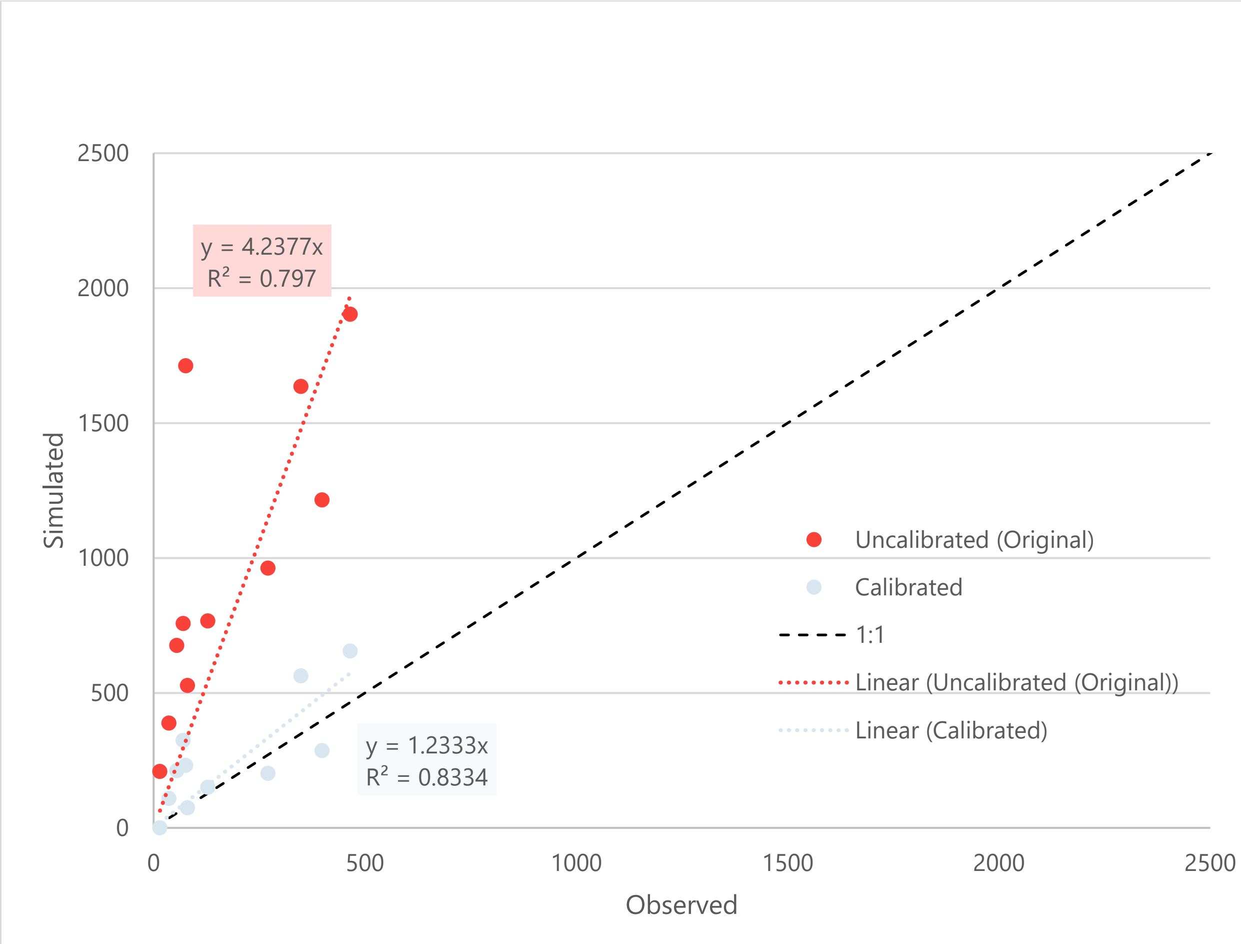


Figure 4.7. Final Calibration Parameters – Screened Events – Event Based Volume (m^3)

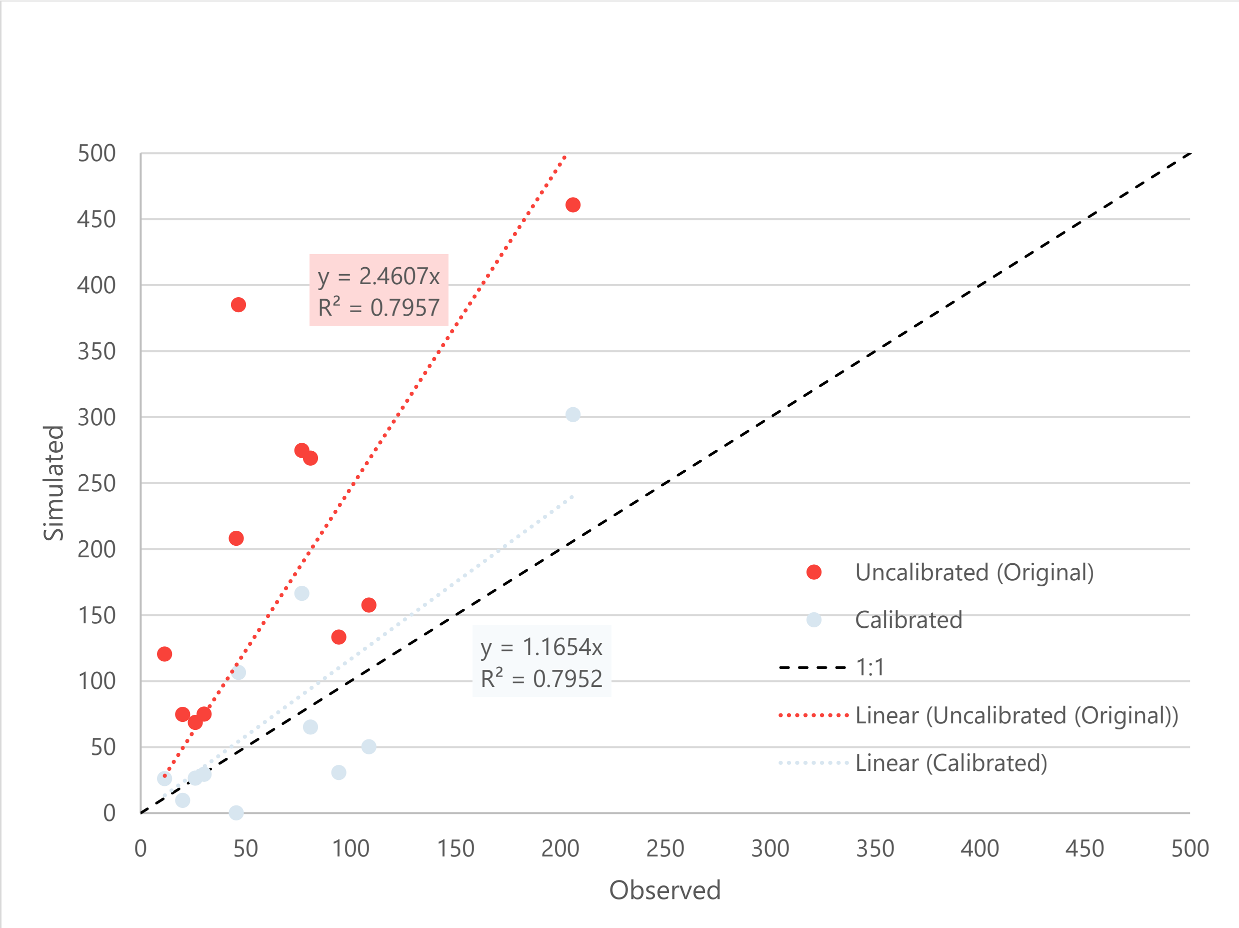


Figure 4.8. Final Calibration Parameters – Screened Events – Event Based Flow (L/s)

As evident, screening outlier events results in a much improved calibration fit with respect to both runoff volume and peak flow, in both the simulated trendline slope and scatter (coefficient of determination).

Based on the preceding, the proposed model calibration is considered reasonable and defensible. The results of the sensitivity analysis and calibration effort indicate that many of the identified calibration events are insensitive to adjustments in modelling parameters, suggesting that other factors may play a role in these areas. Further adjustment of identified calibration parameters would ultimately yield parameters which would trend beyond typically acceptable limits, and reduce any conservativeness on the simulated results.

A key limitation of the PCSWMM modelling with respect to the replication of calibration events is the exclusion of the driveway culverts which can easily impede the runoff conveyance through the ditched systems and reduce the peak flow rates and total volume conveyed to the calibration locations, particularly for smaller to medium sized storm events. Through field reconnaissance, it has been observed that driveway culverts can be blocked or crushed (consistent with the condition of many of the municipal roadway culverts noted in the field survey) which would restrict the flow and cause water to pool and infiltrate behind the culverts. Three (3) road culverts have been included in the calibration modelling according to their blocked or crushed measurements, although these features did not greatly impact the model calibration results, due to their location within the drainage areas. Notwithstanding, private driveway culverts are not included in the calibration modelling and could potentially have a greater impact on the modelling results.

4.4.2 SECONDARY MODEL CALIBRATION

The preceding primary model calibration effort has focused on the primary hydrologic modelling, which applied the US SCS Curve Number methodology for infiltration. As noted in Section 3.2.5, in order to undertake long-term continuous hydrologic simulation, an alternate model version has been required, which in addition to including downstream/external area subcatchments, also applies an alternate infiltration methodology, specifically Green & Ampt. This methodology is necessary in order to address a specific issue with EPA-SWMM (and thus PCSWMM) with respect to continuous simulation using the US SCS Curve Number methodology, particularly where higher depression storage values are specified.

In order to confirm the reasonableness of this secondary hydrologic modelling, a further calibration/validation has been undertaken using the Green & Ampt methodology. As previously described (ref. Section 3.2.5), the Green & Ampt parameter data have been applied to the study area based on available surficial soils mapping (ref. Drawing 15, attached), consistent with the same base data applied for the parameterization using the SCS Curve Number methodology. Area weighting of the parameters has been applied where multiple soil types are located within individual subcatchments.

The study area model has been simulated using the screened event based storms (ref. Section 4.4.1) which have been used for the calibration using the US SCS Curve Number methodology. The simulated runoff volume scatter plot and peak flow rate scatter plot are presented in Figures 4.9 and 4.10 respectively.

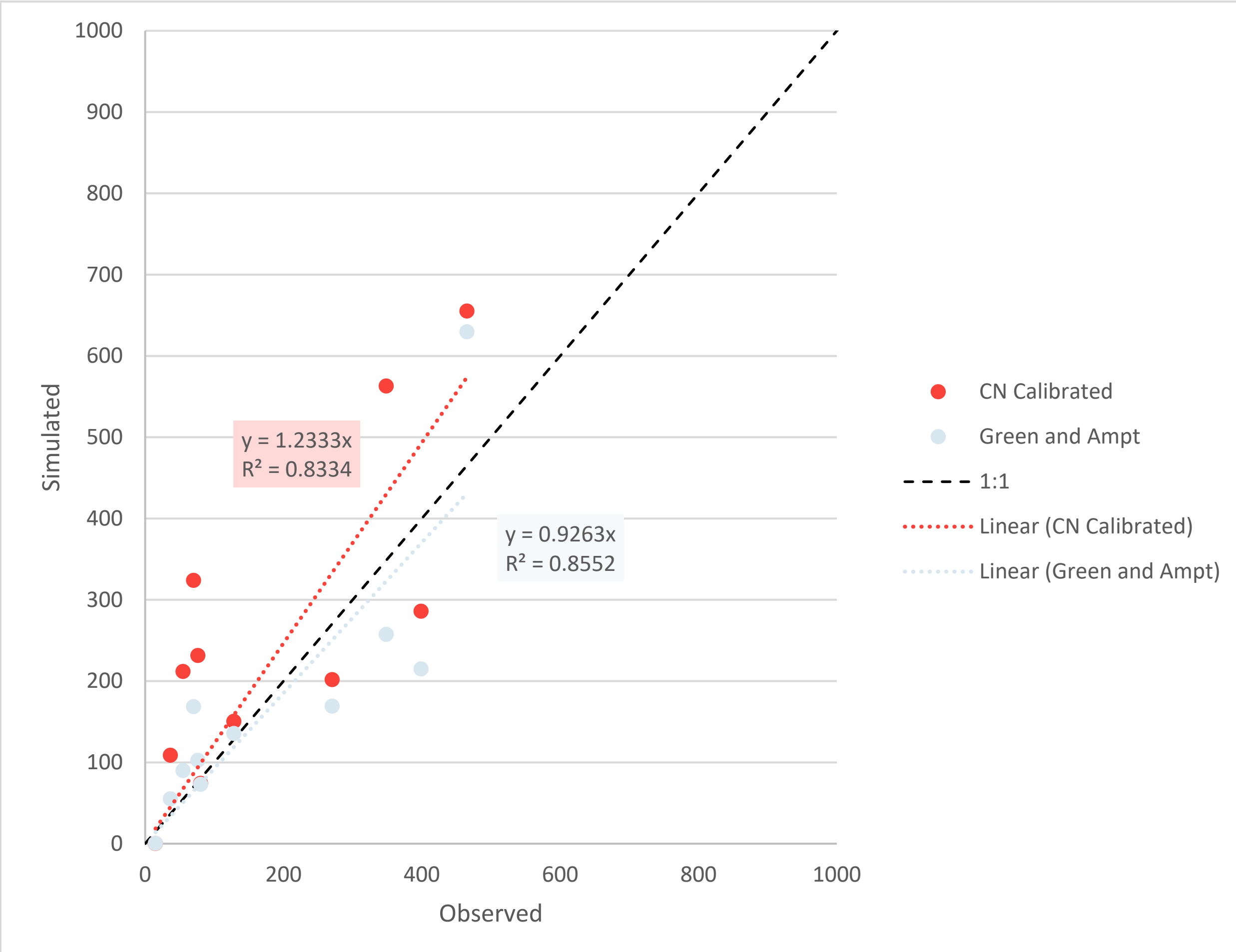


Figure 4.9. Green & Ampt Unadjusted Scenario – Screened Events – Event Based Volume (m^3)

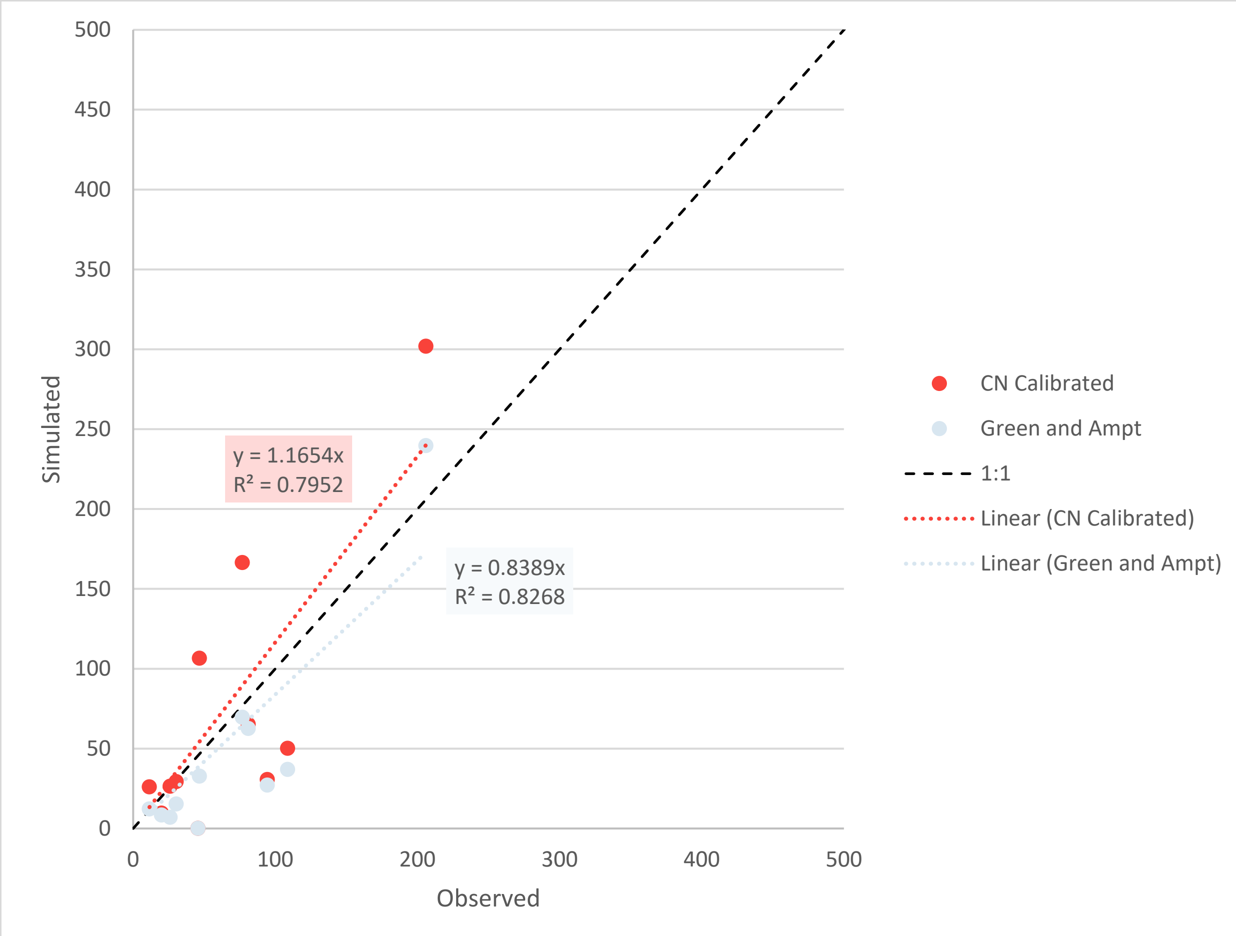


Figure 4.10. Green & Ampt Unadjusted Scenario – Screened Events – Event Based Flow (L/s)

As evident from the volume and flow scatter plot results, the initial Green & Ampt soil parameters demonstrate a reasonable fit for the simulated trendline slope and scatter (coefficient of determination). The overall trendline slope with respect to volume is in fact closer to the line of perfect fit, albeit slightly below. Both the slope for peak flow and volume are slightly less than 1, indicating a slight underestimation of values compared to the line of perfect fit.

Further calibration of the Green & Ampt parameters has therefore been undertaken, to confirm the degree of change required to better fit to the base SCS Curve Number generated results, and achieve slopes greater than 1 to maintain a degree of conservativeness.

From WSP's experience with previous projects using the Green & Ampt infiltration method, the most sensitive of the three (3) input parameters is hydraulic conductivity. Three (3) simulation scenarios for this parameter have been undertaken, with the hydraulic conductivity reduced by 10, 30, and 50%. Summary statistics for these scenarios are presented in Table 4.10.

Table 4.10. Comparison of Scatter Plot Trend Line Results for the Screened Events using the Green and Ampt Infiltration Methodology for the Event Based Simulations

SCENARIO	VOLUME		PEAK FLOW RATE	
	y	R^2	y	R^2
Final US SCS Curve Number Calibration	1.23	0.53	1.17	0.64
Initial Green & Ampt Soil Parameters	0.93	0.69	0.84	0.74
Hydraulic Conductivity -10%	0.95	0.67	0.87	0.73
Hydraulic Conductivity -30%	1.01	0.62	0.94	0.72
Hydraulic Conductivity -50%	1.10	0.54	1.04	0.67

As evident from the results presented in Table 4.10, a reduction in the hydraulic conductivity results in an increased trendline slope for the runoff volume and peak flow rate with a corresponding decrease in hydraulic conductivity. In conjunction, the coefficient of determination decreases with each iteration for both the runoff volume and the peak flow rate indicating that the degree of scatter is increased.

A 50% reduction in the hydraulic conductivity from the initial Green & Ampt parameters produces a slope of greater than 1 for both the volume and the flow scatter plots. While the coefficient of determination of the volume and peak flow rate for the 50 % reduced hydraulic conductivity have been reduced, these values are slightly greater than those of US SCS Curve Number values. Therefore, the 50% reduced hydraulic conductivity generates the scatter plot results that most closely resemble those of the US SCS Curve Number calibrated modelling results.

Given the magnitude of the required change in hydraulic conductivity (50% reduction), a further verification has been undertaken using the 2 year and 5 year SCS design storm events to evaluate the combined peak flow rates at the outlets for each network. This verification is intended to ensure that the results remain reasonably comparable to those using the SCS Curve Number approach.

The results of this comparison (calibrated SCS Curve Number modelling results, and results using base and adjusted Green & Ampt infiltration parameters) are presented in Tables 4.11 and 4.12 for the combined simulated outflows from the primary drainage network areas. The difference in combined peak flow rate and the percent difference are noted in comparison to the base SCS CN generated modelling results.

Table 4.11. Comparison of the Total Simulated 2 Year SCS Design Storm Event Peak Flow Rates (m^3/s) at the Network Drainage Outlets

NETWORK	FINAL CN CALIBRATED	GREEN-AMPT INITIAL PARAMETERS			GREEN & AMPT ADJUSTED (HYDRAULIC CONDUCTIVITY -50 %)		
		PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)	PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)
A	1.54	2.11	0.57	+37	2.43	0.89	+58
B	0.73	0.74	0.01	+1	0.90	0.17	+23
C	1.51	0.99	-0.52	-34	1.54	0.04	+2
D	0.47	0.30	-0.17	-37	0.47	0.00	-1
E	0.76	0.52	-0.24	-32	0.85	0.09	+12
F	1.57	1.43	-0.14	-9	1.99	0.41	+26
G	1.45	1.40	-0.05	-4	1.88	0.43	+29
H	0.28	0.30	0.02	+8	0.34	0.06	+23
I	0.65	0.78	0.13	+20	0.83	0.18	+28

NETWORK	FINAL CN CALIBRATED	GREEN-AMPT INITIAL PARAMETERS			GREEN & AMPT ADJUSTED (HYDRAULIC CONDUCTIVITY -50 %)		
		PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)	PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)
J	0.32	0.21	-0.11	-34	0.35	0.03	+8
K	0.69	0.63	-0.07	-9	0.83	0.14	+20
L	0.16	0.13	-0.04	-22	0.20	0.04	+23
Total	10.13	9.52	-0.60	-6	12.60	2.47	+24

The results presented in Table 4.11 indicate that the peak flows generated using the base Green-Ampt infiltration parameters compare much more favourably with the base SCS CN generated modelling results, with an overall average difference of 6% (ranging from -37% to +37%). By comparison, the simulated peak flows generated using the adjusted Green & Ampt infiltration parameters (hydraulic conductivity reduced by 50%) indicate a relatively consistent over-estimation of peak flows (+24% average, reflecting a range of -1% to +58%).

A similar comparison for the 5-year storm event has also been undertaken; results are presented in Table 4.12.

Table 4.12. Comparison of the Total Simulated 5 Year SCS Design Storm Event Peak Flow Rates (m3/s) at the Network Drainage Outlets

NETWORK	FINAL CN CALIBRATED	GREEN & AMPT INITIAL PARAMETERS			GREEN & AMPT ADJUSTED (HYDRAULIC CONDUCTIVITY -50 %)		
		PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)	PEAK FLOW (m^3/s)	DIFFERENCE (m^3/s)	DIFFERENCE (%)
A	3.01	3.93	0.92	+31	4.25	1.24	+41
B	1.08	1.19	0.12	+11	1.48	0.40	+37
C	2.23	2.01	-0.22	-10	2.53	0.29	+13
D	0.75	0.65	-0.10	-14	0.85	0.10	+13
E	1.17	1.13	-0.05	-4	1.46	0.29	+24
F	2.80	2.88	0.09	+3	3.65	0.86	+31
G	2.34	2.71	0.37	+16	3.04	0.71	+30
H	0.40	0.44	0.04	+10	0.48	0.08	+20
I	0.89	1.10	0.21	23	1.14	0.25	+28
J	0.53	0.50	-0.03	-5	0.62	0.09	+17
K	1.05	1.13	0.08	+8	1.26	0.22	+21
L	0.25	0.29	0.04	+17	0.36	0.11	+45
Total	16.50	17.96	1.46	+9	21.13	4.63	+28

The results presented in Table 4.12 indicate that the peak flows generated using the base Green-Ampt infiltration parameters again compare much more favourably with the base SCS CN generated modelling results, with an overall average difference of 9% (ranging from -4% to +31%). By comparison, the simulated peak flows generated using the adjusted Green & Ampt infiltration parameters (hydraulic conductivity reduced by 50%) indicate a consistent over-estimation of peak flows (+28% average, reflecting a range of +13% to +45%).

Ultimately, the -50 % reduced hydraulic conductivity scenario is considered to relatively over-estimate design storm peak flow rates as compared to the calibrated modelling results using the US SCS Curve Number approach. While the adjusted hydraulic conductivity scenario generates a somewhat better match to the overall scatter plot results for the calibration events, the difference is relatively minor. The required degree of adjustment (-50%) may reflect the lower rainfall depth/intensity associated with the available calibration events, and the associated model insensitivity to changes in hydraulic conductivity. Given the results of the comparison for the 2 and 5 year design storm events, it is considered the application of the base Green & Ampt infiltration parameters is more defensible, and also more consistent overall with the values applied for external area (as per Section 3.2.5). Therefore, the base Green & Ampt parameters (including the unadjusted values of hydraulic conductivity) have been applied for subcatchments within both the study area and external areas.

4.5 HOT SPOT FLOODING

The City has provided a call log and associated mapping data pertaining to flooding complaints from residents within the City of Hamilton. This information has been summarized for the property parcels within the rurally serviced study area based upon the flooding category logged during the inspection. The hot spot flooding results have been summarized in Table 4.13 below.

Table 4.13. Count of Hot Spot Flooding Calls per Rurally Serviced Network

NETWORK	FLOODING ISSUE CATEGORY (FROM CITY RECORDS)							TOTAL SWM RELATED[3]
	CATCHBASIN	CULVERT	DITCH	ROADWAY	MISC.	PROPERTY[1]	SEWER BACKUP[2]	
A	9	0	7	0	6	2	4	24
B	5	2	5	5	0	1	14	18
C	0	0	1	0	2	1	13	4
D	2	1	3	1	0	0	10	7
E	1	0	3	2	0	0	13	6
F	9	4	2	1	4	0	15	20
G	8	1	2	1	4	0	16	16
H	0	1	0	0	0	0	2	1
I	4	1	0	1	0	0	5	6
J	0	0	0	1	1	0	3	2
K	0	0	2	0	0	0	7	2
L	0	3	0	0	1	0	0	4

Note: [1] Property flooded by ground or stormwater – not sewer backup.
[2] Sewer Backup has been summarized to include both sewer lateral backup in basement, and sewer back up (on sewer main).
[3] Total SWM related hot spot flooding calls include all categories except sewer backup.

As evident from Table 4.13, the City of Hamilton applies flooding categories such as, catchbasin, culvert, ditch, roadway, property flooding (by ground or stormwater) and miscellaneous (unknown reason for flooding). Based on these categories, networks A, B, F and G have the highest number of historically reported flooding issues ranging from 16 – 24 occurrences, whereas the other networks range from 1 – 7 reported flooding incidents. These results have been considered when assessing the simulated ditch and culvert performance under existing conditions, in order to further validate the model results. It should be noted, that the flooding issue category logged at the time of the call / inspection may not be the accurate identification of the reason for flooding, therefore any reported flooding issues have been compared with the simulated model results to indicate, or further confirm, any problem areas. In particular, the results of the "sewer backup" category may not directly correlate with study results given the lack of storm sewers, and the number of potential external factors which could affect sanitary sewer backups.

5 SIMULATION SCENARIOS

5.1 DESIGN STORM SIMULATION

Consistent with the Pilot Study, drainage system performance has been evaluated based on four (4) design storm events: the 25 mm 4-hour Chicago storm (water quality storm), as well as the SCS 24-Hour Type-II design storm for the 2 year (53 mm in 24 hours), 5 year (72 mm in 24 hours), and 100 year (123 mm in 24 hours) return periods. The SCS 24-Hour Type-II distribution was also previously applied for the Town of Ancaster Master Drainage Plan Study (Philips Planning and Engineering Limited, November 1987). The Regional Storm (Hurricane Hazel) has also been simulated for the purposes of assessing potential impacts to external/downstream areas.

5.2 CONTINUOUS SIMULATION

As per the approved work plan for the study, continuous simulation modelling has been conducted in addition to more traditional event-based (Design Storm) modelling (ref. Section 5.1). This approach typically yields greater accuracy and insight into changes in runoff volumes specifically, while also supporting the assessment of potential off-site erosion impacts, based on the erosion threshold targets discussed in Section 4.1. The continuous simulation modelling has also been applied to support an assessment of seasonal/annual changes in the water budget.

The most proximal long-term rainfall gauge is Environment Canada's Hamilton Airport gauge, which has an overall data record of some 49 years (1970 – 2018). Based on initial discussions with City staff (November 1, 2018), the preference has been to use this dataset, given that it is closer to the Community of Ancaster. Notwithstanding, based on a subsequent review of available data, several data gaps have been identified. The data available only included rainfall and no precipitation data in the form of a prepared time series. There are insufficient data available to develop a continuous precipitation data set for the Hamilton Airport gauge at this time.

From WSP's work in other municipalities, a continuous hourly precipitation dataset has been developed from the Royal Botanical Gardens (RBG) rain gauge (January 1962 – December 1995). In addition to this data, WSP received a rainfall (May 1997 to November 2016) and precipitation (April 2004 to January 2019) time series data set for the RBG rain gauge from Environment Canada which facilitated an extension of the continuous data series up to December 2016. The primary source for the data set extension is the rainfall time series during the summer months (April to October), as it is quality checked by Environment Canada. The winter months have been supplemented by the precipitation time series and compared with online monthly totals when available.

Where data gaps occurred from malfunctioning equipment or lack of raw data, gaps have been filled from available rainfall or precipitation time series for nearby gauges (Hamilton Airport, Pearson Airport, Toronto City). When yearly/monthly totals differed largely from Environment Canada's online totals and additional time series data are not available, precipitation amounts have been applied hourly to closely match the daily totals. A summary regarding the sources and development of the fifty-five (55) year time series has been outlined in Table 5.1.

Table 5.1. Continuous Rainfall Data Set Sources

TIME PERIOD	SOURCE NOTES
1962-1995	Hamilton RBG Continuous Precipitation file – gap filled by WSP, using Hamilton Airport and Toronto Pearson daily totals from Environment Canada (EC), as part of previous project work
1996	Primary source for the summer months (April-October) is the RBG Hourly Rainfall file received from EC in 2011. Where required, summer months gap filled using available Hamilton Airport Hourly Data, and winter months gap filled using Pearson precipitation time series data.
1997-2016	Primary source for the summer months (April-October) is the RBG Hourly Rainfall file received from EC. These data are assumed to be correct (QA/QC'ed by EC), unless missing information due to gauge malfunction or significant difference when compared to available online totals (i.e. multiple storms missing in a month).
	Where necessary, summer months gap filled with Hamilton Airport Data (April-October) or the Hamilton RBG Precipitation gauge data when available.
	Where necessary, winter months gap filled using Pearson gauge data (1996-2003), Toronto City Centre (2004), and Hamilton RBG Precipitation Data received from EC (November 2005 onwards)
	Where necessary, and for dates where no timeseries data are available from any sources, EC daily totals reviewed online and applied standard volume amounts to gap fill. When larger events (+15 mm) are missing due to gaps, the total daily volume has been applied by replicating a typical storm distribution from an event of a similar magnitude from the Hamilton RBG rainfall data.

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

- A complete time series can be specified:
  - Historic daily pan evaporation data are avaialble 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) is 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 5.2.

Table 5.2. 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 PCSWMM 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 watershed 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. Based on discussions with City staff (November 1, 2018), this approach was considered to be reasonable and acceptable.

Lastly, it is noted that the originally proposed infiltration methodology (SCS Curve Number) was not designed for long-term simulation and soil moisture recovery. A "drying time" value is specified within the PCSWMM modelling input. A default value of 7 days has been implemented in the base SCS Curve Number modelling, however as discussed in Section 3.2.5 and 4.4.2, the SCS Curve Number modelling will not be employed for continuous simulation (single event simulation only), thus the selection of this parameter is not considered critical. A modified version of the hydrologic modelling which employs the Green & Ampt infiltration methodology (which does not require the "drying time" parameter) has been applied for all continuous simulation (i.e. water budget and erosion analysis).

5.3 CLIMATE CHANGE SCENARIOS

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 WSP's experience with other studies, and discussions with City staff (Seradj-Senior, January 31, 2019). A 2080 timeframe has been initially selected for projection of climate change rainfall.

The results from the UWO IDF Climate Change Tool for the Hamilton Airport gauge/station indicate that the 100 year storm event would have a predicted 59.28 mm increase in depth, or 48 % (+/-) greater, in comparison to existing IDF data. Based upon WSP's review, 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.

Due to the significant predicted increase in rainfall totals (as compared to previous versions), WSP has 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 Hamilton Golf and Country Club has been applied as a relatively central location for the study area, 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 Ancaster study area.

The resulting IDF parameters are provided in Tables 5.3 and 5.4; predicted rainfall depth increases in comparison to existing Hamilton Airport IDF data are presented in Tables 5.5 and 5.6. These tables indicate that the MTO and OCCDP tools produce climate change rainfall peak intensities and depths which are generally bracketed by the existing Hamilton Airport IDF data and the current (Version 3.0) UWO IDF data.

Table 5.3. Comparison of Climate Change Generated Rainfalls – 24 hour Rainfall Peak Intensity (mm/hr)

IDF DATA SOURCE	2 YEAR	5 YEAR	10 YEAR	25 YEAR	50 YEAR	100 YEAR
Existing Hamilton Airport IDF Data	2.20	3.00	3.50	4.20	4.60	5.10
MTO IDF Curve Lookup	2.90	3.70	4.20	4.90	5.30	5.80
Ontario Climate Change Data Portal	2.64	3.71	4.42	5.31	5.98	6.64
UWO IDF Climate Change Tool 3.0	2.36	3.43	4.46	5.63	6.55	7.57

Table 5.4. 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 Hamilton Airport IDF Data	52.80	72.00	84.00	100.80	110.40	122.40
MTO IDF Curve Lookup	69.60	88.80	100.80	117.60	127.20	139.20
Ontario Climate Change Data Portal	63.36	89.04	106.08	127.44	143.52	159.36
UWO IDF Climate Change Tool 3.0	56.64	82.32	107.04	135.12	157.20	181.68

Table 5.5. 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	16.80	16.80	16.80	16.80	16.80	16.80
Ontario Climate Change Data Portal	10.56	17.04	22.08	26.64	33.12	36.96
UWO IDF Climate Change Tool 3.0	3.84	10.32	23.04	34.32	46.80	59.28

Table 5.6. 24-hour Rainfall Depth Increase (%) in Comparison to Exiting IDF Data

IDF Data Source	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
MTO IDF Curve Lookup	32	23	20	17	15	14
Ontario Climate Change Data Portal	20	24	26	26	30	30
UWO IDF Climate Change Tool 3.0	7	14	27	34	42	48

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.

5.4 HISTORIC EXTREME STORMS

Three (3) local extreme storm events, as summarized in Table 5.7, have been used to "stress test" the study area. These storms have been generally selected based on their proximity to the current study area, and discussions with City staff (Seradj-Senior, January 31, 2019). The storms selected include:

— July 26, 2009 (Red Hill Valley Storm Event)

— July 22, 2012 (Binbrook/Shadyglen Storm Event)

— August 14, 2014 (Burlington Storm Event)

The preceding storms are all considered "extreme" historic events which occurred locally, and all have a greater precipitation depth than the Hamilton Airport (Mount Hope) 100 year design storm, over a shorter duration (as per Table 5.7). Notwithstanding, the hourly peak intensity of the 100 year storm is greater than all three (3) historical events.

Hyetographs for the three (3) events have been obtained from multiple projects completed by WSP for the City of Hamilton and the City of Burlington respectively. The time series files for the Hamilton (Red Hill) and the Burlington storms were originally developed from the maximum radar cell data from the storms, while the Hamilton (Binbrook) storm was originally developed from a combination of rain gauge data and radar data. Hyetographs of the local extreme storm events have been provided in Appendix C and D.

Table 5.7. Local Extreme Storm Event Summary

EVENT LOCATION	DATE	DURATION (hr)	TOTAL PRECIPITATION (mm)	PEAK INTENSITY (mm/hr)
Hamilton (Red Hill)	26-Jul-09	12.2	139.7	78.6
Hamilton (Binbrook)	22-Jul-12	4.3	140.4	92.6
Burlington	4-Aug-14	6.3	196.1	126.8
Hamilton Airport 100 Year Design Storm	N/A	24.0	122.4	135.7

6 EXISTING CONDITIONS MODELLING RESULTS

6.1 MODEL SETUP

The calibrated/validated PCSWMM model described in Section 4 has been modified for the simulation of existing conditions setup by resizing three (3) crushed culverts used in the calibration process to their standard sizes as provided by the survey (by others). All other culverts, where present, are also assumed to have their full flow capacity, regardless of their surveyed condition, given that this is considered to be a maintenance issue.

All other PCSWMM model parameters have been held constant from the calibration models.

6.2 RURALLY SERVICED NETWORKS – MODEL RESULTS

6.2.1 DESIGN STORMS

Overall Network Results

The existing conditions modelling has been applied for the simulation of the 25 mm, 2 Year, 5 Year, and 100 Year design storm events as outlined in Section 5.1. The total outlet peak flow rates from each network to their ultimate receiver have been summed and are presented in Table 6.1. Detailed peak flow results to individual outlets are presented in Appendix C.

[Note: The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.]

The results in Table 6.1 indicate that overall, Networks A and F have the greatest total peak flow rates for all design storm events, reflecting their larger relative drainage area.

Ditch Performance Analysis

The conveyance performance of the roadside ditch systems have been evaluated based on the simulated depth of water within each ditch section (ref. Drawing 13 for typical sections). The ROW sections within the study area generally have a consistent ROW width (as per discussion and assessment in Section 3.3.1) with the exception of the four (4) identified streets in Section 3.3.1 and are considered appropriate for the analysis of the ditch performance based on the depth of flow conveyance. Consistent with the approach applied in the Pilot Study (Amec Foster Wheeler, August 2016), ditch performance has been classified based on the expected maximum conveyance extents:

— Within the ditch
— Beyond the ditch but within the roadway right-of-way (ROW)

— Beyond the roadway ROW (i.e. onto private property)

The simulated ditch performance under existing conditions for the 5 Year and 100 Year Design Storm events is presented in Drawings DP5 (4-11) and DP100 (4-11) respectively.

A tabular summary of simulated ditch performance for all storm events noted in Section 5 (25 mm, 2-year, 5-year and 100-year storm events) is presented in Table 6.2 (by length) and 6.3 (by percentage), for the total 60 km+/- of modelled ditch systems.

Table 6.1. Total Simulated Peak Flow (m3/s) at Primary Drainage Network Outlets for Design Storm Generated Results – Existing Conditions

NETWORK	NETWORK DRAINAGE AREA (ha)	AREA (ha)	RECEIVER	STORM EVENT			
				25 MM	2 YEAR	5 YEAR	100 YEAR
A	50.02	35.61	Ancaster Creek	0.24	0.94	2.01	4.93
		14.42	Tiffany Creek	0.11	0.60	1.00	2.34
B	29.67	3.75	Ancaster Creek	0.03	0.17	0.30	0.62
		25.92	Tiffany Creek	0.25	0.56	0.78	2.69
C [1]	35.99	57.99	Ancaster Creek	0.41	1.51	2.23	4.52
D [1]	38.89	16.89	Sulphur Creek	0.14	0.47	0.75	1.39
E	31.45	21.35	Big Creek	0.12	0.40	0.57	0.95
		10.09	Sulphur Creek	0.09	0.36	0.61	1.62
F	46.05	46.05	Sulphur Creek	0.39	1.57	2.80	6.27
G	49.88	49.88	Sulphur Creek	0.31	1.45	2.34	5.02
H	4.05	4.05	Ancaster Creek	0.06	0.28	0.40	0.60
I	13.41	13.41	Ancaster Creek	0.22	0.65	0.89	2.08
J	10.84	10.00	Ancaster Creek	0.07	0.27	0.45	0.71
		0.85	Big Creek	0.01	0.05	0.08	0.16
K	13.52	8.07	Ancaster Creek	0.07	0.28	0.42	0.79
		5.45	Tiffany Creek	0.17	0.41	0.63	1.02
L	2.53	2.53	Big Creek	0.04	0.16	0.25	0.51

Table 6.2. Simulated Ditch Performance Summary by Length under Existing Conditions (Design Storms)

STORM EVENT	WITHIN DITCH (m)	WITHIN ROW (m)	BEYOND ROW (m)	TOTAL
25 mm	58,792	1,239	18	60,049
2 Year	54,522	5,159	368	60,049
5 Year	49,228	9,787	1,034	60,049
100 Year	35,684	20,213	4,152	60,049

Table 6.3. Simulated Ditch Performance Summary by Percentage under Existing Conditions (Design Storms)

STORM EVENT	WITHIN DITCH (%)	WITHIN ROW (%)	BEYOND ROW (%)
25 mm	97.9	2.1	0.0
2 Year	90.8	8.6	0.6
5 Year	82.0	16.3	1.7
100 Year	59.4	33.7	6.9

The results presented in Tables 6.2 and 6.3 indicate that the vast majority of the existing ditches/ROW can contain the 25 mm and 2 year design storm event flows (99% +/-). Similarly, greater than 98 % (+/-) and 93 % (+/-) of the ditches/ROW can convey the 5 year and 100 year design storm event flows respectively within the ROW under existing conditions.

A tabular summary of the simulated 5-year and 100-year storm event ditch performance by primary drainage network area is presented in Tables 6.4 and 6.5 respectively. Results in both tables are summarized both by length and by percentage.

The results presented in Table 6.4 demonstrate that the simulated 5-year ditch/ROW performance is poorest for two (2) networks (E and J) which have the highest relative rate of sections exceeding the limits of the ROW (7 and 4% respectively). The remainder of the networks indicates exceedance rates of 2% or less. Network E also has the highest simulated rate of flows outside of the ditch, but within the ROW for the 5-year storm event (28%). Network D and G also have rates of ditch exceedance greater than 20% (24 and 21% respectively).

Table 6.4. Simulated Ditch System Performance under Existing Conditions – 5-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (M)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	6,229	513	69	91	8	1
B	5,119	444	132	90	8	2
C	7,020	1,342	51	81	16	1
D	7,557	2,467	111	75	24	1
E	3,545	1,567	392	64	28	7
F	6,562	1,344	83	82	17	1
G	5,472	1,487	102	78	21	1
H	437	0	0	100	0	0
I	1,557	176	0	90	10	0
J	2,088	178	91	89	8	4
K	2,583	269	3	90	9	0
L	1,059	0	0	100	0	0
Total	**49,228**	**9,787**	**1,034**	**82**	**16**	**2**

Table 6.5. Simulated Ditch System Performance under Existing Conditions – 100-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (m)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	5,214	1,327	271	77	19	4
B	4,096	1,367	233	72	24	4
C	5,144	2,911	358	59	34	4
D	4,436	4,769	929	44	47	9
E	2,578	1,791	1,134	47	33	21
F	4,501	2,955	534	56	37	7
G	3,414	3,284	362	48	47	5
H	297	140	0	68	32	0
I	1,265	406	62	73	23	4
J	1,662	518	177	71	22	8
K	2,018	745	93	71	26	3
L	1,059	0	0	100	0	0
Total	**35,684**	**20,213**	**4,152**	**59**	**34**	**7**

Similar to the simulated ditch/ROW performance for the 5-year storm event, the results shown in Table 6.5 indicate that the 100-year ditch performance is poorest for network E which has the highest relative rate of sections exceeding the limits of the ditch/ROW (21%). The remainder of the networks indicate exceedance rates of 9% or less. Networks H and L indicate no exceedance of the roadway ROW in any location for the 100-year storm event.

The preceding tabular results, as well as Drawings DP5 and DP100 are intended to serve as a basis of comparison to the future "as of right" scenario, as described further in Section 7.

Culvert Performance and Spill Analysis

As noted under existing conditions, the hydraulic modelling has been developed to include spill conditions representing roadway overtopping. These elements have been represented by weirs and / or conduits within the model, set to a spill elevation sourced from either survey, or DEM data.

In order to assess the potential for increased level of flooding and hydraulic capacity issues, the 100-year design storm has been used to assess the following spill types under existing conditions:

- Overtopping of a road from the adjacent ditches due to limited ditch capacity
- Overtopping of a road at a culvert due to limited culvert and ditch capacity
- Overtopping of a road with a storm sewer system and catch basins in the adjacent ditches, due to limited storm sewer and ditch capacity

Although primarily rurally serviced, localized storm sewer sections are present, and have been included in this assessment for identification of rural system road overtopping. It is understood however that storm sewers are not typically designed to convey the peak flow rates generated from the 100-year storm event. Additional spills including roadway overtopping due to spills over driveways or into separate ditch systems have been included in the model for flow continuity. However, these conditions have not been reported, as these are assumed to be minor and unrelated to municipal culvert performance under major storm events. Spills into private property have been reported as part of a separate section.

As previously cited, the subject culverts have been modelled assuming regular maintenance works have been completed (i.e. full conveyance area available). Therefore, any simulated spills or roadway overtopping in the rural networks is considered indicative of limited hydraulic capacity being provided by the existing municipal culverts. Additionally, the "Hot Spot Flooding" information received from the City, as discussed in Section 4.5.3, has been compared to the simulated spill results for each network area.

The number of spills (i.e. flows greater than 0 m3/s) occurring in each network under the 100-year storm event, and comparison to the SWM Hot Spot Flooding history have been summarized in Table 6.6.

Table 6.6. Simulated 100-Year Spill Summary under Existing Conditions

NETWORK AREA	SIMULATED SPILL CONDITION – COUNT			TOTAL NUMBER OF SIMULATED SPILLS	SWM HOT SPOT FLOODING[1]
	OVERTOPPING ROAD (DITCH)	OVERTOPPING ROAD (CULVERT)	OVERTOPPING ROAD (STORM)		
A	5	13	2	20	24
B	2	7	2	11	18
C	4	10	0	14	4
D	6	6	0	12	7
E	4	6	0	10	6
F	3	7	1	11	20
G	4	7	6	17	16
H	0	0	2	2	1
I	1	4	2	7	6
J	2	5	0	7	2
K	1	5	0	6	2
L	0	1	0	1	4
Total	32	71	15	118	110

Note: [1] SWM Hot Spot Flooding totals taken from Table 4.9 in Section 4.5, excluding sewer backups.

The simulation results indicate that areas A to G experience the largest number of simulated spills across roadways, ranging from spills in 10 to 20 different locations. The dominant cause for stormwater reaching the roadway in all network areas is due to culvert overtopping, indicating there are several culverts limiting major flow conveyance under existing conditions.

The larger number of simulated spills in areas A, B, F and G generally corresponds to the frequency of SWM related Hot Spot Flooding calls in these areas. The majority of the Hot Spot Flooding calls in these areas, as received by the City, relate to either catchbasin or ditch flooding. These results are further confirmed through the simulated culvert overtopping results, indicating there are also capacity issues in these "hybrid" areas. These issues are particularly dominant in the most downstream areas of each network, due to the larger upstream drainage areas.

The simulated performance results in areas C, D and E indicate there are major storm capacity issues in several ditches, culverts and major system spill areas, however there are currently fewer Hot Spot Flooding calls in these areas. This could be attributable to a number of different factors, including fewer major storm events in these areas, reduced reporting to the City by residents, or differences in local conditions (potentially soils with relatively higher infiltration capacities), among other reasons.

These road overtopping conditions have been simulated under the assumption that the culverts do not have hydraulic deficiencies such as being crushed or blocked. Culvert improvements, such as upsizing or implementing culverts at spill locations, will be reviewed as part of the mitigation strategy.

Conveyance Through Private Property

Runoff conveyed through private property has been identified and summarized in Table 6.7. ID numbers are also referenced on the attached drainage system performance drawings. No municipal addresses have been included, given concerns about potential impacts to private properties and associated privacy issues.

Table 6.7. Summary of Drainage Systems with Conveyance Through Private Property

NETWORK	ID	DRAINAGE AREA (ha)	SYSTEM TYPE (MAJOR OR MINOR)	DEFINED MAJOR SYSTEM	EASEMENT	STORM EVENTS CONVEYED
A	P1	11.7	Minor	No	No	≥2 Year
	P2	2.00	Minor	No	No	≥2 Year
	P3	21.35	Major/Minor	No	No	≥2 Year
	P4	0.22	Major	Yes	No	≥2 Year
	P5	4.41	Major/Minor	Yes	Yes	≥2 Year
	P6	14.08	Major/Minor	Yes	Yes	≥2 Year
	P7	0.84	Major	Yes	No	≥2 Year
	P8	0.91	Major	No	No	≥2 Year
	P9	4.04	Major/Minor	Yes	No	≥2 Year
	P37	0.04	Minor	No	No	≥2 Year
	P38	0.27	Minor	No	No	≥2 Year
B	P10	12.97	Major/Minor	No	Yes	≥2 Year
	P11	1.51	Major	No	No	≥2 Year
	P12	9.71	Major/Minor	No	No	≥2 Year
	P13	3.23	Minor	No	No	≥2 Year
C	P14	3.41	Major	No	No	≥2 Year
	P15	5.33	Minor	No	No	≥2 Year
	P16	12.94	Major	Yes	No	≥2 Year
	P17	0.68	Minor	No	No	≥2 Year
	P18	1.43	Major	No	No	≥100 Year
E	P19	3.72	Major	No	No	≥2 Year
	P20	0.89	Major/Minor	No	Yes	≥2 Year
	P21	5.44	Major	No	No	≥2 Year
F	P22	1.80	Major	Yes	No	≥2 Year
	P23	2.20	Major	Yes	No	≥2 Year
	P24	3.34	Major	No	No	≥2 Year
	P25	1.76	Major	No	No	≥2 Year
	P26	1.64	Major/Minor	Yes	Yes	≥2 Year
	P27	1.37	Major	No	No	≥2 Year
	P28	1.18	Major	Yes	No	≥2 Year
	P29	12.07	Major	Yes	No	≥2 Year
G	P30	3.68	Major	Yes	No	≥2 Year

NETWORK	ID	DRAINAGE AREA (ha)	SYSTEM TYPE (MAJOR OR MINOR)	DEFINED MAJOR SYSTEM	EASEMENT	STORM EVENTS CONVEYED
	P31	2.33	Major	Yes	Yes	≥2 Year
	P32	1.67	Major	No	Yes	≥2 Year
	P33	2.47	Major	Yes	No	≥2 Year
	P34	5.96	Major	No	No	≥100 Year
I	P35	1.31	Major	Yes	Yes	≥2 Year
K	P36	6.03	Major/Minor	Yes	Yes	≥2 Year

The information presented in Table 6.7 demonstrates that all the identified locations convey modelled (2, 5, and 100 year) design storm events through private property, with the exception of two (2) locations (P18 and P34) which were only required for the 100-year storm event. The simulated peak runoff depth within the ROW at these two (2) locations is considered sufficient to exceed the estimated limits of the ROW due to a lack of an adequate major system outlet. It is expected that the thirty-six (36) locations that convey all design storm events would receive flows as these are the primary outlets for those specific areas. At the nine (9) locations where there is both a major and minor system conveyed through private property, the minor system (culverts or storm sewers) conveys the received flow prior to the major system conveying overflows (i.e. the major system is not engaged until the minor system capacity is exceeded).

The private property locations with both major and minor system conveyance and easements that do not have a defined major system have been reviewed for opportunities to increase or improve minor system capacity as part of the mitigation analysis (ref. Section 8), in order to relieve the conveyance through the major system.

6.2.2 CLIMATE CHANGE SCENARIOS

The existing conditions modelling has been executed for the three (3) climate change adjusted rainfall approaches presented in Section 5.3, namely the Ontario Climate Change Data Portal (OCCDP), MTO IDF Curve Lookup, and the UWO IDF Climate Change Tool (version 3.0). Alternate IDF data from these three (3) sources (2080 forecast year) have been used to generate modified 5 and 100-year return period design storms. The total outlet peak flow rates from each network to their ultimate receiver for the adjusted 5-year storm events have been summed and are presented in Table 6.8, along with≥ calculated differences as compared to base IDF data (Table 6.1). A similar comparison for the 100-year storm event has been presented in Table 6.9. Positive values indicate an increase in peak flows as compared to base IDF data. Detailed peak flow results to individual outlets are presented in Appendix C.

Table 6.8. Total Simulated Peak Flow at Primary Drainage Network Outlets for Climate Change Altered Rainfall Scenarios and Comparison to Existing IDF – 5-Year Storm Event

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)				DIFFERENCE AS COMPARED TO BASE IDF DATA (%)		
			BASE IDF	OCCDP	MTO	UWO	OCCDP	MTO	UWO
A	35.61	Ancaster Creek	2.01	2.92	2.91	2.60	+45	+44	+29
	14.42	Tiffany Creek	1.00	1.31	1.31	1.20	+31	+31	+20
B	3.75	Ancaster Creek	0.30	0.42	0.42	0.38	+39	+39	+24
	25.92	Tiffany Creek	0.78	1.22	1.21	1.04	+57	+56	+34
C[1]	57.99	Ancaster Creek	2.23	2.85	2.84	2.62	+28	+27	+17
D[1]	16.89	Sulphur Creek	0.75	1.03	1.03	0.91	+38	+37	+22
E	21.35	Big Creek	0.57	0.70	0.70	0.65	+23	+22	+15
	10.09	Sulphur Creek	0.61	0.92	0.91	0.79	+51	+51	+30
F	46.05	Sulphur Creek	2.80	3.98	3.96	3.43	+42	+41	+23
G	49.88	Sulphur Creek	2.34	3.15	3.13	2.89	+35	+34	+23
H	4.05	Ancaster Creek	0.40	0.48	0.48	0.44	+21	+21	+12
I	13.41	Ancaster Creek	0.89	1.15	1.15	1.01	+29	+29	+13
J	10.00	Ancaster Creek	0.45	0.56	0.55	0.52	+24	+23	+15
	0.85	Big Creek	0.08	0.10	0.10	0.09	+32	+31	+19
K	8.07	Ancaster Creek	0.42	0.53	0.53	0.49	+26	+25	+16
	5.45	Tiffany Creek	0.63	0.76	0.75	0.71	+21	+21	+13
L	2.53	Big Creek	0.25	0.33	0.33	0.30	+34	+33	+20
Average							**+34**	**+33**	**+20**

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The results presented in Table 6.8 (5-year storm event) indicate that peak flows generated using the OCCDP and MTO datasets generate similar total increases in peak flows of approximately 34% +/- for the 5-year storm event on average. The UWO dataset generated peak flows with a lesser increase of approximately 20% +/-.

Table 6.9. Total Simulated Peak Flow at Primary Drainage Network Outlets for Climate Change Altered Rainfall Scenarios and Comparison to Existing IDF – 100-Year Storm Event

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)				DIFFERENCE AS COMPARED TO BASE IDF DATA (%)		
			BASE IDF	OCCDP	MTO	UWO	OCCDP	MTO	UWO
A	35.61	Ancaster Creek	4.93	7.73	6.34	8.88	+57	+29	+80
	14.42	Tiffany Creek	2.34	3.59	2.91	4.19	+53	+24	+79
B	3.75	Ancaster Creek	0.62	0.83	0.72	0.95	+34	+16	+52
	25.92	Tiffany Creek	2.69	4.57	3.54	5.54	+70	+32	+106
C[1]	57.99	Ancaster Creek	4.52	6.54	5.39	8.01	+45	+19	+77
D[1]	16.89	Sulphur Creek	1.39	1.67	1.52	1.80	+20	+9	+29
E	21.35	Big Creek	0.95	1.26	1.08	1.57	+33	+14	+66
	10.09	Sulphur Creek	1.62	2.34	1.95	2.76	+45	+21	+71
F	46.05	Sulphur Creek	6.27	7.70	6.97	8.52	+23	+11	+36
G	49.88	Sulphur Creek	5.02	7.17	6.04	8.35	+43	+20	+66
H	4.05	Ancaster Creek	0.60	0.65	0.62	0.69	+9	+4	+14
I	13.41	Ancaster Creek	2.08	2.75	2.40	2.99	+33	+16	+44
J	10.00	Ancaster Creek	0.71	0.86	0.78	1.18	+21	+9	+65
	0.85	Big Creek	0.16	0.21	0.18	0.26	+37	+17	+65
K	8.07	Ancaster Creek	0.79	1.08	0.94	1.38	+37	+19	+75
	5.45	Tiffany Creek	1.02	1.17	1.11	1.24	+15	+9	+22
L	2.53	Big Creek	0.51	0.71	0.60	0.82	+40	+18	+63
Average							**+34**	**+33**	**+20**

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The results presented in Table 6.9 (100-year storm event) indicate a greater degree of variability in the predicted increase in peak flows by location than for the 5-year storm event. In some locations, simulated differences are less than 10%, while in others the predicted increase exceeds 40%. The results for the three (3) different IDF sources also vary. Whereas for the 5-year storm event the UWO altered IDF data generated the lowest simulated increase, for the 100-year storm event it generates the greatest.

In addition to the preceding summary of expected changes in peak flows, an assessment of the simulated performance of the ditch systems under the three (3) climate change data sources has also been undertaken. The results for the 5 and 100 year storm events are presented in Table 6.10.

Table 6.10. Simulated Ditch Performance Summary by Length under Existing Conditions for Climate Change Altered Rainfall Scenarios

DATA SOURCE AND EVENT		SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
RETURN PERIOD (YEARS)	DATASET	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
5-Year	Base IDF	49,228	9,787	1,034	82	16	2
	OCCDP	44,619	13,985	1,444	74	23	2
	MTO	44,619	14,052	1,377	74	23	2
	UWO	46,309	12,494	1,246	77	21	2
100-Year	Base IDF	35,684	20,213	4,152	59	34	7
	OCCDP	28,958	23,400	7,691	48	39	13
	MTO	32,048	22,444	5,556	53	37	9
	UWO	24,861	24,336	10,852	41	41	18

The results presented in Table 6.10 indicate that greater than 97 % (+/-) of the modelled ditches/ROW can convey the climate change altered 5-year storm event within the ROW under existing conditions. This represents a marginal decrease from base IDF conditions (Table 6.3) which indicated that greater than 98 % (+/-) of the ditch flow would be expected to be contained within the roadway ROW.

A greater difference and variability is evident under the 100-year storm event, with results indicating between 80 and 90% of the 100-year storm event being contained within the ditches/ROW, as compared to an estimated 92% under base IDF conditions (Table 6.5). As discussed with respect to simulated peak flows (Table 6.9), the results generated by the UWO dataset indicate the largest degree of change (and poorest performance), with an 11% increase in flow exceeding the ditches/ROW, and a 7% increase in flow exceeding the ditches but remaining within the roadway ROW.

6.2.3 HISTORIC EXTREME STORMS

The existing conditions modelling has been executed for the three (3) local historic extreme storm events presented in Section 5.4, specifically:

- July 26, 2009 (Red Hill Valley Storm Event)
- July 22, 2012 (Binbrook/Shadyglen Storm Event)
- August 14, 2014 (Burlington Storm Event)

The total outlet peak flow rates from each network to their ultimate receiver for these storm events have been summed and are presented in Table 6.11. For comparison purposes, the simulated 100-year storm event (design storm) has also been included. Detailed peak flow results to individual outlets are presented in Appendix C.

Table 6.11. Total Simulated Peak Flow at Primary Drainage Network Outlets for Historic Extreme Storm Events

NETWORK	AREA (HA)	RECEIVER	STORM EVENT PEAK FLOWS (m^3/s)			
			100 YEAR DESIGN STORM	RED HILL VALLEY	BINBROOK/ SHADYGLEN	BURLINGTON
A	35.61	Ancaster Creek	4.93	6.35	8.31	4.55
	14.42	Tiffany Creek	2.34	2.77	3.97	2.17
B	3.75	Ancaster Creek	0.62	0.74	0.89	0.54
	25.92	Tiffany Creek	2.69	3.82	5.70	3.19
C[1]	57.99	Ancaster Creek	4.52	6.52	8.64	5.57
D[1]	16.89	Sulphur Creek	1.39	1.63	1.80	1.47
E	21.35	Big Creek	0.95	1.36	1.79	1.33
	10.09	Sulphur Creek	1.62	1.88	2.51	1.36
F	46.05	Sulphur Creek	6.27	7.04	8.31	5.80
G	49.88	Sulphur Creek	5.02	6.64	8.70	5.43
H	4.05	Ancaster Creek	0.60	0.62	0.68	0.58
I	13.41	Ancaster Creek	2.08	2.55	2.94	1.96
J	10.00	Ancaster Creek	0.71	1.00	1.39	0.85
	0.85	Big Creek	0.16	0.19	0.23	0.12
K	8.07	Ancaster Creek	0.79	1.05	1.46	0.82
	5.45	Tiffany Creek	1.02	1.13	1.20	0.83
L	2.53	Big Creek	0.51	0.61	0.73	0.40

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The simulated results demonstrate that these local extreme storms are comparable to, and in many cases greater than, a 100-year return period as generated using a design storm distribution and current IDF data. The simulated peak flows from the Binbrook/Shadyglen storm event in particular are comparable to a climate-change altered 100-year storm event based on the most conservative condition (UWO dataset).

In addition to the preceding summary of peak flows, an assessment of the simulated performance of the ditch systems under the three (3) historic extreme storms has also been undertaken. The results are presented along with the 100 year storm event (design storm-based) in Table 6.12.

Table 6.12. Simulated Ditch Performance Summary by Length under Existing Conditions for Historic Extreme Storm Event

DATA SOURCE AND EVENT	SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
100-Year (Design Storm)	35,684	20,213	4,152	59	34	7
Red Hill Valley	26,050	23,989	10,009	43	40	17
Binbrook/Shadyglen	31,385	21,743	6,920	52	36	12
Burlington	37,578	17,418	5,052	63	29	8

As would be expected, the results presented in Table 6.12 indicate variable results depending on the storm event simulated. All three (3) storm events however indicate an increase in ditches with flows extending outside of the roadway ROW as compared to the 100-year design storm event. Consistent with the change in simulated peak flows (Table 6.11), the results indicate that the Binbrook/Shadyglen storm event would generate the greatest simulated decrease in ditch performance, with 82% contained within the roadway ROW (as compared to 93% for the 100-year design storm event).

6.3 ASSESSMENT OF EXTERNAL AREAS AND DOWNSTREAM LOCATIONS – MODEL RESULTS

6.3.1 DESIGN STORMS

The existing conditions modelling (including external drainage areas, as per Section 3.2.5, and Drawing 16) has been applied for the simulation of the 5 and 100 year synthetic design storms, as well as the Regional Storm Event (Hurricane Hazel). These events have been simulated using the US SCS Curve Number infiltration method, as was initially developed and not the revised Green & Ampt infiltration method, since the results are based on single event simulation (and not continuous simulation). These events have been simulated as a basis of comparison for the continuous simulation peak flow rate frequency analysis presented in subsequent sections.

The resulting simulated peak flow rates at selected locations/nodes of interest for downstream receivers are presented in Table 6.13 for the 5-year, 100-year, and Regional Storm events. The results are presented by watercourse system, typically from upstream to downstream.

Table 6.13. Simulated Peak Flow Rates at Downstream Nodes of Interest for Selected Design Storms and the Regional Event – Existing Conditions Scenario Simulated using the CN Infiltration Methodology

RECEIVER	JUNCTION NAME	SERVICE AREAS	AREA (ha)	EXISTING CONDITIONS PEAK FLOW RATES (m^3/s)		
				5 YEAR	100 YEAR	REGIONAL
Ancaster Creek	AC_01	J and K	369.1	1.04	2.60	15.90
	AC_03	C, J, and K	380.9	1.55	3.49	16.96
	AC_04	C, J, and K	460.5	1.76	4.11	17.30
	AC_06	C and D	48.9	1.71	3.28	4.57
	AC_07	C and D	73.8	2.09	5.08	6.39
	AC_08	C, D, J, and K	533.4	5.14	13.01	30.97
	AC_09	C, D, J, and K	653.4	6.59	17.33	40.30
	AC_10	B-D and I-K	763.4	6.19	16.71	49.36
	AC_12	B-D and H-K	768.7	6.25	16.85	49.56
	AC_13	B-D and H-K	770.2	6.26	16.89	49.65
	AC_14	B-D and H-K	780.6	7.59	19.94	55.93
	AC_15	B-D and H-K	837.1	7.59	19.92	55.96
	AC_16	A-D and H-K	839.7	7.61	19.93	56.25

RECEIVER	JUNCTION NAME	SERVICE AREAS	AREA (ha)	EXISTING CONDITIONS PEAK FLOW RATES (m^3/s)		
				5 YEAR	100 YEAR	REGIONAL
	AC_18	A	33.0	1.46	3.97	4.06
	AC_19	A-D and H-K	872.7	7.95	20.85	59.35
	AC_21	A-D and H-K	1902.4	23.21	65.30	131.60
	AC_22	A-K	3846.1	35.86	99.99	273.60
Sulphur Creek	SC_01	D and E	82.1	9.78	18.94	10.69
	SC_02	D, E, and G	18.1	9.48	18.79	10.71
	SC_03	E	9.1	0.48	1.39	1.09
	SC_04	D, E, and G	109.5	10.73	22.88	14.35
	SC_05	D-G	111.1	11.07	22.68	14.54
	SC_06	D-G	129.2	11.23	24.02	15.83
	SC_07	D-G	235.9	13.29	29.79	27.63
	SC_08	D-G	991.8	14.44	38.60	79.66
	SC_09	D-G	1701.6	15.83	43.75	126.30
	SC_11	F and G	29.6	3.17	7.37	7.36
	SC_12	F and G	478.5	6.03	16.42	38.14
	SC_14	G	46.4	1.62	3.49	3.37
	SC_15A	G	253.0	0.70	3.63	4.02
	SC_15B	G	53.3	2.09	6.57	7.24
Tiffany Creek	TC_01	External	440.2	10.33	21.10	21.85
	TC_02	K	653.1	13.09	28.09	38.33
	TC_03	B and K	787.6	15.31	37.34	50.16
	TC_05	B and K	879.3	16.98	40.53	58.72
	TC_06	A, B, and K	893.8	17.36	41.75	60.13

The values presented in Table 6.13 are intended to serve as a basis of comparison to those generated for the same land use scenario but using continuous simulation (Section 6.3.2) as well as those using the design storm approach however under “as of right” conditions (Section 7), in order to quantify the expected level of impact due to land use changes associated with that scenario.

6.3.2 CONTINUOUS SIMULATION – PEAK FLOWS, EROSION AND WATER BUDGET

Peak Flows

As described in Sections 3.2.5 and 4.4.2, a secondary PCSWMM model has been developed using the Green & Ampt infiltration methodology for use in continuous simulation, as the SCS CN method is not able to adequately address project objectives. The continuous simulation model has been applied to assess frequency flows (for comparison to the design storm generated values), erosion durations at key downstream locations, and generate an overall water budget. As outlined in Section 5.2, a 55-year continuous dataset of hourly precipitation (1962-2016) for the Hamilton RBG station (Environment Canada) has been assembled and executed for this assessment.

The annual maximum series of peak flow rates has been extracted from the modelling results for key junction nodes of interest, consistent with the locations assessed under the previous event-based approach (Section 6.3.1). A frequency analysis of the resulting series has been completed in order to estimate frequency flows using the program HEC-SSP; complete results are included in Appendix C. A Log Pearson Type III frequency/probability distribution has been applied to estimate the return period frequency peak flow rates. The resulting estimated peak flow rates for the 5 and 100 year return periods for key nodes of interest are presented in Table 6.14, and have been compared to the previously estimated values using a design storm approach (Table 6.13). A negative value indicates the design storm peak flow rate is greater than the frequency analysis peak flow rate, while a positive value indicates the frequency analysis peak flow rate is greater than the design peak flow rate.

Table 6.14. Simulated Peak Flow Rates (m^3/s) at Downstream Nodes of Interest based on Continuous Simulation Modelling – Existing Conditions Scenario using the Green & Ampt Infiltration Methodology

RECEIVER	JUNCTION NAME	CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE AS COMPARED TO DESIGN STORM GENERATED PEAK FLOW RATES (m^3/s)		DIFFERENCE AS COMPARED TO DESIGN STORM GENERATED PEAK FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
Ancaster Creek	AC_01	1.80	3.80	+0.76	+1.20	+73	+46
	AC_03	2.20	4.30	+0.65	+0.81	+42	+23
	AC_04	2.30	4.40	+0.54	+0.29	+31	+7
	AC_06	1.40	2.30	-0.31	-0.98	-18	-30
	AC_07	1.70	3.20	-0.39	-1.88	-19	-37
	AC_08	5.90	11.30	+0.76	-1.71	+15	-13
	AC_09	6.80	15.30	+0.21	-2.03	+3	-12
	AC_10	7.50	13.90	+1.31	-2.81	+21	-17
	AC_12	7.50	14.00	+1.25	-2.85	+20	-17
	AC_13	7.50	14.00	+1.24	-2.89	+20	-17
	AC_14	10.10	19.10	+2.51	-0.84	+33	-4
	AC_15	9.80	18.80	+2.21	-1.12	+29	-6
	AC_16	9.80	18.90	+2.19	-1.03	+29	-5
	AC_18	1.30	3.10	-0.16	-0.87	-11	-22
	AC_19	10.70	21.20	+2.75	+0.35	+35	+2
	AC_21	29.40	63.40	+6.19	-1.90	+27	-3
	AC_22	46.00	117.10	+10.14	+17.11	+28	+17
Sulphur Creek	SC_01	4.20	7.50	-5.58	-11.44	-57	-60
	SC_02	4.20	7.50	-5.28	-11.29	-56	-60
	SC_03	0.30	0.60	-0.18	-0.79	-38	-57
	SC_04	5.20	9.70	-5.53	-13.18	-52	-58
	SC_05	5.20	9.80	-5.87	-12.88	-53	-57
	SC_06	5.40	10.60	-5.83	-13.42	-52	-56
	SC_07	8.40	17.10	-4.89	-12.69	-37	-43
	SC_08	13.00	36.50	-1.44	-2.10	-10	-5

RECEIVER	JUNCTION NAME	CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE AS COMPARED TO DESIGN STORM GENERATED PEAK FLOW RATES (m^3/s)		DIFFERENCE AS COMPARED TO DESIGN STORM GENERATED PEAK FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
	SC_09	19.60	54.80	+3.77	+11.05	+24	+25
	SC_11	2.80	5.60	-0.37	-1.77	-12	-24
	SC_12	9.20	19.90	+3.17	+3.48	+53	+21
	SC_14	1.30	2.30	-0.32	-1.19	-20	-34
	SC_15A	0.10	3.70	-0.60	+0.07	-86	+2
	SC_15B	1.40	3.90	-0.69	-2.67	-33	-41
Tiffany Creek	TC_01	6.20	11.20	-4.13	-9.90	-40	-47
	TC_02	10.30	20.70	-2.79	-7.39	-21	-26
	TC_03	13.30	26.10	-2.01	-11.24	-13	-30
	TC_05	15.70	30.10	-1.28	-10.43	-8	-26
	TC_06	16.10	31.10	-1.26	-10.65	-7	-26

The results presented in Table 6.14 generally indicate that the continuous simulation peak flow rates provide lower frequency flows as compared to event-based results, particularly for the 5-year storm event, where the continuous simulation generated results are 4% lower on average than the results from the design storm generated modelling, however differences vary notably between -86% to +73%. Simulated decreases in peak flows likely largely reflect the temporal resolution of the continuous precipitation dataset and relative intensities (i.e. hourly as compared to 10-minute data for design storms). In addition to differences in rainfall intensities, some of the difference is also likely attributable to differences in the infiltration methodology (i.e. Green & Ampt methodology for continuous simulation modelling, and SCS Curve Number methodology for design storm modelling).

The 100 year continuous simulation frequency flow results indicate a more consistent average decrease of 19% in peak flows overall as compared to design storm simulated results. Similar to the results for the 5-year storm event however, differences are not consistent (-60% to +46%), however the overall trend is negative. Reasons for the differences are generally consistent with those suggested for the 5-year storm event results. Differences may also reflect relative sensitivities to the influence of antecedent rainfall conditions in some cases, as well as the greater uncertainty with respect to frequency distribution fitting for the estimation of the 100-year storm event (i.e. based on 55-years worth of data). Differences in overall hydrograph timing may also be a factor in some locations. As an example, the upper reaches of Sulphur Creek in particular indicate that the continuous simulation results generate lower peak flows than those generated using design storms. Contrarily, higher peak flow rates for the 100-year design storm event have been generated at the lower reach of Sulphur Creek at junction SC_09, a confluence location for two Sulphur Creek tributaries.

Overall, the generated peak flow results provided in Table 6.14 are provided for information purposes only. The results generated using the SCS Curve Number modelling (as per Table 6.13) are considered primary for the estimation of peak flows. The developed continuous simulation modelling has been primarily applied for the estimation of erosion and water budget impacts, as described in subsequent sections.

Erosion

The continuous simulation results have also been applied for the erosion assessment based on the duration of flow exceedance above the erosion thresholds generated for the current study, as previously presented in Table 4.1. The results of the duration analyses are presented in Table 6.15.

Table 6.15. Simulated Duration of Erosion Threshold Exceedances under Existing Conditions

WATERCOURSE SITE	JUNCTION NAME	CONTRIBUTING STUDY DRAINAGE AREAS	DRAINAGE AREA (HA)	DURATION OF EXCEEDANCE (DAYS)	DURATION OF EXCEEDANCE (% OF TOTAL SIMULATION)
Ancaster Creek Tributary	AC_07	Area C and D	73.83	190.9	0.95
Ancaster Creek Tributary	AC_18	Area A	33.04	6.4	0.03
Sulphur Creek Tributary	SC_04	Area D and E	109.48	299.5	1.49
Sulphur Creek Tributary	SC_11	Area F	29.6	63.6	0.32
Sulphur Creek Tributary	SC_14	Area G	46.38	4.4	0.02

As per the erosion analysis completed by AquaLogic (Section 4.1), locations SC_04 and SC_11, located on Sulphur Creek, have been noted as being moderately unstable. Location SC_04 indicates the highest simulated rate of exceedance (1.49%), while SC_11 indicates the third highest rate of exceedance (0.32%). The other three locations (AC_07, AC_18, and SC_14) have relatively nominal exceedance rates, which is consistent with the geomorphological assessment, as these locations were classified as stable. These simulated durations are intended to provide a basis of comparison to the future as-of–right land use scenario and associated impacts, as presented in Section 7.

Water Budget

The continuous simulation modelling results have been applied to develop a water budget using the overall system results generated by the existing conditions modelling for both the rurally-serviced areas and external areas. This will provide a basis for the hydrologic relationships within the contributing watershed. Given the length of the continuous simulation (55 years), and the associated high resolution required for hydraulic elements, extracting water budget results for the study area exclusively is not considered appropriate. Given that external areas employ the same parameters under all scenarios, it is considered that the extracting the data on a system-wide basis is appropriate to adequately assess water budget changes under as of right conditions (Section 7) and verify the effectiveness of subsequent proposed mitigation measures (Section 8).

The total rainfall, runoff, and losses depths have been determined for the modelled area and are summarized in Table 6.16 on both an average monthly and annual basis.

The results presented in Table 6.16 indicate that 142 mm of the total 818 mm average annual precipitation becomes surface runoff, which represents only 17 % of the total precipitation. This likely reflects the relatively permeable soils in the area, as well as the higher degree of disconnected impervious area, which provides a secondary opportunity for infiltration given the applied approach to subcatchment routing. Notwithstanding, the generated fraction of runoff is considered relatively low given the nature of the study area and may reflect elevated infiltration potential associated with the application of the Green & Ampt methodology, particularly given the previously presented results for the 5-year storm event (Table 6.14). This may reflect the lower overall simulated flows with the Green & Ampt methodology as compared to the US SCS Curve Number methodology (as described previously), as well as the reduced temporal resolution of continuous simulation rainfall (hourly data) as compared to discrete event simulation.

Table 6.16. Existing Conditions Average Monthly and Annual Water Budget

MONTH	PRECIPITATION (mm)	RUNOFF (mm)	TOTAL LOSSES (mm)
January	52	9	43
February	48	8	39
March	68	13	55
April	67	11	56
May	72	12	61
June	75	12	63
July	78	14	66
August	75	14	62
September	77	13	64
October	70	12	58
November	72	13	59
December	64	11	52
Average Annual	818	142	677

As previously discussed in Section 5.2, PCSWMM 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 the impacts of these processes.

The simulated water budget results presented in Table 6.16 indicate that approximately 83 % 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.

The simulated water budget under existing conditions is intended to provide a relative basis of comparison to the future as–of-right land use scenario and associated impacts, with a focus being placed on any associated changes in runoff volume, as presented in Section 7 and Section 8.

7 AS-OF–RIGHT LAND USE CONDITIONS MODELLING RESULTS AND IMPACT ASSESSMENT

7.1 LAND USE CHANGES

7.1.1 CHANGE IN IMPERVIOUSNESS

A future land use scenario, referred to as "as of right", has been simulated to assess the impacts on system hydraulics and performance. The as-of-right modelling scenario assumes the build-out of building footprints to the maximum allowable (35% of the lot area). In conjunction with the preceding, it is also expected that lot amenity areas (i.e. driveways, walkways, patios etcetera) would similarly increase with re-development, as observed for the Pilot Study.

The as-of-right imperviousness has been calculated from the existing conditions imperviousness by increasing the Existing Residential (ER) zone building footprint to 35% of the lot area. In order to calculate this increase, the overall ER zone within each network (A through L) has been individually assessed to determine the overall existing imperviousness coverage for building (roof) area only, based on the existing lot area. Separately, the overall resulting building imperviousness for ER areas for each Network has been calculated under the "as-of-right" scenario, with building footprints assumed to be increased to 35% of lot area. These calculations are presented in Table 7.1.

Table 7.1. Summary of Expected Building Area Increases under As-of-Right Conditions

NETWORK	TOTAL ER AREA (ha)	EXISTING CONDITIONS ER BUILDING IMPERV. (%)	OVERALL INCREASE IN IMPERV. TO 35% (%)	ADDITIONAL BUILDING AREA (ha)
A	19.38	16.8	18.2	3.53
B	18.54	20.6	14.4	2.66
C	24.91	20.8	14.2	3.54
D	22.03	25.7	9.3	2.05
E	21.98	19.8	15.2	3.34
F	28.67	18.1	16.9	4.85
G	22.45	18.9	16.1	3.62
H	2.02	22.8	16.0	0.39
I	8.04	21.9	13.1	1.05
J	6.04	21.8	13.2	0.80
K	5.93	20.0	14.8	0.87
L	1.50	23.2	11.8	0.18
TOTAL	**181.49**	**20.3**	**14.4**	**26.88**

The values presented in Table 7.1 indicate an overall increase in building imperviousness of approximately 15%, which represents a relative increase of approximately 72% over existing coverage. The increases presented in Table 7.1 have been applied in the calculation of individual building area imperviousness for subcatchments under the as-of-right scenario. The percentage of building coverage for each individual subcatchment under existing conditions has been increased based on the network specific increases presented in Table 7.1, with the assumption that these increases would result in a corresponding decrease in greenspace area.

The preceding reflects the expected increase in building imperviousness only. As noted previously, amenity area (patios, driveways, etcetera) are also expected to increase in conjunction with building areas as part of the as-of-right future land use. An assessment has been undertaken of the relationship between impervious amenity areas in relationship to building areas under existing conditions, based on a review of aerial photography. The imperviousness of 109 properties has been measured from aerial imagery to initially determine the imperviousness for the study area, with a minimum of five (5) representative residential properties identified for each network (A-L). A graphical presentation of the estimated relationship between amenity areas and building footprints is presented in Figure 7.1.

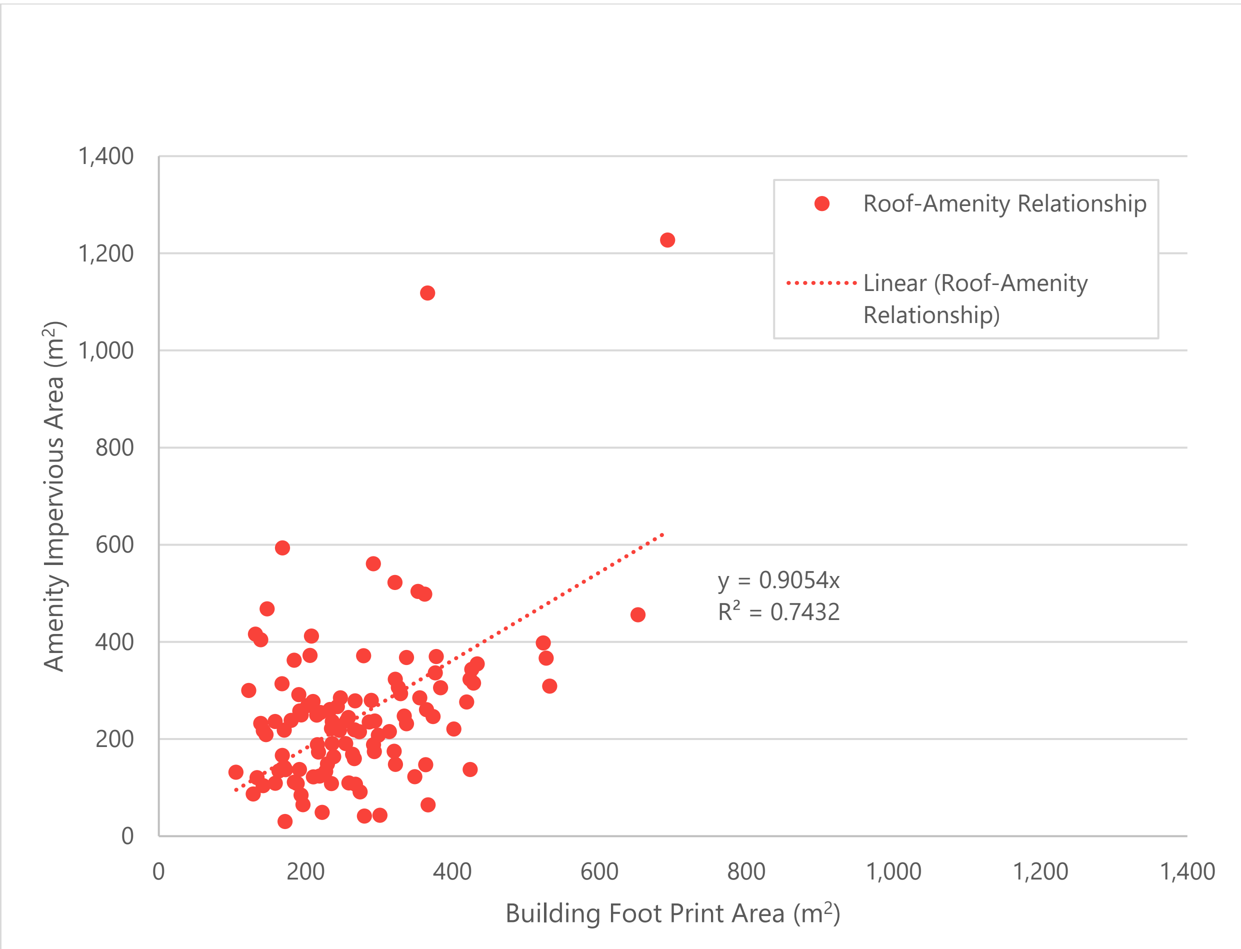


Figure 7.1. Building Footprint Area vs. Amenity Impervious Area

A trendline fit to the observed data indicates that under existing conditions, the area of amenity features is approximately 90.5 % of the size of existing building footprint. It has been assumed that this relationship would remain consistent under the increased building areas expected under the as-of-right scenario. Therefore, in addition to increasing the building footprint to a maximum of 35% of the ER area for each network, the imperviousness associated with amenity areas has been increased to 90.5 % (+/-) of the building footprint increase. Similar to the calculation of the increase in building area, it has been assumed that the increase in amenity area would result in a corresponding decrease in greenspace area.

The future conditions (as-of-right) imperviousness has been calculated for each subcatchment within the ER areas based on the preceding approach. A summary of the increase in total imperviousness is presented in Table 7.2.

Table 7.2. Summary of Expected Overall Increase in Imperviousness under As-of-Right Conditions

NETWORK	EXISTING CONDITIONS IMPERVIOUSNESS (%)	INCREASE IN IMPERVIOUS AREA (ha)	FUTURE CONDITIONS IMPERVIOUSNESS (%)	INCREASE IN IMPERVIOUSNESS (%)
A	31.5	6.73	45.0	13.5
B	43.6	5.07	60.7	17.1
C	43.7	6.75	62.5	18.8
D	48.3	3.90	58.6	10.0
E	42.3	6.36	62.8	20.2
F	40.9	9.25	61.0	20.1
G	39.9	6.90	53.8	13.8
H	45.9	0.74	54.5	13.0
I	46.3	2.01	61.3	14.9
J	44.5	1.52	58.6	14.0
K	46.9	1.65	59.7	12.2
L	46.1	0.34	59.5	13.3
TOTAL	41.6	51.22	57.2	15.6

The total increase in imperviousness for the study area has been estimated as 51.22 ha, which represents a total increase of 15% (relative increase of 38%). Expected increases vary by network, ranging from a low of 10.0% (Network D) to a high of 20.2% (Network E). These variations reflect relative differences in ages of development and associated existing lot coverage, as well as those areas which have experienced relatively greater amounts of intensification to-date.

7.1.2 MODELLING METHODOLOGY

Overview

In order to incorporate the increase in impervious area under as-of-right land use conditions, the PCSWMM model has been developed using a "split subcatchment" method. This approach involves first identifying subcatchments which include expected increases in imperviousness (ER areas), as documented in Table 7.2, and "splitting" the subcatchments into two (2) separate units; one (1) representing the as-of-right increased impervious area, and the other representing the balance of the original subcatchment area (less the as-of-right area). By assessing these units separately, source controls (assessed in Section 8 as part of the mitigation strategy) can be sized based on the contributing increased impervious area only, and not include existing, external drainage areas.

A visual representation of this methodology has been provided in Figure 7.2. Details regarding both subcatchment units have been provided in the subsequent sections.

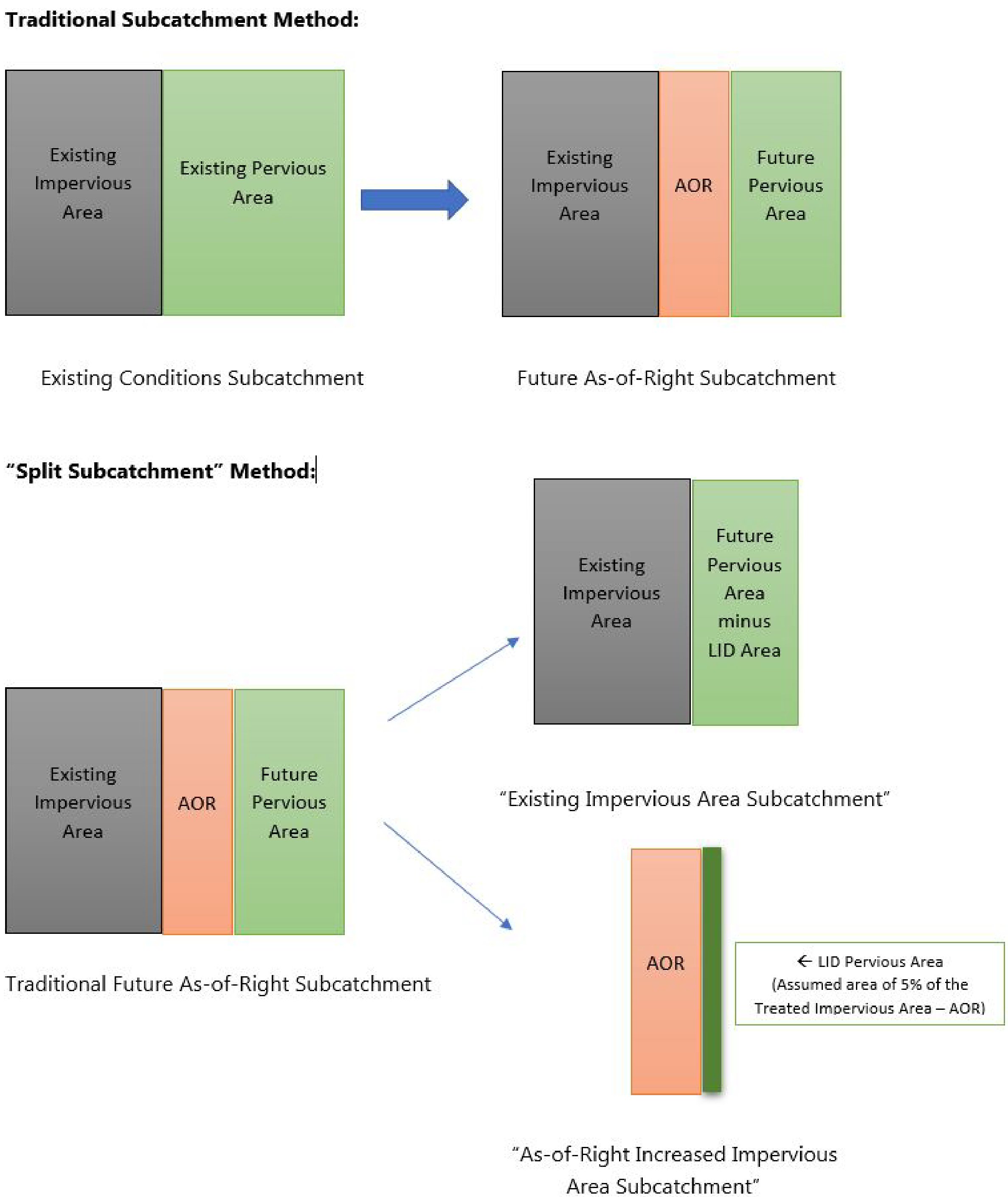


Figure 7.2. As-of-Right Land Use Condition Subcatchment Modelling Methodologhy

As-of-Right Increased Impervious Area Subcatchment

This subcatchment unit represents the net increase in impervious area under as-of-right land use conditions (additional rooftop plus corresponding amenity area), with an assumed pervious area to represent the LID surface area for the mitigation assessment. The Low Impact Development Best Management Practice (LID BMP) surface area has been assumed to be 5% of the total additional impervious area (i.e. if impervious area is 0.5 ha then pervious area is 0.025 ha, thus total subcatchment area becomes 0.525 ha, and the as-of-right subcatchment is 95% impervious).

The subcatchment routing has been set to 100% to pervious, under the assumption that all runoff from the increased impervious area would be directed to an on-site source control element for treatment (discussed further as part of the mitigation assessment in Section 8). Subcatchment flow lengths have been adjusted based on the area reduction of the parent subcatchment, however this parameter is relatively insensitive given the high level of imperviousness and routing to pervious areas. Slope has been maintained from the parent subcatchment under existing conditions.

The as-of-right impervious subcatchment unit has been set to outlet to the associated existing impervious area subcatchment, under the assumption that in practice, under a major storm event an LID Best Management Practice (LID BMP) located on a residential property would likely pond and flow overland across surrounding areas prior to reaching the drainage outlet (i.e. pervious ditch for rurally serviced areas). Under the mitigation assessment, this allows for control by the LID BMP, and the representation of the additional infiltration potential provided by the pervious downstream receivers (additional lawn areas and the roadside ditching system).

Under the uncontrolled scenario (i.e. no LID BMP in place), the pervious depression storage has been set to 10 mm, consistent with the approach for existing conditions. For the mitigation assessment, the depression storage has been adjusted to incorporate storage provided by source control measures (LID BMPs); further discussion is provided in Section 8.0.

Existing Impervious Area Subcatchment

This subcatchment unit contains only the existing impervious area and the net remaining pervious area (i.e. = existing pervious area – (AOR impervious increase + assumed LID BMP surface area)). This assumes that the new impervious area comes at the replacement of an equivalent existing pervious area. The resulting total subcatchment area and imperviousness have been recalculated and updated based on the preceding approach. The flow length for each of the subcatchments has been maintained from existing conditions, under the assumption that the as-of-right increase on a particular lot would not impact the flow length to the ditch or subcatchment outlet to any significant degree. Subcatchment slope and outlet location have been maintained from existing conditions. The subcatchment routing of 90% to pervious area has also been maintained, to reflect that impervious surfaces would be expected to largely discharge to pervious surfaces (residential lawns and ditches) which tend to slow flows and provide a secondary opportunity to infiltrate, as compared to direct and rapid routing of impervious surfaces as is the case in more typical urbanized roadway cross-sections.

Considering pervious depression storage and subcatchment routing have been used in the existing conditions model calibration, it has been assumed that the pervious depression storage (originally 10 mm) represents available storage in both the pervious areas/vegetation and in the ditches/driveway culverts of the entire system under existing conditions. Notionally, this available storage volume would be maintained for the existing impervious areas represented in these subcatchment units. Therefore, the total volume provided by the original 10 mm of pervious depression storage has been maintained, by adjusting the pervious depression depth (mm) for the remaining pervious area, to provide the same volume as per existing conditions and thereby avoid modelling bias.

7.2 RURALLY SERVICED NETWORKS – MODEL RESULTS

7.2.1 DESIGN STORMS

Overall Network Results

The as-of-right conditions modelling has been applied for the simulation of the 25 mm, 2 Year, 5 Year, and 100 Year design storm events as outlined in Section 5.1. The total outlet peak flow rates from each network to their ultimate receiver have been summed and are presented in Table 7.3. Detailed peak flow results to individual outlets are presented in Appendix D. A comparison to the simulated results under Existing Conditions (Table 6.1) is presented in Table 7.4.

Table 7.3. Total Simulated Peak Flow at Primary Drainage Network Outlets for Design Storm Generated Results – As-of-Right Uncontrolled Conditions

NETWORK	AREA (ha)	RECEIVER	STORM EVENT PEAK FLOWS (m^3/s)			
			25 MM	2 YEAR	5 YEAR	100 YEAR
A	35.61	Ancaster Creek	0.43	1.21	2.49	5.49
	14.42	Tiffany Creek	0.31	0.84	1.22	2.63
B	3.75	Ancaster Creek	0.06	0.23	0.37	0.68
	25.92	Tiffany Creek	0.33	0.66	1.03	3.65
C[1]	57.99	Ancaster Creek	0.83	2.03	2.82	5.41
D[1]	16.89	Sulphur Creek	0.20	0.59	0.91	1.46
E	21.35	Big Creek	0.24	0.57	0.73	1.15
	10.09	Sulphur Creek	0.22	0.55	0.98	2.05
F	46.05	Sulphur Creek	0.83	2.45	3.82	6.85
G	49.88	Sulphur Creek	0.63	1.86	2.86	5.89
H	4.05	Ancaster Creek	0.12	0.33	0.44	0.61
I	13.41	Ancaster Creek	0.35	0.75	0.98	2.24
J	10.00	Ancaster Creek	0.13	0.40	0.55	0.78
	0.85	Big Creek	0.03	0.06	0.09	0.18
K	8.07	Ancaster Creek	0.16	0.37	0.50	0.91
	5.45	Tiffany Creek	0.19	0.45	0.65	1.08
L	2.53	Big Creek	0.07	0.20	0.29	0.57

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

Table 7.4. Difference in total Simulated Peak Flow (%) at Primary Drainage Network Outlets between As-of-Right Uncontrolled and Existing Conditions – Design Storm

Network	Area (ha)	Receiver	Storm Event							
			25 mm		2 Year		5 Year		100 Year	
			m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	+0.19	+79	+0.27	+29	+0.48	+24	+0.56	+11
	14.42	Tiffany Creek	+0.20	+174	+0.24	+40	+0.22	+22	+0.29	+12
B	3.75	Ancaster Creek	+0.04	+133	+0.06	+38	+0.07	+22	+0.06	+10
	25.92	Tiffany Creek	+0.08	+32	+0.09	+17	+0.26	+33	+0.96	+36
C[1]	57.99	Ancaster Creek	+0.42	+102	+0.52	+35	+0.58	+26	+0.89	+20
D[1]	16.89	Sulphur Creek	+0.07	+50	+0.12	+26	+0.16	+21	+0.07	+5
E	21.35	Big Creek	+0.13	+111	+0.17	+44	+0.16	+29	+0.20	+22
	10.09	Sulphur Creek	+0.14	+157	+0.19	+52	+0.37	+61	+0.43	+27
F	46.05	Sulphur Creek	+0.44	+113	+0.88	+56	+1.02	+37	+0.59	+9
G	49.88	Sulphur Creek	+0.33	+107	+0.41	+28	+0.52	+22	+0.86	+17
H	4.05	Ancaster Creek	+0.06	+90	+0.05	+19	+0.04	+10	+0.02	+3
I	13.41	Ancaster Creek	+0.13	+61	+0.10	+16	+0.09	+10	+0.16	+8
J	10.00	Ancaster Creek	+0.06	+94	+0.13	+49	+0.10	+22	+0.07	+10
	0.85	Big Creek	+0.01	+90	+0.01	+24	+0.01	+18	+0.02	+12
K	8.07	Ancaster Creek	+0.08	+117	+0.09	+31	+0.08	+19	+0.13	+16
	5.45	Tiffany Creek	+0.02	+13	+0.04	+10	+0.03	+4	+0.06	+6
L	2.53	Big Creek	+0.04	+100	+0.04	+25	+0.05	+19	+0.06	+12
Average			-	+89	-	+34	-	+26	-	+15

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The simulated results indicate the largest relative increase in peak flows would be expected for the smallest, most frequent storm events, such as the 25 mm storm event, which indicates peak flows would be expected to approximately double (average increase of 89%), or greater in some locations. Simulated increases for larger, less frequent storm events are lower, with average increases in peak flows of approximately 26% for the 5-year storm event, and 15% for the 100-year storm event.

Ditch Performance Analysis

In addition to the preceding summary of expected changes in peak flows associated with the as-of-right land use, an assessment of the simulated performance of the ditch systems under as-of-right conditions has also been undertaken. Tabular summaries of the simulated ditch performance under as-of-right conditions by primary drainage network area are presented in Tables 7.5 and 7.6 for the 5 and 100 year storm events respectively. The results in both tables are summarized by length and by percentage. Percentage differences as compared to existing conditions for both the 5 and 100 year storm events are presented in Table 7.7. Positive values indicate an increase under as of right conditions.

Table 7.5. Simulated Ditch System Performance under As-of-Right Uncontrolled Conditions by Drainage Network – 5-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (m)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	6,156	563	93	90	8	1
B	4,926	626	144	86	11	3
C	6,068	2,264	81	70	26	1
D	7,190	2,812	133	71	28	1
E	3,181	1,797	525	58	33	10
F	5,596	2,286	108	70	29	1
G	4,714	2,191	155	67	31	2
H	437	0	0	100	0	0
I	1,501	232	0	87	13	0
J	2,035	171	151	86	7	6
K	2,498	311	46	87	11	2
L	1,059	0	0	100	0	0
Total / Average	45,360	13,252	1,436	76	22	2

Table 7.6. Simulated Ditch System Performance under As-of-Right Uncontrolled Conditions by Drainage Network – 100-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (m)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	5,121	1,350	341	75	20	5
B	3,969	1,291	435	70	23	8
C	4,559	3,542	312	53	41	4
D	4,023	4,968	1,144	40	49	11
E	1,941	1,956	1,606	35	36	29
F	4,147	3,111	732	52	39	9
G	3,081	3,274	705	44	46	10
H	180	257	0	41	59	0
I	1,191	481	62	69	28	4
J	1,487	614	255	63	26	11
K	1,847	878	130	65	31	5
L	1,059	0	0	100	0	0
Total / Average	32,605	21,723	5,721	54	36	10

Table 7.7. Difference in Simulated Ditch Performance between Existing and As-of-Right Uncontrolled Conditions by Drainage Network

NETWORK	PERCENTAGE CHANGE – 5-YEAR STORM			PERCENTAGE CHANGE – 100-YEAR STORM		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	-1	+1	+0	-1	+0	+1
B	-3	+3	+0	-2	-1	+4
C	-11	+11	+0	-7	+7	-1
D	-4	+3	+0	-4	+2	+2
E	-7	+4	+2	-12	+3	+9
F	-12	+12	+0	-4	+2	+2
G	-11	+10	+1	-5	-0	+5
H	0	0	0	-27	+27	0
I	-3	+3	0	-4	+4	0
J	-2	-0	+3	-7	+4	+3
K	-3	+1	+2	-6	+5	+1
L	0	0	0	0	0	0
Total	-6	+6	+1	-5	+3	+3

The results in Tables 7.5 and 7.6 demonstrate that networks E and J have the poorest performance for the 5-year (10 % and 6 % beyond the ROW) and 100-year (29 % and 11 % beyond the ROW) as-of-right conditions, similar to the existing conditions results. Network E and G indicate the largest increase in 100-year flooding beyond the ROW, with increases of 9% and 5% respectively. Networks H and L do not indicate any change in performance from existing conditions to as-of-right conditions for the 5 year storm events. Network L also does not indicate any change for the 100-year storm event; Network H indicates an increase in flows within the ROW but no exceedance of these limits. This may reflect the smaller area and associated increases in development in these areas, and potentially that these areas have additional drainage system capacity as compared to other areas. A comparison of the overall as-of-right condition and existing condition ditch performance results for all design storm events (25 mm, 2-year, 5-year, and 100-year) are presented in Table 7.8.

Table 7.8. Simulated Ditch Performance Summary by Length under As-of-Right Uncontrolled Conditions and Comparison to Existing Conditions

SCENARIO	STORM EVENT	SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
		WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As of Right Conditions	25 mm	57,078	2,860	111	95	5	0
	2-Year	50,712	8,655	681	84	14	1
	5-Year	45,360	13,252	1,436	76	22	2
	100-Year	32,605	21,723	5,721	54	36	10
Difference from Existing Conditions	25 mm	-1,714	+1,621	+93	-3	+3	0
	2-Year	-3,810	+3,496	+313	-6	+6	+1
	5-Year	-3,868	+3,466	+402	-6	+6	+1
	100-Year	-3,079	+1,510	+1,569	-5	+3	+3

The results presented in Table 7.8 indicate that for more frequent storm events (up to the 5-year storm event), there would be an increase of approximately 6% in flows exceeding the ditches/ROWs but remaining within the ROW, with an increase of only 1% in the number of ditch sections which would be expected to exceed the roadway ROW. A greater increase in flows exceeding the ROW is indicated for the 100-year storm event, with a 3% increase in exceedance of the ROW.

A comparison of the difference in peak flow results (Table 7.4) and ditch performance (Table 7.8) indicates that the relative increase in peak flows does not directly correspond to an increase in roadway flooding (i.e. beyond the ROW). For the 100-year storm event, peak flows have been estimated to increase by approximately 20%, however ditch flooding beyond the ROW is only predicted to increase by 4%. This suggest that there is some residual conveyance capacity available within the ditch conveyance system before it exceeds the ROW. Notwithstanding, the preceding does not directly assess the magnitude of the exceedance of the ROW, and the associated magnitude of impact to private property.

Culvert Performance and Road Overtopping Analysis

As noted under existing conditions, the hydraulic modelling has been developed to include spill conditions representing roadway overtopping. These elements have been represented by weirs and / or conduits within the model, set to a spill elevation sourced from either survey, or DEM data.

In order to assess the potential for increased level of flooding and hydraulic capacity issues, the 100-year design storm has been used to assess the following spill types under as-of-right conditions:

- Overtopping of a road from the adjacent ditches due to limited ditch capacity
- Overtopping of a road at a culvert due to limited culvert and ditch capacity
- Overtopping of a road with a storm sewer system, with catch basins in the adjacent ditches, due to limited storm sewer and ditch capacity

The modelled storm sewers have been included in this assessment for identification of rural system road overtopping, although it is understood that storm sewers are not typically designed to convey the peak flow rates generated from the 100-year storm event, Additional spills including roadway overtopping due to spills over driveways or into separate ditch systems have been included in the model for flow continuity. However, these conditions have not been reported, as these are assumed to be minor and unrelated to municipal culvert performance under major storm events. Spills into private property have been reported in the conveyance through private property section.

As previously cited, the subject culverts have been modelled assuming regular maintenance works have been completed (i.e. full conveyance area available). Therefore, any simulated spills / roadway overtopping in the rural networks is considered indicative of further hydraulic capacity issues of the existing municipal culverts under the future as-of-right condition.

The number of spills (i.e. flows greater than 0 m^3/s) occurring in each network under the 100 year storm event, and comparison to the existing conditions performance have been summarized in Table 7.9.

Table 7.9. Simulated 100-Year Spill Summary under As-of-Right Conditions as Compared with Existing Conditions

NETWORK AREA	SIMULATED SPILL CONDITION – COUNT (+/- CHANGE FROM EXISTING)			TOTAL NUMBER OF SIMULATED SPILLS
	OVERTOPPING ROAD (DITCH)	OVERTOPPING ROAD (CULVERT)	OVERTOPPING ROAD (STORM)	
A	5 (0)	14 (+1)	2 (0)	21 (+1)
B	3 (+1)	7 (0)	2	12 (+1)
C	4 (0)	11 (+1)	0 (0)	15 (+1)
D	6 (0)	7 (+1)	0 (0)	13 (+1)
E	6 (+2)	8 (+2)	2 (+2)	16 (+6)
F	4 (+1)	9 (+2)	2 (+1)	15 (+4)
G	4 (0)	8 (+1)	7 (+1)	19 (+2)
H	0 (0)	0 (0)	2 (0)	2 (0)
I	1 (0)	4 (0)	2 (0)	7 (0)
J	2 (0)	5 (0)	0 (0)	7 (0)
K	1 (0)	5 (0)	0 (0)	6 (0)
L	0 (0)	1 (0)	0 (0)	1 (0)
Total	36 (+4)	79 (+8)	19 (+4)	134 (+16)

The results indicate that under as-of-right conditions, the number of simulated spills has increased for the areas with the poorest simulated hydraulic performance under existing conditions (i.e. Areas A – G). These increases are primarily caused by culvert overtopping, with an increase of twelve (12) spills, and less so in the ditch overtopping and private property spills, with an increase of four (4) spills.

The network areas with fewer spills / hydraulic capacity issues under existing conditions (i.e. Areas H – L) remained unchanged in the total number of spills under the as-of-right conditions. However, it should be noted that these networks are smaller in terms of total drainage area, therefore the cumulative increase in flows may not be as large as the results shown in the larger networks (Areas A – G).

7.2.2 CLIMATE CHANGE SCENARIOS

The as-of-right conditions modelling has been executed for the three (3) climate change adjusted rainfall sources presented in Section 5.3, namely the Ontario Climate Change Data Portal (OCCDP), MTO IDF Curve Lookup, and the UWO IDF Climate Change Tool (version 3.0). Alternate IDF data from these three (3) sources (2080 forecast year) have been used to generate modified 5- and 100-year return period design storms. The total outlet peak flow rates from each network to their ultimate receiver for the adjusted 5-year storm events have been summed and are presented in Table 7.10 along with calculated differences as compared to existing conditions in Table 7.11 (ref. Table 6.10). A similar comparison for the 100-year storm event has been presented in Table 7.12 and 7.13 (compared to existing conditions values presented in Table 6.11). Positive values indicate an increase in peak flows as compared to base IDF data. Detailed peak flow results to individual outlets are presented in Appendix D.

Table 7.10. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Climate Change Altered Rainfall Scenarios under As-of-Right Uncontrolled Conditions – 5-Year Return Period

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)			
			AOR BASE IDF	OCCDP	MTO	UWO
A	35.61	Ancaster Creek	2.49	3.43	3.41	2.96
	14.42	Tiffany Creek	1.22	1.51	1.50	1.39
B	3.75	Ancaster Creek	0.37	0.49	0.49	0.45
	25.92	Tiffany Creek	1.03	1.77	1.75	1.40
C[1]	57.99	Ancaster Creek	2.82	3.54	3.52	3.25
D[1]	16.89	Sulphur Creek	0.91	1.17	1.17	1.09
E	21.35	Big Creek	0.73	0.86	0.86	0.81
	10.09	Sulphur Creek	0.98	1.38	1.38	1.22
F	46.05	Sulphur Creek	3.82	5.15	5.14	4.70
G	49.88	Sulphur Creek	2.86	3.81	3.80	3.40
H	4.05	Ancaster Creek	0.44	0.53	0.53	0.49
I	13.41	Ancaster Creek	0.98	1.41	1.41	1.20
J	10.00	Ancaster Creek	0.55	0.63	0.63	0.59
	0.85	Big Creek	0.09	0.12	0.12	0.11
K	8.07	Ancaster Creek	0.50	0.64	0.64	0.59
	5.45	Tiffany Creek	0.65	0.78	0.78	0.73
L	2.53	Big Creek	0.29	0.38	0.38	0.35

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

Table 7.11. Change Altered Rainfall Scenarios under As-of-Right Uncontrolled Conditions Comparison to Existing Conditions – 5-Year Return Period

NETWORK	AREA (ha)	RECEIVER	AOR BASE IDF (m^3/s)	OCCDP		MTO		UWO	
				m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	2.49	+0.51	+17	+0.51	+17	+0.36	+14
	14.42	Tiffany Creek	1.22	+0.19	+15	+0.20	+15	+0.19	+16
B	3.75	Ancaster Creek	0.37	+0.07	+17	+0.07	+17	+0.07	+19
	25.92	Tiffany Creek	1.03	+0.55	+45	+0.54	+44	+0.36	+35
C[1]	57.99	Ancaster Creek	2.82	+0.68	+24	+0.68	+24	+0.63	+24
D[1]	16.89	Sulphur Creek	0.91	+0.14	+13	+0.14	+13	+0.18	+19
E	21.35	Big Creek	0.73	+0.17	+24	+0.17	+24	+0.16	+25
	10.09	Sulphur Creek	0.98	+0.46	+51	+0.46	+51	+0.43	+55
F	46.05	Sulphur Creek	3.82	+1.18	+30	+1.18	+30	+1.27	+37
G	49.88	Sulphur Creek	2.86	+0.66	+21	+0.67	+21	+0.51	+18
H	4.05	Ancaster Creek	0.44	+0.05	+10	+0.05	+10	+0.05	+11
I	13.41	Ancaster Creek	0.98	+0.26	+23	+0.26	+22	+0.19	+19
J	10.00	Ancaster Creek	0.55	+0.07	+13	+0.07	+13	+0.07	+14
	0.85	Big Creek	0.09	+0.02	+15	+0.02	+15	+0.02	+16
K	8.07	Ancaster Creek	0.50	+0.11	+21	+0.11	+21	+0.10	+20
	5.45	Tiffany Creek	0.65	+0.02	+3	+0.02	+3	+0.02	+3
L	2.53	Big Creek	0.29	+0.05	+15	+0.05	+15	+0.05	+16
Average				-	+21	-	+21	-	+21

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

Table 7.12. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Climate Change Altered Rainfall Scenarios under As-of-Right Uncontrolled Conditions – 100-Year Return Period

NETWORK	AREA (HA)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)			
			AOR BASE IDF	OCCDP	MTO	UWO
A	35.61	Ancaster Creek	5.49	8.06	6.77	9.18
	14.42	Tiffany Creek	2.63	3.87	3.30	4.45
B	3.75	Ancaster Creek	0.68	0.87	0.77	1.00
	25.92	Tiffany Creek	3.65	5.76	4.48	6.41
C[1]	57.99	Ancaster Creek	5.41	7.89	6.55	9.46
D[1]	16.89	Sulphur Creek	1.46	1.72	1.59	1.84
E	21.35	Big Creek	1.15	1.64	1.37	2.00
	10.09	Sulphur Creek	2.05	2.79	2.39	3.22
F	46.05	Sulphur Creek	6.85	8.51	7.48	9.67
G	49.88	Sulphur Creek	5.89	7.93	6.74	9.13
H	4.05	Ancaster Creek	0.61	0.67	0.64	0.70
I	13.41	Ancaster Creek	2.24	2.86	2.55	3.07
J	10.00	Ancaster Creek	0.78	1.18	0.88	1.50
	0.85	Big Creek	0.18	0.23	0.20	0.29
K	8.07	Ancaster Creek	0.91	1.45	1.03	1.61
	5.45	Tiffany Creek	1.08	1.20	1.13	1.26
L	2.53	Big Creek	0.57	0.77	0.66	0.89

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

Table 7.13. Change Altered Rainfall Scenarios under As-of-Right Uncontrolled Conditions Comparison to Existing Conditions – 100-Year Return Period

NETWORK	AREA (ha)	RECEIVER	AOR BASE IDF (m^3/s)	OCCDP		MTO		UWO	
				m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	5.49	+0.34	+4	+0.43	+7	+0.30	+3
	14.42	Tiffany Creek	2.63	+0.28	+8	+0.39	+13	+0.26	+6
B	3.75	Ancaster Creek	0.68	+0.04	+5	+0.05	+7	+0.05	+5
	25.92	Tiffany Creek	3.65	+1.19	+26	+0.93	+26	+0.87	+16
C[1]	57.99	Ancaster Creek	5.41	+1.35	+21	+1.16	+22	+1.45	+18
D[1]	16.89	Sulphur Creek	1.46	+0.05	+3	+0.07	+5	+0.04	+2
E	21.35	Big Creek	1.15	+0.38	+30	+0.30	+27	+0.44	+28
	10.09	Sulphur Creek	2.05	+0.44	+19	+0.44	+23	+0.45	+16
F	46.05	Sulphur Creek	6.85	+0.80	+10	+0.51	+7	+1.14	+13
G	49.88	Sulphur Creek	5.89	+0.76	+11	+0.70	+12	+0.78	+9
H	4.05	Ancaster Creek	0.61	+0.01	+2	+0.01	+2	+0.01	+2
I	13.41	Ancaster Creek	2.24	+0.10	+4	+0.15	+6	+0.08	+3
J	10.00	Ancaster Creek	0.78	+0.32	+37	+0.10	+13	+0.32	+27
	0.85	Big Creek	0.18	+0.02	+9	+0.02	+11	+0.03	+13
K	8.07	Ancaster Creek	0.91	+0.37	+35	+0.10	+11	+0.23	+16
	5.45	Tiffany Creek	1.08	+0.03	+2	+0.02	+2	+0.02	+2
L	2.53	Big Creek	0.57	+0.06	+8	+0.06	+10	+0.07	+8
Average				-	+14	-	+12	-	+11

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The simulated results for the 5-year storm event indicate that under as-of-right conditions, peak flows would be expected to increase by an average of 23% for the climate change altered rainfall scenario. This simulated increase in peak flows would be slightly below the previously simulated increase in peak flows of approximately 29% (average of all three (3) climate change scenarios for the 5-year storm event) due to the impacts of climate-change altered rainfall alone (as per Table 6.8).

The simulated results for the 100-year storm event indicate a greater variability for individual network peak flow changes than for the 5-year storm event, consistent with the previously presented results under existing conditions. Under each climate change altered scenario, there is an expected increase of approximately 13% when compared to existing conditions.

In addition to the preceding summary of expected changes in peak flows, an assessment of the simulated performance of the ditch systems under the three (3) climate change data sources has also been undertaken for as-of-right conditions, along with a comparison to the previously presented results under existing conditions (Table 6.12). Results for the 5 and 100 year storm events are presented in Table 7.14.

Table 7.14. Simulated Ditch Performance Summary by Length under As-of-Right Uncontrolled Conditions and Comparison to Existing Conditions – Climate Change Altered Rainfall Scenarios

SCENARIO	RETURN PERIOD (YEARS)	DATASET	SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
			WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As of Right Conditions	5-Year	OCCDP	40,325	17,095	2,628	67	28	4
		MTO	40,268	17,226	2,555	67	29	4
		UWO	42,707	15,005	2,336	71	25	4
	100-Year	OCCDP	26,349	23,702	9,998	44	39	17
		MTO	29,728	22,858	7,463	50	38	12
		UWO	23,469	23,958	12,622	39	40	21
Difference from Existing Conditions	5-Year	OCCDP	-4,294	+3,110	+1,184	-7	+5	+2
		MTO	-4,351	+3,173	+1,178	-7	+5	+2
		UWO	-3,602	+2,511	+1,090	-6	+4	+2
	100-Year	OCCDP	-2,609	+301	+2,308	-4	+1	+4
		MTO	-2,321	+413	+1,908	-4	+1	+3
		UWO	-1,392	-378	+1,770	-2	-1	+3

The results presented in Table 7.14 indicate under as-of-right conditions and climate change altered rainfall, peak flow rates would be expected to exceed the ROW limits by 2% and 4% more than under existing conditions for the 5-year and 100-year storm events respectively. These increases would be above and beyond the simulated increases solely due to the application of climate change altered rainfall to existing conditions land use (Table 6.12). The results presented in Table 7.14 further indicate the increases for the 5-year storm event would be generally consistent with the ROW exceedance for the existing conditions (climate change-altered rainfall scenario) performance (i.e. an additional 2% on average as presented in Table 6.10), however for the 100-year storm event the incremental increase associated with the application of as-of-right conditions (3-4%) is relatively lower than the increase associated with the application of climate change altered rainfall alone (increases of between 9 and 18% as presented in Table 6.10).

7.2.3 HISTORIC EXTREME STORMS

The as-of-right conditions modelling has been executed for the three (3) historic extreme storm events presented in Section 5.3, specifically:

- July 26, 2009 (Red Hill Valley Storm Event)
- July 22, 2012 (Binbrook/Shadyglen Storm Event)
- August 14, 2014 (Burlington Storm Event)

The total outlet peak flow rates from each network to their ultimate receiver for these storm events have been summed and are presented in Table 7.15, along with a comparison to the simulated results under existing conditions (as per Table 6.13). Detailed peak flow results to individual outlets are presented in Appendix D.

Table 7.15. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Historic Extreme Storm Events – As-of-Right Uncontrolled Conditions

NETWORK	AREA (HA)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)			
			AOR BASE IDF	RED HILL VALLEY	BINBROOK/ SHADYGLEN	BURLINGTON
A	35.61	Ancaster Creek	5.49	6.98	8.43	4.92
	14.42	Tiffany Creek	2.63	3.39	4.07	2.39
B	3.75	Ancaster Creek	0.68	0.80	0.92	0.59
	25.92	Tiffany Creek	3.65	4.88	6.11	3.92
C[1]	57.99	Ancaster Creek	5.41	7.78	9.70	6.24
D[1]	16.89	Sulphur Creek	1.46	1.72	1.85	1.56
E	21.35	Big Creek	1.15	1.66	2.14	1.53
	10.09	Sulphur Creek	2.05	2.42	2.77	1.66
F	46.05	Sulphur Creek	6.85	8.14	9.38	6.40
G	49.88	Sulphur Creek	5.89	7.14	9.21	5.80
H	4.05	Ancaster Creek	0.61	0.64	0.69	0.60
I	13.41	Ancaster Creek	2.24	2.75	2.95	2.08
J	10.00	Ancaster Creek	0.78	1.24	1.72	0.99
	0.85	Big Creek	0.18	0.20	0.25	0.14
K	8.07	Ancaster Creek	0.91	1.39	1.53	0.98
	5.45	Tiffany Creek	1.08	1.16	1.22	0.89
L	2.53	Big Creek	0.57	0.68	0.76	0.44

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

Table 7.16. Historic Extreme Storm Events under As-of-Right Uncontrolled Conditions Comparison to Existing Conditions

NETWORK	AREA (ha)	RECEIVER	RED HILL VALLEY		BINBROOK/SHADYGLEN		BURLINGTON	
			m³/s	%	m³/s	%	m³/s	%
A	35.61	Ancaster Creek	+0.63	+10	+0.12	+1	+0.36	+8
	14.42	Tiffany Creek	+0.62	+22	+0.10	+3	+0.22	+10
B	3.75	Ancaster Creek	+0.07	+9	+0.03	+3	+0.04	+8
	25.92	Tiffany Creek	+1.06	+28	+0.41	+7	+0.73	+23
C[1]	57.99	Ancaster Creek	+1.26	+19	+1.05	+12	+0.66	+12
D[1]	16.89	Sulphur Creek	+0.09	+6	+0.05	+3	+0.09	+6
E	21.35	Big Creek	+0.30	+22	+0.34	+19	+0.20	+15
	10.09	Sulphur Creek	+0.54	+29	+0.26	+10	+0.31	+23
F	46.05	Sulphur Creek	+1.10	+16	+1.07	+13	+0.60	+10
G	49.88	Sulphur Creek	+0.49	+7	+0.51	+6	+0.37	+7
H	4.05	Ancaster Creek	+0.02	+4	+0.01	+2	+0.02	+4
I	13.41	Ancaster Creek	+0.21	+8	+0.01	+0	+0.12	+6
J	10.00	Ancaster Creek	+0.24	+24	+0.33	+24	+0.14	+16
	0.85	Big Creek	+0.02	+10	+0.03	+11	+0.01	+11
K	8.07	Ancaster Creek	+0.34	+33	+0.07	+5	+0.16	+20
	5.45	Tiffany Creek	+0.03	+3	+0.01	+1	+0.06	+7
L	2.53	Big Creek	+0.07	+11	+0.03	+5	+0.04	+11
Average			-	+15	-	+7	-	+11

Note: [1] The summed peak flow rates for Sub-Network D2 are conveyed to Sub-Network C5 which outlet to a tributary of Ancaster Creek; results are therefore included as part of Network C rather than Network D.

The simulated results indicate that the application of as-of-right land use conditions results in additional simulated increases in peak flows of between 7 and 15%, with the greatest increases indicated for the Red Hill Valley (July 26, 2009) storm event.

In addition to the preceding summary of expected changes in peak flows, an assessment of the simulated performance of the ditch systems under the three (3) historic extreme storms has also been undertaken. The results are presented in Table 7.17, along with a comparison to the previously presented values under existing conditions (Table 6.12).

Table 7.17. Simulated Ditch Performance Summary by Length under As-of-Right Uncontrolled Conditions for Historic Extreme Storm Events

DATA SOURCE AND EVENT		SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
SCENARIO	STORM EVENT	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As of Right Conditions	Red Hill Valley	24,712	23,543	11,794	41	39	20
	Binbrook	28,951	22,294	8,803	48	37	15
	Burlington	35,016	18,823	6,210	58	31	10
Difference from Existing Conditions	Red Hill Valley	-1,338	-447	+1,785	-2	-1	+3
	Binbrook	-2,434	+551	+1,883	-4	+1	+3
	Burlington	-2,562	+1,405	+1,158	-4	+2	+2

The results presented in Table 7.17 indicate under as-of-right conditions, for the three (3) noted historic extreme storms, between 80% and 89% of the ditch sections are able to convey the associated flows within the limits of the roadway ROW. This represents an increase of between 2 and 3% as compared to existing conditions results for the same historic extreme storm events.

7.3 ASSESSMENT OF EXTERNAL AREAS AND IMPACTS TO DOWNSTREAM LOCATIONS

7.3.1 DESIGN STORMS

The as-of-right conditions modelling (including external drainage areas, as per Section 3.2.5, and Drawing 16) has been applied for the simulation of the 5 and 100 year synthetic design storms as well as the Regional Storm Event (Hurricane Hazel). The resulting simulated peak flow rates at selected locations/nodes of interest for downstream receivers are presented in Table 7.18, along with a comparison to existing conditions (positive difference indicates an increase in flows under as of right conditions). The results are presented by watercourse system, typically from upstream to downstream.

Table 7.18. Simulated Peak Flow Rates at Downstream Nodes of Interest for Selected Storms and the Regional Storm Event – As-of-Right Uncontrolled Conditions

RECEIVER	JUNCTIO N NAME	SERVICE AREAS	AREA (ha)	AS-OF-RIGHT CONDITIONS PEAK FLOW RATES (m^3/s)			DIFFERENCE IN PEAK FLOWS AS COMPARED TO EXISTING CONDITIONS (%)		
				5 YR	100 YR	REGIONAL	5 YR	100 YR	REGIONAL
Ancaster Creek	AC_01	J and K	369.1	1.23	2.79	15.98	+17.9	+7.5	+0.5
	AC_03	C, J, and K	380.9	1.94	3.85	17.10	+24.8	+10.3	+0.8
	AC_04	C, J, and K	460.5	2.24	4.51	17.45	+26.9	+9.9	+0.9
	AC_06	C and D	48.9	1.99	3.55	4.73	+16.5	+8.2	+3.5

RECEIVER	JUNCTION NAME	SERVICE AREAS	AREA (ha)	AS-OF-RIGHT CONDITIONS PEAK FLOW RATES (m^3/s)			DIFFERENCE IN PEAK FLOWS AS COMPARED TO EXISTING CONDITIONS (%)		
				5 YR	100 YR	REGIONAL	5 YR	100 YR	REGIONAL
	AC_07	C and D	73.8	2.53	5.49	6.64	+21.0	+8.1	+3.9
	AC_08	C, D, J, and K	533.4	6.05	13.81	31.32	+17.7	+6.2	+1.1
	AC_09	C, D, J, and K	653.4	7.77	18.87	40.65	+18.0	+8.9	+0.9
	AC_10	B-D and I-K	763.4	6.59	17.69	49.76	+6.5	+5.8	+0.8
	AC_12	B-D and H-K	768.7	6.66	17.88	50.37	+6.5	+6.1	+1.6
	AC_13	B-D and H-K	770.2	6.67	17.91	50.47	+6.5	+6.0	+1.7
	AC_14	B-D and H-K	780.6	8.10	21.12	56.76	+6.7	+5.9	+1.5
	AC_15	B-D and H-K	837.1	8.10	21.09	56.78	+6.7	+5.9	+1.5
	AC_16	A-D and H-K	839.7	8.12	21.12	57.07	+6.7	+6.0	+1.5
	AC_18	A	33.0	2.03	4.51	4.12	+39.4	+13.6	+1.3
	AC_19	A-D and H-K	872.71	8.57	22.29	60.23	+7.8	+6.9	+1.5
	AC_21	A-D and H-K	1902.4	25.23	67.27	132.60	+8.7	+3.0	+0.8
	AC_22	A-K	3846.1	37.90	102.90	275.20	+5.7	+2.9	+0.6
Sulphur Creek	SC_01	D and E	82.1	9.93	19.05	10.72	+1.6	+0.6	+0.3
	SC_02	D, E, and G	18.1	9.64	18.89	10.74	+1.6	+0.5	+0.3
	SC_03	E	9.1	0.77	1.80	1.18	+58.9	+28.8	+8.0
	SC_04	D, E, and G	109.5	11.08	23.41	14.47	+3.3	+2.3	+0.8
	SC_05	D-G	111.1	11.51	23.27	14.67	+4.0	+2.6	+0.9
	SC_06	D-G	129.2	12.03	24.83	16.03	+7.1	+3.4	+1.3
	SC_07	D-G	235.9	14.13	30.64	27.83	+6.3	+2.9	+0.7
	SC_08	D-G	991.8	15.37	39.52	79.86	+6.4	+2.4	+0.3
	SC_09	D-G	1701.6	17.22	44.90	126.80	+8.8	+2.6	+0.4
	SC_11	F and G	29.6	3.87	8.15	7.56	+22.2	+10.5	+2.7
	SC_12	F and G	478.5	6.88	17.29	38.41	+14.2	+5.3	+0.7
	SC_14	G	46.4	2.15	3.64	3.48	+32.7	+4.4	+3.3
	SC_15A	G	253.0	0.76	3.66	4.06	+7.9	+0.7	+1.1
	SC_15B	G	53.3	2.59	6.78	7.38	+23.8	+3.3	+2.0
Tiffany Creek	TC_01	External	440.2	10.33	21.10	21.85	0.0	0.0	0.0
	TC_02	K	653.1	13.14	28.18	38.34	+0.4	+0.3	+0.0

RECEIVER	JUNCTION NAME	SERVICE AREAS	AREA (ha)	AS-OF-RIGHT CONDITIONS PEAK FLOW RATES (m^3/s)			DIFFERENCE IN PEAK FLOWS AS COMPARED TO EXISTING CONDITIONS (%)		
				5 YR	100 YR	REGIONAL	5 YR	100 YR	REGIONAL
	TC_03	B and K	787.6	15.37	38.04	50.19	+0.4	+1.9	+0.1
	TC_05	B and K	879.3	17.15	41.51	58.79	+1.0	+2.4	+0.1
	TC_06	A, B, and K	893.8	17.61	42.90	60.21	+1.4	+2.8	+0.1

As evident from Table 7.18, the greatest relative increases in simulated peak flows under as-of-right conditions are for smaller, more formative storm events, specifically the 5-year storm. This is consistent with the results presented for the Drainage Network outlets (Tables 7.3 and 7.4). For the 100-year storm event, increases range between zero (no change) and 28% depending on location, with a more modest relative increase of 6% on average. The results for the Regional Storm Event (Hurricane Hazel) indicate generally nominal differences, with an average increase of only 1%, however localized areas demonstrate potential increases of between 3% and 8%. Certain locations indicate relatively higher increases based on the contributing drainage area at those locations; upstream sections of Ancaster Creek and Sulphur Creek in particular.

7.3.2 CONTINUOUS SIMULATION – PEAK FLOWS, EROSION AND WATER BUDGET

Consistent with the approach applied for existing conditions (Section 6.3.2), a 55-year continuous simulation (1962-2016) has been completed for as-of-right uncontrolled conditions, based on the previously noted dataset from Environment Canada's Hamilton RBG gauge site. Continuous simulation has been undertaken to support the completion of a water budget and analysis of erosion potential. As outlined in Section 6.3.2 and previous sections, for the purposes of undertaking a continuous simulation, the Green & Ampt infiltration methodology has been applied, rather than the SCS Curve Number methodology which is applied for all single event based analyses. This is described further in Section 3.2.5 and 4.4.2.

Peak Flows

The annual maximum series of peak flow rates has been extracted from the modelling results for key junction nodes of interest, consistent with the locations assessed under the previous event-based approach (Section 7.2.1). A frequency analysis of the resulting peak flows has been completed in order to estimate frequency flows using the program HEC-SSP; complete results are included in Appendix D. A Log Pearson Type III frequency/probability distribution has been applied to estimate the return period frequency peak flow rates. The resulting estimated peak flow rates for the 5 and 100-year return periods for key nodes of interest are presented in Table 7.19, and have been compared to the previously estimated values for existing conditions (Table 6.16). Positive values indicate a simulated increase as compared to existing conditions; negative values indicate a simulated decrease.

Table 7.19. Simulated Peak Flow Rates at Downstream Nodes of Interest based on Continuous Simulation Modelling under As-of-Right Uncontrolled Conditions and Comparison to Existing Conditions

RECEIVER	JUNCTION NAME	AS OF RIGHT UNCONTROLLED CONDITIONS CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m³/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (m³/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
Ancaster Creek	AC_01	1.90	3.90	+0.10	+0.10	+6	+3
	AC_03	2.30	4.50	+0.10	+0.20	+5	+5
	AC_04	2.50	4.60	+0.20	+0.20	+9	+5
	AC_06	1.50	2.50	+0.10	+0.20	+7	+9
	AC_07	1.80	3.50	+0.10	+0.30	+6	+9
	AC_08	6.20	11.80	+0.30	+0.50	+5	+4
	AC_09	7.10	15.90	+0.30	+0.60	+4	+4
	AC_10	7.70	14.20	+0.20	+0.30	+3	+2
	AC_12	7.70	14.40	+0.20	+0.40	+3	+3
	AC_13	7.70	14.40	+0.20	+0.40	+3	+3
	AC_14	10.20	19.30	+0.10	+0.20	+1	+1
	AC_15	10.00	19.00	+0.20	+0.20	+2	+1
	AC_16	10.00	19.10	+0.20	+0.20	+2	+1
	AC_18	1.30	3.20	0.00	+0.10	0	+3
	AC_19	10.90	21.50	+0.20	+0.30	+2	+1
	AC_21	29.80	63.90	+0.40	+0.50	+1	+1
	AC_22	46.60	118.60	+0.60	+1.50	+1	+1
Sulphur Creek	SC_01	4.30	7.60	+0.10	+0.10	+2	+1
	SC_02	4.30	7.50	+0.10	+0.00	+2	0
	SC_03	0.30	0.70	0.00	+0.10	0	+17
	SC_04	5.30	9.90	+0.10	+0.20	+2	+2
	SC_05	5.30	10.00	+0.10	+0.20	+2	+2
	SC_06	5.70	11.00	+0.30	+0.40	+6	+4
	SC_07	8.60	17.60	+0.20	+0.50	+2	+3
	SC_08	13.20	37.10	+0.20	+0.60	+2	+2
	SC_09	20.00	55.70	+0.40	+0.90	+2	+2
	SC_11	2.90	6.20	+0.10	+0.60	+4	+11
	SC_12	9.40	20.40	+0.20	+0.50	+2	+3
	SC_14	1.40	2.50	+0.10	+0.20	+8	+9
	SC_15A	0.10	4.20	0.00	+0.50	0	+14
	SC_15B	1.50	4.10	+0.10	+0.20	+7	+5

RECEIVER	JUNCTION NAME	AS OF RIGHT UNCONTROLLED CONDITIONS CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m³/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (m³/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
Tiffany Creek	TC_01	6.20	11.20	0.00	0.00	0	0
	TC_02	10.30	20.60	0.00	-0.10	0	0
	TC_03	13.40	26.50	+0.10	+0.40	+1	+2
	TC_05	15.80	30.60	+0.10	+0.50	+1	+2
	TC_06	16.20	31.60	+0.10	+0.50	+1	+2

The frequency flow rates presented in Table 7.19 indicate that under as-of-right conditions, peak flow rates increase on average by 2.3% and 3.4% for the 5 and 100 year storm events respectively. This would suggest that the uncontrolled as-of-right scenario would result in a minor simulated impact to the downstream receivers based on continuous simulation results. This result is notably different from the previously presented results for the design storm (event based) simulation as per Table 7.18. For the continuous simulation results, the simulated increases to the 5 year frequency flow rates range between 1 and 9%, while the simulated increases to the 100 year frequency flow rates range between 1 and 17%. The greatest relative peak flow rate increases have been simulated at Sulphur Creek junction SC_03, which indicates an increase of 17% for the 100 year storm event. This relative higher frequency flow rate increase is considered to be a result of the relatively low simulated existing conditions frequency flow rate of 0.6 m3/s.

A decrease in the 100 year frequency flow rate of 0.1 m3/s has been noted at Junction TC_02 on Tiffany Creek. This is likely attributable to a rounding error within the PCSWMM simulation results, as there were no adjustments made to the contributing drainage areas to this junction, which consist of external drainage areas Ext 370 and Ext 371 (the junction node does not receive drainage from the primary study area). . No simulated decreases are indicated for the 5 year as-of-right uncontrolled frequency flow rates in comparison to the existing conditions values.

Erosion

The generated continuous simulation results have also been applied to complete an erosion assessment based on the duration of flow exceedance above the erosion thresholds generated for the current study (Table 4.1). The results of this analysis are presented in Table 7.20, along with a comparison to the simulated results under existing conditions (Table 6.17).

Table 7.20. Simulated Duration of Erosion Threshold Exceedances under As-of-Right Uncontrolled Conditions and Comparison to Existing Conditions

WATERCOURSE SITE	JUNCTION NAME	DRAINAGE AREA (ha)	AS-OF-RIGHT UNCONTROLLED CONDITIONS		DIFFERENCE FROM EXISTING CONDITIONS	
			DURATION OF EXCEEDANCE (DAYS)	DURATION OF EXCEEDANCE (% OF TOTAL DURATION)	DURATION OF EXCEEDANCE (DAYS)	DURATION OF EXCEEDANCE (% OF TOTAL DURATION)
Ancaster Creek Tributary	AC_07	73.83	219.9	1.1	28.99	15.2
Ancaster Creek Tributary	AC_18	33.04	7.9	0.0	1.50	23.5
Sulphur Creek Tributary	SC_04	109.48	304.0	1.5	4.53	1.5
Sulphur Creek Tributary	SC_11	29.6	68.0	0.3	4.36	6.9
Sulphur Creek Tributary	SC_14	46.38	6.0	0.0	1.59	36.3

Locations SC_04 and SC_11 were noted as being moderately unstable based on the completed erosion analysis (Section 4.1). These locations indicate increases in the duration of exceedance of the critical flow of approximately 1.5 % and 6.9 % respectively in comparison to the existing conditions results. The remaining three (3) sites, each classified as stable based on the erosion analysis, demonstrated greater erosion duration exceedances of the stability flows over the existing conditions ranging from 15.2 to 36.3%. The total duration exceedance over the 55-year simulation period is relatively minor for the locations at AC_18, SC_11, and SC_14 ranging from 0 to 0.3%.

Water Budget

The continuous simulation results have also been applied to develop a revised water budget under uncontrolled as-of-right conditions (with external areas maintained under the same conditions in both modelling scenarios). The same approach as was applied for existing conditions (Section 6.3.2) has again been employed; results from that assessment (Table 6.16) have been used as a basis of comparison, with results presented in Table 7.22.

As evident from Table 7.21 and 7.22, the as-of-right conditions average annual results indicate an increase of runoff by 9.6 mm or 6.8% and a reduction in total losses of 3.5 mm or 0.5% over the 55-year simulation period. The greatest increases in average annual runoff occurred during the summer months (July, August, and September) which is likely due to the increase in high intensity storm events during this seasonal period. Overall, increases in runoff may be somewhat mitigated by the available infiltration capacity of available soils, as impervious areas are still largely routed across pervious surfaces in the as-of-right development scenario.

Table 7.21. As-of-Right Uncontrolled Conditions – Average Monthly and Annual Water Budget

MONTH	RAINFALL (mm)	RUNOFF (mm) (+/- CHANGE FROM EXISTING CONDITIONS)	TOTAL LOSSES (mm) (+/- CHANGE FROM EXISTING CONDITIONS)
January	52	10 (+0.4)	43 (-0.1)
February	48	9 (+0.4)	39 (-0.1)
March	68	13 (+0.7)	55 (-0.2)
April	67	12 (+0.8)	56 (-0.3)
May	72	13 (+0.9)	60 (-0.3)
June	75	13 (+1.0)	63 (-0.3)
July	78	15 (+1.1)	65 (-0.4)
August	75	15 (+1.1)	61 (-0.4)
September	77	15 (+1.1)	64 (-0.4)
October	70	13 (+0.9)	57 (-0.3)
November	72	14 (+0.7)	59 (-0.3)
December	63	12 (+0.5)	51 (-0.4)
Average Annual	**818**	**152 (+9.6)**	**674 (-3.5)**

Table 7.22. Comparison of Water Budget Results for As-of-Right Uncontrolled and Existing Conditions

MONTH	RAINFALL (%)	RUNOFF (%)	TOTAL LOSSES (%)
January	0.0	+4.7	-0.3
February	0.0	+5.0	-0.4
March	0.0	+5.2	-0.4
April	0.0	+7.4	-0.5
May	0.0	+7.8	-0.6
June	0.0	+8.2	-0.5
July	0.0	+8.3	-0.6
August	0.0	+7.8	-0.6
September	0.0	+8.0	-0.6
October	0.0	+7.2	-0.5
November	0.0	+5.5	-0.4
December	0.0	+4.6	-0.8
Average Annual	**0.0**	**+6.8**	**-0.5**

It would be expected that the increase in runoff would be equivalent to the decrease in the total losses since the model has been simulated with an average annual precipitation of 818 mm which can either be accounted for with runoff or total losses. However, the decrease in the average annual total losses is not exactly equivalent to the increase in the runoff which may be attributed to the routing error within PCSWMM over the 55-year simulation period. Overall, the results correspond with expected trends, namely an increase in overall surface runoff associated with an increase in impervious land coverage.

8 MANAGEMENT STRATEGIES AND IMPLEMENTATION

8.1 LONG-LIST OF ALTERNATIVES

A "long-list" of potential management strategies has been developed in order to address the potential impacts of re-development to "as of right" conditions. Based on the preceding sections, and premised on the core purpose of this study, the primary impacts to be mitigated are related to runoff quantity, including worsened conveyance performance (i.e. roadside ditches and culverts, including spills beyond the right-of-way onto private property), and potential downstream (off-site) flooding impacts. Other related impacts would be expected to include increased potential for downstream erosion, as well as changes to the overall area water budget associated with decreased infiltration and increased surface runoff. Separately, potential impacts to water quality may also be expected, associated with increased impervious surfaces, specifically those subject to vehicular traffic and increased contaminant loadings (i.e. for detached residential areas, driveways). Ecological impacts, specifically to aquatic systems, may also be anticipated, particularly thermal impacts, due to a change of shift in the runoff regime.

It should be understood that the alternatives to be assessed as part of this study are focused solely on addressing and mitigating the impacts associated with "as of right" development and ensuring that an existing level of service is maintained. Although the assessment of existing conditions (Section 6) has identified a number of existing drainage system deficiencies, additional measures to mitigate these existing issues are beyond the scope of the current study and is deferred to future study and works by the City of Hamilton, potentially in partnership with the Hamilton Conservation Authority, where appropriate.

The following "long list" of alternatives has been developed based on the preceding considerations.

1. Do Nothing
2. Increase size of ditch conveyance systems
3. Increase size of storm sewers/culverts, or twinning
4. Flow diversions and new conveyance routes
5. Roadway Re-Profiling (Grading Changes)
6. Retrofit existing "end-of-pipe" stormwater management (SWM) facilities
7. Implement new "end-of-pipe" stormwater management (SWM) facilities
8. Private Side Source controls (on lot measures, including Low Impact Development Best Management Practices (LID BMPs))
9. Public Side Roadway right-of-way controls (including LID BMPs)

The following alternatives have been initially screened from further consideration as part of the alternative assessment:

— **Alternative 1 (Do Nothing)**
  — The Do Nothing alternative is a requirement of the Class EA process, however this study is not being completed as a formal Class EA

  - In this case "Do Nothing" would not address the fundamental issues of potential impacts from uncontrolled development to "as of right" conditions; including impacts to both public and private property as assessed in Section 7
  - Based on the preceding, Alternative 1 has been screened from further consideration
- **Alternative 2 (Increase size of ditch conveyance systems)**
  - This alternative would not control or restrict increased flows associated with development to as of right, but would rather provide adequate conveyance capacity for the increased flows
  - Potential flooding and erosion impacts would still be expected to downstream receivers, likewise this alternative would not address water quality impacts
  - Based on the preceding, Alternative 2 has been screened from further consideration
- **Alternative 3 (Increase size of storm sewers/municipal culverts, or twinning)**
  - This alternative would involve upgrading/increasing the size of storm sewer/culverts (or twinning) to increase the conveyance capacity and reduce the frequency of roadway overtopping or spilling
  - This alternative would not control or restrict increased flows associated with development to as of right condition, but would increase conveyance capacity to accommodate increased flows
  - Similar to Alternative 2, potential flooding and erosion impacts would still be expected to downstream receivers, likewise this alternative would not address water quality impacts
  - Alternative 3 may be appropriate in select locations to address existing conveyance system deficiencies, however it is not considered appropriate to address the overall impacts associated with development to as of right conditions
  - Based on the preceding Alternative 3 has been screened from further consideration with respect to mitigating as of right development impacts
- **Alternative 4 (Flow diversions and new conveyance routes)**
  - This alternative would involve assessing the potential to locally divert flows or generate new conveyance routes to address the increased flows associated with development or remediate key constraints
  - In and of itself, this alternative would not control or restrict increased flows associated with development, but would simply shift the increased flows to different locations (existing or new) which can accommodate the impacts
  - Similar to Alternatives 2 and 3, this alternative would still be expected to result in potential flooding and erosion impacts to downstream receivers, and would not address water quality impacts
  - Further, it is considered there are limited opportunities for flow diversions, given existing topography and the developed nature of the study area
  - Based on the preceding, Alternative 4 has been screened from further consideration
- **Alternative 5 (Roadway Re-Profiling (Grading Changes))**
  - This alternative would involve making changes to the roadway profiles where feasible to improve conveyance, including steepening or flattening slopes as necessary
  - In and of itself, this alternative would not control or restrict increased flows associated with development, but would simply address existing conveyance deficiencies to the extent possible
  - Similar to Alternatives 2-4, this alternative would still be expected to result in potential flooding and erosion impacts to downstream receivers, and would not address water quality impacts
  - This alternative would also likely have limited application, given the developed nature of the study area and need to generally match driveway elevations

  - Based on the preceding, Alternative 5 has been screened from further consideration
- **Alternative 6 (Retrofit existing "end-of-pipe" SWM facilities)**
  - There are very few existing "end-of-pipe" SWM facilities within the study area (i.e. one (1) SWM facility receives rurally serviced flows while three (3) SWM facilities are located in adjacent external areas), thus this alternative is not considered effective in this setting, and has been screened from further consideration
- **Alternative 7 (Implement new "end-of-pipe" SWM facilities)**
  - This alternative would involve implementing new "end-of-pipe" SWM facilities near outfalls to receiving watercourses to control and potentially treat stormwater
  - Based on a review of available land use mapping, there are few if any potential locations where there is available public land to implement this alternative
  - This alternative would also not address the impacts to upstream conveyance features between development sites and the "end-of-pipe" SWM facility
  - Based on the preceding, Alternative 6 has been screened from further consideration
- **Alternative 8 (Private Side On Lot Source Controls, including LID BMPs)**
  - This alternative would involve placing controls on the private side of lots, i.e. generally on the undeveloped portion of the residential property lot, including rear yard and front yard areas not encumbered by the residential structure or other amenity features
  - Source controls could include both typical measures (i.e. sub-surface storage features) as well as Low Impact Development Best Management Practices (LID BMPs), including filtration and infiltration measures (bioretention area, enhanced grassed swales, soakaway pits, permeable pavement, rainwater harvesting, green roofs, etcetera)
  - If sized appropriately, this alternative would be able to address expected impacts to quantity control, quality control, erosion and water budget
  - This alternative has therefore been short-listed for further consideration
- **Alternative 9 (Public Side Roadway ROW controls, including LID BMPs)**
  - This alternative would be similar to Alternative 8, but would place LID BMPs and source controls within the public domain within the municipal right-of-way
  - Measures could include sub-surface (exfiltration pipes or chambers) as well as surface (bioretention areas, enhanced grassed swales) measures
  - Similar to Alternative 8, if sized appropriately, this alternative would be able to address expected impacts to quantity control, quality control, erosion and water budget
  - This alternative has therefore been short-listed for further consideration

The following primary alternatives have been short-listed for further consideration:

- **Alternative 8 (Private Side On Lot Source Controls, including LID BMPs)**
- **Alternative 9 (Public Side Roadway ROW controls, including LID BMPs)**

In addition to the preceding, it is considered that Alternative 3 (Increase size of storm sewers/culverts, or twinning) may be applied selectively to address existing drainage system deficiencies, however it is not considered an appropriate alternative to address the primary mitigation requirements associated with development to as of right conditions.

Alternative 8 and 9 have thus been assessed further in order to establish the preferred Alternative(s) for the rurally serviced areas in Ancaster (ref. Section 8.2).

8.2 ASSESSMENT OF SHORT-LISTED ALTERNATIVES

The short-listed Alternatives are generally similar, in that they both involve controlling or managing runoff at its source and would be expected to include primarily Low Impact Development Best Management Practices, with a focus on storage-based measures, including filtration and infiltration. Such controls, properly sized, would be expected to manage both runoff peaks and runoff volumes associated with uncontrolled development; this would include preserving conveyance capacity, addressing flood impacts to downstream receivers, mitigating erosion impacts and water budget (through the control of less formative, more frequent storm events and promoting infiltration). As well, water quality impacts can be managed, through the filtration of stormwater (particularly if treatment is provided for driveway areas, which would be expected to yield the greatest overall contaminant loading as compared to rooftop and other amenity areas).

The primary distinction between Alternatives 8 and 9 relates to location. Alternative 8 would be located on private property, on the properties where the proposed re-development to "as of right" conditions is to occur (i.e. Private Realm). Alternative 9 would locate the source controls outside of the private property and along the adjacent public roadway right-of-way limits (i.e. Public Realm). There are relative advantages and disadvantages to each of the proposed approaches.

By locating the source controls on the developing site (Alternative 8 – On Lot Source Controls), the controls can be constructed in tandem with the proposed property re-development. This would provide the developer/property owner with more options with respect to locating and siting the controls, along with greater certainty with respect to construction scheduling (i.e. construction is not dependent on the construction of downstream controls). Alternative 8 would also ensure that the developer/property owner is responsible for managing the impacts associated with the development (the general "polluter pay" principle) rather than the Municipality. The potential disadvantage of Alternative 8 is that these controls will ultimately be located on private property, which could potentially limit the ability of the City of Hamilton to ensure ongoing functionality, and that required operations and maintenance activities are properly completed. Notwithstanding, the source controls could potentially be included as part of the property title, and operations and maintenance requirements addressed through a City easement or other legal mechanisms. City staff has however noted (Winterton-Senior, October 4, 2019) that historically the City has not included SWM infrastructure as part of property titles. Formal changes to City practices would likely therefore be required, to ensure that the City retains an element of control by formally registering the source control measures on property title. An additional alternative may to leverage the Drainage Act to define source controls as formal features and share costs and responsibilities between the homeowner and the City. This approach would be consistent with ongoing efforts of Credit Valley Conservation (CVC) in particular to leverage the Drainage Act to advance private side LID BMPs (ref. "The Drainage Act as a Tool to Facilitate the Aggregation and Wide-Scale Implementation of Green, Low Impact Drainage Infrastructure on Private Property" – Credit Valley Conservation, January 2018). The City of Hamilton should confirm a preferred approach and ensure that any associated policy changes are implemented accordingly. Alternatively, the City may consider a level of over-control or redundancy in its planning for Private Realm controls to off-set the potential for future 'loss' of functionality. A review of policy alternatives is included in Appendix F.

Conversely, Alternative 9 (Roadway ROW Controls) would locate the controls on public property, placing them entirely in Municipal (City) control. Notwithstanding, this arrangement would necessitate that the controls be constructed by the City in advance or in tandem of the development of the site (which may be problematic from a scheduling perspective in the case where numerous distributed properties re-develop concurrently), or that the developer constructs works to support private property along the municipal ROW (necessitating City review and oversight, and potentially compromising the ability of the City to utilize the ROW to address existing drainage system deficiencies). Overall, Alternative 9 would result in the City being more responsible to provide SWM controls to off-set the impacts of private development, which is contrary to standard development practice. Further as noted, implementing such controls within the ROW would limit the ability of the City to provide additional controls in the future to mitigate any potential existing drainage system deficiencies (as outlined in Section 6) through future roadway reconstructions and other measures (beyond the scope of the current study).

Based on the preceding, Alternative 8 (On Lot Source Controls) is considered to be the preferred Alternative to address the impacts associated with As of Right Development and has been carried forward for further assessment. Policy and implementation implications are discussed further in Appendix F.

8.3 MODELLING METHODOLOGY

As described in Section 7.1.2, the as-of-right land use modelling has been developed to analyze the existing and as-of-right impervious areas as two (2) separate subcatchment units. This approach permits source controls to be more directly assessed by setting infiltration capture targets, specific to the increased impervious area resulting from as-of-right development only, as would be expected.

Source controls, such as LID BMPs, have been represented in the modelling through the adjustment of the pervious depression storage parameter of the subcatchment, representing the as-of-right impervious increase. By adjusting the pervious depression storage depth, the influence of source controls on not only quantity control, but also on the local water budget can be assessed through simulated infiltration / evaporation using continuous simulation.

Infiltration capture targets have been iteratively adjusted by setting a capture depth (mm), across the as-of-right impervious area (ha) for those subcatchments where future development is expected. This runoff volume is then converted to a depth (mm) based on the available pervious area in the subcatchment which is representing the LID BMP; as per Section 7.1.2, this pervious area has been assumed as 5% of the total impervious area draining to it. The resulting depth (mm), representing the storage volume available in the LID BMP, is added to the base 10 mm of depression storage included in the uncontrolled modeling scenario. Numerical modelling results and sizing are presented in Section 8.4.

8.4 RURALLY SERVICED NETWORKS – MODEL RESULTS

8.4.1 DESIGN STORMS

Source Control Sizing

As described in Section 8.3, infiltration capture targets have been iteratively sized for peak flow and runoff volume control of the 100-year design storm event for each individual network. The variability in capture targets per individual networks inherently incorporates any effects resulting from differing soil conditions, which would affect the relative amount of required capture and infiltration, in order to match to existing conditions.

The resulting developed capture targets have been represented as both an infiltration depth, and an equivalent volume per impervious hectare. This value is to be applied to only the increase in impervious area resulting from as-of-right conditions and would provide control for any existing impervious area. The increased impervious area should also consider not only the additional building area on a lot (to 35% coverage), but also the estimated or actual amenity area, as per Section 7.1 (amenity area typically assumed to be 90% of building area). The source control sizing details have been presented in Table 8.1, and a visual representation on Drawing 20.

While the capture depths presented in Table 8.1 are notably higher than typical industry values for source controls and LID BMP measures, it should be understood that source controls for the current application are intended to provide quantity/flood control up to and including the 100-year storm event; thus an inherently higher capture depth is required. Based on WSP's professional experience, the results presented in Table 8.1 compare reasonably to similar values generated for equivalent end of pipe controls for greenfield developments for other municipalities and watersheds. The precise form of the source controls to be applied would vary by site, and would need to be determined by the designer in consultation with the City.

The developed capture targets have been applied to the mitigation assessment; results and performance have been summarized in the subsequent sections.

Table 8.1. Source Control Capture Sizing for As-of-Right Land Use Conditions – 100-Year Design Storm Sizing

NETWORK AREA	CAPTURE DEPTH (mm / imp ha)	CAPTURE VOLUME (m^3 / imp ha)
A	60	600
B	70	700
C	70	700
D	70	700
E	70	700
F	60	600
G	70	700
H	55	550
I	55	550
J	70	700
K	60	600
L	60	600

Overall Network Results

Simulation of as of right conditions with source controls in place has been undertaken for the 25 mm, 2 Year, 5 Year, and 100 Year design storm events as per previous analyses. The total peak flow rates from each network outfall to their ultimate receiver have been summed and are presented in Table 8.2. Detailed peak flow results to individual outlets are presented in Appendix E. A comparison to the simulated results under Existing Conditions (Table 6.1) is presented in Table 8.3.

Table 8.2. Total Simulated Peak Flow at Primary Drainage Network Outlets for Design Storm Generated Results – As-of-Right Conditions with Source Controls

NETWORK	AREA (ha)	RECEIVER	STORM EVENT PEAK FLOWS (m^3/s)			
			25 mm	2 YEAR	5 YEAR	100 YEAR
A	35.61	Ancaster Creek	0.23	0.91	1.71	4.85
	14.42	Tiffany Creek	0.10	0.57	0.93	2.24
B	3.75	Ancaster Creek	0.03	0.17	0.30	0.60
	25.92	Tiffany Creek	0.25	0.56	0.76	2.57
C[1]	57.99	Ancaster Creek	0.42	1.52	2.20	4.48
D	16.89	Sulphur Creek	0.14	0.47	0.75	1.38
E	21.35	Big Creek	0.12	0.41	0.58	0.98
	10.09	Sulphur Creek	0.09	0.38	0.60	1.55
F	46.05	Sulphur Creek	0.39	1.52	2.69	6.14
G	49.88	Sulphur Creek	0.31	1.44	2.29	4.94
H	4.05	Ancaster Creek	0.07	0.28	0.39	0.59
I	13.41	Ancaster Creek	0.22	0.64	0.86	2.09
J	10.00	Ancaster Creek	0.07	0.28	0.46	0.72
	0.85	Big Creek	0.01	0.05	0.08	0.15
K	8.07	Ancaster Creek	0.08	0.29	0.43	0.80
	5.45	Tiffany Creek	0.17	0.41	0.63	1.01
L	2.53	Big Creek	0.04	0.16	0.24	0.49

Table 8.3. Difference in Total Simulated Peak Flow (%) at Primary Drainage Network Outlets between As-of-Right with Source Controls and Existing Conditions – Design Storm

NETWORK	AREA (HA)	RECEIVER	STORM EVENT							
			25 mm		2 YEAR		5 YEAR		100 YEAR	
			m^3/s	%	m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	-0.01	-4	-0.02	-3	-0.31	-15	-0.08	-2
	14.42	Tiffany Creek	-0.01	-9	-0.03	-5	-0.07	-7	-0.10	-4
B	3.75	Ancaster Creek	-0.00	-0	+0.01	+3	+0.00	+0	-0.02	-3
	25.92	Tiffany Creek	-0.00	-2	-0.00	-0	-0.01	-2	-0.12	-4
C	57.99	Ancaster Creek	+0.01	+2	+0.01	+1	-0.03	-1	-0.04	-1
D	16.89	Sulphur Creek	+0.00	+2	+0.00	+0	-0.00	-1	-0.01	-1
E	21.35	Big Creek	+0.00	+4	+0.01	+4	+0.01	+2	+0.03	+3
	10.09	Sulphur Creek	+0.01	+8	+0.01	+4	-0.01	-1	-0.07	-4
F	46.05	Sulphur Creek	-0.00	-1	-0.05	-3	-0.11	-4	-0.12	-2
G	49.88	Sulphur Creek	+0.00	+1	-0.01	-1	-0.05	-2	-0.09	-2
H	4.05	Ancaster Creek	+0.00	+3	-0.00	-1	-0.01	-2	-0.00	-1
I	13.41	Ancaster Creek	+0.01	+3	-0.01	-2	-0.03	-3	+0.02	+1
J	10.00	Ancaster Creek	+0.00	+2	+0.01	+4	+0.01	+2	+0.01	+2
	0.85	Big Creek	+0.00	+6	+0.00	+2	-0.00	-1	-0.01	-4
K	8.07	Ancaster Creek	+0.00	+6	+0.01	+3	+0.00	+1	+0.02	+2
	5.45	Tiffany Creek	+0.00	+0	+0.00	+1	+0.00	+0	-0.01	-1
L	2.53	Big Creek	+0.00	+5	+0.00	+1	-0.00	-1	-0.02	-3

The simulated results indicate the infiltrative capture targets outlined in Table 8.1 for each network are able to achieve peak flow control for all design storm events. There are slight variabilities in peak flows within the individual networks whereby some minor increases are noted, however these differences are considered to be negligible, between +0.01 m3/s to 0.03 m3/s. Contrarily in some cases a slight over-control is noted, generally in the range of -0.01 m3/s to 0.05 m3/s, which is similarly considered negligible.

The combined outlets of Network A to Ancaster Creek have demonstrated the greatest peak flow rate change during the 5 year design storm event at -0.31 m3/s, or a decrease of 15 %. While this is a combined decrease for all the Network A outlets to Ancaster Creek, a specific location at the north side of the intersection of Montgomery Drive and Massey Drive indicated a 0.22 m3/s peak flow rate reduction at an identified spill point over the roadway, which largely explains the notable result in this location.

The assumed runoff routing of 90% of the impervious catchment portion to the pervious surface for the existing areas results in a higher sensitivity to changes. This sensitivity has been the rationale for the adjustment of pervious depression storage for the existing impervious subcatchment (ref. Section 7.1.2). Notwithstanding, it is considered likely that there will be slight variability in results, particularly for the more frequent storm events (i.e. 25 mm, 2-, 5-year storm events), considering the primary source of runoff during these events is from the existing impervious subcatchments due to over control of the as-of-right areas provided by the source controls, which have been sized for the 100 year storm event. This effect is evident in the minor increases during the 25 mm and 2-year storm events.

Ditch Performance Analysis

In addition to the preceding summary of peak flow controls achieved through source controls under as-of-right land use, an assessment of the simulated performance of the ditch systems under as-of-right conditions with source controls has also been undertaken. Tabular summaries of the simulated ditch performance under as-of-right conditions with source controls by primary drainage network area are presented in Tables 8.4 and 8.5 for the 5 and 100 year storm events respectively. The results in both tables are summarized by length and by percentage. Percentage differences as compared to existing conditions for both the 5 and 100 year storm events are presented in Table 8.6. Positive values indicate an increase under as of right conditions with source controls, negative values indicate a decrease.

Table 8.4. Simulated Ditch System Performance under As-of-Right Conditions with Source Controls by Drainage Network – 5-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (m)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	6,254	498	59	92	7	1
B	5,119	491	86	90	9	2
C	6,797	1,478	137	79	17	2
D	7,557	2,467	111	75	24	1
E	3,733	1,378	392	68	25	7
F	6,562	1,344	83	82	17	1
G	5,472	1,534	55	78	22	1
H	437	0	0	100	0	0
I	1,557	176	0	90	10	0
J	2,088	178	91	89	8	4
K	2,583	269	3	90	9	0
L	1,059	0	0	100	0	0
Total	49,219	9,813	1,016	82	16	2

The results in Table 8.6 indicate that the overall performance under existing conditions is generally replicated under as of right conditions with the proposed source controls in place. Overall changes are 1% +\- for the 5 and 100-year storm events. In some locations a slight improvement is achieved (increased percentages of ditch sections "within ditch"), which may reflect the slight over-control evident in Table 8.3 with respect to overall drainage network flows. Other minor differences may also be attributable to differences in the subcatchment modelling methodology between existing and as-of-right conditions (i.e. the creation of a separate subcatchment to represent additional imperviousness, as per Section 7.1.2).

Table 8.5. Simulated Ditch System Performance under As-of-Right Conditions with Source Controls by Drainage Network – 100-Year Storm Event

NETWORK	PERFORMANCE BY LENGTH (m)			PERFORMANCE BY LENGTH (%)		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	5,279	1,261	271	78	19	4
B	4,222	1,241	233	74	22	4
C	5,323	2,815	275	61	33	3
D	4,509	4,696	929	44	46	9
E	2,660	1,709	1,134	48	31	21
F	4,452	2,960	578	56	37	7
G	3,486	3,263	311	49	46	4
H	297	140	0	68	32	0
I	1,265	406	62	73	23	4
J	1,679	501	177	71	21	8
K	2,018	745	93	71	26	3
L	1,059	0	0	100	0	0
Total	36,248	19,738	4,062	60	33	7

Table 8.6. Difference in Simulated Ditch Performance between Existing and As-of-Right Conditions with Source Controls by Drainage Network

NETWORK	PERCENTAGE CHANGE – 5-YEAR STORM			PERCENTAGE CHANGE – 100-YEAR STORM		
	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
A	0	0	0	+1	-1	0
B	0	+1	-1	+2	-2	0
C	-3	+2	+1	+2	-1	-1
D	0	0	0	+1	-1	0
E	+3	-3	0	+1	-1	0
F	0	0	0	-1	0	+1
G	0	+1	-1	+1	0	-1
H	0	0	0	0	0	0
I	0	0	0	0	0	0
J	0	0	0	+1	-1	0
K	0	0	0	0	0	0
L	0	0	0	0	0	0
Total	0	0	0	+1	-1	0

A comparison of the overall as-of-right condition with source controls and existing condition ditch performance results for all design storm events (25 mm, 2-year, 5-year, and 100-year) is presented in Table 8.7.

The results indicate that the 5-year and 100-year performance are either improved or closely match existing conditions (differences of 1% or less). The simulated performance for the 25 mm and 2-year storm event indicates a minor decrease in performance for flows exceeding the ditch but remaining within ROW (up to 0.5 %). This is likely due to the model sensitivity to the pervious area component as discussed previously, considering the as-of-right impervious subcatchment runoff is completely controlled by the LID BMP during these minor storm events. This is considered a negligible difference in results, particularly given some of the preceding considerations.

Table 8.7. Simulated Ditch Performance Summary by Length under As-of-Right Conditions with Source Controls and Comparison to Existing Conditions

SCENARIO	STORM EVENT	SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
		WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As of Right Conditions	25 mm	58,713	1,317	18	98	2	0
	2-Year	54,297	5,478	274	90	9	0
	5-Year	49,219	9,813	1,016	82	16	2
	100-Year	36,248	19,738	4,062	60	33	7
Difference from Existing Conditions	25 mm	-78	+78	0	-0.1	+0.1	0
	2-Year	-225	+319	-94	-0.4	+0.5	-0.2
	5-Year	-9	+27	-18	0	0	0
	100-Year	+565	-475	-90	+0.9	-0.8	-0.1

Given that both peak flows and ditch performance for the 100-year event under as of right conditions (with source controls in place) have been demonstrated to be controlled to existing conditions, it has been reasonably assumed that the spills performance of culverts, ditches and into / through private property would also be controlled to existing conditions. Therefore, an additional/updated spill summary table has not been considered warranted. Likewise, the preparation of ditch performance summary graphics has not been considered warranted for the mitigation scenario, as the results would be expected to closely replicate those generated for existing conditions.

8.4.2 CLIMATE CHANGE SCENARIOS

Overall Network Results

The as-of-right conditions with source controls modelling scenario has also been applied for the simulation of three (3) climate change adjusted rainfall sources as per Section 5.3 (Ontario Climate Change Data Portal (OCCDP), MTO IDF Curve Lookup, and the UWO IDF Climate Change Tool (version 3.0)). Alternate IDF data from these three (3) sources (2080 forecast year) have been applied to generate modified 5 and 100 year return period design storms. The total outlet peak flow rates from each network to their ultimate receiver for the adjusted 5-year storm events have been summed and are presented in Table 8.8; calculated differences as compared to existing conditions are presented in Table 8.9. A similar comparison for the 100-year storm event has been presented in Table 8.10 and 8.11 respectively. Positive values indicate an increase in peak flows as compared to existing conditions under the same storm event; negative values indicate a decrease as compared to existing conditions. Detailed peak flow results to individual outlets are presented in Appendix E.

Table 8.8. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Climate Change Altered Rainfall Scenarios under As-of-Right Conditions with Source Controls – 5-Year Return Period

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)		
			OCCDP	MTO	UWO
A	35.61	Ancaster Creek	2.71	2.70	2.44
	14.42	Tiffany Creek	1.20	1.19	1.10
B	3.75	Ancaster Creek	0.42	0.41	0.37
	25.92	Tiffany Creek	1.09	1.08	0.89
C	57.99	Ancaster Creek	2.78	2.78	2.57
D	16.89	Sulphur Creek	1.01	1.01	0.90
E	21.35	Big Creek	0.70	0.70	0.66
	10.09	Sulphur Creek	0.90	0.89	0.76
F	46.05	Sulphur Creek	3.60	3.59	3.26
G	49.88	Sulphur Creek	3.05	3.05	2.83
H	4.05	Ancaster Creek	0.46	0.46	0.43
I	13.41	Ancaster Creek	1.08	1.08	0.97
J	10.00	Ancaster Creek	0.56	0.56	0.52
	0.85	Big Creek	0.10	0.10	0.09
K	8.07	Ancaster Creek	0.53	0.53	0.49
	5.45	Tiffany Creek	0.75	0.75	0.70
L	2.53	Big Creek	0.32	0.32	0.29

Table 8.9. Change Altered Rainfall Scenarios under As-of-Right Conditions with Source Controls Comparison to Existing Conditions – 5-Year Return Period

NETWORK	AREA (ha)	RECEIVER	OCCDP		MTO		UWO	
			m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	-0.20	-7	-0.20	-7	-0.16	-6
	14.42	Tiffany Creek	-0.11	-9	-0.11	-9	-0.10	-8
B	3.75	Ancaster Creek	-0.01	-2	-0.01	-2	0.00	-1
	25.92	Tiffany Creek	-0.13	-11	-0.13	-11	-0.15	-14
C	57.99	Ancaster Creek	-0.07	-3	-0.07	-2	-0.05	-2
D	16.89	Sulphur Creek	-0.02	-2	-0.02	-2	-0.01	-2
E	21.35	Big Creek	0.00	0	+0.00	0	+0.01	+1
	10.09	Sulphur Creek	-0.02	-2	-0.02	-2	-0.02	-3
F	46.05	Sulphur Creek	-0.38	-9	-0.37	-9	-0.17	-5
G	49.88	Sulphur Creek	-0.10	-3	-0.09	-3	-0.06	-2
H	4.05	Ancaster Creek	-0.02	-4	-0.02	-4	-0.01	-3
I	13.41	Ancaster Creek	-0.07	-6	-0.07	-6	-0.04	-4
J	10.00	Ancaster Creek	+0.00	+1	+0.00	+1	+0.01	+1
	0.85	Big Creek	-0.00	-2	-0.00	-2	-0.00	-2
K	8.07	Ancaster Creek	0.00	0	0.00	0	0.00	0
	5.45	Tiffany Creek	0.00	0	-0.01	-1	0.00	0
L	2.53	Big Creek	-0.01	-3	-0.01	-3	-0.01	-2

Table 8.10. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Climate Change Altered Rainfall under As-of-Right Conditions with Source Controls – 100-Year Return Period

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)		
			OCCDP	MTO	UWO
A	35.61	Ancaster Creek	7.86	6.44	9.09
	14.42	Tiffany Creek	3.75	2.94	4.38
B	3.75	Ancaster Creek	0.83	0.71	0.97
	25.92	Tiffany Creek	4.85	3.74	6.36
C	57.99	Ancaster Creek	7.10	5.66	8.72
D	16.89	Sulphur Creek	1.67	1.52	1.82
E	21.35	Big Creek	1.44	1.13	1.85
	10.09	Sulphur Creek	2.52	1.94	3.13
F	46.05	Sulphur Creek	8.04	7.09	9.46
G	49.88	Sulphur Creek	7.34	6.16	8.72
H	4.05	Ancaster Creek	0.67	0.63	0.70
I	13.41	Ancaster Creek	2.83	2.47	3.04
J	10.00	Ancaster Creek	1.01	0.80	1.39
	0.85	Big Creek	0.22	0.18	0.28
K	8.07	Ancaster Creek	1.26	0.98	1.59
	5.45	Tiffany Creek	1.20	1.11	1.26
L	2.53	Big Creek	0.75	0.61	0.89

Table 8.11. Change Altered Rainfall Scenarios under As-of-Right Conditions with LID Controls Comparison to Existing Conditions – 100-Year Return Period

NETWORK	AREA (ha)	RECEIVER	OCCDP		MTO		UWO	
			m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	+0.13	+2	+0.09	+1	+0.21	+2
	14.42	Tiffany Creek	+0.16	+5	+0.03	+1	+0.20	+5
B	3.75	Ancaster Creek	+0.00	+0	-0.01	-2	+0.02	+2
	25.92	Tiffany Creek	+0.27	+6	+0.20	+6	+0.81	+15
C	57.99	Ancaster Creek	+0.56	+9	+0.27	+5	+0.70	+9
D	16.89	Sulphur Creek	+0.01	+0	-0.00	-0	+0.02	+1
E	21.35	Big Creek	+0.19	+15	+0.06	+5	+0.28	+18
	10.09	Sulphur Creek	+0.17	+7	-0.01	-1	+0.37	+13
F	46.05	Sulphur Creek	+0.34	+4	+0.12	+2	+0.94	+11
G	49.88	Sulphur Creek	+0.17	+2	+0.12	+2	+0.37	+4
H	4.05	Ancaster Creek	+0.01	+2	+0.01	+2	+0.01	+2
I	13.41	Ancaster Creek	+0.07	+3	+0.07	+3	+0.05	+2
J	10.00	Ancaster Creek	+0.15	+17	+0.02	+3	+0.21	+18
	0.85	Big Creek	+0.01	+4	-0.00	-2	+0.02	+8
K	8.07	Ancaster Creek	+0.18	+17	+0.04	+5	+0.21	+15
	5.45	Tiffany Creek	+0.02	+2	+0.00	+0	+0.02	+2
L	2.53	Big Creek	+0.04	+6	+0.01	+2	+0.06	+8

The simulated results for the 5-year storm event indicate that under as-of-right with source controls, peak flows can be controlled to existing conditions values during each of the climate change altered rainfall scenarios, with differences typically less than 5%. The greatest peak flow rate reduction (ref. Table 8.9) has been simulated at the outlet to Tiffany Creek in Network B, and in particular at the major system road sag near the intersection of Oneida Boulevard and Algonquin Avenue. The spill through private property at this location has been reduced by 0.13 m3/s below the existing conditions peak flow rate and has contributed to the combined simulated peak flow reduction of 0.15 m3/s for the network.

The simulated results for the 100-year storm event indicate that the source controls are able to control the total peak flows within between 2 and 8% of existing conditions values overall, based on simulated average increases (individual locations indicate larger increases in some cases). These results likely reflect the original sizing basis of the source controls, namely 100-year base (unadjusted) IDF data. As such, selected network outlets, for example Network E, have resulted simulated increases in peak flow rates of between 11 and 18% for the UWO climate change scenario, despite the application of LID controls. The climate change altered rainfall events have both higher intensities, and higher precipitation depths which would therefore be expected to exceed the proposed storage volumes presented in Table 8.1.

In addition to the preceding summary of expected changes in peak flows, an assessment of the simulated performance of the ditch systems under the three (3) climate change data sources has also been undertaken for as-of-right conditions with source controls, along with a comparison to the previously presented results under existing conditions (Table 6.12). Ditch performance results have been presented for the 100-year scenario only (Table 8.12), given that overall over-control is indicated for the 5-year storm event.

Table 8.12. Simulated Ditch Performance Summary by Length under As-of-Right Conditions with Source Controls and Comparison to Existing Conditions – Climate Change Altered Rainfall Scenarios – 100-Year

SCENARIO	RETURN PERIOD (YEARS)	DATASET	SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
			WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As-of-Right with LID Controls	100-Year	OCCDP	27,602	23,815	8,631	46	40	14
		MTO	31,857	22,490	5,701	53	37	9
		UWO	23,785	24,571	11,693	40	41	19
Difference from Existing Conditions	100-Year	OCCDP	-1,356	+415	+941	-2.3	+0.7	+1.6
		MTO	-191	+46	+145	-0.3	+0.1	+0.2
		UWO	-1,076	+235	+841	-1.8	+0.4	+1.4

The simulated ditch performance results for the 100-year event presented in Table 8.12 indicate that the proposed source controls are able to control ditch performance to within approximately 2% of existing conditions, which is generally consistent with the results based on peak flows (Table 8.11). Notwithstanding, an increase in ditch conveyance exceeding the right-of-way is predicted.

Additional Storage Requirements

As presented in previous sections, climate change altered rainfall has the potential to increase peak flows up to 60 % under the 100-year storm event (ref. Table 6.11). Source control sizing (Table 8.1) has been completed on the basis of mitigating the impacts of future development to as of right conditions for current IDF relationships; this sizing does not include any additional capacity to account for the potential impacts of climate change altered rainfall. As a supplementary analysis, the additional on-site capture requirements associated with climate change altered rainfall have been assessed.

Currently, there is no formal City policy in place regarding climate change and its specific implications to stormwater management design. In the absence of any such specific direction, the previously applied three (3) climate change scenarios/tools have been applied.

As previously discussed, the capture targets (sized for the 100-year base IDF scenario) do not provide sufficient storage capacity to control climate change-altered rainfall flows back to existing condition targets. Of the three (3) scenarios presented, the University of Western Ontario (UWO) climate change altered 100-year design storm generated the highest flows and greatest degree of storage exceedance. The UWO 100-year design storm event reflects an approximate 60 mm increase in total rainfall depth, and a 48% increase in peak intensity, as compared to base (non-climate change adjusted) IDF data. This storm event is the most formative of the three (3) climate change scenarios and has therefore conservatively been applied for the additional storage assessment.

In order to assess the additional storage requirements, the same hydrologic-hydraulic modelling applied for the sizing of the base source controls (i.e. to control the additional imperviousness associated with as of right development) has been applied. In order to confirm sizing requirements based on overall flow impacts at drainage network outlets, the modelling has applied the climate change altered rainfall design storms only to those subcatchments which reflect the additional impervious area. The remaining areas have continued to apply the base (non-climate change adjusted) rainfall data. Source control storage requirements have been assessed using the same methodology for as of right impacts described in Section 8.3. The additional capture targets for climate change mitigation are presented in Table 8.13.

Table 8.13. Additional Capture Targets for Climate Change Control – As-of-Right Land use Conditions – 100-Year (UWO)

NETWORK	AS-OF-RIGHT CAPTURE DEPTH (mm/imp ha)	CLIMATE CHANGE CAPTURE DEPTH (mm/imp ha)	TOTAL CAPTURE DEPTH TARGET (mm / imp ha)	TOTAL CAPTURE VOLUME TARGET (m^3 / imp ha)
A	60	45	105	1,050
B	70	40	110	1,100
C	70	45	115	1,150
D	70	40	110	1,100
E	70	40	110	1,100
F	60	40	100	1,000
G	70	40	110	1,100
H	55	35	90	900
I	55	35	90	900
J	70	35	105	1,050
K	60	40	100	1,000
L	60	30	90	900

The results indicate that an additional 30 to 45 mm of storage would be required to mitigate the impacts of climate change altered rainfall such that flows are fully controlled to base (i.e. current) IDF results.

The peak flow results for existing conditions (100-year base IDF), as-of-right with base source controls (split rainfall) and as-of-right with additional climate change source controls (split rainfall) have been summarized in Table 8.14.

The results indicate the additional source control storage volume would be generally effective in mitigating the impacts of more intense rainfall associated with climate change. The average difference is generally 1% +\-; the maximum change for selected networks is 7% +\-, which is considered nominal.

It should be noted that the as-of-right modelling methodology routes any overflow from the as-of-right impervious subcatchment to the existing subcatchment to represent the expected potential for infiltration along the downstream overland flow path (i.e. front yards and roadside ditches). Overflow from the as-of-right impervious subcatchment therefore has the potential to limit depression storage and associated infiltration in the base existing subcatchment (which applies base IDF data). A further sensitivity assessment would be necessary to confirm the impact of this modelling consideration; specifically comparing the results of the current assessment against a scenario that assesses source control storage for all areas using a uniform application of climate change-altered rainfall. This is currently beyond the scope of this study. In the absence of a formal City climate change policy, the current assessment is considered a reasonable preliminary estimate of potential additional source control storage requirements to address climate change.

Table 8.14. Total Simulated Peak Flow (m^3/s) at Primary Drainage Network Outlets for Climate Change Altered 100 Year Scenario – As-of-Right Conditions with Source Controls

NETWORK	AREA (ha)	RECEIVER	STORM EVENT SCENARIO (100-YEAR STORM)				
			EXISTING CONDITIONS	AOR SOURCE CONTROLS ONLY [1]	AOR + CC SOURCE CONTROLS [2]	DIFFERENCE (m^3/s)	DIFFERENCE (%)
A	35.61	Ancaster Creek	4.93	5.74	4.83	-0.09	-2
	14.42	Tiffany Creek	2.34	2.89	2.18	-0.16	-7
B	3.75	Ancaster Creek	0.62	0.70	0.60	-0.02	-3
	25.92	Tiffany Creek	2.69	3.74	2.71	+0.03	+1
C	57.99	Ancaster Creek	4.52	5.60	4.58	+0.05	+1
D	16.89	Sulphur Creek	1.39	1.46	1.39	-0.01	0
E	21.35	Big Creek	0.95	1.17	1.01	+0.06	+7
	10.09	Sulphur Creek	1.62	2.17	1.56	-0.06	-4
F	46.05	Sulphur Creek	6.27	7.05	6.35	+0.08	+1
G	49.88	Sulphur Creek	5.02	5.90	5.04	+0.01	0
H	4.05	Ancaster Creek	0.60	0.62	0.59	-0.00	-1
I	13.41	Ancaster Creek	2.08	2.36	2.07	-0.01	0
J	10.00	Ancaster Creek	0.71	0.79	0.73	+0.01	+2
	0.85	Big Creek	0.16	0.18	0.15	-0.01	-4
K	8.07	Ancaster Creek	0.79	0.95	0.83	+0.04	+6
	5.45	Tiffany Creek	1.02	1.09	1.01	-0.01	-1
L	2.53	Big Creek	0.51	0.60	0.50	-0.01	-1

Note: [1] These results represent the source control originally sized for as-of-right impervious area only, with the split rainfall events – 100-year base IDF for existing subcatchments, and UWO 100-year climate change altered rainfall for as-of-right impervious subcatchments.

[2] These results represent the source control sized for both the as-of-right impervious area increase and climate change, with the split rainfall events (see note 1).

8.4.3 HISTORIC EXTREME STORMS

The as-of-right conditions with source control scenario model has also been simulated for the three (3) historic extreme storm events presented in Section 5.3, specifically:

— July 26, 2009 (Red Hill Valley Storm Event)

— July 22, 2012 (Binbrook/Shadyglen Storm Event)

— August 14, 2014 (Burlington Storm Event)

The total outlet peak flow rates from each network to their ultimate receiver for these storm events have been summed and are presented in Table 8.15, along with a comparison to the simulated results under existing conditions (as per Table 6.13). Detailed peak flow results to individual outlets are presented in Appendix E.

Table 8.15. Total Simulated Peak Flow (m3/s) at Primary Drainage Network Outlets for Historic Extreme Storm Events – As-of-Right Conditions with Source Controls

NETWORK	AREA (ha)	RECEIVER	SIMULATED PEAK FLOW (m^3/s)		
			RED HILL VALLEY	BINBROOK/SHADYGLEN	BURLINGTON
A	35.61	Ancaster Creek	6.25	8.40	4.88
	14.42	Tiffany Creek	2.54	4.06	2.35
B	3.75	Ancaster Creek	0.72	0.91	0.56
	25.92	Tiffany Creek	3.96	5.97	3.55
C	57.99	Ancaster Creek	6.73	9.20	5.95
D	16.89	Sulphur Creek	1.65	1.81	1.53
E	21.35	Big Creek	1.50	2.02	1.45
	10.09	Sulphur Creek	1.84	2.74	1.51
F	46.05	Sulphur Creek	7.00	9.11	6.29
G	49.88	Sulphur Creek	6.66	8.92	5.67
H	4.05	Ancaster Creek	0.64	0.69	0.60
I	13.41	Ancaster Creek	2.60	2.94	2.02
J	10.00	Ancaster Creek	1.09	1.55	0.96
	0.85	Big Creek	0.18	0.25	0.13
K	8.07	Ancaster Creek	1.17	1.51	0.97
	5.45	Tiffany Creek	1.13	1.22	0.88
L	2.53	Big Creek	0.59	0.76	0.44

Table 8.16. Historic Extreme Storm Events under As-of-Right Conditions with Source Controls Comparison to Existing Conditions

NETWORK	AREA (ha)	RECEIVER	RED HILL VALLEY		BINBROOK/SHADYGLEN		BURLINGTON	
			m^3/s	%	m^3/s	%	m^3/s	%
A	35.61	Ancaster Creek	-0.10	-2	+0.09	+1	+0.33	+7
	14.42	Tiffany Creek	-0.23	-8	+0.09	+2	+0.18	+8
B	3.75	Ancaster Creek	-0.01	-2	+0.02	+2	+0.02	+3
	25.92	Tiffany Creek	+0.15	+4	+0.26	+5	+0.36	+11
C	57.99	Ancaster Creek	+0.21	+3	+0.56	+6	+0.37	+7
D	16.89	Sulphur Creek	+0.01	+1	+0.02	+1	+0.06	+4
E	21.35	Big Creek	+0.14	+10	+0.22	+13	+0.12	+9
	10.09	Sulphur Creek	-0.04	-2	+0.23	+9	+0.16	+12
F	46.05	Sulphur Creek	-0.04	-1	+0.80	+10	+0.49	+8
G	49.88	Sulphur Creek	+0.01	+0	+0.22	+2	+0.24	+4
H	4.05	Ancaster Creek	+0.02	+3	+0.01	+1	+0.02	+3
I	13.41	Ancaster Creek	+0.05	+2	-0.00	-0	+0.07	+3
J	10.00	Ancaster Creek	+0.09	+9	+0.16	+11	+0.11	+13
	0.85	Big Creek	-0.01	-4	+0.02	+9	+0.01	+4
K	8.07	Ancaster Creek	+0.12	+12	+0.05	+3	+0.15	+18
	5.45	Tiffany Creek	-0.01	-1	+0.01	+1	+0.05	+6
L	2.53	Big Creek	-0.02	-4	+0.03	+5	+0.04	+10

The simulated results indicate that the proposed base source controls do not provide sufficient control to also fully mitigate the impacts of formative historic storm events, with additional simulated increases in peak flows of between 1 and 7 % as compared to existing land use conditions, with the greatest increases indicated for the Burlington (August 14, 2014) storm event.

It should be noted that the source controls have been sized based on the 100-year design storm event, which has a total precipitation depth of 122 mm within a 24 hour period. The three (3) extreme storm events included in this assessment all experienced a higher precipitation depth (up to 192 mm), within shorter periods of time (ref. Table 5.7). Once the source control storage is exceeded, peak flows from the additional impervious area would be expected to spill uncontrolled, and would generate greater peak flows than comparable pervious areas under existing conditions. Hence, the simulated peak flow increases under these events of varying intensities and volumes are to be expected. The results are presented for comparison purposes only, as part of a system stress-test.

In addition to the preceding summary of expected differences in peak flows, an assessment of the simulated performance of the ditch systems under the three (3) historic extreme storms has also been undertaken. The results are presented in Table 8.17, along with a comparison to the previously presented values under existing conditions (Table 6.12).

Table 8.17. Simulated Ditch Performance Summary by Length under As-of-Right Conditions with Source Controls for Historic Extreme Storm Events

DATA SOURCE AND EVENT		SIMULATED PERFORMANCE BY LENGTH OF DITCH (m)			SIMULATED PERFORMANCE BY PERCENTAGE (%)		
SCENARIO	STORM EVENT	WITHIN DITCH	WITHIN ROW	BEYOND ROW	WITHIN DITCH	WITHIN ROW	BEYOND ROW
As of Right Conditions	Red Hill Valley	25,007	23,820	11,221	42	40	19
	Binbrook	31,798	21,146	7,104	53	35	12
	Burlington	35,999	18,300	5,750	60	30	10
Difference from Existing Conditions	Red Hill Valley	-1,043	-169	+1,212	-2	0	+2
	Binbrook	+413	-597	+184	+1	-1	0
	Burlington	-1,579	+881	+698	-3	+1	+1

The simulated results presented in Table 8.17 indicate under as-of-right conditions with source controls, for the three (3) noted historic extreme storms, between 84% and 90% of the ditch sections are able to convey the associated flows within the limits of the roadway ROW. This represents a slight improved performance under the Binbrook/Shadyglen event (1%), and a slight increase in flows exceeding beyond the ROW during the Red Hill and Burlington storm events (1 to 2%) as compared to existing conditions.

8.5 ASSESSMENT OF EXTERNAL AREAS AND DOWNSTREAM LOCATIONS

8.5.1 DESIGN STORMS

The as-of-right conditions with source controls model (including external drainage areas, as per Section 3.2.5, and Drawing 16) has been applied for the simulation of the 5 and 100 year synthetic design storms, as well as the Regional Storm Event (Hurricane Hazel). The resulting simulated peak flow rates at selected locations/nodes of interest for downstream receivers are presented in Table 8.18, along with a comparison to existing conditions (as per Table 6.13). Positive difference indicates an increase in flows under as of right conditions, negative a decrease. The results are presented by watercourse system, typically from upstream to downstream.

Table 8.18. Simulated Peak Flow Rates at Downstream Nodes of Interest for Selected Design Storms and the Regional Event – As-of-Right Conditions with LID Mitigation

RECEIVER	LOCATION NAME	SERVICE AREAS	AREA (ha)	AOR CONDITION LID PEAK FLOW RATES (m^3/s)			DIFFERENCE IN PEAK FLOWS AS COMPARED TO EXISTING CONDITIONS (%)		
				5 YEAR	100 YEAR	REG'L	5 YEAR	100 YEAR	REG'L
Ancaster Creek	AC_01	J and K	369.1	1.06	2.62	15.98	+1.8	+1.1	+0.5
	AC_03	C, J, and K	380.9	1.56	3.49	17.10	+0.5	+0.1	+0.8
	AC_04	C, J, and K	460.5	1.75	4.07	17.46	-0.7	-1.0	+0.9
	AC_06	C and D	48.9	1.70	3.24	4.73	-0.3	-1.1	+3.5
	AC_07	C and D	73.8	2.14	5.11	6.64	+2.4	+0.5	+4.0
	AC_08	C, D, J, and K	533.4	5.22	13.01	31.32	+1.4	0.0	+1.1
	AC_09	C, D, J, and K	653.4	6.58	17.39	40.66	-0.2	+0.4	+0.9
	AC_10	B-D and I-K	764.4	6.15	16.83	49.77	-0.7	+0.7	+0.8
	AC_12	B-D and H-K	768.7	6.21	16.97	50.38	-0.8	+0.7	+1.7
	AC_13	B-D and H-K	770.2	6.21	17.02	50.47	-0.8	+0.8	+1.7
	AC_14	B-D and H-K	780.6	7.54	20.08	56.77	-0.7	+0.7	+1.5
	AC_15	B-D and H-K	837.1	7.53	20.07	56.79	-0.8	+0.8	+1.5
	AC_16	A-D and H-K	839.7	7.55	20.10	57.08	-0.8	+0.9	+1.5
	AC_18	A	33.0	1.12	3.98	4.12	-23.0	+0.3	+1.3
	AC_19	A-D and H-K	872.71	7.82	21.03	60.25	-1.6	+0.9	+1.5
	AC_21	A-D and H-K	1,902.4	22.89	65.46	132.60	-1.4	+0.3	+0.8
	AC_22	A-K	3,846.1	35.47	100.10	275.20	-1.1	+0.1	+0.6
Sulphur Creek	SC_01	D and E	82.1	9.78	18.91	10.73	+0.1	-0.2	+0.4
	SC_02	D, E, and G	18.1	9.49	18.76	10.75	+0.1	-0.2	+0.4
	SC_03	E	9.1	0.48	1.33	1.18	+0.2	-4.7	+8.2
	SC_04	D, E, and G	109.5	10.74	22.79	14.48	+0.1	-0.4	+0.9
	SC_05	D-G	111.1	11.08	22.62	14.67	+0.1	-0.3	+0.9
	SC_06	D-G	129.2	11.25	23.94	16.04	+0.2	-0.3	+1.3
	SC_07	D-G	235.9	13.30	29.74	27.84	+0.1	-0.2	+0.8
	SC_08	D-G	991.8	14.43	38.51	79.86	-0.1	-0.2	+0.3

RECEIVER	LOCATION NAME	SERVICE AREAS	AREA (ha)	AOR CONDITION LID PEAK FLOW RATES (m³/s)			DIFFERENCE IN PEAK FLOWS AS COMPARED TO EXISTING CONDITIONS (%)		
				5 YEAR	100 YEAR	REG'L	5 YEAR	100 YEAR	REG'L
	SC_09	D-G	1,701.6	15.68	43.70	126.80	-1.0	-0.1	+0.4
	SC_11	F and G	29.6	3.01	7.33	7.56	-4.9	-0.6	+2.8
	SC_12	F and G	478.5	5.83	16.40	38.42	-3.3	-0.1	+0.7
	SC_14	G	46.4	1.57	3.42	3.48	-2.8	-2.0	+3.3
	SC_15A	G	53.3	0.70	3.62	4.06	-0.3	-0.2	+1.0
	SC_15B	G	253.0	2.04	6.46	7.38	-2.5	-1.6	+2.0
Tiffany Creek	TC_01	External	440.2	10.32	21.09	21.85	-0.1	-0.1	0.0
	TC_02	K	653.1	13.08	28.14	38.34	-0.1	+0.2	+0.0
	TC_03	B and K	787.6	15.30	37.06	50.19	-0.1	-0.8	+0.1
	TC_05	B and K	879.4	16.96	40.31	58.79	-0.1	-0.5	+0.1
	TC_06	A, B, and K	893.8	17.26	41.68	60.22	-0.6	-0.2	+0.2

As evident from Table 8.18, the results indicate that the peak flows at the downstream nodes are generally controlled to existing conditions for both the 5- and 100-year storm events, with an average reduction in peak flows of 1.7 and 0.2% respectively. Source over-control is generally indicated for the 5-year storm event at AC_17 and AC_18 respectively, however overall peak flows are maintained at, or below, existing condition values for both the 5- and 100-year storm events, consistent with the design basis.

The results for the Regional Storm Event (Hurricane Hazel) indicate that peak flow rates are generally unaffected by the source controls, with an average increase of 1% +/-, and a maximum increase of 8.2% at node SC_03. All other nodes are controlled below 5%, and generally to the average of 1% as noted previously. It should be noted that the source controls have been sized for control up to and including the 100-year storm event; additional Regional Storm controls have not been considered as part of the current assessment. In some cases, minor increases may also be attributable to changes in hydrograph timing from the combination of urban areas (with source controls) and larger, more rural, downstream areas.

8.5.2 CONTINUOUS SIMULATION – PEAK FLOWS, EROSION AND WATER BUDGET

Peak Flows

Consistent with the approach applied for existing and as-of-right uncontrolled conditions (Sections 6.3.2 and 7.3.2), a 55-year continuous simulation (1962-2016) has been completed for as-of-right conditions with LID controls, based on a dataset from Environment Canada's Hamilton RBG gauge site. Continuous simulation for the as-of-right controlled scenario has been undertaken to support the completion of a water budget and analysis of erosion potential. For the purposes of undertaking a continuous simulation, the Green & Ampt infiltration methodology has been applied, rather than the SCS Curve Number methodology which is applied for all single event-based analyses. This is described further in Section 3.2.5 and 4.4.2.

The annual maximum series of peak flow rates has been extracted from the modelling results for key junction nodes of interest, consistent with the locations assessed under the previous event-based approach (Section 8.4.1). A frequency analysis of the resulting peak flows has been completed in order to estimate frequency flows using the program HEC-SSP; complete results are included in Appendix D. A Log Pearson Type III frequency/probability distribution has been applied to estimate the return period frequency peak flow rates. The resulting estimated frequency flow rates for the 5 and 100-year return periods for key nodes of interest are presented in Table 8.19, and have been compared to the previously estimated values for existing conditions (Table 6.16). Positive values indicate a simulated increase as compared to existing conditions; negative values indicate a simulated decrease.

Table 8.19. Simulated Peak Flow Rates at Downstream Nodes of Interest Based on Continuous Simulation Modelling under As-of-Right Conditions with LID Controls and Comparison to Existing Conditions

RECEIVER	JUNCTION NAME	AS-OF-RIGHT CONTROLLED CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
Ancaster Creek	AC_01	1.80	3.80	0.00	0.00	0	0
	AC_03	2.20	4.20	0.00	-0.10	0	-2
	AC_04	2.30	4.20	0.00	-0.20	0	-5
	AC_06	1.40	2.30	0.00	0.00	0	0
	AC_07	1.70	3.10	0.00	-0.10	0	-3
	AC_08	5.90	11.20	0.00	-0.10	0	-1
	AC_09	6.80	15.30	0.00	0.00	0	0
	AC_10	7.50	13.90	0.00	0.00	0	0
	AC_12	7.50	13.90	0.00	-0.10	0	-1
	AC_13	7.40	13.90	-0.10	-0.10	-1	-1
	AC_14	10.00	19.10	-0.10	0.00	-1	0
	AC_15	9.80	18.80	0.00	0.00	0	0
	AC_16	9.80	18.80	0.00	-0.10	0	-1
	AC_18	1.30	3.20	0.00	+0.10	0	+3
	AC_19	10.60	21.20	-0.10	0.00	-1	0
	AC_21	29.20	63.00	-0.20	-0.40	-1	-1
	AC_22	45.70	116.40	-0.30	-0.70	-1	-1
Sulphur Creek	SC_01	4.20	7.40	0.00	-0.10	0	-1
	SC_02	4.20	7.40	0.00	-0.10	0	-1
	SC_03	0.20	0.50	-0.10	-0.10	-33	-17
	SC_04	5.10	9.60	-0.10	-0.10	-2	-1
	SC_05	5.20	9.60	0.00	-0.20	0	-2
	SC_06	5.40	10.30	0.00	-0.30	0	-3
	SC_07	8.40	16.90	0.00	-0.20	0	-1
	SC_08	12.90	36.40	-0.10	-0.10	-1	0
	SC_09	19.40	54.50	-0.20	-0.30	-1	-1
	SC_11	2.60	5.20	-0.20	-0.40	-7	-7
	SC_12	9.00	19.70	-0.20	-0.20	-2	-1

RECEIVER	JUNCTION NAME	AS-OF-RIGHT CONTROLLED CONTINUOUS SIMULATION GENERATED FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (m^3/s)		DIFFERENCE TO EXISTING CONDITIONS CONTINUOUS SIMULATION FREQUENCY FLOW RATES (%)	
		5 YEAR	100 YEAR	5 YEAR	100 YEAR	5 YEAR	100 YEAR
	SC_14	1.20	2.30	-0.10	0.00	-8	0
	SC_15A	0.10	3.80	0.00	+0.10	0	+3
	SC_15B	1.30	3.80	-0.10	-0.10	-7	-3
Tiffany Creek	TC_01	6.20	11.20	0.00	0.00	0	0
	TC_02	10.30	20.70	0.00	0.00	0	0
	TC_03	13.20	25.70	-0.10	-0.40	-1	-2
	TC_05	15.60	29.70	-0.10	-0.40	-1	-1
	TC_06	16.00	30.70	-0.10	-0.40	-1	-1

The frequency flows presented in Table 8.19 indicate that all the identified locations have been mitigated to be equivalent to or less than the existing conditions 5 year frequency flow rates with the application of simulated source controls to offset the impacts of the as-of-right condition. The overall average of the difference in 5 year frequency flow rates is a decrease of -1.9 % with a reduction range of 1 % to 33 %. The greatest decrease in frequency flow rate of 33 % is a result of the relatively low existing conditions frequency flow rate of 0.3 m3/s, with a reduction of 0.1 m3/s for the controlled as-of-right conditions.

The as-of-right controlled 100 year frequency flow rates have also been mitigated to be equivalent to or less than the existing conditions 100 year frequency flow rates with the exception of two (2) locations; junction AC_18 on Ancaster Creek and SC_15A on Sulphur Creek. The simulated source controls could not fully mitigate the 100 year frequency flows to existing conditions, as a 3% exceedance is noted at both locations which equates to an increase of 0.1 m3/s. Despite the two (2) instances of exceedance for the 100 year frequency flow rates, the application of source controls as prescribed has been demonstrated to mitigate the impacts due to the as-of-right scenario suggesting that the source controls have been appropriately sized.

Erosion

The generated continuous simulation results have also been applied to complete an erosion assessment based on the duration of flow exceedance above the erosion thresholds generated for the current study (Table 4.1). The results of this analysis are presented in Table 8.20, along with a comparison to the simulated results under existing conditions (Table 6.17).

Table 8.20. Simulated Duration of Erosion Threshold Exceedances under As-of-Right Conditions with LID Controls and Comparison to Existing Conditions

WATERCOURSE SITE	JUNCTION NAME	AS-OF-RIGHT CONDITIONS WITH LID CONTROLS		DIFFERENCE FROM EXISTING CONDITIONS	
		DURATION OF EXCEEDANCE (DAYS)	DURATION OF EXCEEDANCE (% OF TOTAL DURATION)	DURATION OF EXCEEDANCE (DAYS)	DURATION OF EXCEEDANCE (% OF TOTAL DURATION)
Ancaster Creek Tributary	AC_07	194.9	1.0	+3.98	+2.1
Ancaster Creek Tributary	AC_18	6.4	0.0	+0.05	+0.8
Sulphur Creek Tributary	SC_04	299.6	1.5	+0.10	+0.0
Sulphur Creek Tributary	SC_11	56.8	0.3	-6.84	-10.8
Sulphur Creek Tributary	SC_14	4.3	0.0	-0.09	-2.1

Locations SC_04 and SC_11 were previously noted as being moderately unstable based on the erosion analysis (Section 4.1). The difference of duration exceedances for the controlled as-of-right scenario of 0.0% and -10.8% indicates that these two (2) sites will meet or exceed the existing conditions duration exceedance targets with mitigation in place. As such, the impacts due to the as-of-right conditions would be fully mitigated at these two (2) sites with the implementation of the appropriately sized source controls. The third Sulphur Creek site (SC_14) would similarly result in a simulated decrease in the exceedance duration with the implementation of source control (2.1% less than existing conditions). The remaining two (2) sites at AC_07 and AC_18 on Ancaster Creek indicate slight residual increases in the simulated erosion threshold exceedance of 2.1 and 0.8% respectively during the 55-year simulation period. These sites were classified as stable through the erosion analysis and therefore may not be significantly impacted due to the minor duration exceedances which have been identified through the simulation modelling.

Water Budget

The continuous simulation modelling results have also been applied to develop a water budget using the overall system results generated by the as-of-right conditions with LID controls modelling (with external areas maintained under the same conditions as in all other modelling scenarios). The same approach as was applied for existing conditions (Section 6.3.2) has again been employed; results from that assessment (Table 6.16) have been used as a basis of comparison, with results presented in Table 8.21.

Table 8.21. As-of-Right Conditions with LID Controls – Average Monthly and Annual Water Budget

MONTH	RAINFALL (mm)	RUNOFF (mm) (+/- CHANGE FROM EXISTING CONDITIONS)	TOTAL LOSSES (mm) (+/- CHANGE FROM EXISTING CONDITIONS)
January	52	9 (+0.1)	43 (0.0)
February	48	8 (+0.1)	39 (0.0)
March	68	13 (+0.1)	55 (-0.1)
April	67	11 (+0.1)	56 (0.0)
May	72	12 (+0.1)	61 (0.0)
June	75	12 (+0.1)	63 (0.0)
July	78	14 (+0.1)	66 (0.0)
August	75	14 (+0.1)	62 (0.0)
September	77	14 (+0.1)	64 (0.0)
October	70	12 (+0.1)	58 (0.0)
November	72	13 (+0.1)	59 (-0.1)
December	63	11 (+0.1)	52 (-0.2)
Average Annual	818	143 (+1.1)	677 (-0.5)

Table 8.22. Comparison of Water Budget Results for As-of-Right with LID Controls and Existing Conditions

MONTH	RAINFALL (%)	RUNOFF (%)	TOTAL LOSSES (%)
January	0.0	+0.8	0.0
February	0.0	+0.8	-0.1
March	0.0	+1.0	-0.1
April	0.0	+0.8	0.0
May	0.0	+0.7	0.0
June	0.0	+0.6	0.0
July	0.0	+0.6	0.0
August	0.0	+0.6	0.0
September	0.0	+0.8	0.0
October	0.0	+1.1	-0.1
November	0.0	+0.9	-0.1
December	0.0	+0.6	-0.5
Average Annual	0.0	+0.8	-0.1

As evident from the information provided in Tables 8.21 and 8.22, the average annual runoff results indicate that the source controls would not fully mitigate the as-of-right conditions to the average annual runoff results produced from the existing conditions scenario. The annual average runoff for the as-of-right conditions with source would increase by 1.1 mm or 0.8 % over the existing conditions average annual runoff. Furthermore, the average annual total losses due to evaporation and infiltration would be reduced by 0.5 mm or 0.1 % over the existing conditions scenario. Notwithstanding, these differences are generally considered nominal, particularly when compared the uncontrolled scenario results (as per Tables 7.21 and 7.22), which indicated a runoff increase of 9.6 mm (6.8%).

8.6 CONVEYANCE IMPROVEMENTS

8.6.1 METHODOLOGY

Road Overtopping Spill Analysis

A supplementary assessment has been undertaken to identify locations where potential hydraulic conveyance improvements, such as upsizing existing culverts or installing new culverts (twinning), could be implemented to mitigate road overtopping during the 100 year storm event under existing conditions. The road overtopping locations previously summarized (ref. Section 6.2.1) have been targeted for this assessment. The as-of-right conditions scenario has not been considered for this assessment, as the proposed source controls are considered to have been designed to offset the increase in imperviousness to approximately match existing conditions flows and ditch performance.

The 100-year design storm (base IDF) has been applied for this assessment as the major system within the ROW are typically required to convey the 100-year flows. Consistent with the preceding, the culverts connecting ditched systems should, where feasible, convey the 100-year storm event to prevent roadway overtopping. Two (2) types of locations have been identified for this assessment:

— Road overtopping occurring at City culverts or storm sewers within the ROW; and

— Road overtopping occurring at locations where City base mappings assumes a culvert is located, however has been confirmed during site reconnaissance to be non-existent.

The same assessment process has been applied for both scenarios.

Prior to determining if a culvert could be upsized, an estimation of the available cover depth has been performed. Based on the Height of Fill Table (OPSD 805.010), the minimum depth of fill/cover required for round corrugated steel pipe 300 – 1400 mm in diameter is 300 mm. The pipe invert elevation, spill elevation of the crossroad, and geometry data obtained for each culvert has been used to determine the existing cover depth over each culvert. The obvert elevations of the individual pipes have been calculated and subtracted from the assumed spill elevation. If this calculated value is less than 300 mm, than it has been assumed there is insufficient cover depth to consider a culvert upgrade to mitigate the road overtopping.

The identified crossroad overtopping locations (fifteen (15) storm sewers and seventy-one (71) culverts, for a total of eighty-six (86) locations), have been screened to determine if these locations meet the criteria for a minimum of 300 mm of cover depth. The screening has resulted in twenty-five (25) overtopping locations which have a sufficient depth of cover based on this methodology. These locations have been assessed for culvert or storm upgrades to mitigate the road overtopping (ref. Table 8.23).

While storm sewers are not typically designed to convey the 100-year design storm flow rate and are usually designed for the minor system (5-year design storm peak flow rate), some of the storm sewers in the study area have been identified as relatively shorter lengths (< 100 m) and may be considered for upsizing if warranted.

Table 8.23. Existing Conditions Culvert and Storm Sewer Locations Assessed for Road Overtopping Mitigation

NETWORK	CROSS ROAD	ROAD	INFRASTRUCTURE TYPE	EXISTING DIAMETER (mm)	COVER DEPTH (m)
A	Philip Place	Massey Drive	Culvert	500	0.32
A	Montgomery Drive	Massey Drive	Storm	600	0.92
A	Mewburn Road	Bailey Avenue	Culvert	400	0.58
A	Montgomery Drive	Haig Road	Storm	650	0.38
B	Seneca Drive	Algonquin Avenue	Culvert	300	0.34
B	Oneida Boulevard	North of Algonquin Avenue	Culvert	450	0.42
B	Algonquin Avenue	North of Iroquois Avenue	Culvert	450	0.97
B	Hiawatha Boulevard	West of Algonquin Avenue	Storm	450	1.42
B	Oneida Boulevard	East of Seneca Drive	Storm	380	1.47
C	Brooks Road	East of Mapledene Drive	Culvert	550	0.56
C	Ravina Crescent	South of Rosemary Lane	Culvert	750	1.05
D	Ravina Crescent	West side of Fiddler's Green Road	Culvert	450	0.86
E	Parkview Drive	West of Taylor Road	Culvert	400	0.45
F	Beverly Court	West side of Lloyminn Avenue	Culvert	250	0.32
F	Crestview Avenue	North of Colleen Crescent	Culvert	300	1.05
F	Brookview Court	North of Crestview Avenue	Culvert	400	0.36
G	McGregor Crescent	East of Hadley Drive	Storm	300	2.13
G	McGregor Crescent	East of Hadley Drive	Storm	300	2.13
G	Joanne Court	West side of Lover's Lane	Storm	300	2.50
G	Sulphur Springs Road	West side of Mansfield Drive	Culvert	525	0.33
G	Reding Road	East side of Mansfield Drive	Storm	750	1.04
G	Sulphur Springs Road	East side of Mansfield Drive	Storm	900	0.43

NETWORK	CROSS ROAD	ROAD	INFRASTRUCTURE TYPE	EXISTING DIAMETER (mm)	COVER DEPTH (m)
G	Judith Crescent	South of Maureen Avenue	Storm	450	1.93
H	Lowden Avenue	North of Cedargrove Court	Storm	750	0.58
I	Rousseaux Street	East side of Lodor Street	Storm	300	0.70

An additional three (3) locations have been identified where no culverts were found despite the City's records indicating that culverts are present (ref. Table 8.24). The analysis of the 100-year design storm event during the existing conditions scenario has resulted in simulated road overtopping at two (2) of these locations, Cumming Court and Garden Avenue. The third location, at Oakley Court, receives flow conveyed from the Cumming Court location and has been considered for a new culvert despite no simulated road overtopping indicated during the 100-year design storm event. It has been assumed that the additional flow conveyed from Cumming Court to Oakley Court could potentially be sufficient to commence road overtopping.

A cover depth assessment at these three (3) locations based on the assumed spill elevation and the ditch invert elevations has demonstrated that there is insufficient cover depth (300 mm or greater) based on the expected size within the City of Hamilton's database. Notwithstanding, potential culverts in these locations have been assessed as part of the subsequent assessment, given that there appears to be no alternative means for the stormwater to be conveyed out of these ditched locations, other than overtopping the road or infiltrating within the ditches. 450 mm diameter culverts have been assessed at these three (3) locations to attempt to mitigate the road overtopping based on the preceding criteria and assumed cover requirements.

Table 8.24. Road Overtopping Locations for Mitigation Consideration

NETWORK	CROSS ROAD	ROAD	ROAD OVERTOPPING
D	Oakley Court	West side of Fiddler's Green Road	No
D	Cumming Court	West side of Fiddler's Green Road	Yes
J	Garden Avenue	East side of Anson Drive	Yes

Conveyance Through Private Property

Of the thirty-eight (38) private property locations which convey flow during the 100-year design storm event under existing conditions, two (2) locations have been selected for the mitigation assessment (ref. Table 8.25), as the City holds an easement in these locations, and would be legally entitled to access these areas to consider hydraulic upgrades to mitigate the simulated spills onto private property.

The mitigation alternatives that could potentially be implemented at these locations include upsizing culverts, installing new culverts (twinning), or upsizing the catch basin connected to the culvert if the culvert has available capacity to receive additional flow. A cover depth assessment at these two locations based on the available data, survey and DEM, has indicated they both have sufficient cover depth for pipe upsizing.

Table 8.25. Summary of Drainage Systems Conveyed through Private Property for Mitigation

NETWORK	ID NUMBER	DRAINAGE AREA (ha)	EASEMENT	INFRASTRUCTURE TYPE	DIAMETER (mm)	COVER DEPTH (m)
B	P10	12.97	Yes	Culvert	400	0.83
E	P20	0.89	Yes	Culvert with a Catch Basin	300	1.00

8.6.2 MODELLING RESULTS

Culvert Performance and Spill Analysis

An iterative process has been undertaken to assess potential culvert upgrades. The pipes have been increased to a diameter which still provides a minimum depth of cover (300 mm). Twinned pipes, where the existing pipe has been maintained with the addition of a second pipe with similar geometry, have been implemented where there is insufficient cover depth for a reasonable pipe upgrade, based on commercially available pipe sizes.

The mitigation alternatives have been implemented into the modelling at the identified locations, and the model has been re-simulated with the 100-year design storm. A road overtopping flow rate of 0 m3/s has been considered indicative of a successful mitigation; where overtopping continues to occur, an increased pipe size has been considered, where feasible. This process has been repeated until the overtopping is addressed, or the limits of minimum cover reached.

The storm sewers segments identified for the road overtopping assessment could not be suitably increased in diameter without increasing the downstream network pipes as well to convey the peak flow rates for the 100-year design storm. Sufficient cover depth is not available for the multiple pipes required for upsizing and in some instances the pipe size increases have not been considered practical given the limited mitigation benefit.

Based on the preceding, a total of five (5) locations have been identified where pipe upsizing or twinning would be appropriate in mitigating simulated 100-year road overtopping. These locations are presented in Table 8.26.

Table 8.26. Road Overtopping Locations for Mitigation – At Existing Culverts and Proposed Mitigation

NETWORK	CROSS ROAD	ROAD	INFRASTRUCTURE TYPE	EXISTING CONDITIONS DIAMETER/HEIGHT (mm)	EXISTING DEPTH OF COVER (m)	MITIGATION
A	Philip Place	Massey Drive	Culvert	500	0.32	Twin
B	Seneca Drive	Algonquin Avenue	Culvert	300	0.34	Twin
C	Brooks Road	East of Mapledene Drive	Culvert	550	0.56	750 mm Upgrade
C	Ravina Crescent	South of Rosemary Lane	Culvert	750	1.05	Twin
D	Ravina Crescent	West side of Fiddler's Green Road	Culvert	450	0.86	900 mm Upgrade

The simulation of the new culverts at the three (3) locations presented in Table 8.27 (those where City mapping indicates a culvert is present, but was not identified as part of the field reconnaissance) demonstrated no meaningful impact to mitigating road overtopping at Cumming Court or Garden Avenue during the 100 year design storm event. Furthermore, the Oakley Court location does not demonstrate road overtopping despite the conveyance of the unattenuated flow from the Cumming Court location. As such, with insufficient cover depth and the demonstration that culverts would not be mitigating road overtopping, implementing culverts at these three (3) locations is not considered beneficial.

Table 8.27. Road Overtopping Locations for Mitigation Consideration – No Existing Culverts

NETWORK	CROSS ROAD	ROAD	ROAD OVERTOPPING
D	Oakley Court	West side of Fiddler's Green Road	No
D	Cumming Court	West side of Fiddler's Green Road	Yes
J	Garden Avenue	East side of Anson Drive	Yes

Conveyance Through Private Property

The two (2) private property locations identified for conveyance mitigation (those locations where the City holds an easement) have been reviewed for improved conveyance requirements. As presented in Table 8.28, a 900 mm diameter pipe has been identified at location P10, and a ditch inlet catch basin at location P20. Both alternatives are considered capable of mitigating overland flow conveyance through the private properties for the 100-year storm event.

The proposed upgrade at location P10 represents a notable upgrade from the existing 400 mm diameter pipe. The required upgrade reflects the larger contributing drainage area of 12.97 ha to this location, and also the nature of the site topography (sag point in the roadway).

The existing 300 mm diameter pipe at location P20 has sufficient capacity to convey the additional flows associated with a larger inlet. As such, the pipe itself is not considered to required upgrading.

Table 8.28. Summary of Mitigation Results for Drainage Systems Conveyed through Private Property

NETWORK	I.D. NUMBER	DRAINAGE AREA (ha)	INFRASTRUCTURE TYPE	EXISTING DIAMETER (mm)	MITIGATION
B	P10	12.97	Culvert	400	900 mm Pipe
E	P20	0.89	Culvert with a Catch Basin	300	Install a honeycomb style ditch inlet structure

8.7 IMPLEMENTATION PROCESS

8.7.1 SOURCE CONTROLS

As noted in the preceding section, the preferred alternative involves the implementation of source controls on private property. These controls would be intended to provide quantity, quality, erosion and water budget controls for the increase in expected imperviousness associated with development to "as of right" conditions. This includes not only the additional building footprint (to a maximum 35% lot coverage) but also the associated amenity areas, which have been estimated in this study to be 90% of the building area.

The preferred approach places the responsibility for the design and approval of source controls upon the homeowner/developer. As discussed in Section 8.2, the City of Hamilton should however determine a preferred approach to ensure source controls are either implemented on the property title (or on a defined easement) or defined through another legal instrument (such as the Drainage Act). This is necessary to ensure that the City of Hamilton is able to continue to verify that the controls remain in place and are suitably maintained. Implementation and enforcement mechanisms are also discussed separately in Appendix F.

In general, site measures should be designed and planned in accordance with the City of Hamilton's "Comprehensive Development Guidelines and Financial Policies Manual" (2019 or latest revision). Reference is made in particular to Section G.2.5 (Stormwater Quantity and Quality Controls) and Tables G.1 and G.2 (Comprehensive List of Available SWMP's), for the City's current perspective and requirements with respect to different potential lot level measures/source controls. In general, preferred measures are considered to include:

— Permeable Pavement (Paving Stones and/or Permeable Surfaces - Driveway Areas)

— Bioretention Areas

— Enhanced Grassed Swales and Bioswales

— Sub-surface infiltration areas (open-bottom chambers, soakaway pits, etcetera)

Notwithstanding the preceding, the City of Hamilton supports the implementation of innovative solutions as required to address specific site conditions and site constraints. The City's principle of a "treatment train" is also recommended where feasible, which would involve the implementation of more than a single source control measure.

Supporting studies are expected to be required to guide the practitioner in the selection of appropriate measures. This should include a geotechnical assessment, which will specifically characterize sub-surface soil strata, infiltration potential of surface and sub-surface soils, and the expected seasonally high groundwater table, in order to confirm the applicability of the proposed measures.

In general, it is recommended that source control measures be placed in the front yard area where possible, in order to facilitate access, and given the expected density of amenity areas and features in rear-yard areas (including pools). Specific measures should also be implemented to ensure that the proposed feature cannot be removed or altered by the homeowner, such as placing the details of the measure on the property title. An easement should also be ceded to the City of Hamilton to ensure access as required for inspection and to confirm that the feature continues to operate as approved. Specific requirements for periodic inspection reports by a qualified professional engineer may also be included. The specific requirements in this regard should be discussed with the City of Hamilton.

As part of the approvals process for re-developments, a Stormwater Management (SWM) Design Brief should be prepared by a qualified Professional Engineer in the Province of Ontario, to outline the design and function of the proposed source controls on site. The Design Brief should be consistent with the requirements of the City of Hamilton's "Comprehensive Development Guidelines and Financial Policies Manual" (2019 or latest revision). In general, the Design Brief Should identify:

- Existing drainage boundaries (on-site and external contributing areas) and estimated impervious coverages and peak flow rates (to be determined in a consistent manner to the assumptions of the current study)
- Proposed drainage boundaries (on-site) and estimated impervious coverages and peak flow rates, including proposed source control measures
  - Imperviousness calculations should consider both the building footprint (assumed to be 35% of lot) and amenity areas (greater of actually calculated proposed areas or assumed 90% of building area). Rear-yard patio and pool areas shall be considered as impervious areas.
  - Hydrologic parameterization should be completed consistent with the methodology applied as part of the current study
  - Source control volume requirements should be sized based on the additional (new) impervious area on site as noted above, and the volumetric storage requirements outlined in this study depending on the site location (refer to Drawing 1 and Table 8.1)
  - Provide drawing details and calculations to confirm the design of the proposed source control measures
  - Hydrologic modelling should be completed to confirm that the proposed measures achieve post-development to pre-development peak flow quantity control requirements
  - Volumetric reduction and on-site storage should also be quantified
  - Estimated drawdown time for infiltration features should be calculated based on actual on-site infiltration rates determined from geotechnical study
  - Overflow system for source controls should be explicitly designed, and should be directed to the public right-of-way
- Proposed quality control treatment should also be quantified
  - Ensure that all additional driveway area (or other storage area subject to vehicular traffic) is treated to City of Hamilton standards, namely 80% average annual TSS removal ("Enhanced" Criteria)
  - Rooftop and other amenity areas may be considered to be "clean" for the purposes of quality control calculations, provided that these areas do not discharge across driveway areas or any other area subject to vehicular storage or travel

The City of Hamilton may wish to consider verifying the effectiveness of the implemented measures periodically through the application of the hydrologic and hydraulic modelling tools developed as part of the current study.

8.7.2 CONVEYANCE IMPROVEMENTS (CULVERTS)

Recommendations for improvements/upsizing to existing roadway culverts and locations where culverts would be expected (but not been located) to address identified hydraulic capacity deficiencies have also been made. Based on the completed assessment, a total of five (5) such locations have been identified where upsizing or twinning would be beneficial, as per Table 8.26 in the current report. A further two (2) locations have been identified where mitigation measures would be beneficial in addressing drainage system deficiencies through private property (refer to Table 8.27).

It is expected that the City of Hamilton will incorporate these proposed works into the long-term capital planning efforts. Where the proposed measures correlate with reported instances of flooding (through the City's Hot Spot Flooding or otherwise), a higher priority should be applied. Notwithstanding, it is expected that culvert replacement works would likely be correlated with overall roadway works, depending on the age and condition of the local roadway.

8.7.3 OTHER IMPROVEMENTS

In conjunction with the preceding recommended conveyance improvements, the culvert inventory (completed by others) noted a number of locations where culverts are damaged or obstructed, and require replacement, repair, or clean-out/maintenance. These locations have been identified in the Culvert Classification Drawings (Drawings C4 to C11). Where feasible, repairs to address these deficiencies should be implemented by the City's Roads Group should be implemented as soon as possible, particularly if the works can be implemented relatively easily (i.e. flushing). Notwithstanding, where more substantial repairs or replacement are warranted, these works may necessarily be deferred and included as part of capital works (i.e. roadway reconstruction).

Ditch conveyance improvements, related to conveyance area, slope, or sedimentation, have not been assessed as part of the study, and would require further study.

Opportunities for City-led roadway retrofits which incorporate LID BMPs/conveyance controls should be considered and where feasible, incorporated, into future roadway reconstruction projects.

Localized erosion issues have been noted in certain locations in downstream receivers. Repair works for these areas are beyond the scope of the current study. These works should be considered as part of the City's overall capital projects planning, in co-ordination with the Hamilton Conservation Authority and other area partners.

As noted previously, the City of Hamilton does not currently have a defined Climate Change adaptation strategy (however it is understood that a study has been commenced in 2020). A preliminary assessment of potential additional on-site source control storage volumes has been completed as part of the current study; however, this may require refinement should the City better define requirements in this regard. An overall mitigation strategy for the study area (beyond control of increased "as of right" development) may be warranted accordingly.

9 SUMMARY AND CONCLUSIONS

9.1 SUMMARY OF ANALYSES

The preceding analyses have provided a detailed understanding of the performance of the existing drainage system within the rurally-serviced existing residential areas of the Community of Ancaster. A resolute hydrologic-hydraulic model has been developed to represent existing land use conditions and calibrated/validated based on available local flow monitoring data. Under existing conditions, the simulated results indicate that the majority of the existing ditch systems would be capable of conveying the 100-year storm event within the public roadway right-of-way. A baseline with respect to erosion conditions and water budget has been established for existing land use conditions. The potential impacts of more formative storm events, both with respect to climate change adjusted rainfall, and recent local extreme storm events, have been assessed accordingly.

Under an assumed build out to the currently permissible limits of development (houses built out to 35% of the available lot area – “as–of-right” conditions), impervious surfaces within the study area would be increased, due to increased home areas and associated amenity areas (driveways, patios, etcetera). The overall expected impervious coverage would increase from approximately 41% to 57%, representing 51.0 ha of additional impervious area in the study area. As would be expected, the simulated results indicate that this change would result in an increase in peak flows, resulting in decreased ditch conveyance performance, increased peak flows to downstream receivers, increased erosion potential, and an altered water budget for the overall area.

Based on a review of potential alternatives, the preferred alternative is considered to be the application of source controls on private property. This alternative places the onus for control on the developing property, while allowing the works to be designed and constructed in conjunction with the overall development. The City of Hamilton should however determine a preferred approach to ensure source controls are either implemented on the property title (or on a defined easement) or defined through another legal instrument (such as the Drainage Act). This is necessary to ensure that the City of Hamilton is able to continue to verify that the controls remain in place and are suitably maintained.

A separate review of implementation considerations with respect to policy and procedures is provided in Appendix F of this report.

Source controls are expected to provide not only primary flood/quantity control benefits, but also ensure adequate control with respect to erosion, water budget, and water quality.

The developed hydrologic-hydraulic modelling has been applied to determine required capture targets for source controls. Based on these analyses, capture depths of 55 – 70 mm/imp ha (550 – 700 m^3/imp ha) are considered necessary to provide control up to, and including, the 100-year storm event. Required targets vary by primary drainage network, reflecting the variability in surficial soils and topography. The simulated results indicate that the preceding source controls would be sufficient to mitigate the expected impacts of full “as of right” development.

In addition to the preceding, the hydrologic-hydraulic modelling has been used to determine the additional potential requirements associated with climate change impacts. An estimated additional 30 – 45 mm of capture would be required (based on the most formative of the three (3) assessed climate change scenarios) for a total capture target of 90 – 115 mm / imp ha (900 – 1150 m^3/imp ha)

In addition to the preceding primary mitigation measures, recommendations for hydraulic structure (culvert) upgrades to address existing drainage system deficiencies has also been undertaken. The analysis has considered minimum depth of cover requirements, to ensure that the proposed culvert upgrades are reasonable and realistic.

A proposed implementation plan has been developed, in order to support the City of Hamilton in staging and implementing the proposed measures.

9.2 FUTURE STUDIES

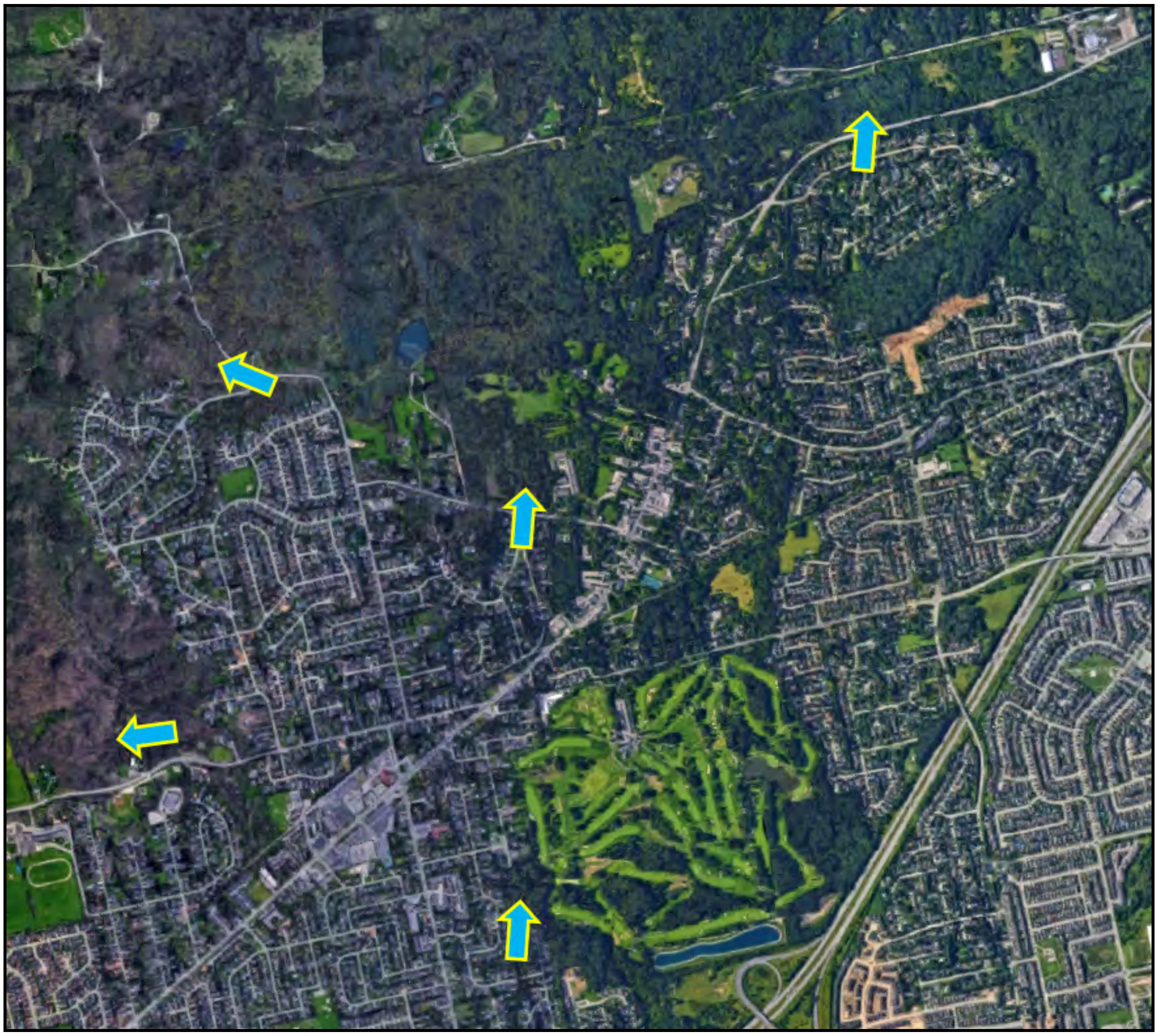
In addition to the current study, there are a number of potential additional future studies which may be considered by the City of Hamilton, as well as its partners (such as the Hamilton Conservation Authority). Potential additional studies for the study area may include:

- Additional study of potential mitigation measures to address existing drainage system deficiencies, including ditch conveyance improvements (not assessed as part of the current scope), and measures around identified private property drainage features. It is expected that such a study would be connected to future roadway reconstructions.
- In conjunction with the preceding, a review of potential opportunities to implement conveyance controls (i.e. LID BMPs) within the municipal roadway right-of-way to provide quantity, quality and erosion control to downstream receivers.
- Further study of downstream erosion issues, and a strategy with respect to reconstruction/remediation.
- A future Climate Change mitigation/adaptation strategy, including specific recommendations on stormwater management design requirements. A subsequent climate change vulnerability and adaptation strategy could also be considered. It is understood that the City has commenced a climate change study in 2020.

APPENDIX A

Erosion Analysis

Erosion Threshold Analysis DRAFT
Tiffany Creek Tributary, Ancaster Creek Tributary, & Sulphur Creek Tributaries
Ancaster Rural Service Drainage Assessment
City of Hamilton



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November 8, 2018

AquaLogic

Erosion Threshold Analysis
Tiffany Creek Tributary, Ancaster Creek Tributary, & Sulphur Creek Tributaries
Ancaster Rural Service Drainage Assessment
City of Hamilton

Erosion threshold analysis has been undertaken for tributaries of Tiffany Creek, Ancaster Creek, and Sulphur Creek with regard to rural service assessment in Ancaster. The selected locations for threshold analysis are based on existing catchment discharge points under concurrent engineering assessment (note: drainage area identifiers in this report match engineering reporting identification). Study site locations are shown on an appended figure. Analysis has been done based on field review of channel sensitivity and detailed cross-section surveys of the selected locations. Field measurements were used for erosion threshold modelling and results have been summarized for consideration in stormwater management scenarios.

Given the relatively small drainage areas and that all receivers are essentially in natural areas without immediately adjacent urban infrastructure, a less rigorous approach was taken. Each site was surveyed with three sections instead of the typical five. One site from concurrent engineering assessment was not reviewed because the receiver is a high capacity manmade channel (drainage area B).

Study Area Summary

All study area tributaries are first order watercourses with small drainage areas of less than approximately one square kilometre. Contributing land use is dominantly low density residential with adjacent natural forested slopes and valleys. Tiffany and Sulphur Creek Tributary receiving reaches flow directly into natural areas of the Niagara Escarpment physiographic region. The Ancaster Creek Tributary flows through rolling plain topography before confluence with the main branch which also flows over the Niagara Escarpment further downstream. The immediate receiving sub-reach of Ancaster Creek also flows into an online stormwater pond at the western border of the Hamilton Golf and Country Club.

Tiffany Creek Tributary

The Tiffany Creek Tributary is a waterfall and steep cascade channel that falls down a Niagara Escarpment chute slope. Limestone bedrock in weathered condition consisting of large cobble to boulder slabs underlies the channel. Topsoil depth over bedrock is highly variable along channel edges and a range of thin groundcover to mature forest defines the face of the valley slope. Flows are ephemeral to intermittent. Minor low flow at time of field work was influent to weathered rock along the channel fall line. Given the lack of flow and steepness of the channel there is no intrinsic aquatic habitat.

Ancaster Creek Tributary

The Ancaster Creek Tributary is a swamp forest moderate gradient channel with low yield base flow. The channel is moderately entrenched in a shallow valley. Mature lowland forest and shrub thicket with moderately dense groundcover fills the channel corridor and organic soils are dominant. The channel is confluent with a similar tributary from the north and the combined feature becomes depositional, presumably due to backwater influence from the noted online stormwater management pond.

Sulphur Creek Tributary (Drainage Area D/E)

The Sulphur Creek Tributary that receives drainage from areas D and E flows through a mixed forest valley in Jerseyville Park. The channel is partially entrenched and is in contact with alluvial sand to cobble material that defines riffle-pool sequences through modest meandering. Moderate erosion and channel adjustment is evident through widening channel processes. The surveyed reach is upstream of a trail crossing that has a perched outfall on the downstream side which results in a scour pool and significant widening erosion.

Sulphur Creek Tributary (Drainage Area F)

The Sulphur Creek Tributary that receives drainage from area F flows through a mixed forest at moderately high gradient. The combined flow from an existing stormwater pond and close proximity of a tributary confluence results in moderately high base flow. Channel incision and widening creates significant erosion at the confluence area with gradual improvement further downstream. Large deposits of eroded trees also occur in the channel and the stormwater pond outfall is elevated above the incised bed.

Sulphur Creek Tributary (Drainage Area G)

The Sulphur Creek Tributary that receives drainage from area G flows through swamp thicket and forest conditions with presence of weathered bedrock deposits along the channel. Base flow yield is low over the low gradient profile and this results in muted channel definition and occasional influent conditions.

Rapid Assessment Analysis

Three rapid assessment protocols were undertaken for each study reach. Field observations were used to score relative geomorphic and environmental attributes. Rapid Geomorphic Assessment (RGA) was used to rate channel stability and infrastructure impact. Rapid Habitat Assessment (RHA) was used to define in-stream and riparian habitat. Rapid Stream Assessment Technique (RSAT) was used to test broad indicators of channel stability, aquatic habitat, and water quality. A prorated score out of 100 was transposed from the results of each protocol and a combined average score was determined from the three tests. Four qualifying ranges of poor, fair, good, and optimal are maintained in the RHA and RSAT protocols, between the original scoring and the weighted scoring out of 100, while the three original ranges in RGA scoring are reflected as poor, fair, and good. The combined average score is qualified by poor to optimal ranges designed as a best fit of the individual protocol ranges. The detailed results are appended. Summary results are shown in **Table 1**.

Table 1: Rapid assessment results

	RGA Score	RHA Score	RSAT Score	Combined Score
Tiffany Creek Tributary	90	n/a	n/a	n/a
Ancaster Creek Tributary	90	63	64	72
Sulphur Creek Tributary (DA= D/E)	79	77	70	75
Sulphur Creek Tributary (DA= F)	67	63	60	63
Sulphur Creek Tributary (DA =G)	88	65	62	72

The results of rapid assessment confirm observations and summary characterization. Tiffany, Ancaster, and Sulphur Creek Tributary for drainage area G are highly stable. The Sulphur Creek Tributaries for drainage areas D/E and F are transitional with respect to stability. Adjustment is evident due to incision and widening processes in these two features. Channel forming flows are not relatively high however, because of the small drainage area response. The evident erosion is somewhat typical of forest systems with high levels of shading canopy. Shading results in lack of groundcover and shrub growth that provides higher rooting and stem density than tree cover. Exposed bank faces with lack of groundcover are also more susceptible to weathering from flow piping, wetting and drying cycles, and frost heave.

Erosion Threshold Analysis

Erosion threshold analysis proceeded as a detailed confirmation exercise of the observed channel stability conditions. Modelling analysis was undertaken using three representative cross-section surveys made over approximately 30m of channel length. Backwater influences caused by organic debris were avoided. Channel forming flow lines, fallen and matted vegetation lines where visible, and well defined sediment stain lines were used as field indicators to identify cross-section width under a variety of conditions. Channel geometry was measured laterally at each cross-section and the longitudinal profile was shot and subsequently compared to topographic plans. Channel bed substrates were measured through random-step Wolman pebble counts and recorded using the Wentworth sediment distribution scale.

Geomorphic open channel flow models were created for each cross-section location. Each model required input of channel bed substrate data, cross-section dimensions, gradient, and bank geometry. Model calculation was done for a range of hydraulic geometry, flow condition, and sediment transport parameters. Erosion indicators and thresholds were reviewed from each model.

Table 2 presents the threshold criteria used for this analysis based on small watercourse channel typology which displays some influence of vegetation control.

Table 2: Critical stability threshold criteria

	low flow morphology		
	riffle	run	pool / glide
semi-alluvial firm to dense till channels	D_{84} pavement	D_{84} pavement or vegetation control*	D_{100} pavement or vegetation control*
alluvial cohesionless channels	D_{50} pavement	D_{50} pavement or vegetation control*	D_{84} pavement or vegetation control*

*vegetation control criteria varies depending on vegetation type and density
note: step-pool and cascade-step-pool channels require case by case study

The second row criteria are applied conservatively for this study case, based on soil and sediment conditions, and channel type. Conservative vegetation control criteria are identified as 40N m^{-2} for shear stress and 1.2m s^{-1} for channel velocity. Higher thresholds for vegetation control are common, approximately 80N m^{-2} and 1.8m s^{-l}, and viable under very high levels of vegetative encroachment. Channel run and pool sections that have partial vegetation control but are not judged to be fully protected are deemed to have thresholds of approximately 0.4-0.7m s^{-1} for velocities acting on pure sand to graded sediments, with shear stress values approximately 10-15N m^{-1} being acceptable when large volumes of sub coarse sand sized sediment forms both the channel pavement and subpavement (individual sand particle size values would be too low to be practical). More cohesive gradations of silt-clay or gradations that include some gravel with sand are deemed to have thresholds of approximately 30N m^{-2} and 0.8m s^{-1} respectively for shear stress and velocity (ranges summarized in Fischenich 2001). Several references vary on specific erosion threshold levels for sediment sizing, mixes of sizes, vegetative influence, entrenchment risk, and duration of flow effects, but notwithstanding the multiplicity of methods, the noted targets have proven practical over several similar studies and modelling efforts.

Subsequent checks were done to determine if a critical stability threshold discharge is reached under lower or higher flow rates and stages than the channel forming or bankfull flow. Typically, the bankfull or active channel flow might not be dynamically stable, but a sub-bankfull rate is stable based on an integration of the testing criteria described above. The threshold is a target discharge representing a reach based average point at which channel instability is deemed to begin with rising flow stage and rising discharge, and conversely when instability stops with falling flow stage and falling discharge. This discharge then becomes the comparative flow regime target for detailed analysis of SWM hydrology.

The modelling exercise showed and confirmed that three features are stable at bankfull or channel forming flow. The Sulphur Creek Tributaries for drainage areas D/E and F are moderately unstable and required lower flow stages to achieve dynamic stability. Detailed modelling results for the three sections at each of the five sites, are appended. The additional adjustment models for Sulphur Creek Tributaries drainage areas D/E and F are also appended. Erosion threshold summary models are presented after the section models for each site. Table 3 shows the determined bankfull or channel forming flow and for Sulphur Creek Tributary drainage areas D/E and F, the dynamic stability flow adjustment.

Table 3: Cross-section results summary

	bankfull Q cms	stability Q cms
Tiffany Creek Tributary	0.41	0.41
Ancaster Creek Tributary	0.12	0.12
Sulphur Creek Tributary (DA= D/E)	0.23	0.23
Sulphur Creek Tributary (DA= F)	0.67	0.33
Sulphur Creek Tributary (DA =G)	0.61	0.53

Recommendations

Recognizing that the drainage assessment being undertaken is for existing development conditions, the retrofit opportunities to infrastructure may have constraints that preclude full realization of targets. Arguably, flows that access the flood plain do not explicitly require erosion potential control because these flows have lower indicators than flows below top of bank, whether bankfull or entrenched. As a result, the two systems that are essentially not entrenched and are stable, Ancaster and Sulphur drainage area G, do not need explicit peak control for erosion potential. The Tiffany Creek Tributary is stable and entrenched but the physical characteristics of Niagara Escarpment bedrock slope are unique and not equivalent to lower gradient streams. Based on qualitative observations, the lateral slope face on either side of the fall line is in bedrock or underlain by shallow bedrock. Flows over the bedrock slope are unlikely to be detrimental over these highly resistant conditions. The natural roughness also results in diffusion at peak events so that flow is not fully concentrated in a consistent pattern. It is recommended that the Tiffany Creek Tributary does not need explicit peak control for erosion potential.

Sulphur Creek Tributaries drainage areas D/E and F arguably require erosion potential control to a target rate less than channel forming or bankfull flow. The systems are relatively entrenched and a consideration is that they only require flow control adjustment up to events that do not access the flood plain. The top of bank capacity was not surveyed and is highly variable under existing conditions, especially on the Sulphur Creek Tributary. The equivalent of the 25 year event is a reasonable upper level for entrenchment consideration, representing qualitatively the frequent event regime. It would therefore be recommended that duration exceedance analysis be done for Sulphur Creek Tributaries drainage areas D/E and F using flow stages between the stability flows in Table 3 and the 25 year event.

A supplemental recommendation of this study regards outfall and culvert crossings in close proximity to receiving reaches. Two sites were observed in the field to have local site specific scour issues. These sites are worthy of monitoring and consideration of site specific remediation. Included in this recommendation are the Sulphur Creek Tributary from drainage area D/E that exhibits scour pool widening on the downstream side of a trail crossing in Jerseyville Park, and the Sulphur Creek Tributary from drainage area F that has an elevated SWM pond outfall with channel incision (photos appended).

Conclusions

Erosion threshold analysis has been undertaken for tributaries of Tiffany Creek, Ancaster Creek, and Sulphur Creek with regard to rural service assessment in Ancaster. Field measurements used for erosion threshold modelling have produced results for consideration in stormwater management scenarios. Additional recommendations have been made regarding infrastructure observations, The methods and results presented in this report do not address future potential erosion caused by unforeseen circumstances (e.g. SWM pond failure, culvert failures, major debris jam scour, beaver dam construction/breaching, or combinations thereof, etc.). The results presented here are also contingent on long term preservation and maintenance of natural vegetation conditions within the respective corridors. The results are also contingent on maintenance of upstream drainage characteristics that do not adversely modify future flow regime.

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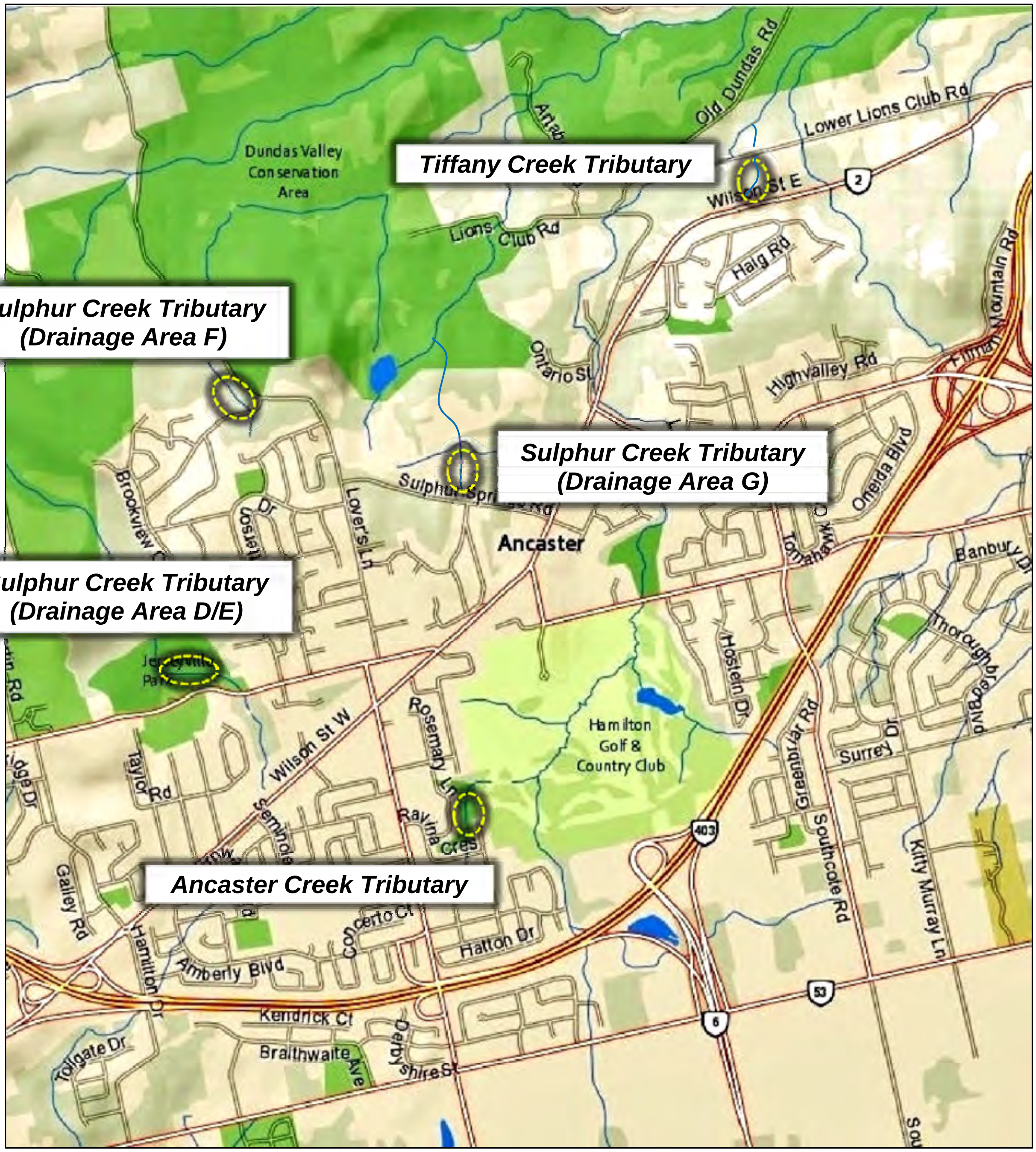
Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment

Study Site Locations

N▲ not to scale



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Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Tiffany Creek Tributary

1) Rapid Geomorphic Assessment (RGA)

Aggradation	Lobate bar	
	Coarse material in riffles embedded	
	Siltation in pools	
	Medial bars	
	Accretion on point bars	
	Poor longitudinal sorting of bed materials	
	Deposition in the overbank zone	
	n/7 =	0.00
Degradation	Exposed bridge footing(s)	
	Exposed sanitary/storm sewer/pipeline etc.	
	Elevated stormsewer outfall(s)	1
	Undermined gabion baskets/concrete aprons etc.	
	Scour pools d/s of culverts/stormsewer outlets	
	Cut face on bar forms	
	Head cutting due to knick point migration	
	Terrace cut through older bar material	
	Suspended armour layer visible in bank	1
	Channel worn into undisturbed overburden/bedrock	1
	n/10 =	0.30
Widening	Fallen/leaning trees/fence posts etc.	
	Occurrence of Large Organic Debris	
	Exposed tree roots	1
	Basal scour on inside meander bends	
	Basal scour on both sides of channel through riffle	
	Gabion baskets/concrete walls etc. out flanked	
	Length of basal scour >50% through subject reach	
	Exposed length of previously buried pipe/cable etc.	
	Fracture lines along top of bank	
	Exposed building foundation	
	n/10 =	0.10
Planimetric Form	Formation of chute(s)	
	Single thread channel to multiple channel	
	Evolution of pool-riffle form to low bed relief form	
	Cut-off channel(s)	
	Formation of island(s)	
	Thalweg alignment out of phase meander form	
	Bar forms poorly formed/reworked/removed	
	n/7 =	0.00

STABILITY INDEX (SI) = (A + D + W + P) / 4 = **0.10**

SI < 0.2	In Regime
0.2 < SI < 0.4	Transitional
SI > 0.4	In Adjustment

100 - (100*SI) = **90.0**

2) Rapid Habitat Assessment (RHA)

Riffle Run Channel Type

		Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Embeddedness		20--16	15-11	10-6	5-0
Velocity / Depth Regime		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Frequency of Riffles		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

Glide Pool Channel Type

		Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Pool Substrate Characterization		20--16	15-11	10-6	5-0
Pool Variability		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Channel Sinuosity		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

3) Rapid Stream Assessment Technique (RSAT)

		Optimal	Good	Fair	Poor
Channel Stability		11-9	8-6	5-3	2-0
Channel Scouring/Deposition		8-7	6-5	4-3	2-0
Physical Instream Habitat		8-7	6-5	4-3	2-0
Water Quality		8-7	6-5	4-3	2-0
Riparian Habitat Conditions		7-6	5-4	3-2	1-0
Biological Indicators		8-7	6-5	4-3	2-0
/50					
/100		Optimal	Good	Fair	Poor
		100-83	82-59	58-31	30-0

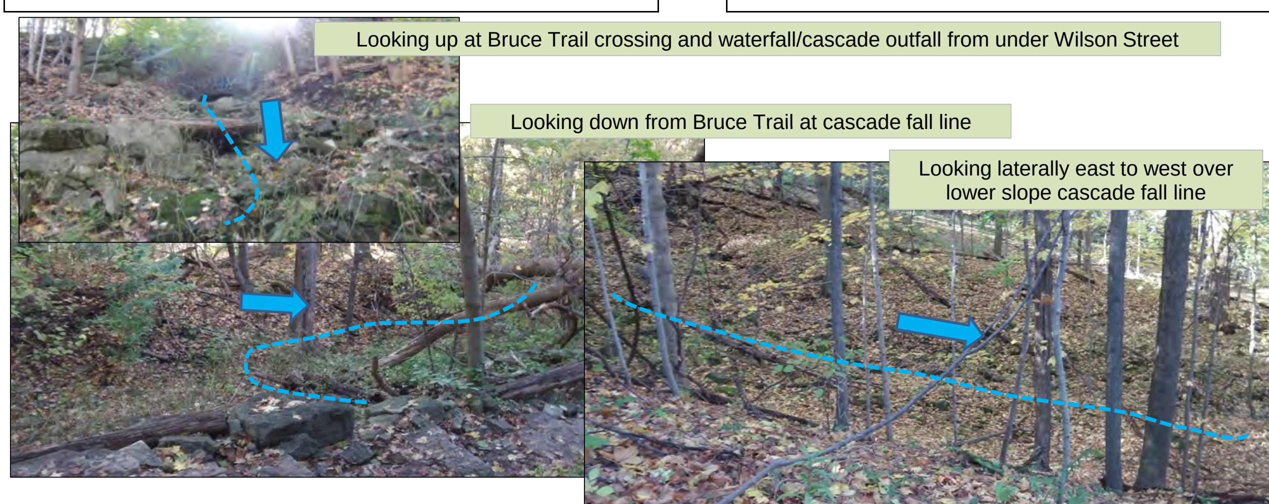
Combined Assessment

Riffle Run Channel Type

(RGA + RHA + RSAT) / 3 =		Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0

Glide Pool Channel Type

(RGA + RHA + RSAT) / 3 =		Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0



References
1) Ontario Ministry of Environment and Energy. 2003. Stormwater Management Planning and Design Manual. Appendix C.
2) USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.
3) Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments.

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Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Ancaster Creek Tributary

1) Rapid Geomorphic Assessment (RGA)

Aggradation	Lobate bar	
	Coarse material in riffles embedded	
	Siltation in pools	1
	Medial bars	
	Accretion on point bars	
	Poor longitudinal sorting of bed materials	
	Deposition in the overbank zone	1
	n/7 =	0.29
Degradation	Exposed bridge footing(s)	
	Exposed sanitary/storm sewer/pipeline etc.	
	Elevated stormsewer outfall(s)	
	Undermined gabion baskets/concrete aprons etc.	
	Scour pools d/s of culverts/stormsewer outlets	
	Cut face on bar forms	
	Head cutting due to knick point migration	
	Terrace cut through older bar material	
	Suspended armour layer visible in bank	
	Channel worn into undisturbed overburden/bedrock	
	n/10 =	0.00

Widening	Fallen/leaning trees/fence posts etc.	
	Occurrence of Large Organic Debris	1
	Exposed tree roots	
	Basal scour on inside meander bends	
	Basal scour on both sides of channel through riffle	
	Gabion baskets/concrete walls etc. out flanked	
	Length of basal scour >50% through subject reach	
	Exposed length of previously buried pipe/cable etc.	
	Fracture lines along top of bank	
	Exposed building foundation	
	n/10 =	0.10
Planimetric Form	Formation of chute(s)	
	Single thread channel to multiple channel	
	Evolution of pool-riffle form to low bed relief form	
	Cut-off channel(s)	
	Formation of island(s)	
	Thalweg alignment out of phase meander form	
	Bar forms poorly formed/reworked/removed	
	n/7 =	0.00

STABILITY INDEX (SI) = (A + D + W + P) / 4 = **0.10**

SI < 0.2	In Regime
0.2 < SI < 0.4	Transitional
SI > 0.4	In Adjustment

100 - (100*SI) = **90.4**

2) Rapid Habitat Assessment (RHA)

Riffle Run Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Embeddedness		20--16	15-11	10-6	5-0
Velocity / Depth Regime		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Frequency of Riffles		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

Glide Pool Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover	17	20--16	15-11	10-6	5-0
Pool Substrate Characterization	7	20--16	15-11	10-6	5-0
Pool Variability	8	20--16	15-11	10-6	5-0
Sediment Deposition	7	20--16	15-11	10-6	5-0
Channel Flow Status	7	20--16	15-11	10-6	5-0
Channel Alteration	12	20--16	15-11	10-6	5-0
Channel Sinuosity	12	20--16	15-11	10-6	5-0
Bank Stability u/s L	9	10-8	7-6	5-3	2-0
u/s R	9	10-8	7-6	5-3	2-0
Vegetative Protection u/s L	9	10-8	7-6	5-3	2-0
u/s R	9	10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L	10	10-8	7-6	5-3	2-0
u/s R	10	10-8	7-6	5-3	2-0
/200	126				
/100	63	Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

3) Rapid Stream Assessment Technique (RSAT)

Parameter	Score	Optimal	Good	Fair	Poor
Channel Stability	9	11-9	8-6	5-3	2-0
Channel Scouring/Deposition	6	8-7	6-5	4-3	2-0
Physical Instream Habitat	5	8-7	6-5	4-3	2-0
Water Quality	5	8-7	6-5	4-3	2-0
Riparian Habitat Conditions	6	7-6	5-4	3-2	1-0
Biological Indicators	1	8-7	6-5	4-3	2-0
/50	32				
/100	64.0	Optimal	Good	Fair	Poor
		100-83	82-59	58-31	30-0

Combined Assessment

Riffle Run Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =		Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0

Glide Pool Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =	72	Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0

Typical conditions at depositional transition into existing SWM pond

Typical swamp forest conditions with moderate entrenchment upstream of SWM pond

References
1) Ontario Ministry of Environment and Energy. 2003. Stormwater Management Planning and Design Manual. Appendix C.
2) USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.
3) Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments.

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Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E)

1) Rapid Geomorphic Assessment (RGA)

Aggradation	Lobate bar	
	Coarse material in riffles embedded	1
	Siltation in pools	
	Medial bars	
	Accretion on point bars	
	Poor longitudinal sorting of bed materials	
	Deposition in the overbank zone	
	n/7 =	0.14
Degradation	Exposed bridge footing(s)	
	Exposed sanitary/storm sewer/pipeline etc.	
	Elevated stormsewer outfall(s)	
	Undermined gabion baskets/concrete aprons etc.	1
	Scour pools d/s of culverts/stormsewer outlets	1
	Cut face on bar forms	
	Head cutting due to knick point migration	
	Terrace cut through older bar material	
	Suspended armour layer visible in bank	
	Channel worn into undisturbed overburden/bedrock	1
	n/10 =	0.30
Widening	Fallen/leaning trees/fence posts etc.	1
	Occurrence of Large Organic Debris	1
	Exposed tree roots	1
	Basal scour on inside meander bends	
	Basal scour on both sides of channel through riffle	1
	Gabion baskets/concrete walls etc. out flanked	
	Length of basal scour >50% through subject reach	
	Exposed length of previously buried pipe/cable etc.	
	Fracture lines along top of bank	
	Exposed building foundation	
	n/10 =	0.40
Planimetric Form	Formation of chute(s)	
	Single thread channel to multiple channel	
	Evolution of pool-riffle form to low bed relief form	
	Cut-off channel(s)	
	Formation of island(s)	
	Thalweg alignment out of phase meander form	
	Bar forms poorly formed/reworked/removed	
	n/7 =	0.00

STABILITY INDEX (SI) = (A + D + W + P) / 4 = **0.21**

SI < 0.2	In Regime
0.2 < SI < 0.4	Transitional
SI > 0.4	In Adjustment
100 - (100*SI) =	**78.9**

2) Rapid Habitat Assessment (RHA)

Riffle Run Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover	16	20--16	15-11	10-6	5-0
Embeddedness	12	20--16	15-11	10-6	5-0
Velocity / Depth Regime	17	20--16	15-11	10-6	5-0
Sediment Deposition	15	20--16	15-11	10-6	5-0
Channel Flow Status	17	20--16	15-11	10-6	5-0
Channel Alteration	16	20--16	15-11	10-6	5-0
Frequency of Riffles	13	20--16	15-11	10-6	5-0
Bank Stability u/s L	8	10-8	7-6	5-3	2-0
u/s R	8	10-8	7-6	5-3	2-0
Vegetative Protection u/s L	7	10-8	7-6	5-3	2-0
u/s R	7	10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L	9	10-8	7-6	5-3	2-0
u/s R	9	10-8	7-6	5-3	2-0
/200	154				
/100	**77.0**	Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

Glide Pool Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Pool Substrate Characterization		20--16	15-11	10-6	5-0
Pool Variability		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Channel Sinuosity		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

3) Rapid Stream Assessment Technique (RSAT)

Parameter	Score	Optimal	Good	Fair	Poor
Channel Stability	8	11-9	8-6	5-3	2-0
Channel Scouring/Deposition	6	8-7	6-5	4-3	2-0
Physical Instream Habitat	6	8-7	6-5	4-3	2-0
Water Quality	5	8-7	6-5	4-3	2-0
Riparian Habitat Conditions	5	7-6	5-4	3-2	1-0
Biological Indicators	5	8-7	6-5	4-3	2-0
/50	35				
/100	**70.0**	Optimal	Good	Fair	Poor
		100-83	82-59	58-31	30-0

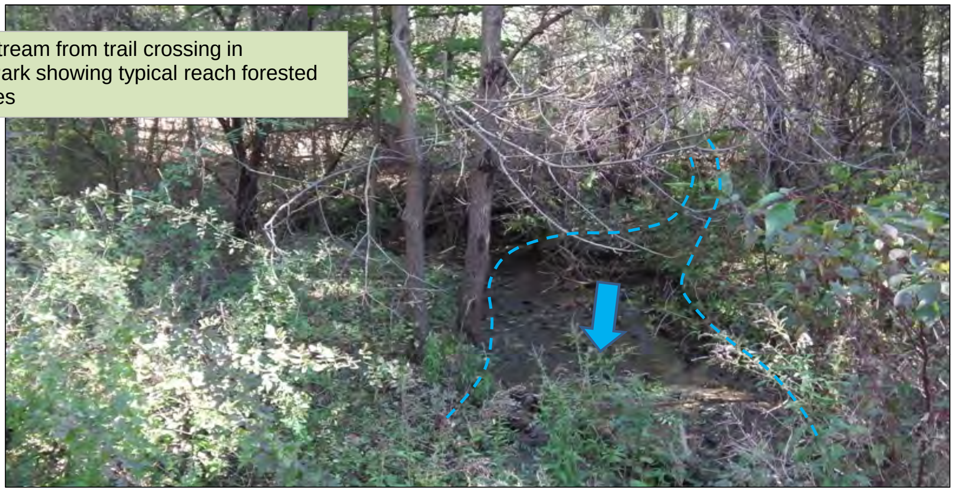
Combined Assessment

Riffle Run Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =	**75.3**	100-80	80-56	55-30	29-0

Glide Pool Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =		100-80	80-56	55-30	29-0



Looking upstream from trail crossing in Jerseyville Park showing typical reach forested riparian zones

References
1) Ontario Ministry of Environment and Energy. 2003. Stormwater Management Planning and Design Manual. Appendix C.
2) USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.
3) Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments.

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Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F)

1) Rapid Geomorphic Assessment (RGA)

Aggradation	Lobate bar	
	Coarse material in riffles embedded	1
	Siltation in pools	1
	Medial bars	
	Accretion on point bars	
	Poor longitudinal sorting of bed materials	1
	Deposition in the overbank zone	
	n/7 =	0.43
Degradation	Exposed bridge footing(s)	
	Exposed sanitary/storm sewer/pipeline etc.	
	Elevated stormsewer outfall(s)	1
	Undermined gabion baskets/concrete aprons etc.	
	Scour pools d/s of culverts/stormsewer outlets	
	Cut face on bar forms	
	Head cutting due to knick point migration	1
	Terrace cut through older bar material	
	Suspended armour layer visible in bank	
	Channel worn into undisturbed overburden/bedrock	1
	n/10 =	0.30
Widening	Fallen/leaning trees/fence posts etc.	1
	Occurrence of Large Organic Debris	1
	Exposed tree roots	1
	Basal scour on inside meander bends	
	Basal scour on both sides of channel through riffle	
	Gabion baskets/concrete walls etc. out flanked	
	Length of basal scour >50% through subject reach	
	Exposed length of previously buried pipe/cable etc.	
	Fracture lines along top of bank	
	Exposed building foundation	
	n/10 =	0.30
Planimetric Form	Formation of chute(s)	
	Single thread channel to multiple channel	
	Evolution of pool-riffle form to low bed relief form	
	Cut-off channel(s)	
	Formation of island(s)	
	Thalweg alignment out of phase meander form	1
	Bar forms poorly formed/reworked/removed	1
	n/7 =	0.29

STABILITY INDEX (SI) = (A + D + W + P) / 4 = **0.33**

SI < 0.2	In Regime
0.2 < SI < 0.4	Transitional
SI > 0.4	In Adjustment
100 - (100*SI) =	**67.1**

2) Rapid Habitat Assessment (RHA)

Riffle Run Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover	14	20--16	15-11	10-6	5-0
Embeddedness	10	20--16	15-11	10-6	5-0
Velocity / Depth Regime	7	20--16	15-11	10-6	5-0
Sediment Deposition	12	20--16	15-11	10-6	5-0
Channel Flow Status	14	20--16	15-11	10-6	5-0
Channel Alteration	12	20--16	15-11	10-6	5-0
Frequency of Riffles	13	20--16	15-11	10-6	5-0
Bank Stability u/s L	7	10-8	7-6	5-3	2-0
u/s R	7	10-8	7-6	5-3	2-0
Vegetative Protection u/s L	7	10-8	7-6	5-3	2-0
u/s R	7	10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L	8	10-8	7-6	5-3	2-0
u/s R	8	10-8	7-6	5-3	2-0
/200	126				
/100	**63.0**	Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

Glide Pool Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Pool Substrate Characterization		20--16	15-11	10-6	5-0
Pool Variability		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Channel Sinuosity		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

3) Rapid Stream Assessment Technique (RSAT)

Parameter	Score	Optimal	Good	Fair	Poor
Channel Stability	7	11-9	8-6	5-3	2-0
Channel Scouring/Deposition	4	8-7	6-5	4-3	2-0
Physical Instream Habitat	5	8-7	6-5	4-3	2-0
Water Quality	5	8-7	6-5	4-3	2-0
Riparian Habitat Conditions	5	7-6	5-4	3-2	1-0
Biological Indicators	4	8-7	6-5	4-3	2-0
/50	30				
/100	**60.0**	Optimal	Good	Fair	Poor
		100-83	82-59	58-31	30-0

Combined Assessment

Riffle Run Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =	**63.4**	Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0

Glide Pool Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =		Optimal	Good	Fair	Poor
		100-80	80-56	55-30	29-0

Typical reach conditions showing entrenchment, shade canopy, and eroded and fallen trees in background

References

1) Ontario Ministry of Environment and Energy. 2003. Stormwater Management Planning and Design Manual. Appendix C.
2) USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.
3) Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments.

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Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area G)

1) Rapid Geomorphic Assessment (RGA)

Aggradation	Lobate bar	
	Coarse material in riffles embedded	1
	Siltation in pools	
	Medial bars	
	Accretion on point bars	
	Poor longitudinal sorting of bed materials	
	Deposition in the overbank zone	
	n/7 =	0.14
Degradation	Exposed bridge footing(s)	
	Exposed sanitary/storm sewer/pipeline etc.	
	Elevated stormsewer outfall(s)	
	Undermined gabion baskets/concrete aprons etc.	
	Scour pools d/s of culverts/stormsewer outlets	
	Cut face on bar forms	
	Head cutting due to knick point migration	
	Terrace cut through older bar material	
	Suspended armour layer visible in bank	
	Channel worn into undisturbed overburden/bedrock	
	n/10 =	0.00
Widening	Fallen/leaning trees/fence posts etc.	
	Occurrence of Large Organic Debris	1
	Exposed tree roots	1
	Basal scour on inside meander bends	
	Basal scour on both sides of channel through riffle	
	Gabion baskets/concrete walls etc. out flanked	
	Length of basal scour >50% through subject reach	
	Exposed length of previously buried pipe/cable etc.	
	Fracture lines along top of bank	
	Exposed building foundation	
	n/10 =	0.20
Planimetric Form	Formation of chute(s)	
	Single thread channel to multiple channel	
	Evolution of pool-riffle form to low bed relief form	
	Cut-off channel(s)	
	Formation of island(s)	
	Thalweg alignment out of phase meander form	1
	Bar forms poorly formed/reworked/removed	
	n/7 =	0.14

STABILITY INDEX (SI) = (A + D + W + P) / 4 = **0.12**

SI < 0.2	In Regime
0.2 < SI < 0.4	Transitional
SI > 0.4	In Adjustment

100 - (100*SI) = **87.9**

2) Rapid Habitat Assessment (RHA)

Riffle Run Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover	18	20--16	15-11	10-6	5-0
Embeddedness	12	20--16	15-11	10-6	5-0
Velocity / Depth Regime	5	20--16	15-11	10-6	5-0
Sediment Deposition	10	20--16	15-11	10-6	5-0
Channel Flow Status	6	20--16	15-11	10-6	5-0
Channel Alteration	12	20--16	15-11	10-6	5-0
Frequency of Riffles	10	20--16	15-11	10-6	5-0
Bank Stability u/s L	9	10-8	7-6	5-3	2-0
u/s R	9	10-8	7-6	5-3	2-0
Vegetative Protection u/s L	10	10-8	7-6	5-3	2-0
u/s R	10	10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L	10	10-8	7-6	5-3	2-0
u/s R	10	10-8	7-6	5-3	2-0
/200	131				
/100	**65.5**	Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

Glide Pool Channel Type

Parameter	Score	Optimal	Good	Fair	Poor
Epifaunal Substrate / Available Cover		20--16	15-11	10-6	5-0
Pool Substrate Characterization		20--16	15-11	10-6	5-0
Pool Variability		20--16	15-11	10-6	5-0
Sediment Deposition		20--16	15-11	10-6	5-0
Channel Flow Status		20--16	15-11	10-6	5-0
Channel Alteration		20--16	15-11	10-6	5-0
Channel Sinuosity		20--16	15-11	10-6	5-0
Bank Stability u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Vegetative Protection u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
Riparian Vegetation Zone Width u/s L		10-8	7-6	5-3	2-0
u/s R		10-8	7-6	5-3	2-0
/200					
/100		Optimal	Good	Fair	Poor
		100-78	77-53	52-28	27-0

3) Rapid Stream Assessment Technique (RSAT)

Parameter	Score	Optimal	Good	Fair	Poor
Channel Stability	9	11-9	8-6	5-3	2-0
Channel Scouring/Deposition	4	8-7	6-5	4-3	2-0
Physical Instream Habitat	6	8-7	6-5	4-3	2-0
Water Quality	5	8-7	6-5	4-3	2-0
Riparian Habitat Conditions	6	7-6	5-4	3-2	1-0
Biological Indicators	1	8-7	6-5	4-3	2-0
/50	31				
/100	**62.0**	Optimal	Good	Fair	Poor
		100-83	82-59	58-31	30-0

Combined Assessment

Riffle Run Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =	**71.8**	100-80	80-56	55-30	29-0

Glide Pool Channel Type

	Score	Optimal	Good	Fair	Poor
(RGA + RHA + RSAT) / 3 =		100-80	80-56	55-30	29-0

Typical reach conditions showing swamp thicket riparian zones and groundcover encroachment

References
1) Ontario Ministry of Environment and Energy. 2003. Stormwater Management Planning and Design Manual. Appendix C.
2) USEPA. 2004. Wadeable Stream Assessment: Field Operations Manual. EPA841-B-04-004. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, DC.
3) Galli, J., 1996. Rapid stream assessment technique, field methods. Metropolitan Washington Council of Governments.

Tiffany Creek Tributary

Sections 1 to 3 existing conditions
&
Erosion Threshold Summary

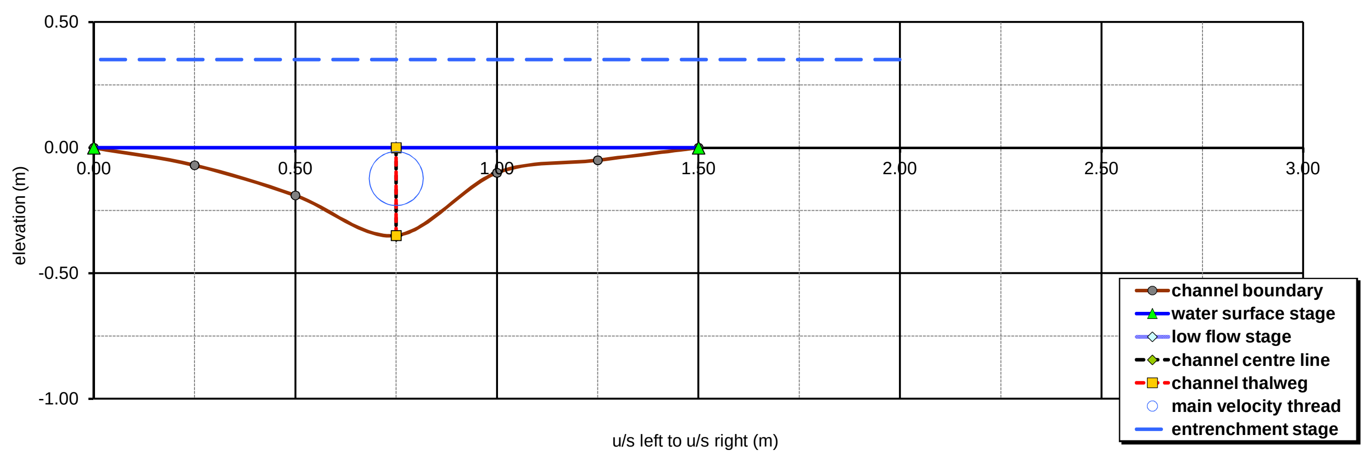
GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

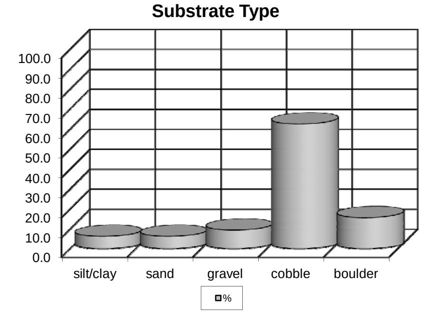
B. de Geus 05.11

Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Tiffany Creek Tributary - Section 1

Cross Section Plot



Substrate Type



Morphology Type	
cascade	●
step	
riffle	
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.19
R (m)	0.11
TW (m)	1.50
WP (m)	1.70
max d (m)	0.35
mean d (m)	0.13
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.45
ff V mean/V*	2.61
ff D_{84}	1.15
ff mean	1.88
ROUGH BED	

Hydraulic Ratios	
ER max d	2.67
r_c / TW	
TW / Lf_w	#DIV/0!
TW/max d	4.3
TW/mean d	11.8

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	1.674	15.75	NO	NO	NO	NO
V_* (m s^{-1})	0.259	D_{50}	1.914	18.01	NO	NO	NO	NO
		D_{84}	2.322	21.84	NO	NO	NO	NO

Section Data

ER_e (m)	0.35	ER stations L / R	-2.00	2.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.50	1.50
Lf_e (m)	-0.350	Lf stations L / R	0.75	0.75	
W_{fp} (m)	4.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.35	0.75	
E_g (m m^{-1})	0.3000				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				2.6	2.0	1.4
B3	0.0015	0.0011	saltation	YES	NO	NO
C3	0.0001	0.0000	rolling	YES	YES	YES
C4	0.0042	0.0028	Ø	NO	NO	NO

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	25.00	130.00	170.00	250.00	380.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})	24.25	126.10	164.90	242.50	368.60
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.400	Q (cms)	
V (m s^{-1})	2.11	V (m s^{-1})	
n	0.060	n	
Fr	1.89	Fr	
D_c rectangular (m)	0.20	D_c rectangular (m)	
D_c trapezoidal (m)	0.25	D_c trapezoidal (m)	
D_c triangular (m)	0.32	D_c triangular (m)	
D_c parabolic (m)	0.23	D_c parabolic (m)	
D_c mean (m)	0.25	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	1175.86	Ω (watts m^{-1})	
ω_a (watts m^{-2})	692.82	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	461.88	ω_a/TW (watts m^{-1})	
$Re*$	492.6	$Re*$	
Re	206714	Re	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	33.58		
τ_{calc} (N m^{-2})	329.13		
τ D_{crit} (gr-co) (mm)	339.31		
D_{50} V_c (vcs +) (m s^{-1})	2.02	1.37	
D_{84} V_c (vcs +) (m s^{-1})	2.45	1.66	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
6.3	6.3	9.4	62.5	15.6

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

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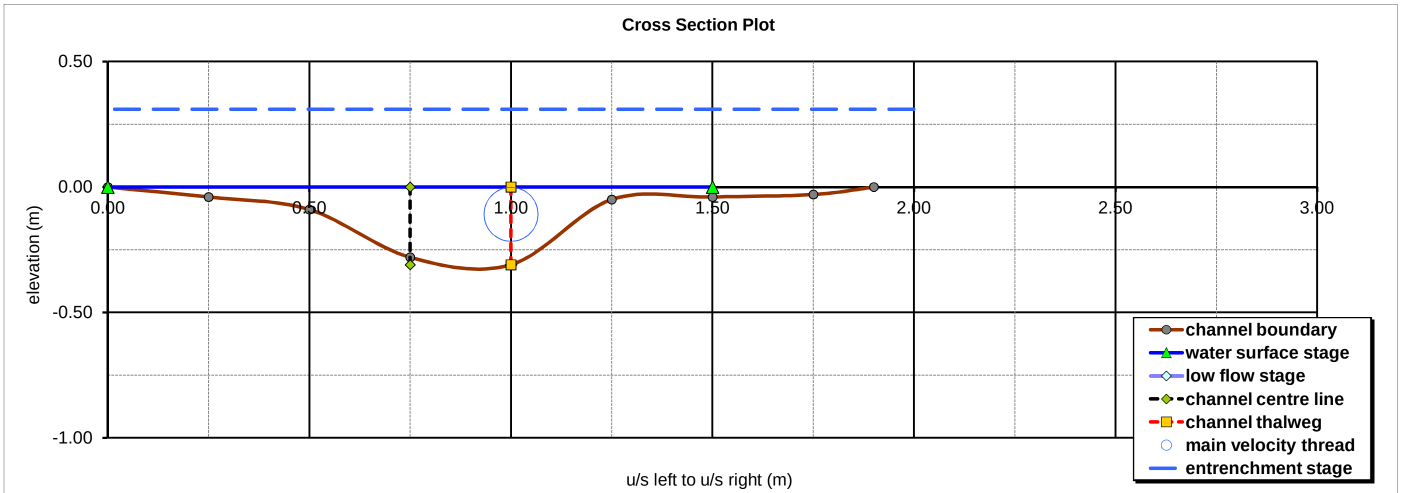
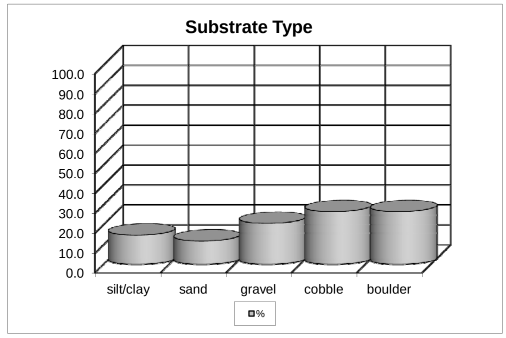
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Tiffany Creek Tributary - Section 2





Morphology Type	
cascade	●
step	
riffle	
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.21
R (m)	0.10
TW (m)	1.90
WP (m)	2.09
max d (m)	0.31
mean d (m)	0.11
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.34
ff V mean/V*	2.23
ff D_{84}	0.42
ff mean	1.33
ROUGH BED	

Hydraulic Ratios	
ER max d	2.11
r_c / TW	
TW / Lf_w	#DIV/0!
TW/max d	6.1
TW/mean d	17.3

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.412	4.11	NO	NO	NO	YES
V_* (m s^{-1})	0.245	D_{50}	1.737	17.30	NO	NO	NO	NO
		D_{84}	2.500	24.90	NO	NO	NO	NO

Section Data

ER_e (m)	0.31	ER stations L / R	-2.00	2.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.50	1.50
Lf_e (m)	-0.310	Lf stations L / R	1.00	1.00	
W_{fp} (m)	4.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.31	1.00	
E_g (m m^{-1})	0.3000				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})		D_{30}	D_{50}	D_{84}
			T_*	37.8	2.2	1.0
B3	0.0015	0.0010	saltation	YES	YES	NO
C3	0.0001	0.0000	rolling	YES	YES	YES
C4	0.0042	0.0022	Ø	NO	NO	NO

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.50	8.00	140.00	290.00	320.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})		7.76	135.80	281.30	310.40
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.407	Q (cms)	
V (m s^{-1})	1.95	V (m s^{-1})	
n	0.060	n	
Fr	1.88	*Fr*	
D_c rectangular (m)	0.17	D_c rectangular (m)	
D_c trapezoidal (m)	0.24	D_c trapezoidal (m)	
D_c triangular (m)	0.33	D_c triangular (m)	
D_c parabolic (m)	0.24	D_c parabolic (m)	
D_c mean (m)	0.24	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	1195.21	Ω (watts m^{-1})	
ω_a (watts m^{-2})	572.42	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	301.27	ω_a/TW (watts m^{-1})	
*Re**	407.6	*Re**	
Re	170790	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	29.96		
τ_{calc} (N m^{-2})	293.58		
τ D_{crit} (gr-co) (mm)	302.66		
D_{50} V_c (vcs +) (m s^{-1})	1.83	1.34	
D_{84} V_c (vcs +) (m s^{-1})	2.64	1.93	

Substrate Type (%)

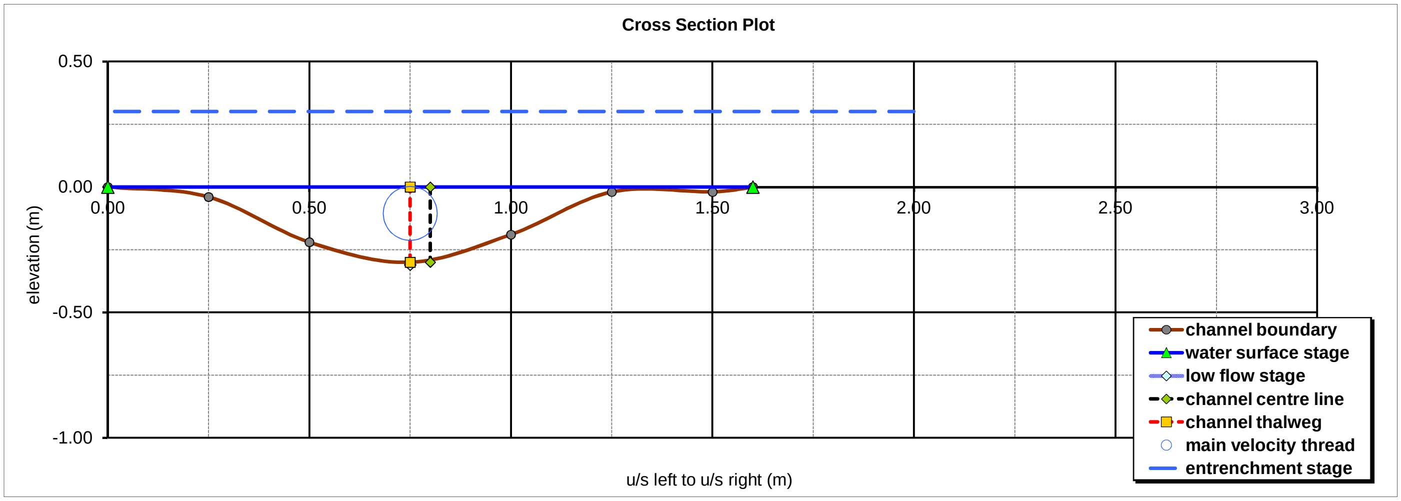
silt/clay	sand	gravel	cobble	boulder
14.7	11.8	20.6	26.5	26.5

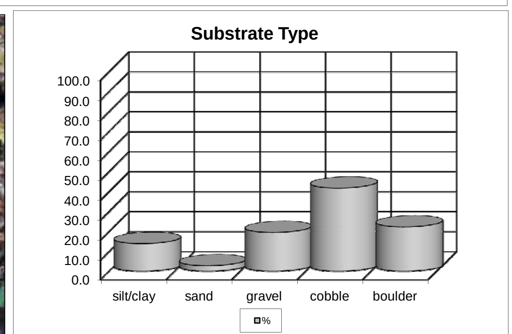
Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

B. de Geus 05.11

Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Tiffany Creek Tributary - Section 3





Morphology Type

cascade	●
step	
riffle	
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	0.20
R (m)	0.11
TW (m)	1.60
WP (m)	1.75
max d (m)	0.30
mean d (m)	0.12
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr R/D_{84}	0.39
ff V mean/V*	2.39
ff D_{84}	0.70
ff mean	1.55
ROUGH BED	

Hydraulic Ratios

ER max d	2.50
r_c / TW	
TW / Lf_w	#DIV/0!
TW/max d	5.3
TW/mean d	13.1

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.803	7.56	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.259	D_{50}	1.674	15.75	NO	NO	NO	NO
		D_{84}	2.500	23.52	NO	NO	NO	NO

Section Data

ER_e (m)	0.30	ER stations L / R	-2.00	2.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.60	1.60
Lf_e (m)	-0.310	Lf stations L / R	0.75	0.75	
W_{fp} (m)	4.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.30	0.75	
E_g ($m\ m^{-1}$)	0.3000				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				11.3	2.6	1.2
B3	0.0015	0.0010	saltation	YES	YES	NO
C3	0.0001	0.0000	rolling	YES	YES	YES
C4	0.0043	0.0024	Ø	NO	NO	NO

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	2.00	30.00	130.00	290.00	370.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})		29.10	126.10	281.30	358.90
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.413	Q (cms)	
V ($m\ s^{-1}$)	2.10	V ($m\ s^{-1}$)	
n	0.060	n	
Fr	1.92	*Fr*	
D_c rectangular (m)	0.19	D_c rectangular (m)	
D_c trapezoidal (m)	0.25	D_c trapezoidal (m)	
D_c triangular (m)	0.33	D_c triangular (m)	
D_c parabolic (m)	0.23	D_c parabolic (m)	
D_c mean (m)	0.25	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	1212.82	Ω (watts m^{-1})	
ω_a (watts m^{-2})	692.58	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	432.86	ω_a/TW (watts m^{-1})	
*Re**	370.5	*Re**	
Re	206642	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	33.58		
τ_{calc} (N m^{-2})	329.06		
τ D_{crit} (gr-co) (mm)	339.24		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	1.77	1.20	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	2.64	1.79	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
13.9	2.8	19.4	41.7	22.2

GEO - ESUM v.1.3 Erosion Threshold Summary Model

AquaLogic
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Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Tiffany Creek Tributary

Existing	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Xsec. 1	0.400	2.11	n/a	Y	Y	329	n/a	N	Y	1175	n/a
Xsec. 2	0.407	1.95	n/a	Y	Y	294	n/a	N	Y	1195	n/a
Xsec. 3	0.413	2.10	n/a	Y	Y	329	n/a	N	Y	1212	n/a

Dynamic Stability

Xsec. 1			
Xsec. 2			
Xsec. 3			

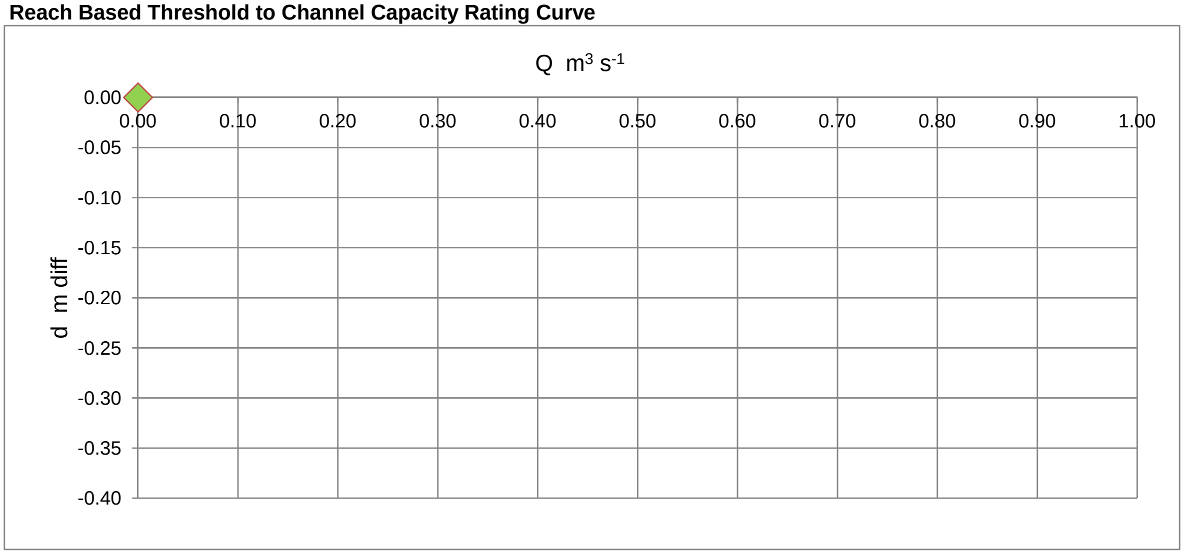
Stability Criteria Met: Y - Yes, N - No, D - Dynamic

* - within 5 mm

Dynamic Stability
Dynamic Stability = Cautionary
Unstable

	Q $m^3 s^{-1}$ existing	Q $m^3 s^{-1}$ stable	Q $m^3 s^{-1}$ diff	d m diff
Xsec. 1	0.40			0.00
Xsec. 2	0.41			0.00
Xsec. 3	0.41			0.00
mean	**0.41**			0.00

Reach Based Threshold to Channel Capacity Rating Curve



Ancaster Creek Tributary

Sections 1 to 3 existing conditions
&
Erosion Threshold Summary

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

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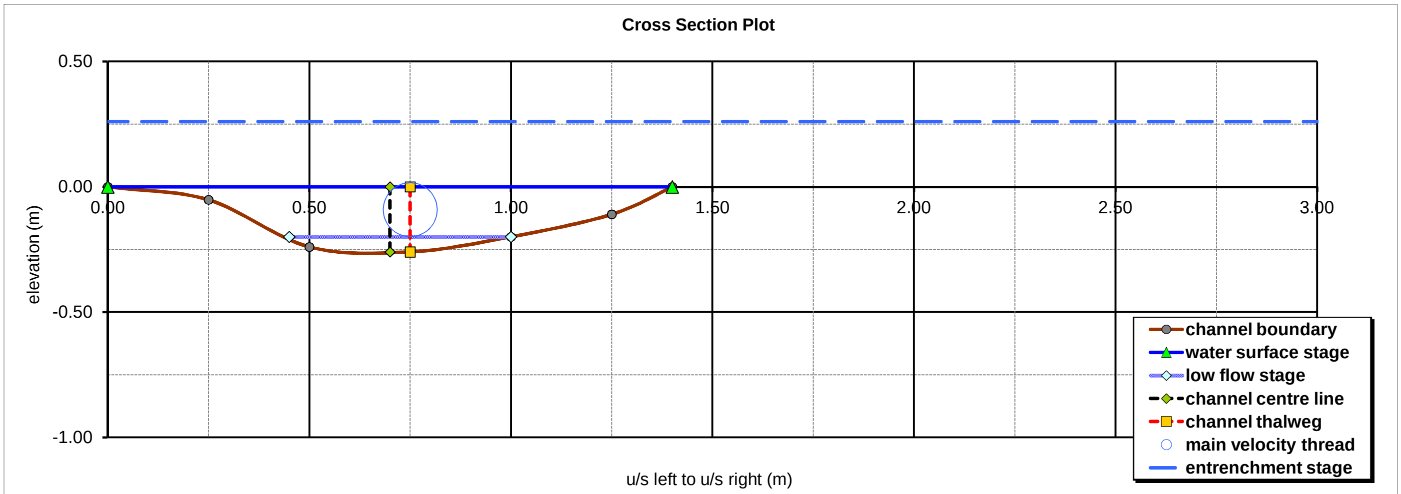
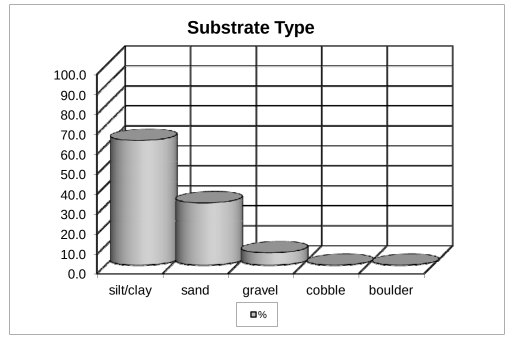
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Ancaster Creek Tributary - Section 1





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.21
R (m)	0.14
TW (m)	1.40
WP (m)	1.53
max d (m)	0.26
mean d (m)	0.15
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	549.82
ff V mean/V*	12.43
ff D_{84}	18.67
ff mean	15.55
SMOOTH BED	

Hydraulic Ratios	
ER max d	14.29
r_c / TW	
TW / Lf_w	2.55
TW/max d	5.4
TW/mean d	9.3

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.000	0.02	YES	YES	YES	YES
V_* ($m\ s^{-1}$)	0.041	D_{50}	0.002	0.13	YES	YES	YES	YES
		D_{84}	0.032	1.91	NO	NO	YES	YES

Section Data

ER_e (m)	0.26	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.40	1.40
Lf_e (m)	-0.200	Lf stations L / R	0.45	1.00	
W_{fp} (m)	20.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.26	0.75	
E_g ($m\ m^{-1}$)	0.0060				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})		D_{30}	D_{50}	D_{84}
			T_*	416.6	166.6	33.3
B3	0.0010	0.0014	saltation	YES	YES	YES
C3	0.0000	0.0000	rolling	YES	YES	YES
C4	0.0024	0.0039	Ø	NO	NO	NO

Substrate Gradation	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.01	0.02	0.05	0.25	8.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)					7.76
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime Strickler method		Flow Regime Limerinos method	
Q (cms)	0.123	Q (cms)	
V ($m\ s^{-1}$)	0.59	V ($m\ s^{-1}$)	
n	0.035	n	
Fr	0.48	*Fr*	
D_c rectangular (m)	0.09	D_c rectangular (m)	
D_c trapezoidal (m)	0.14	D_c trapezoidal (m)	
D_c triangular (m)	0.20	D_c triangular (m)	
D_c parabolic (m)	0.12	D_c parabolic (m)	
D_c mean (m)	0.14	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	7.23	Ω (watts m^{-1})	
ω_a (watts m^{-2})	4.73	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	3.38	ω_a/TW (watts m^{-1})	
*Re**	0.1	*Re**	
Re	70605	*Re*	
turbulence	LOW	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	0.82		
τ_{calc} ($N\ m^{-2}$)	8.08		
τ D_{crit} (gr-co) (mm)	8.33		
D_{50} V_c (vcs +) ($m\ s^{-1}$)			
D_{84} V_c (vcs +) ($m\ s^{-1}$)			

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
62.5	31.3	6.3	0.0	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

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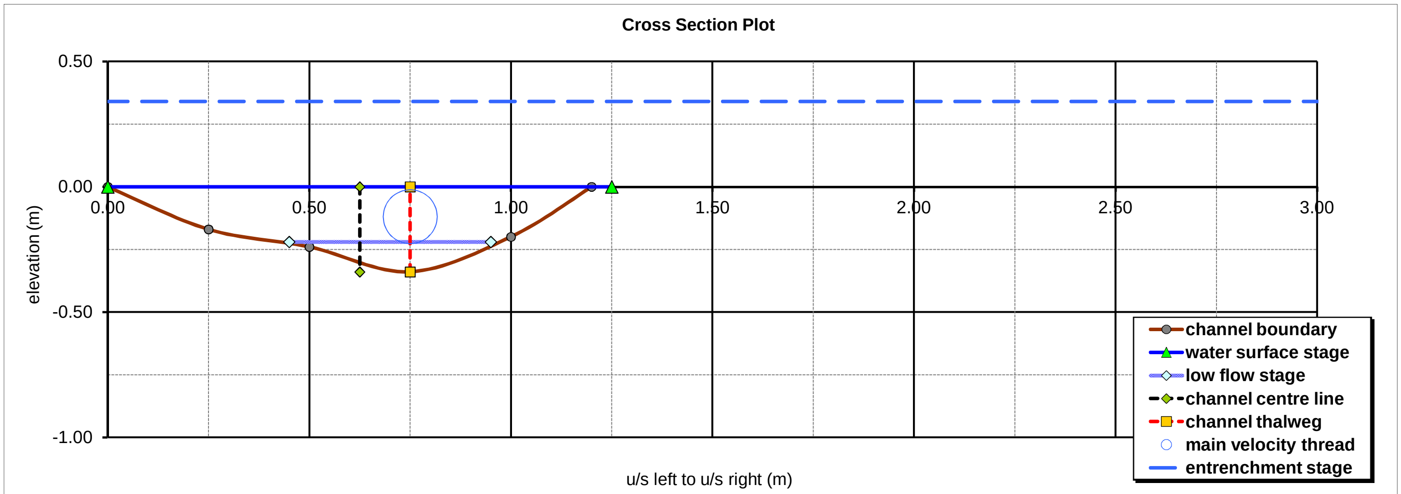
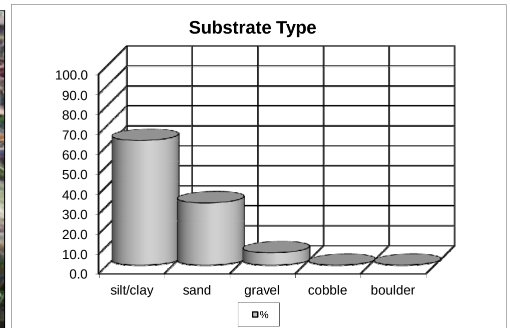
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Ancaster Creek Tributary - Section 2





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	●
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.23
R (m)	0.17
TW (m)	1.20
WP (m)	1.40
max d (m)	0.34
mean d (m)	0.19
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	664.01
ff V mean/V*	12.75
ff D_{84}	19.30
ff mean	16.03
SMOOTH BED	

Hydraulic Ratios	
ER max d	16.67
r_c / TW	
TW / Lf_w	2.40
TW/max d	3.5
TW/mean d	6.2

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.000	0.02	YES	YES	YES	YES
V_* ($m\ s^{-1}$)	0.036	D_{50}	0.002	0.14	YES	YES	YES	YES
		D_{84}	0.032	2.13	NO	NO	YES	YES

Section Data

ER_e (m)	0.34	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.25	1.25
Lf_e (m)	-0.220	Lf stations L / R	0.45	0.95	
W_{fp} (m)	20.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.34	0.75	
E_g ($m\ m^{-1}$)	0.0040				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)		D_{30}	D_{50}	D_{84}
			T_*	335.4	134.2	26.8
B3	0.0010	0.0014	saltation	YES	YES	YES
C3	0.0000	0.0000	rolling	YES	YES	YES
C4	0.0024	0.0040	Ø	NO	NO	NO

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.01	0.02	0.05	0.25	8.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)					7.76
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.126	Q (cms)	
V ($m\ s^{-1}$)	0.54	V ($m\ s^{-1}$)	
n	0.035	n	
Fr	0.39	*Fr*	
D_c rectangular (m)	0.11	D_c rectangular (m)	
D_c trapezoidal (m)	0.14	D_c trapezoidal (m)	
D_c triangular (m)	0.20	D_c triangular (m)	
D_c parabolic (m)	0.11	D_c parabolic (m)	
D_c mean (m)	0.14	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	4.94	Ω (watts m^{-1})	
ω_a (watts m^{-2})	3.53	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	2.94	ω_a/TW (watts m^{-1})	
*Re**	0.1	*Re**	
Re	79005	*Re*	
turbulence	LOW	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	0.66		
τ_{calc} ($N\ m^{-2}$)	6.51		
τ D_{crit} (gr-co) (mm)	6.71		
D_{50} V_c (vcs +) ($m\ s^{-1}$)			
D_{84} V_c (vcs +) ($m\ s^{-1}$)			

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
62.5	31.3	6.3	0.0	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

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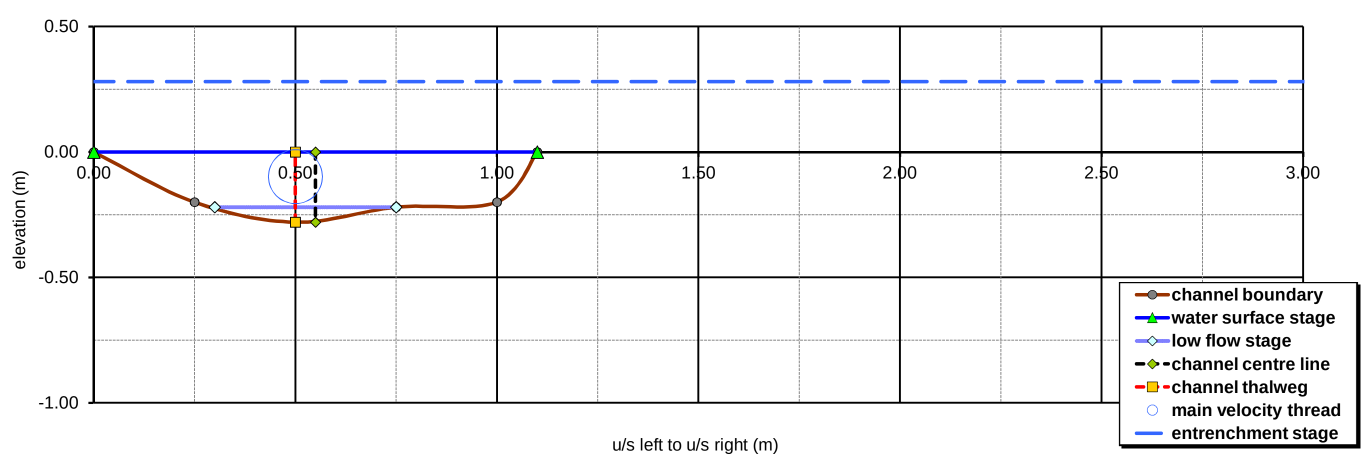
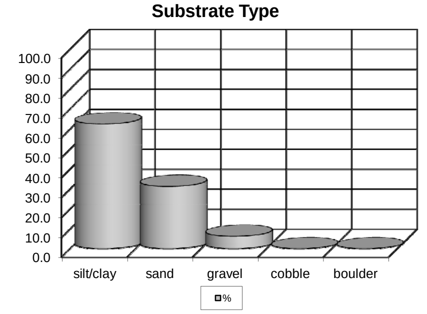
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Ancaster Creek Tributary - Section 3

Cross Section Plot



Substrate Type



Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.21
R (m)	0.16
TW (m)	1.10
WP (m)	1.31
max d (m)	0.28
mean d (m)	0.19
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	639.20
ff V mean/V*	12.68
ff D_{84}	19.26
ff mean	15.97
SMOOTH BED	

Hydraulic Ratios	
ER max d	18.18
r_c / TW	
TW / Lf_w	2.44
TW/max d	3.9
TW/mean d	5.8

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.000	0.02	YES	YES	YES	YES
V_* ($m\ s^{-1}$)	0.040	D_{50}	0.002	0.13	YES	YES	YES	YES
		D_{84}	0.032	1.94	NO	NO	YES	YES

Section Data

ER_e (m)	0.28	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.10	1.10
Lf_e (m)	-0.220	Lf stations L / R	0.30	0.75	
W_{fp} (m)	20.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) / $T_{o/s}$ (m)	-0.28	0.50	
E_g ($m\ m^{-1}$)	0.0050				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})		D_{30}	D_{50}	D_{84}
			T_*	403.6	161.4	32.3
B3	0.0010	0.0014	saltation	YES	YES	YES
C3	0.0000	0.0000	rolling	YES	YES	YES
C4	0.0024	0.0039	Ø	NO	NO	NO

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.01	0.02	0.05	0.25	8.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)					7.76
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.124	Q (cms)	
V ($m\ s^{-1}$)	0.59	V ($m\ s^{-1}$)	
n	0.035	n	
Fr	0.43	*Fr*	
D_c rectangular (m)	0.11	D_c rectangular (m)	
D_c trapezoidal (m)	0.14	D_c trapezoidal (m)	
D_c triangular (m)	0.20	D_c triangular (m)	
D_c parabolic (m)	0.11	D_c parabolic (m)	
D_c mean (m)	0.14	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	6.08	Ω (watts m^{-1})	
ω_a (watts m^{-2})	4.63	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	4.21	ω_a/TW (watts m^{-1})	
*Re**	0.1	*Re**	
Re	82886	*Re*	
turbulence	LOW	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	0.80		
τ_{calc} (N m^{-2})	7.83		
τ D_{crit} (gr-co) (mm)	8.07		
D_{50} V_c (vcs +) ($m\ s^{-1}$)			
D_{84} V_c (vcs +) ($m\ s^{-1}$)			

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
62.5	31.3	6.3	0.0	0.0

GEO - ESUM v.1.3 Erosion Threshold Summary Model

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Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Ancaster Creek Tributary

Existing

	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Xsec. 1	0.123	0.59	Y	n/a	Y	8	Y	n/a	Y	7	Y
Xsec. 2	0.126	0.54	Y	n/a	Y	7	Y	n/a	Y	5	Y
Xsec. 3	0.124	0.59	Y	n/a	Y	8	Y	n/a	Y	6	Y

Dynamic Stability

Xsec. 1											
Xsec. 2											
Xsec. 3											

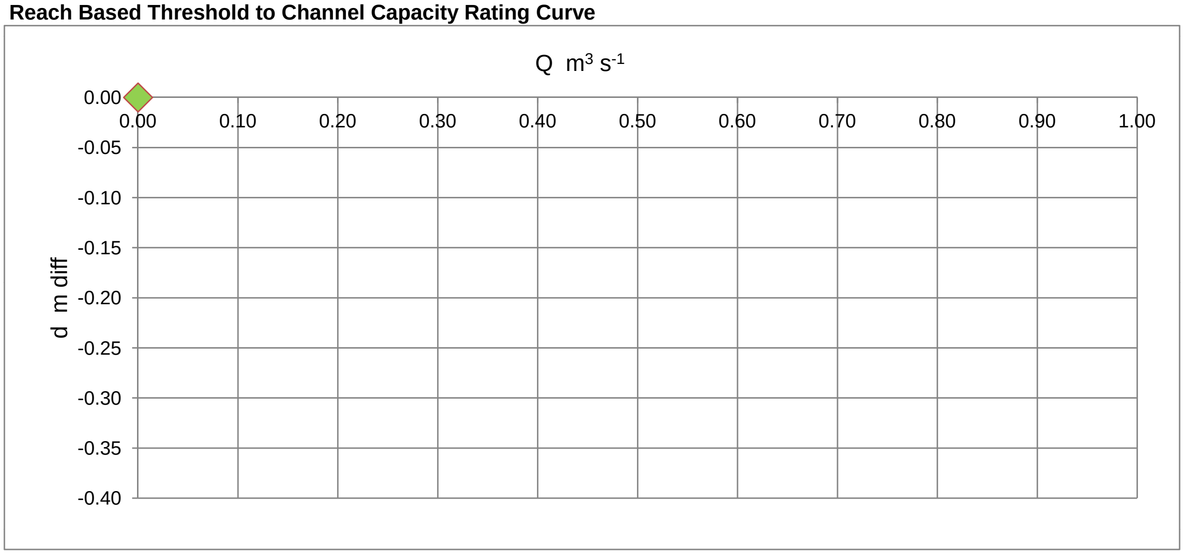
Stability Criteria Met: Y - Yes, N - No, D - Dynamic

* - within 5 mm

Dynamic Stability
Dynamic Stability = Cautionary
Unstable

	Q $m^3 s^{-1}$ existing	Q $m^3 s^{-1}$ stable	Q $m^3 s^{-1}$ diff	d m diff
Xsec. 1	0.12			0.00
Xsec. 2	0.13			0.00
Xsec. 3	0.12			0.00
mean	**0.12**			0.00

Reach Based Threshold to Channel Capacity Rating Curve



Sulphur Creek Tributary (Drainage Area D/E)

Sections 1 to 3 existing conditions
Sections 1 to 3 stability tests
&
Erosion Threshold Summary

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

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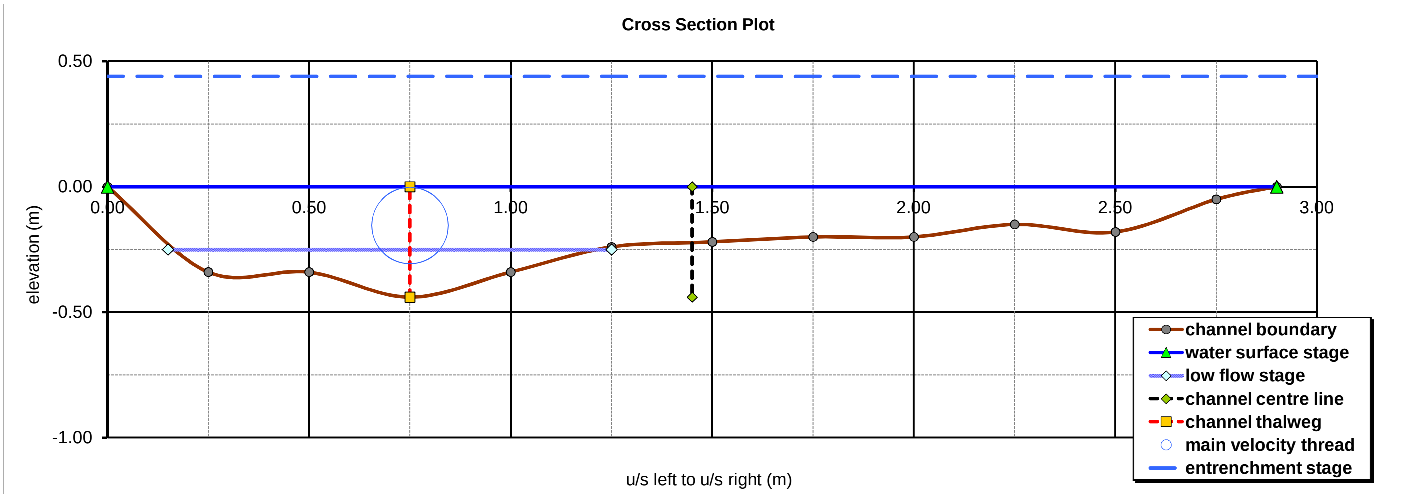
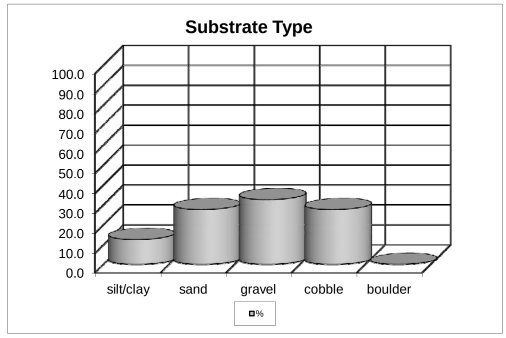
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 1





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	●
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.67
R (m)	0.21
TW (m)	2.90
WP (m)	3.18
max d (m)	0.44
mean d (m)	0.23
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	2.12
ff V mean/V*	5.66
ff D_{84}	4.91
ff mean	5.28
ROUGH BED	

Hydraulic Ratios	
ER max d	4.48
r_c / TW	
TW / Lf_w	2.64
TW/max d	6.6
TW/mean d	12.5

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.071	2.33	NO	NO	YES	YES
V_* ($m\ s^{-1}$)	0.074	D_{50}	0.462	15.18	NO	NO	NO	NO
		D_{84}	1.468	48.25	NO	NO	NO	NO

Section Data

ER_e (m)	0.44	ER stations L / R	-3.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	2.90	2.90
Lf_e (m)	-0.250	Lf stations L / R	0.15	1.25	
W_{fp} (m)	13.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.44	0.75	
E_g ($m\ m^{-1}$)	0.0130				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)		D_{30}	D_{50}	D_{84}
			T_*	55.6	2.8	0.3
B3	0.0017	0.0016	saltation	YES	YES	NO
C3	0.0001	0.0001	rolling	YES	YES	NO
C4	0.0054	0.0050	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	0.50	10.00	100.00	190.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)			9.70	97.00	184.30
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.677	Q (cms)	
V ($m\ s^{-1}$)	1.01	V ($m\ s^{-1}$)	
n	0.040	n	
Fr	0.67	*Fr*	
D_c rectangular (m)	0.18	D_c rectangular (m)	
D_c trapezoidal (m)	0.28	D_c trapezoidal (m)	
D_c triangular (m)	0.40	D_c triangular (m)	
D_c parabolic (m)	0.25	D_c parabolic (m)	
D_c mean (m)	0.28	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω ($watts\ m^{-1}$)	86.27	Ω ($watts\ m^{-1}$)	
ω_a ($Watts\ m^{-2}$)	27.15	ω_a ($watts\ m^{-2}$)	
ω_a/TW ($watts\ m^{-1}$)	9.36	ω_a/TW ($watts\ m^{-1}$)	
*Re**	17.1	*Re**	
Re	186917	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	2.75		
τ_{calc} ($N\ m^{-2}$)	26.96		
$\tau\ D_{crit}$ (gr-co) (mm)	27.79		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	0.49	0.70	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.55	2.20	

Substrate Type (%)

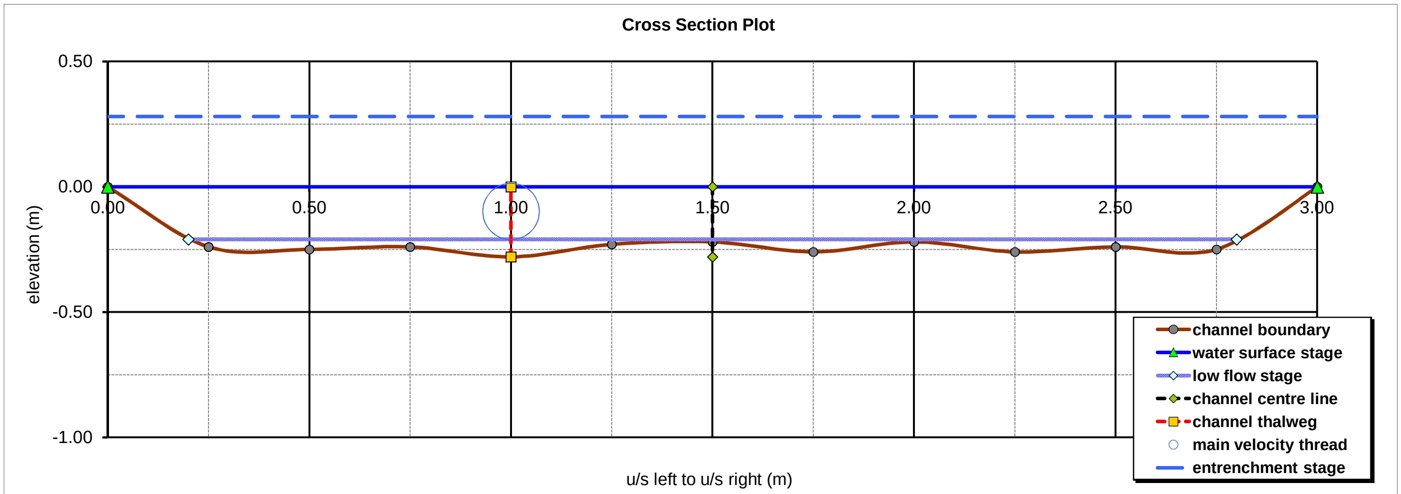
silt/clay	sand	gravel	cobble	boulder
12.5	27.5	32.5	27.5	0.0

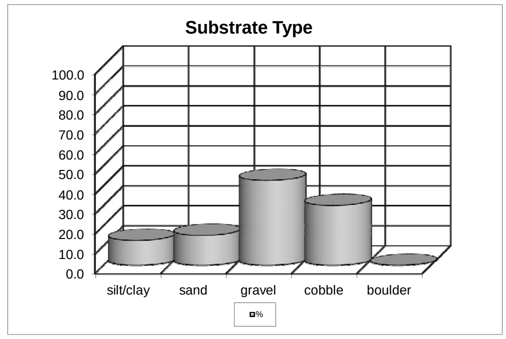
Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 2

B. de Geus 05.11





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.67
R (m)	0.21
TW (m)	3.00
WP (m)	3.22
max d (m)	0.28
mean d (m)	0.22
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	1.39
ff V mean/V*	5.13
ff D_{84}	3.82
ff mean	4.48
ROUGH BED	

Hydraulic Ratios	
ER max d	4.33
r_c / TW	
TW / Lf_w	1.15
TW/max d	10.7
TW/mean d	13.4

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.324	10.70	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.074	D_{50}	0.567	18.76	NO	NO	NO	NO
		D_{84}	1.798	59.48	NO	NO	NO	NO

Section Data

ER_e (m)	0.28	ER stations L / R	-3.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	3.00	3.00
Lf_e (m)	-0.210	Lf stations L / R	0.20	2.80	
W_{fp} (m)	13.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.28	1.00	
E_g ($m\ m^{-1}$)	0.0130				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)		D_{30}	D_{50}	D_{84}
			T_*	5.5	1.8	0.2
B3	0.0017	0.0015	saltation	YES	NO	NO
C3	0.0001	0.0001	rolling	YES	YES	NO
C4	0.0054	0.0045	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	5.00	15.00	150.00	190.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)			14.55	145.50	184.30
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.671	Q (cms)	
V ($m\ s^{-1}$)	1.00	V ($m\ s^{-1}$)	
n	0.040	n	
Fr	0.67	*Fr*	
D_c rectangular (m)	0.18	D_c rectangular (m)	
D_c trapezoidal (m)	0.28	D_c trapezoidal (m)	
D_c triangular (m)	0.40	D_c triangular (m)	
D_c parabolic (m)	0.25	D_c parabolic (m)	
D_c mean (m)	0.28	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	85.53	Ω (watts m^{-1})	
ω_a (watts m^{-2})	26.57	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	8.86	ω_a/TW (watts m^{-1})	
*Re**	25.4	*Re**	
Re	182925	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	2.72		
τ_{calc} ($N\ m^{-2}$)	26.61		
τ D_{crit} (gr-co) (mm)	27.44		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	0.60	0.86	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.90	2.72	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

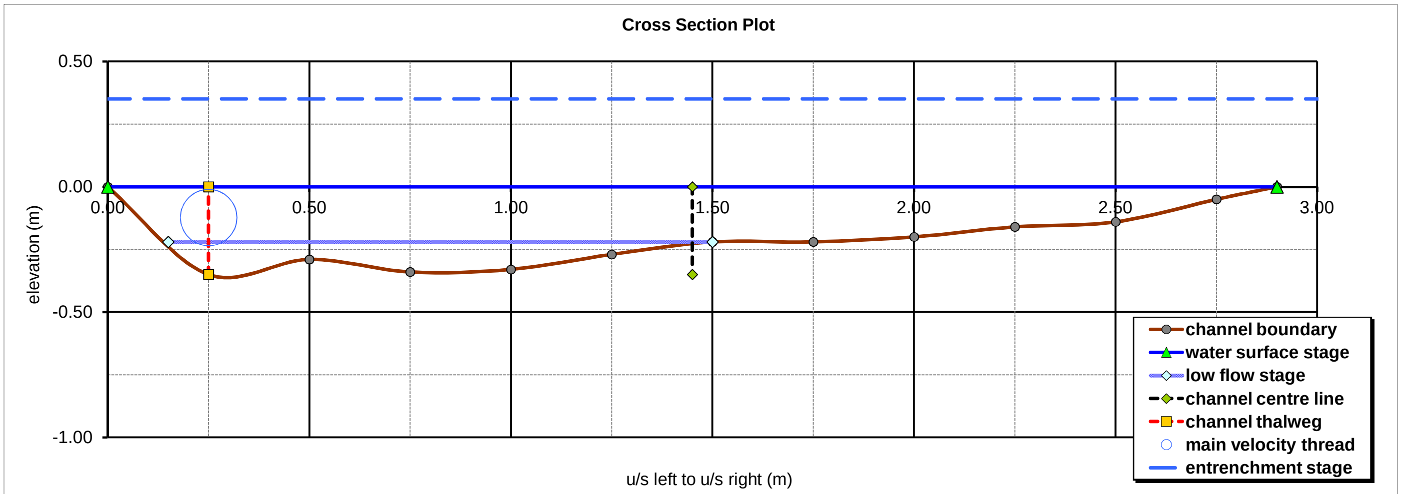
silt/clay	sand	gravel	cobble	boulder
12.5	15.0	42.5	30.0	0.0

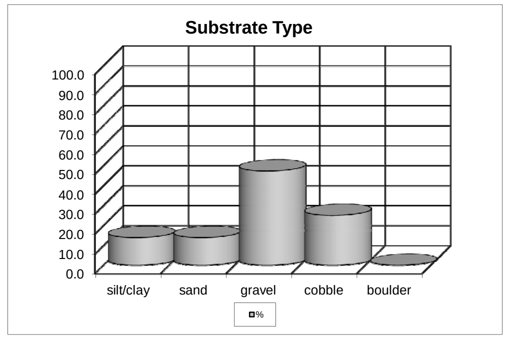
GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 3





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	●
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.64
R (m)	0.20
TW (m)	2.90
WP (m)	3.13
max d (m)	0.35
mean d (m)	0.22
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	2.55
ff V mean/V*	5.85
ff D_{84}	5.34
ff mean	5.60
ROUGH BED	

Hydraulic Ratios	
ER max d	5.17
r_c / TW	
TW / Lf_w	2.15
TW/max d	8.3
TW/mean d	13.1

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.247	7.68	NO	NO	NO	NO
V_* (m s^{-1})	0.078	D_{50}	0.655	20.41	NO	NO	NO	NO
		D_{84}	1.313	40.89	NO	NO	NO	NO

Section Data

ER_e (m)	0.35	ER stations L / R	-5.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	2.90	2.90
Lf_e (m)	-0.220	Lf stations L / R	0.15	1.50	
W_{fp} (m)	15.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.35	0.25	
E_g (m m^{-1})	0.0150				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				10.3	1.5	0.4
B3	0.0017	0.0017	saltation	YES	NO	NO
C3	0.0001	0.0001	rolling	YES	YES	NO
C4	0.0054	0.0052	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	3.00	20.00	80.00	140.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})			19.40	77.60	135.80
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.676	Q (cms)	
V (m s^{-1})	1.06	V (m s^{-1})	
n	0.040	n	
Fr	0.72	Fr	
D_c rectangular (m)	0.18	D_c rectangular (m)	
D_c trapezoidal (m)	0.28	D_c trapezoidal (m)	
D_c triangular (m)	0.40	D_c triangular (m)	
D_c parabolic (m)	0.26	D_c parabolic (m)	
D_c mean (m)	0.28	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	99.39	Ω (watts m^{-1})	
ω_a (watts m^{-2})	31.72	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	10.94	ω_a/TW (watts m^{-1})	
$Re*$	34.1	$Re*$	
Re	189297	Re	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	3.06		
τ_{calc} (N m^{-2})	30.03		
τ D_{crit} (gr-co) (mm)	30.96		
D_{50} V_c (vcs +) (m s^{-1})	0.69	0.94	
D_{84} V_c (vcs +) (m s^{-1})	1.39	1.87	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
13.9	13.9	47.2	25.0	0.0

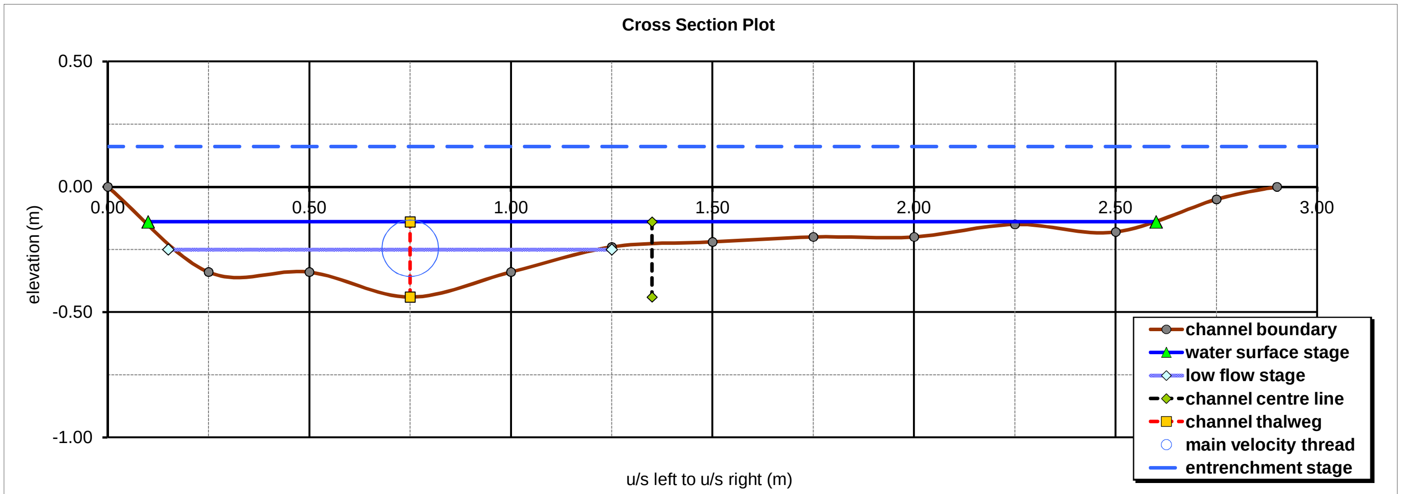
Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

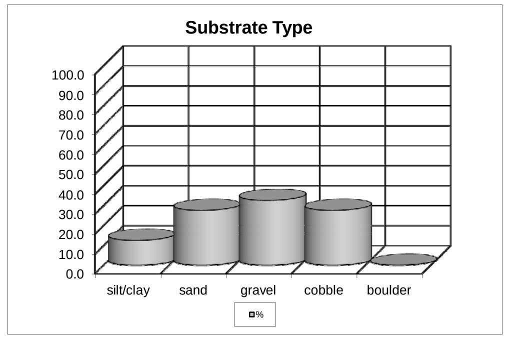
GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 1 Stability Test





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	●
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.30
R (m)	0.11
TW (m)	2.47
WP (m)	2.65
max d (m)	0.30
mean d (m)	0.12
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	1.13
ff V mean/V*	4.56
ff D_{84}	3.30
ff mean	3.93
ROUGH BED	

Hydraulic Ratios	
ER max d	5.25
r_c / TW	
TW / Lf_w	2.25
TW/max d	8.2
TW/mean d	20.5

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.071	3.20	NO	NO	NO	YES
V_* ($m\ s^{-1}$)	0.054	D_{50}	0.462	20.80	NO	NO	NO	NO
		D_{84}	1.468	66.12	NO	NO	NO	NO

Section Data

ER_e (m)	0.16	ER stations L / R	-3.00	10.00	TW ck
WS_e (m)	-0.140	WS stations L / R	0.10	2.60	2.50
Lf_e (m)	-0.250	Lf stations L / R	0.15	1.25	
W_{fp} (m)	13.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.44	0.75	
E_g ($m\ m^{-1}$)	0.0130				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)		D_{30}	D_{50}	D_{84}
			T_*	29.6	1.5	0.1
B3	0.0012	0.0010	saltation	YES	NO	NO
C3	0.0000	0.0000	rolling	YES	YES	NO
C4	0.0030	0.0025	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	0.50	10.00	100.00	190.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)			9.70	97.00	184.30
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	1.46		
τ_{calc} ($N\ m^{-2}$)	14.36		
$\tau\ D_{crit}$ (gr-co) (mm)	14.80		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	0.49	1.06	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.55	3.35	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
12.5	27.5	32.5	27.5	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Flow Regime – Strickler method

Q (cms)	0.197
V ($m\ s^{-1}$)	0.66
n	0.040
Fr	0.61
D_c rectangular (m)	0.09
D_c trapezoidal (m)	0.16
D_c triangular (m)	0.24
D_c parabolic (m)	0.16
D_c mean (m)	0.16
flow type	SUBCRITICAL
Ω ($watts\ m^{-1}$)	25.13
ω_a ($watts\ m^{-2}$)	9.48
ω_a/TW ($watts\ m^{-1}$)	3.83
$Re*$	18.8
Re	65260
turbulence	HIGH

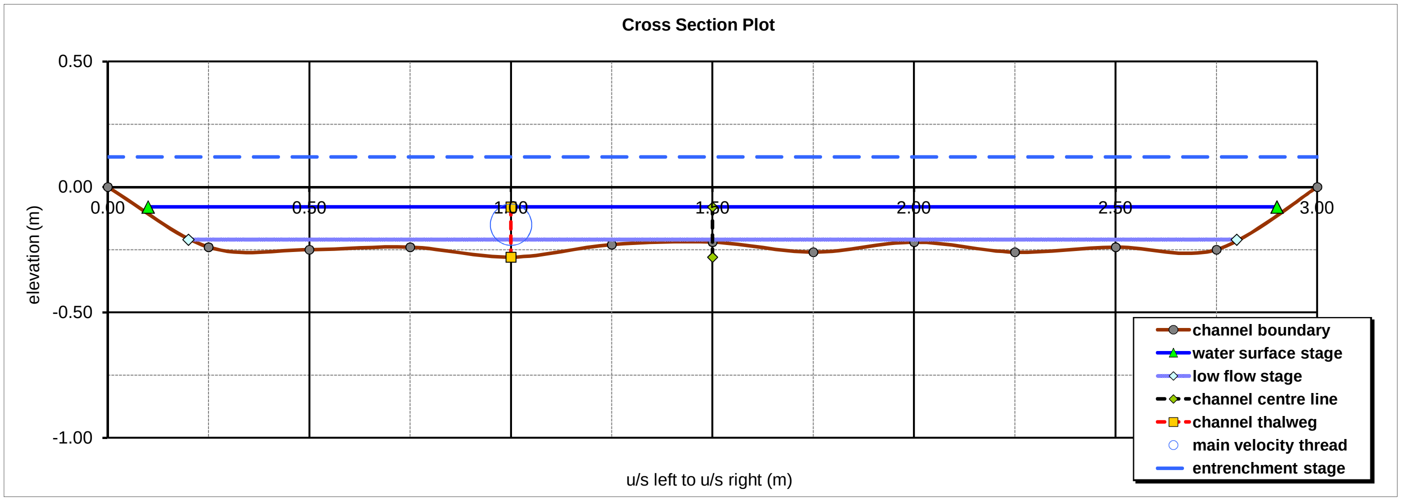
Flow Regime – Limerinos method

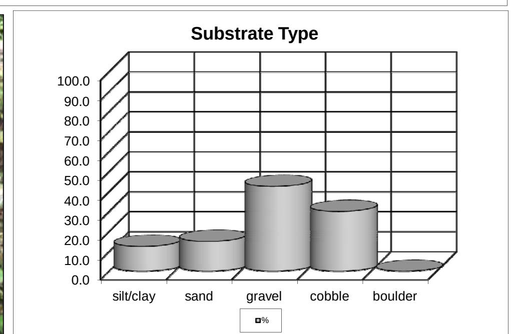
Q (cms)	
V ($m\ s^{-1}$)	
n	
Fr	
D_c rectangular (m)	
D_c trapezoidal (m)	
D_c triangular (m)	
D_c parabolic (m)	
D_c mean (m)	
flow type	
Ω ($watts\ m^{-1}$)	
ω_a ($watts\ m^{-2}$)	
ω_a/TW ($watts\ m^{-1}$)	
$Re*$	
Re	
turbulence	

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 2 Stability Test

B. de Geus 05.11





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.44
R (m)	0.15
TW (m)	2.84
WP (m)	2.99
max d (m)	0.20
mean d (m)	0.15
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.98
ff V mean/V*	4.51
ff D_{84}	2.91
ff mean	3.71
ROUGH BED	

Hydraulic Ratios	
ER max d	4.58
r_c / TW	
TW / Lf_w	1.09
TW/max d	14.2
TW/mean d	18.3

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.324	12.77	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.062	D_{50}	0.567	22.38	NO	NO	NO	NO
		D_{84}	1.798	70.95	NO	NO	NO	NO

Section Data

ER_e (m)	0.12	ER stations L / R	-3.00	10.00	TW ck
WS_e (m)	-0.080	WS stations L / R	0.10	2.90	2.80
Lf_e (m)	-0.210	Lf stations L / R	0.20	2.80	
W_{fp} (m)	13.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.28	1.00	
E_g ($m\ m^{-1}$)	0.0130				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)	T_*	D_{30}	D_{50}	D_{84}
				3.9	1.3	0.1
B3	0.0014	0.0012	saltation	YES	NO	NO
C3	0.0000	0.0000	rolling	YES	YES	NO
C4	0.0039	0.0030	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	5.00	15.00	150.00	190.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)			14.55	145.50	184.30
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.346	Q (cms)	
V ($m\ s^{-1}$)	0.79	V ($m\ s^{-1}$)	
n	0.040	n	
Fr	0.64	*Fr*	
D_c rectangular (m)	0.12	D_c rectangular (m)	
D_c trapezoidal (m)	0.21	D_c trapezoidal (m)	
D_c triangular (m)	0.31	D_c triangular (m)	
D_c parabolic (m)	0.20	D_c parabolic (m)	
D_c mean (m)	0.21	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	44.08	Ω (watts m^{-1})	
ω_a (watts m^{-2})	14.74	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	5.20	ω_a/TW (watts m^{-1})	
*Re**	26.7	*Re**	
Re	101492	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	1.91		
τ_{calc} ($N\ m^{-2}$)	18.70		
τ D_{crit} (gr-co) (mm)	19.28		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	0.60	1.09	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.90	3.44	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
12.5	15.0	42.5	30.0	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E) - Section 3 Stability Test

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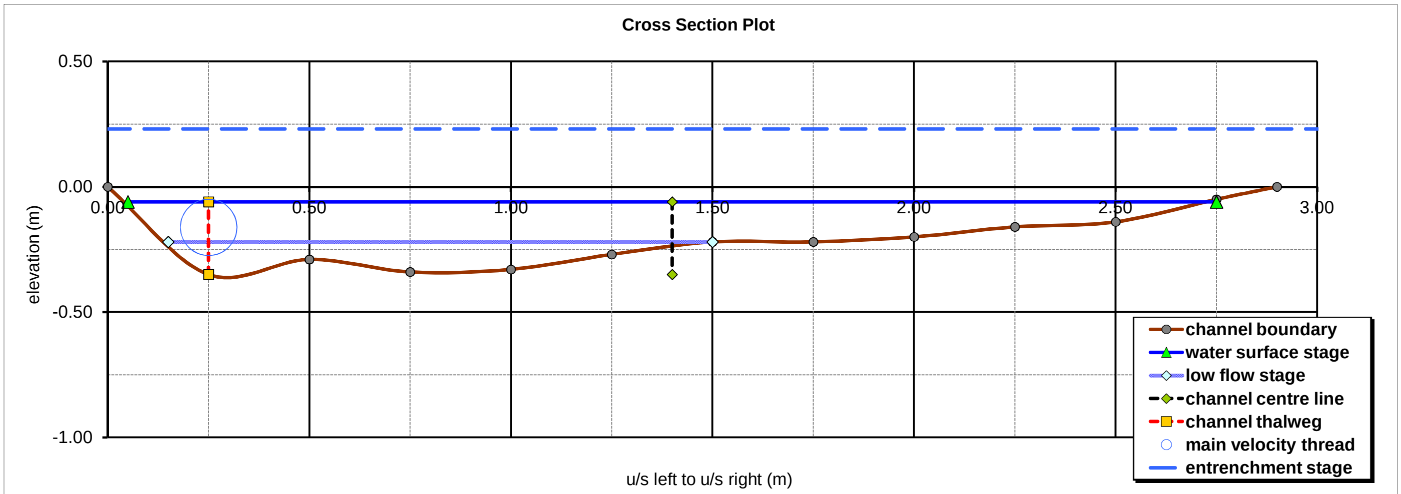
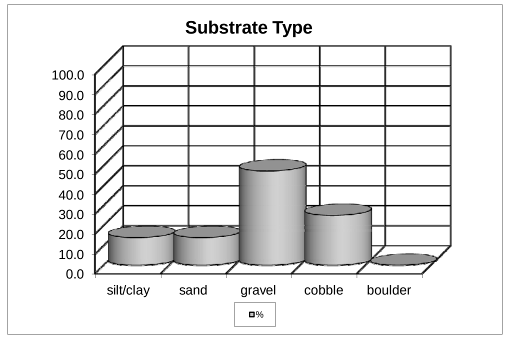




Morphology Type		Hydraulic Geometry	
cascade		A (m^2)	0.47
step		*R* (m)	0.16
riffle		TW (m)	2.68
run	●	WP (m)	2.87
glide		max d (m)	0.29
pool	●	mean d (m)	0.18
thalweg out of phase		$E_{s\ (Limerinos)}$ (m) [+]	
		$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness		Hydraulic Ratios	
rr R/D_{84}	2.06	ER max d	5.60
ff V mean/V*	5.47	r_c / TW	
ff D_{84}	4.79	TW / Lf_w	1.98
ff mean	5.13	TW/max d	9.2
ROUGH BED		TW/mean d	15.2

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.247	8.55	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.070	D_{50}	0.655	22.74	NO	NO	NO	NO
		D_{84}	1.313	45.55	NO	NO	NO	NO

Section Data

ER_e (m)	0.23	ER stations L / R	-5.00	10.00	TW ck
WS_e (m)	-0.060	WS stations L / R	0.05	2.75	2.70
Lf_e (m)	-0.220	Lf stations L / R	0.15	1.50	
W_{fp} (m)	15.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) / $T_{o/s}$ (m)	-0.35	0.25	
E_g ($m\ m^{-1}$)	0.0150				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				8.3	1.2	0.3
B3	0.0015	0.0014	saltation	YES	NO	NO
C3	0.0001	0.0000	rolling	YES	YES	NO
C4	0.0044	0.0041	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	3.00	20.00	80.00	140.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)			19.40	77.60	135.80
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.432	Q (cms)	
V ($m\ s^{-1}$)	0.91	V ($m\ s^{-1}$)	
n	0.040	n	
Fr	0.70	*Fr*	
D_c rectangular (m)	0.14	D_c rectangular (m)	
D_c trapezoidal (m)	0.23	D_c trapezoidal (m)	
D_c triangular (m)	0.34	D_c triangular (m)	
D_c parabolic (m)	0.22	D_c parabolic (m)	
D_c mean (m)	0.23	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	63.51	Ω (watts m^{-1})	
ω_a (watts m^{-2})	22.12	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	8.25	ω_a/TW (watts m^{-1})	
*Re**	35.2	*Re**	
Re	131984	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	2.47		
τ_{calc} (N m^{-2})	24.20		
τ D_{crit} (gr-co) (mm)	24.94		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	0.69	1.08	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.39	2.17	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
13.9	13.9	47.2	25.0	0.0

GEO - ESUM v.1.3 Erosion Threshold Summary Model

AquaLogic
B. de Geus 8.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area D/E)

	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Existing											
Xsec. 1	0.677	1.01	Y	N	Y	27	Y	N	Y	86	Y
Xsec. 2	0.671	1.00	Y	N	Y	27	Y	N	Y	86	Y
Xsec. 3	0.676	1.06	Y	N	Y	30	Y	N	Y	99	Y
Dynamic Stability											
Xsec. 1	0.197	0.66	Y	Y	Y	14	Y	Y	Y	25	Y
Xsec. 2	0.346	0.79	Y	Y	Y	19	Y	Y	Y	44	Y
Xsec. 3	0.432	0.91	Y	Y	Y	24	Y	Y	Y	64	Y

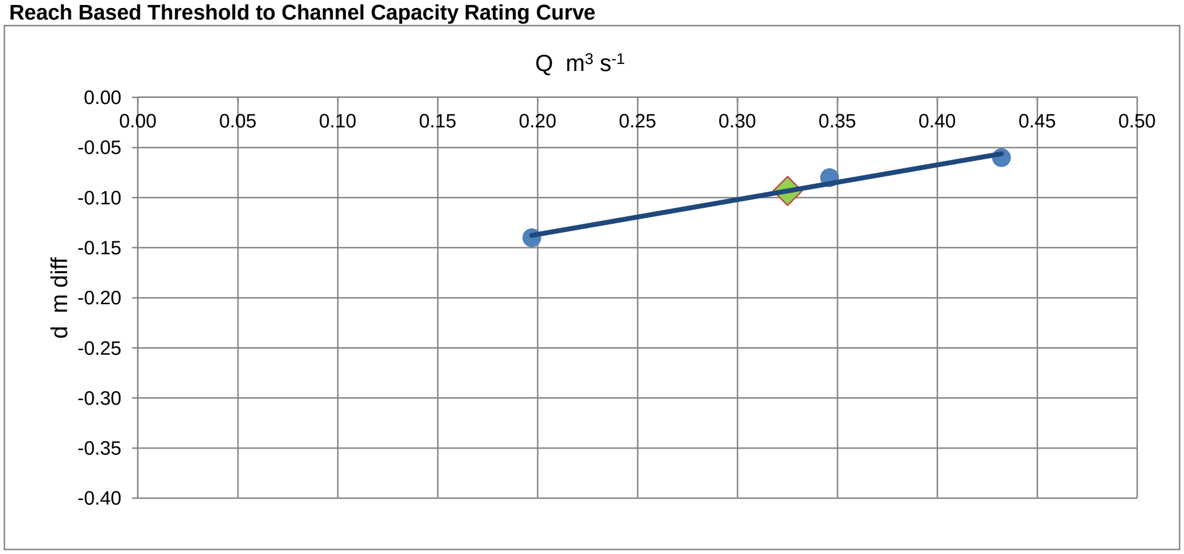
Stability Criteria Met: Y - Yes, N - No, D - Dynamic

* - within 5 mm

Dynamic Stability
Dynamic Stability = Cautionary
Unstable

	Q $m^3 s^{-1}$ existing	Q $m^3 s^{-1}$ stable	Q $m^3 s^{-1}$ diff	d m diff
Xsec. 1	0.68	0.20	0.48	-0.14
Xsec. 2	0.67	0.35	0.33	-0.08
Xsec. 3	0.68	0.43	0.24	-0.06
mean	**0.67**	**0.33**	0.35	-0.09

Reach Based Threshold to Channel Capacity Rating Curve



Sulphur Creek Tributary (Drainage Area F)

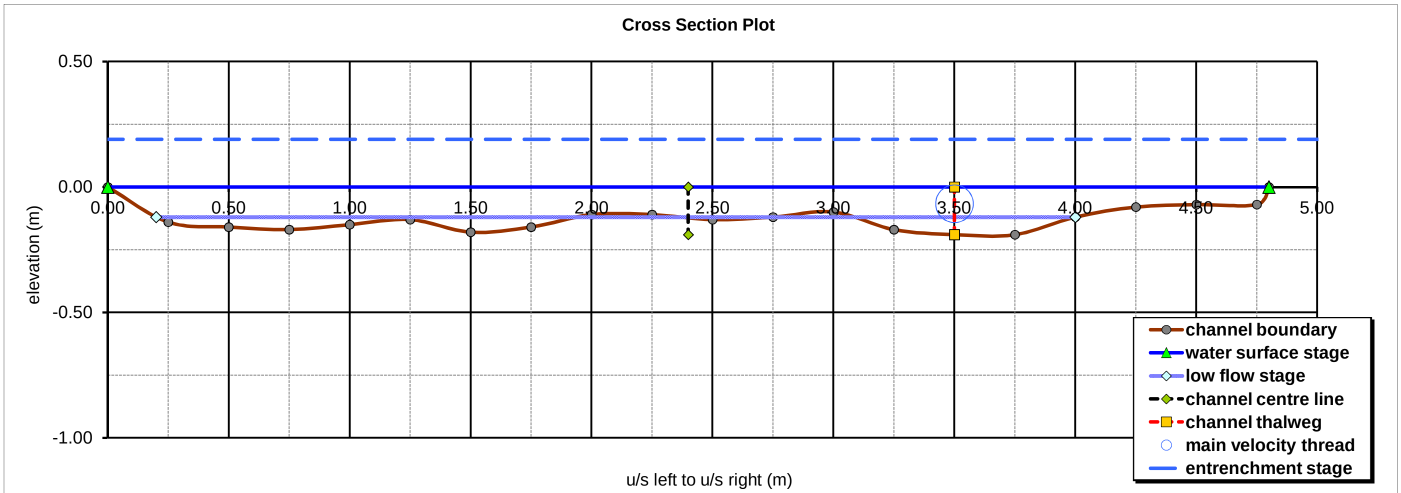
Sections 1 to 3 existing conditions
Sections 2 & 3 stability tests
&
Erosion Threshold Summary

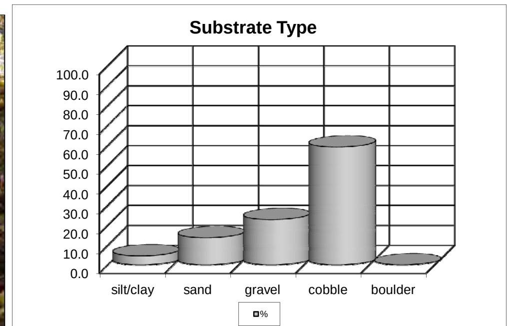
GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F) - Section 1





Morphology Type

cascade	
step	
riffle	●
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry

A (m^2)	0.63
R (m)	0.13
TW (m)	4.80
WP (m)	4.91
max d (m)	0.19
mean d (m)	0.13
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness

rr R/D_{84}	0.92
ff V mean/V*	3.57
ff D_{84}	2.67
ff mean	3.12
ROUGH BED	

Hydraulic Ratios

ER max d	1.46
r_c / TW	
TW / Lf_w	1.26
TW/max d	25.3
TW/mean d	36.5

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.567	12.86	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.108	D_{50}	1.228	27.85	NO	NO	NO	NO
		D_{84}	1.737	39.40	NO	NO	NO	NO

Section Data

ER_e (m)	0.19	ER stations L / R	-1.00	6.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	4.80	4.80
Lf_e (m)	-0.120	Lf stations L / R	0.20	4.00	
W_{fp} (m)	7.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.19	3.50	
E_g ($m\ m^{-1}$)	0.0450				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				3.9	0.8	0.4
B3	0.0016	0.0015	saltation	YES	NO	NO
C3	0.0001	0.0001	rolling	YES	NO	NO
C4	0.0052	0.0045	Ø	NO	YES	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	1.00	15.00	70.00	140.00	160.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)		14.55	67.90	135.80	155.20
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.615	Q (cms)	
V ($m\ s^{-1}$)	0.97	V ($m\ s^{-1}$)	
n	0.055	n	
Fr	0.86	*Fr*	
D_c rectangular (m)	0.12	D_c rectangular (m)	
D_c trapezoidal (m)	0.26	D_c trapezoidal (m)	
D_c triangular (m)	0.39	D_c triangular (m)	
D_c parabolic (m)	0.28	D_c parabolic (m)	
D_c mean (m)	0.26	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	271.06	Ω (watts m^{-1})	
ω_a (watts m^{-2})	55.19	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	11.50	ω_a/TW (watts m^{-1})	
*Re**	172.7	*Re**	
Re	109787	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	5.78		
τ_{calc} ($N\ m^{-2}$)	56.62		
$\tau\ D_{crit}$ (gr-co) (mm)	58.37		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	1.30	1.90	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.83	2.69	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

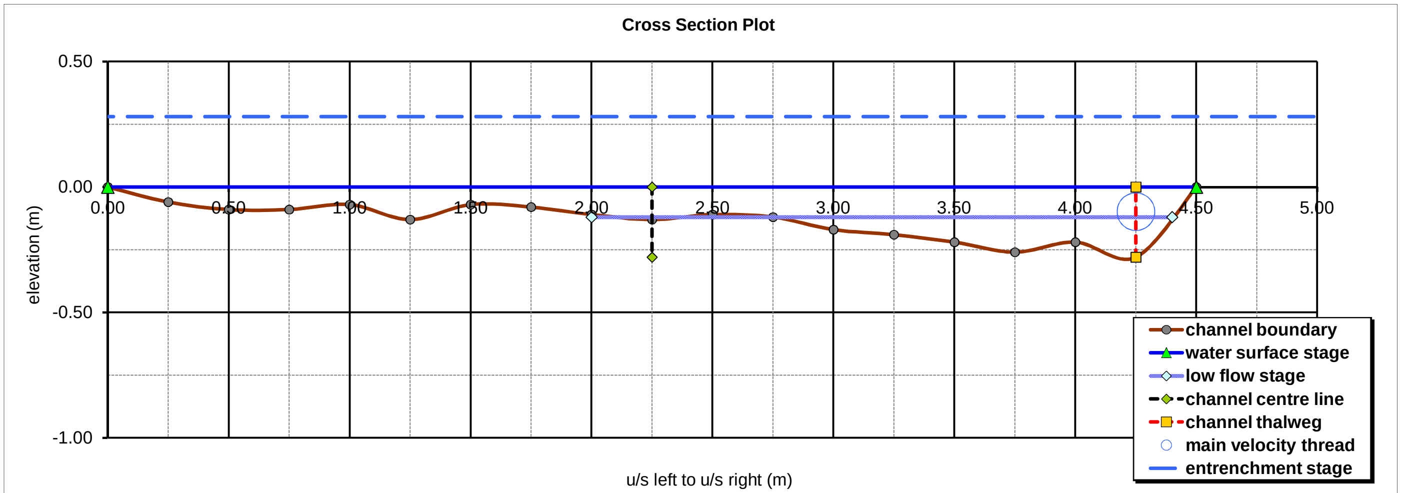
Substrate Type (%)

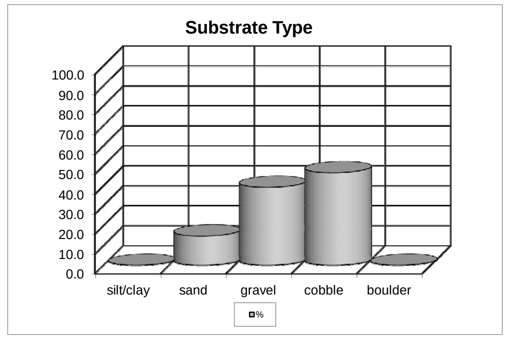
silt/clay	sand	gravel	cobble	boulder
4.5	13.6	22.7	59.1	0.0

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F) - Section 2





Morphology Type	
cascade	
step	
riffle	●
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.60
R (m)	0.13
TW (m)	4.50
WP (m)	4.67
max d (m)	0.28
mean d (m)	0.13
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.92
ff V mean/V*	3.58
ff D_{84}	2.71
ff mean	3.15
ROUGH BED	

Hydraulic Ratios	
ER max d	2.00
r_c / TW	
TW / Lf_w	1.88
TW/max d	16.1
TW/mean d	33.8

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.655	14.10	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.113	D_{50}	1.089	23.42	NO	NO	NO	NO
		D_{84}	1.737	37.38	NO	NO	NO	NO

Section Data

ER_e (m)	0.28	ER stations L / R	-2.00	7.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	4.50	4.50
Lf_e (m)	-0.120	Lf stations L / R	2.00	4.40	
W_{fp} (m)	9.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.28	4.25	
E_g ($m\ m^{-1}$)	0.0500				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)	T_*	D_{30} 3.2	D_{50} 1.2	D_{84} 0.5
B3	0.0016	0.0015	saltation	YES	NO	NO
C3	0.0001	0.0001	rolling	YES	YES	NO
C4	0.0052	0.0045	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	5.00	20.00	55.00	140.00	210.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)		19.40	53.35	135.80	203.70
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.617	Q (cms)	
V ($m\ s^{-1}$)	1.03	V ($m\ s^{-1}$)	
n	0.055	n	
Fr	0.90	*Fr*	
D_c rectangular (m)	0.13	D_c rectangular (m)	
D_c trapezoidal (m)	0.26	D_c trapezoidal (m)	
D_c triangular (m)	0.39	D_c triangular (m)	
D_c parabolic (m)	0.28	D_c parabolic (m)	
D_c mean (m)	0.26	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω ($watts\ m^{-1}$)	302.09	Ω ($watts\ m^{-1}$)	
ω_a ($watts\ m^{-2}$)	64.63	ω_a ($watts\ m^{-2}$)	
ω_a/TW ($watts\ m^{-1}$)	14.36	ω_a/TW ($watts\ m^{-1}$)	
*Re**	136.7	*Re**	
Re	115702	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	6.42		
τ_{calc} ($N\ m^{-2}$)	62.90		
τ D_{crit} (gr-co) (mm)	64.85		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	1.15	1.60	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.83	2.55	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
0.0	14.6	39.0	46.3	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

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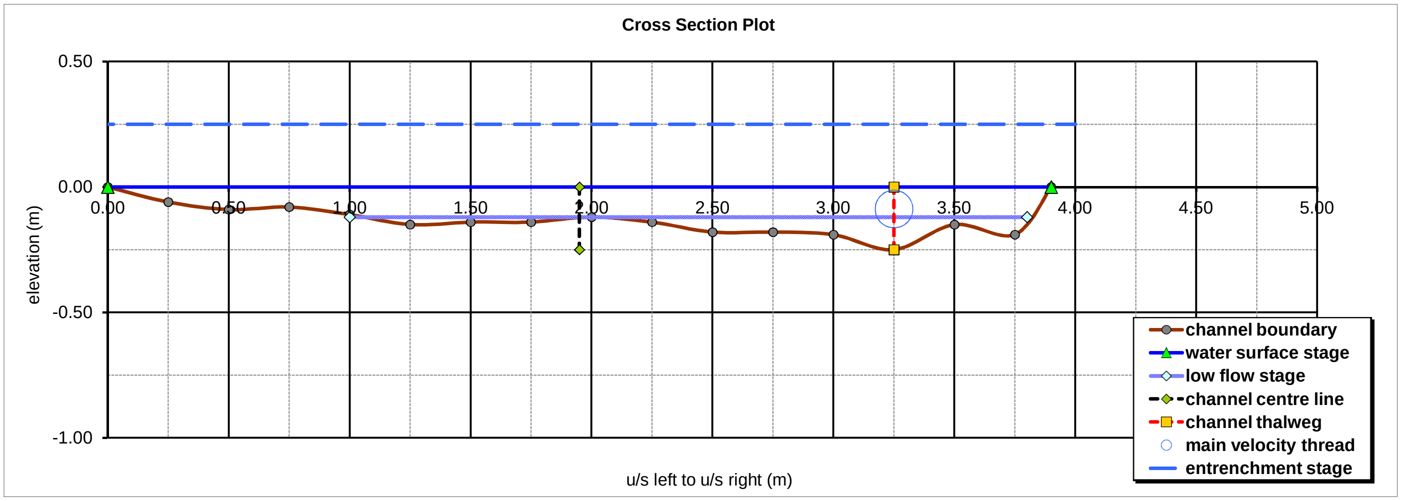
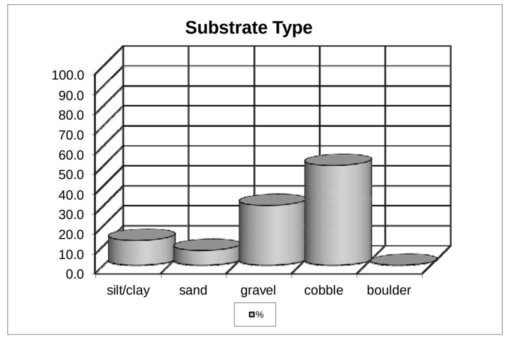
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F) - Section 3





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.53
R (m)	0.13
TW (m)	3.90
WP (m)	4.04
max d (m)	0.25
mean d (m)	0.14
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.94
ff V mean/V*	3.62
ff D_{84}	2.77
ff mean	3.20
ROUGH BED	

Hydraulic Ratios	
ER max d	1.54
r_c / TW	
TW / Lf_w	1.39
TW/max d	15.6
TW/mean d	28.5

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.462	8.95	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.126	D_{50}	1.137	22.03	NO	NO	NO	NO
		D_{84}	1.737	33.66	NO	NO	NO	NO

Section Data

ER_e (m)	0.25	ER stations L / R	-2.00	4.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	3.90	3.90
Lf_e (m)	-0.120	Lf stations L / R	1.00	3.80	
W_{fp} (m)	6.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.25	3.25	
E_g ($m\ m^{-1}$)	0.0600				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)	T_*	D_{30}	D_{50}	D_{84}
				8.0	1.3	0.6
B3	0.0016	0.0015	saltation	YES	NO	NO
C3	0.0001	0.0001	rolling	YES	YES	NO
C4	0.0052	0.0045	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	10.00	60.00	140.00	200.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)		9.70	58.20	135.80	194.00
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	7.91		
τ_{calc} ($N\ m^{-2}$)	77.56		
$\tau\ D_{crit}$ (gr-co) (mm)	79.96		
$D_{50}\ V_c$ (vcs +) ($m\ s^{-1}$)	1.20	1.50	
$D_{84}\ V_c$ (vcs +) ($m\ s^{-1}$)	1.83	2.29	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
12.5	7.5	30.0	50.0	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Flow Regime Strickler method		Flow Regime Limerinos method	
Q (cms)	0.611	Q (cms)	
V ($m\ s^{-1}$)	1.15	V ($m\ s^{-1}$)	
n	0.055	n	
Fr	0.99	*Fr*	
D_c rectangular (m)	0.14	D_c rectangular (m)	
D_c trapezoidal (m)	0.27	D_c trapezoidal (m)	
D_c triangular (m)	0.38	D_c triangular (m)	
D_c parabolic (m)	0.27	D_c parabolic (m)	
D_c mean (m)	0.27	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω ($watts\ m^{-1}$)	359.24	Ω ($watts\ m^{-1}$)	
ω_a ($watts\ m^{-2}$)	88.90	ω_a ($watts\ m^{-2}$)	
ω_a/TW ($watts\ m^{-1}$)	22.80	ω_a/TW ($watts\ m^{-1}$)	
*Re**	148.3	*Re**	
Re	132627	*Re*	
turbulence	HIGH	turbulence	

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

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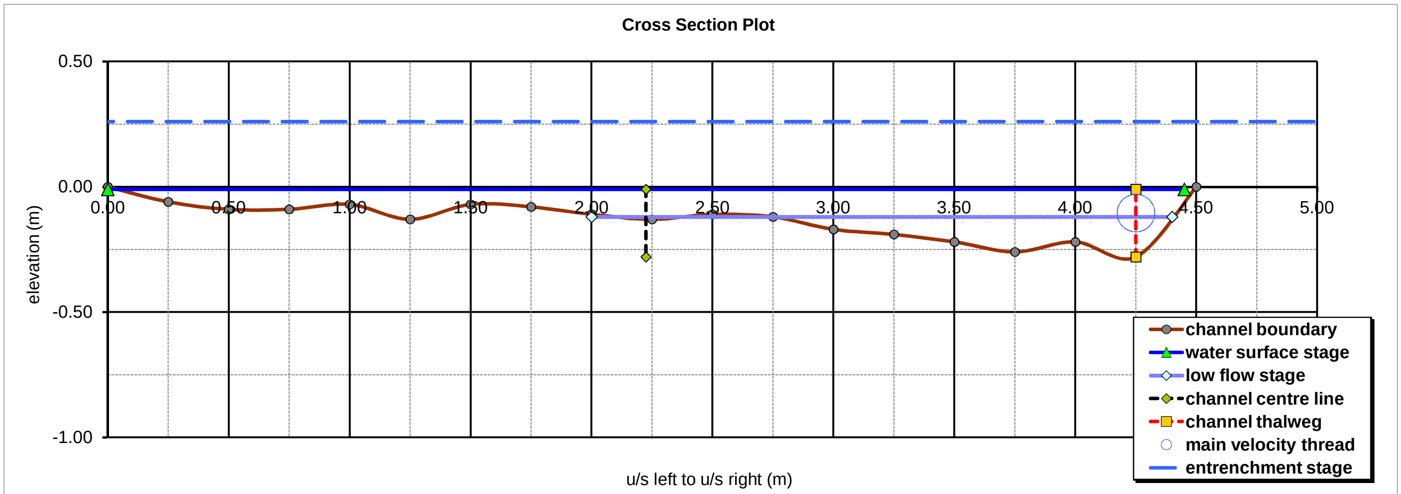
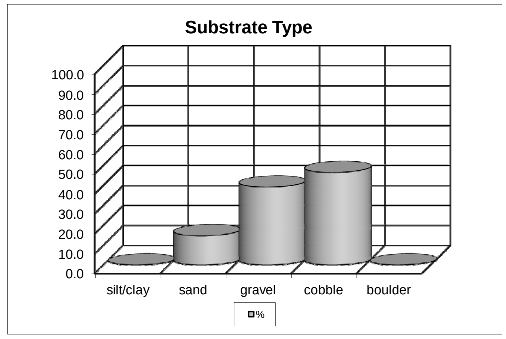
Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F) - Section 2 Stability Test





Morphology Type	
cascade	
step	
riffle	●
run	
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.56
R (m)	0.12
TW (m)	4.45
WP (m)	4.62
max d (m)	0.27
mean d (m)	0.12
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr R/D_{84}	0.86
ff V mean/V*	3.48
ff D_{84}	2.55
ff mean	3.01
ROUGH BED	

Hydraulic Ratios	
ER max d	2.02
r_c / TW	
TW / Lf_w	1.85
TW/max d	16.5
TW/mean d	35.7

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.655	14.57	NO	NO	NO	NO
V_* (m s^{-1})	0.110	D_{50}	1.089	24.20	NO	NO	NO	NO
		D_{84}	1.737	38.62	NO	NO	NO	NO

Section Data

ER_e (m)	0.26	ER stations L / R	-2.00	7.00	TW ck
WS_e (m)	-0.010	WS stations L / R	0.00	4.45	4.45
Lf_e (m)	-0.120	Lf stations L / R	2.00	4.40	
W_{fp} (m)	9.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.28	4.25	
E_g (m m^{-1})	0.0500				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				3.0	1.1	0.4
B3	0.0016	0.0014	saltation	YES	NO	NO
C3	0.0001	0.0000	rolling	YES	YES	NO
C4	0.0049	0.0042	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	5.00	20.00	55.00	140.00	210.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})		19.40	53.35	135.80	203.70
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.546	Q (cms)	
V (m s^{-1})	0.98	V (m s^{-1})	
n	0.055	n	
Fr	0.89	*Fr*	
D_c rectangular (m)	0.12	D_c rectangular (m)	
D_c trapezoidal (m)	0.25	D_c trapezoidal (m)	
D_c triangular (m)	0.37	D_c triangular (m)	
D_c parabolic (m)	0.27	D_c parabolic (m)	
D_c mean (m)	0.25	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	267.58	Ω (watts m^{-1})	
ω_a (watts m^{-2})	57.94	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	13.02	ω_a/TW (watts m^{-1})	
*Re**	138.2	*Re**	
Re	103732	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	6.01		
τ_{calc} (N m^{-2})	58.92		
τ D_{crit} (gr-co) (mm)	60.74		
D_{50} V_c (vcs +) (m s^{-1})	1.15	1.67	
D_{84} V_c (vcs +) (m s^{-1})	1.83	2.66	

Bank Data u/s L u/s R

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

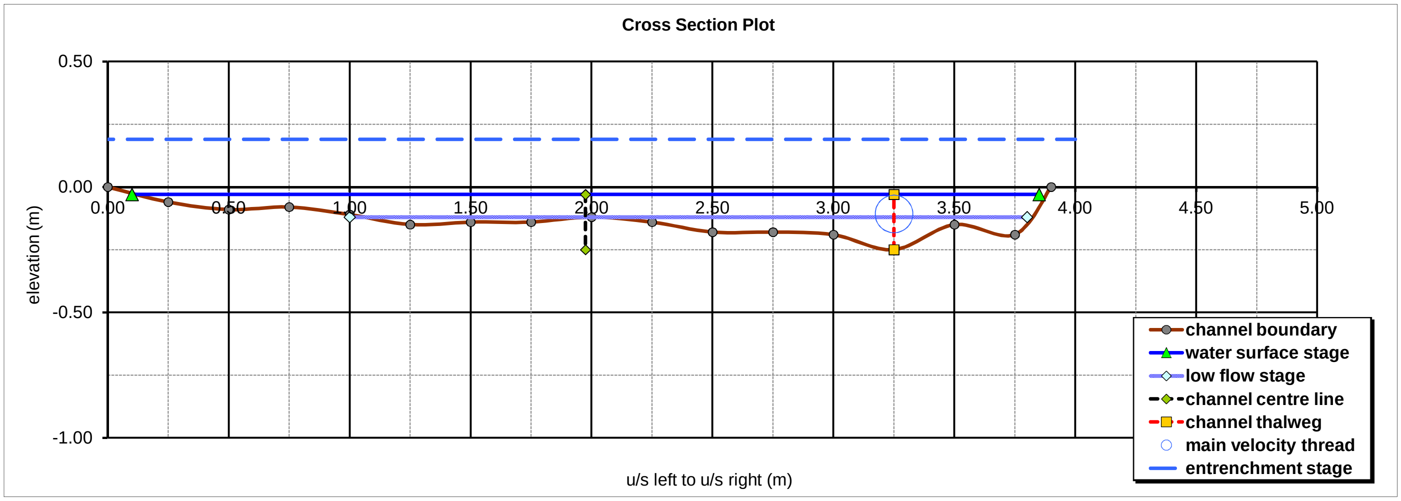
Substrate Type (%)

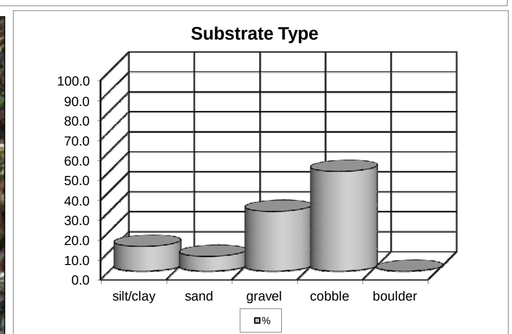
silt/clay	sand	gravel	cobble	boulder
0.0	14.6	39.0	46.3	0.0

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F) - Section 3 Stability Test





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.42
R (m)	0.11
TW (m)	3.75
WP (m)	3.87
max d (m)	0.22
mean d (m)	0.11
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr *R* /D_{84}	0.77
ff V mean/V*	3.31
ff D_{84}	2.27
ff mean	2.79
ROUGH BED	

Hydraulic Ratios	
ER max d	1.60
r_c / TW	
TW / Lf_w	1.34
TW/max d	17.1
TW/mean d	33.6

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.462	9.89	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.114	D_{50}	1.137	24.35	NO	NO	NO	NO
		D_{84}	1.737	37.21	NO	NO	NO	NO

Section Data

ER_e (m)	0.19	ER stations L / R	-2.00	4.00	TW ck
WS_e (m)	-0.030	WS stations L / R	0.10	3.85	3.75
Lf_e (m)	-0.120	Lf stations L / R	1.00	3.80	
W_{fp} (m)	6.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.25	3.25	
E_g ($m\ m^{-1}$)	0.0600				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} ($kg\ sec^{-1}$)	Limerinos Q Q_{sb} ($kg\ sec^{-1}$)	T_*	D_{30}	D_{50}	D_{84}
				6.5	1.1	0.5
B3	0.0015	0.0013	saltation	YES	NO	NO
C3	0.0001	0.0000	rolling	YES	YES	NO
C4	0.0043	0.0036	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	0.10	10.00	60.00	140.00	200.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)		9.70	58.20	135.80	194.00
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} ($kg\ m^{-2}$)	6.48		
τ_{calc} ($N\ m^{-2}$)	63.48		
$\tau\ D_{crit}$ (gr-co) (mm)	65.44		
$D_{50}\ V_c$ (vcs +) ($m\ s^{-1}$)	1.20	1.71	
$D_{84}\ V_c$ (vcs +) ($m\ s^{-1}$)	1.83	2.61	

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
12.5	7.5	30.0	50.0	0.0

Bank Data	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Flow Regime Strickler method		Flow Regime Limerinos method	
Q (cms)	0.419	Q (cms)	
V ($m\ s^{-1}$)	1.00	V ($m\ s^{-1}$)	
n	0.055	n	
Fr	0.96	*Fr*	
D_c rectangular (m)	0.11	D_c rectangular (m)	
D_c trapezoidal (m)	0.23	D_c trapezoidal (m)	
D_c triangular (m)	0.33	D_c triangular (m)	
D_c parabolic (m)	0.24	D_c parabolic (m)	
D_c mean (m)	0.23	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω ($watts\ m^{-1}$)	246.48	Ω ($watts\ m^{-1}$)	
ω_a ($watts\ m^{-2}$)	63.62	ω_a ($watts\ m^{-2}$)	
ω_a/TW ($watts\ m^{-1}$)	16.96	ω_a/TW ($watts\ m^{-1}$)	
*Re**	153.2	*Re**	
Re	94914	*Re*	
turbulence	HIGH	turbulence	

GEO - ESUM v.1.3 Erosion Threshold Summary Model

AquaLogic
B. de Geus 8.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area F)

Existing

	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Xsec. 1	0.615	0.97	Y	Y	Y	57	N	Y	Y	271	Y
Xsec. 2	0.617	1.03	Y	Y	Y	63	N	N	Y	302	Y
Xsec. 3	0.611	1.15	Y	Y	Y	78	N	N	Y	360	Y

Dynamic Stability

	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Xsec. 1	0.615	0.97	Y	Y	Y	57	N	Y	Y	271	Y
Xsec. 2	0.546	0.98	Y	Y	Y	59	N	Y	Y	268	Y
Xsec. 3	0.419	1.00	Y	Y	Y	63	N	Y	Y	246	Y

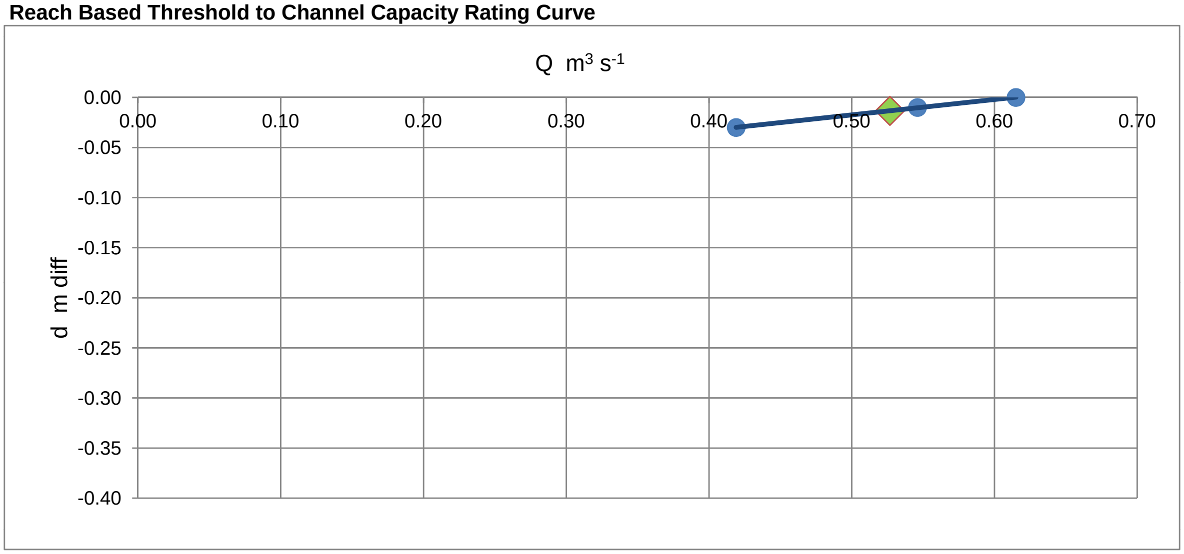
Stability Criteria Met: Y - Yes, N - No, D - Dynamic

* - within 5 mm

Dynamic Stability
Dynamic Stability = Cautionary
Unstable

	Q $m^3 s^{-1}$ existing	Q $m^3 s^{-1}$ stable	Q $m^3 s^{-1}$ diff	d m diff
Xsec. 1	0.62	0.62	0.00	0.00
Xsec. 2	0.62	0.55	0.07	-0.01
Xsec. 3	0.61	0.42	0.19	-0.03
mean	**0.61**	**0.53**	0.09	-0.01

Reach Based Threshold to Channel Capacity Rating Curve



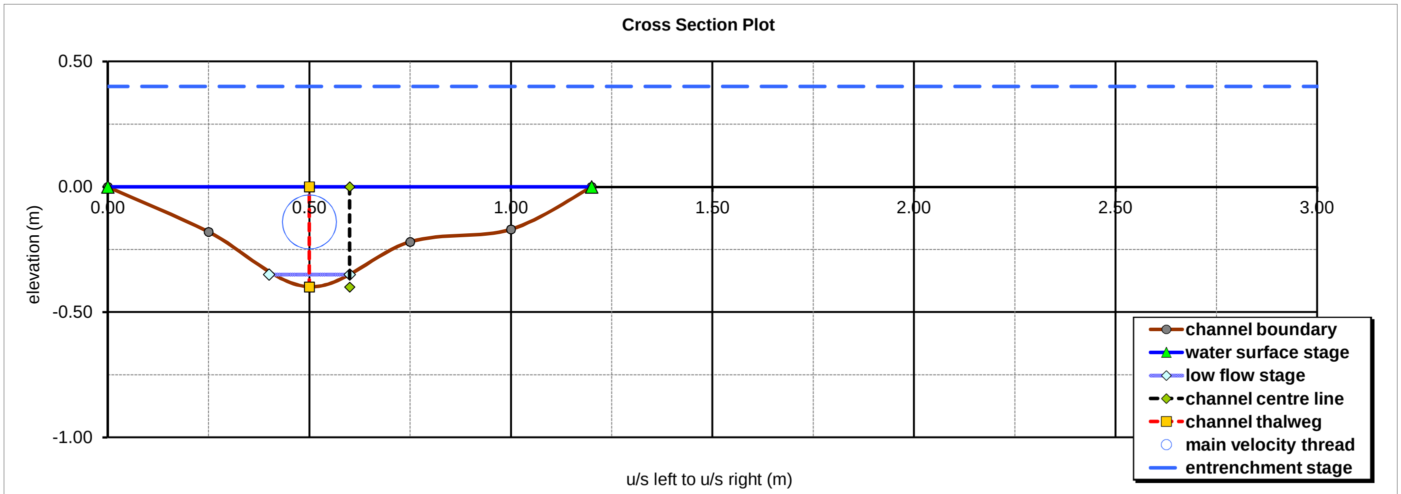
Sulphur Creek Tributary (Drainage Area G)

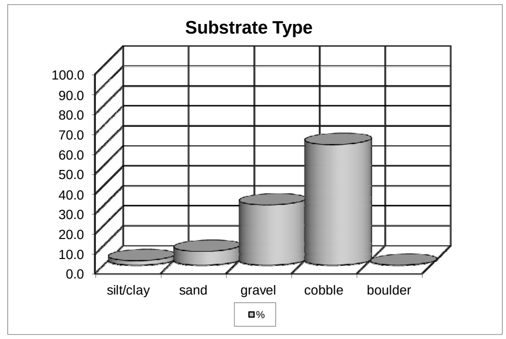
Sections 1 to 3 existing conditions
&
Erosion Threshold Summary

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic
B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area G) - Section 1





Morphology Type	
cascade	
step	
riffle	
run	●
glide	
pool	
thalweg out of phase	

Hydraulic Geometry	
A (m^2)	0.24
R (m)	0.16
TW (m)	1.20
WP (m)	1.47
max d (m)	0.40
mean d (m)	0.20
$E_{s\ (Limerinos)}$ (m) [+]	
$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness	
rr *R* /D_{84}	1.25
ff V mean/V*	4.01
ff D_{84}	3.88
ff mean	3.94
ROUGH BED	

Hydraulic Ratios	
ER max d	16.67
r_c / TW	
TW / Lf_w	6.00
TW/max d	3.0
TW/mean d	6.0

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.733	15.68	NO	NO	NO	NO
V_* (m s^{-1})	0.114	D_{50}	1.393	29.78	NO	NO	NO	NO
		D_{84}	1.674	35.80	NO	NO	NO	NO

Section Data

ER_e (m)	0.40	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.20	1.20
Lf_e (m)	-0.350	Lf stations L / R	0.40	0.60	
W_{fp} (m)	20.00	E_s sta. (Limerinos) L / R			
r_c (m)		E_s sta. (Strickler) L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.40	0.50	
E_g (m m^{-1})	0.0400				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})		D_{30}	D_{50}	D_{84}
			T_*	2.6	0.7	0.5
B3	0.0012	0.0013	saltation	YES	NO	NO
C3	0.0000	0.0000	rolling	YES	NO	NO
C4	0.0033	0.0034	Ø	NO	YES	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	8.00	25.00	90.00	130.00	170.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})	7.76	24.25	87.30	126.10	164.90
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime

Strickler method		Limerinos method	
Q (cms)	0.235	Q (cms)	
V (m s^{-1})	0.99	V (m s^{-1})	
n	0.060	n	
Fr	0.71	*Fr*	
D_c rectangular (m)	0.16	D_c rectangular (m)	
D_c trapezoidal (m)	0.19	D_c trapezoidal (m)	
D_c triangular (m)	0.26	D_c triangular (m)	
D_c parabolic (m)	0.16	D_c parabolic (m)	
D_c mean (m)	0.19	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	92.13	Ω (watts m^{-1})	
ω_a (watts m^{-2})	62.82	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	52.35	ω_a/TW (watts m^{-1})	
*Re**	254.4	*Re**	
Re	140570	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	6.50		
τ_{calc} (N m^{-2})	63.68		
τ D_{crit} (gr-co) (mm)	65.65		
D_{50} V_c (vcs +) (m s^{-1})	1.47	2.13	
D_{84} V_c (vcs +) (m s^{-1})	1.77	2.56	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

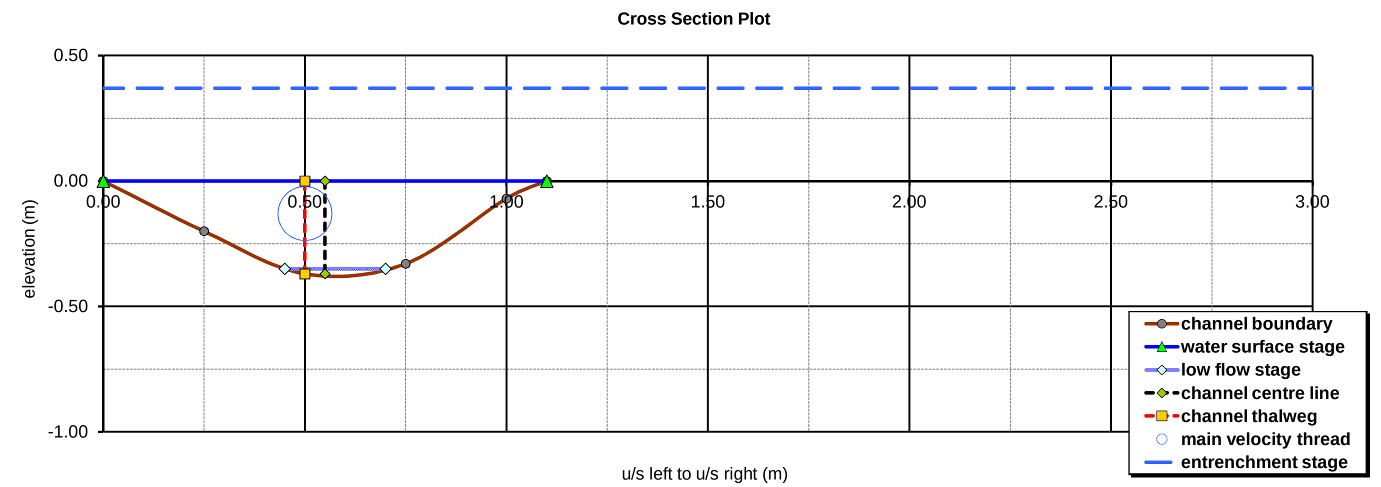
silt/clay	sand	gravel	cobble	boulder
2.3	7.0	30.2	60.5	0.0

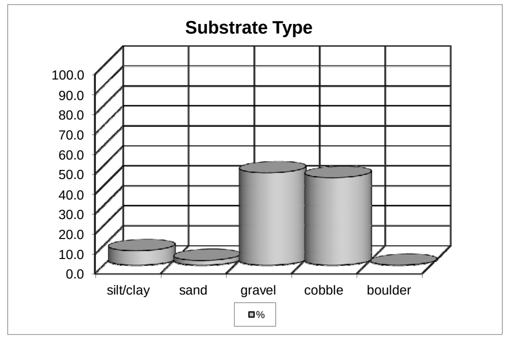
GEO-X v.5.1 Geomorphic Cross-section Analysis Model

AquaLogic

B. de Geus 05.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area G) - Section 2





Morphology Type		Hydraulic Geometry	
cascade		A (m^2)	0.24
step		R (m)	0.17
riffle		TW (m)	1.10
run	●	WP (m)	1.36
glide		max d (m)	0.37
pool		mean d (m)	0.22
thalweg out of phase		$E_{s\ (Limerinos)}$ (m) [+]	
		$E_{s\ (Strickler)}$ (m) [+]	

Hydraulic Roughness		Hydraulic Ratios	
rr R/D_{84}	1.75	ER max d	18.18
ff V mean/V*	4.43	r_c / TW	
ff D_{84}	4.73	TW / Lf_w	4.40
ff mean	4.58	TW/max d	3.0
ROUGH BED		TW/mean d	5.1

Sediment Transport Mode

			w_s ($m\ s^{-1}$)	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.655	14.45	NO	NO	NO	NO
V_* ($m\ s^{-1}$)	0.111	D_{50}	1.089	24.00	NO	NO	NO	NO
		D_{84}	1.468	32.37	NO	NO	NO	NO

Section Data

ER_e (m)	0.37	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.10	1.10
Lf_e (m)	-0.350	Lf stations L / R	0.45	0.70	
W_{fp} (m)	20.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.37	0.50	
E_g ($m\ m^{-1}$)	0.0350				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				3.1	1.1	0.6
B3	0.0012	0.0013	saltation	YES	NO	NO
C3	0.0000	0.0000	rolling	YES	YES	NO
C4	0.0032	0.0036	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	8.00	20.00	55.00	100.00	130.00
Stability Design Targets (mm)					
τ_{cr} ($N\ m^{-2}$)	7.76	19.40	53.35	97.00	126.10
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime Strickler method		Flow Regime Limerinos method	
Q (cms)	0.230	Q (cms)	
V ($m\ s^{-1}$)	0.97	V ($m\ s^{-1}$)	
n	0.060	n	
Fr	0.67	Fr	
D_c rectangular (m)	0.17	D_c rectangular (m)	
D_c trapezoidal (m)	0.19	D_c trapezoidal (m)	
D_c triangular (m)	0.26	D_c triangular (m)	
D_c parabolic (m)	0.15	D_c parabolic (m)	
D_c mean (m)	0.19	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	78.82	Ω (watts m^{-1})	
ω_a (watts m^{-2})	58.02	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	52.75	ω_a/TW (watts m^{-1})	
$Re*$	154.4	$Re*$	
Re	148390	Re	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	Limerinos
τ_{calc} (kg m^{-2})	6.11		
τ_{calc} ($N\ m^{-2}$)	59.91		
τ D_{crit} (gr-co) (mm)	61.76		
D_{50} V_c (vcs +) ($m\ s^{-1}$)	1.15	1.70	
D_{84} V_c (vcs +) ($m\ s^{-1}$)	1.55	2.29	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

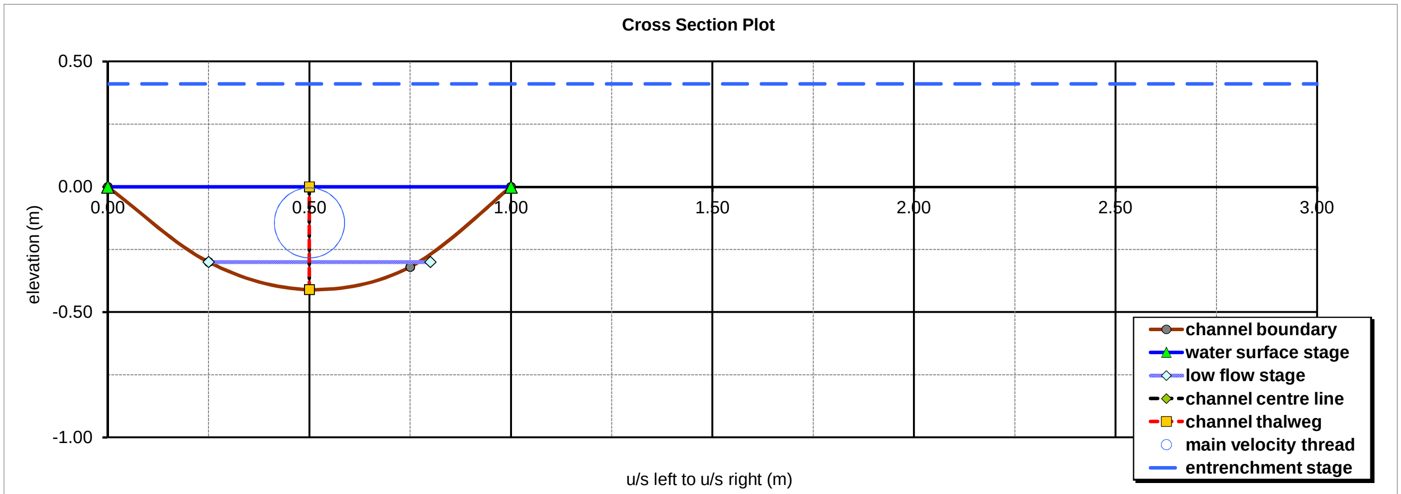
Substrate Type (%)

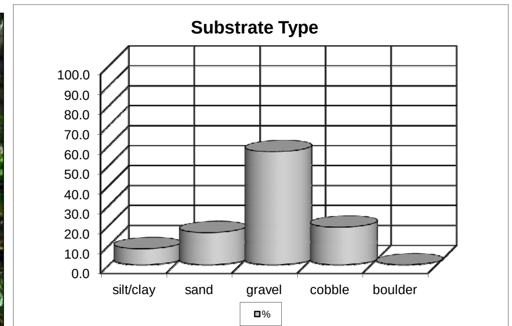
silt/clay	sand	gravel	cobble	boulder
7.3	2.4	46.3	43.9	0.0

GEO-X v.5.1 Geomorphic Cross-section Analysis Model

B. de Geus 05.11

Project: **Erosion Threshold Analysis**
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area G) - Section 3





Morphology Type		Hydraulic Geometry	
cascade		A (m^2)	0.26
step		*R* (m)	0.19
riffle		TW (m)	1.00
run		WP (m)	1.34
glide		max d (m)	0.41
pool	●	mean d (m)	0.26
thalweg out of phase		$E_{s\,(Limerinos)}$ (m) [+]	
Hydraulic Roughness		$E_{s\,(Strickler)}$ (m) [+]	
rr R/D_{84}	2.57	**Hydraulic Ratios**	
ff V mean/V*	5.64	ER max d	20.00
ff D_{84}	5.88	r_c / TW	
ff mean	5.76	TW / Lf_w	1.82
		TW/max d	2.4
ROUGH BED		TW/mean d	3.9

Sediment Transport Mode

			w_s (m s^{-1})	P	wash load	high sus. load	low sus. load	bedload
k	0.41	D_{30}	0.324	10.37	NO	NO	NO	NO
V_* (m s^{-1})	0.076	D_{50}	0.567	18.18	NO	NO	NO	NO
		D_{84}	1.271	40.75	NO	NO	NO	NO

Section Data

ER_e (m)	0.41	ER stations L / R	-10.00	10.00	TW ck
WS_e (m)	0.000	WS stations L / R	0.00	1.00	1.00
Lf_e (m)	-0.300	Lf stations L / R	0.25	0.80	
W_{fp} (m)	20.00	E_s sta. $_{(Limerinos)}$ L / R			
r_c (m)		E_s sta. $_{(Strickler)}$ L / R			
z		T_e (m) $T_{o/s}$ (m)	-0.41	0.50	
E_g (m m^{-1})	0.0150				

Bedload Transport Data

Rosgen type	Strickler Q Q_{sb} (kg sec^{-1})	Limerinos Q Q_{sb} (kg sec^{-1})	T_*	D_{30}	D_{50}	D_{84}
				5.8	1.9	0.4
B3	0.0012	0.0013	saltation	YES	NO	NO
C3	0.0000	0.0000	rolling	YES	YES	NO
C4	0.0033	0.0034	Ø	NO	NO	YES

Substrate Gradation

	D_{15}	D_{30}	D_{50}	D_{84}	D_{100}
Existing Conditions (mm)	1.00	5.00	15.00	75.00	120.00
Stability Design Targets (mm)					
τ_{cr} (N m^{-2})			14.55	72.75	116.40
high turbulence - angular (mm)					
high turbulence - rounded (mm)					
low turbulence - angular (mm)					
low turbulence - rounded (mm)					

Flow Regime Strickler method		Flow Regime Limerinos method	
Q (cms)	0.233	Q (cms)	
V (m s^{-1})	0.90	V (m s^{-1})	
n	0.045	n	
Fr	0.57	*Fr*	
D_c rectangular (m)	0.18	D_c rectangular (m)	
D_c trapezoidal (m)	0.20	D_c trapezoidal (m)	
D_c triangular (m)	0.26	D_c triangular (m)	
D_c parabolic (m)	0.14	D_c parabolic (m)	
D_c mean (m)	0.20	D_c mean (m)	
flow type	SUBCRITICAL	flow type	
Ω (watts m^{-1})	34.20	Ω (watts m^{-1})	
ω_a (watts m^{-2})	25.61	ω_a (watts m^{-2})	
ω_a/TW (watts m^{-1})	25.61	ω_a/TW (watts m^{-1})	
*Re**	32.3	*Re**	
Re	152806	*Re*	
turbulence	HIGH	turbulence	

Erosion Thresholds

		V_c / V_b Strickler	V_c / V_b Limerinos
τ_{calc} (kg m^{-2})	2.89		
τ_{calc} (N m^{-2})	28.34		
τ D_{crit} (gr-co) (mm)	29.22		
D_{50} V_c (vcs +) (m s^{-1})	0.60	0.95	
D_{84} V_c (vcs +) (m s^{-1})	1.34	2.12	

Bank Data

	u/s L	u/s R
H_b (m)		
Bf_d (m)		
RDp (m)		
H_b/Bf_d		
RDp/H_b		
RDn (%)		
BA (°)		
BFP (%)		

Substrate Type (%)

silt/clay	sand	gravel	cobble	boulder
8.1	16.2	56.8	18.9	0.0

GEO - ESUM v.1.3 Erosion Threshold Summary Model

B. de Geus 8.11

Project: Erosion Threshold Analysis
Ancaster Rural Service Drainage Assessment
Sulphur Creek Tributary (Drainage Area G)

Existing	Q $m^3 s^{-1}$	V $m s^{-1}$	veg control	D_{50} particle	D_{84}-D_{100} particle	τ_{calc} $N m^{-2}$	veg control	D_{50} particle*	D_{84}-D_{100} particle*	Ω watts m^{-1}	Ω threshold
Xsec. 1	0.235	0.99	Y	Y	Y	64	N	N	Y	92	Y
Xsec. 2	0.230	0.97	Y	Y	Y	60	N	Y	Y	79	Y
Xsec. 3	0.233	0.90	Y	Y	Y	28	Y	N	Y	34	Y

Dynamic Stability

Xsec. 1			
Xsec. 2			
Xsec. 3			

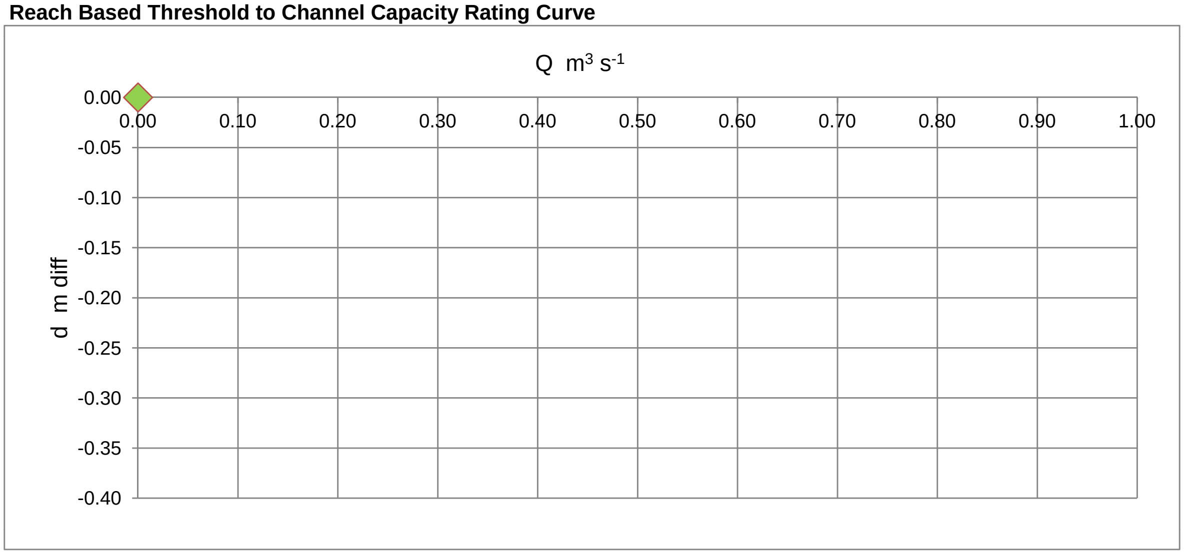
Stability Criteria Met: Y - Yes, N - No, D - Dynamic

* - within 5 mm

Dynamic Stability
Dynamic Stability = Cautionary
Unstable

	Q $m^3 s^{-1}$ existing	Q $m^3 s^{-1}$ stable	Q $m^3 s^{-1}$ diff	d m diff
Xsec. 1	0.24			0.00
Xsec. 2	0.23			0.00
Xsec. 3	0.23			0.00
mean	**0.23**			0.00

Reach Based Threshold to Channel Capacity Rating Curve



Ancaster Rural Service Drainage Assessment

Supplemental Recommendation Site Photos

Sulphur Creek Tributary (Drainage Area F)

Outfall from existing SWM Pond elevated with bed incision on downstream side to foundation invert.

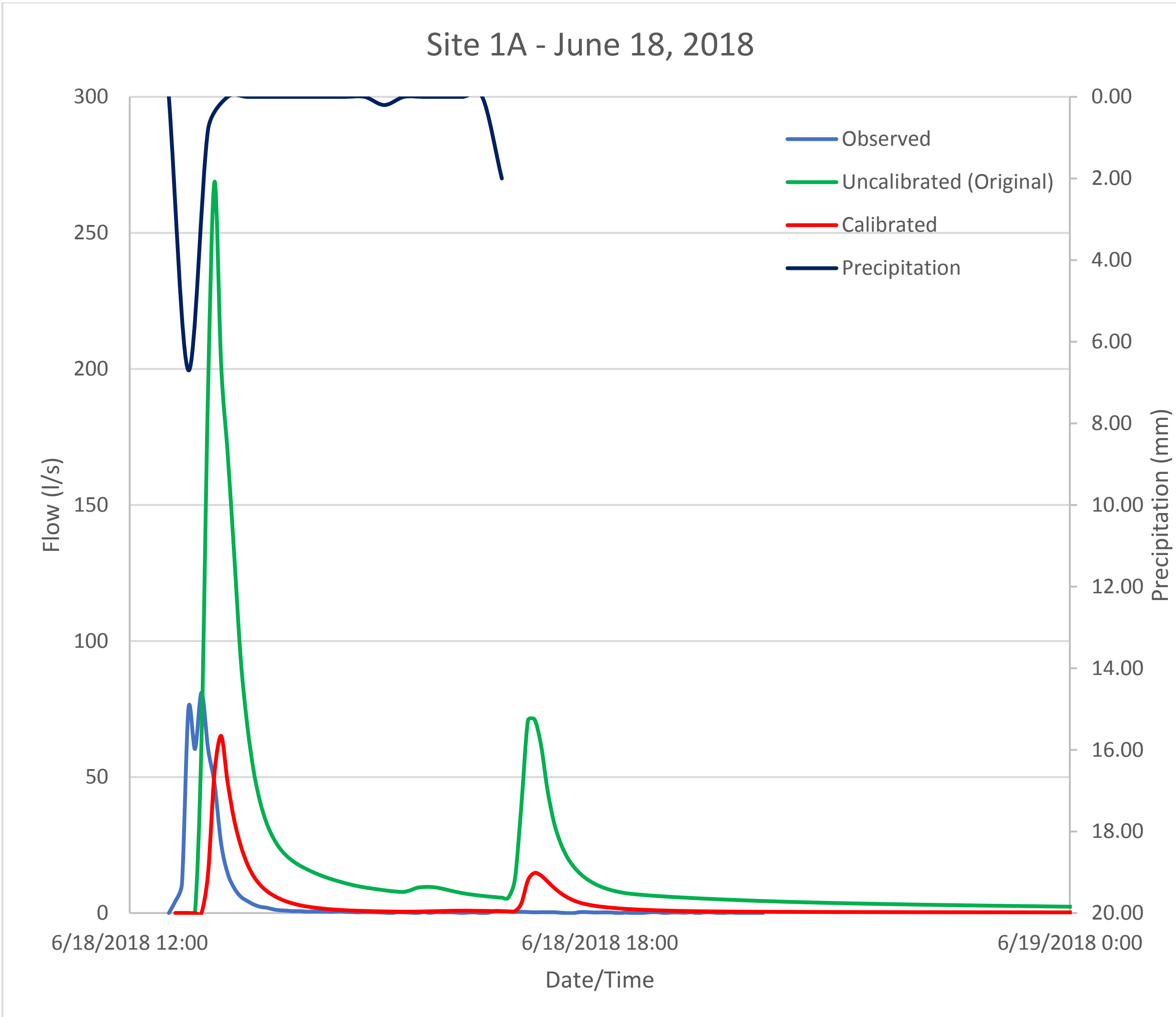
Sulphur Creek Tributary (Drainage Area D/E)

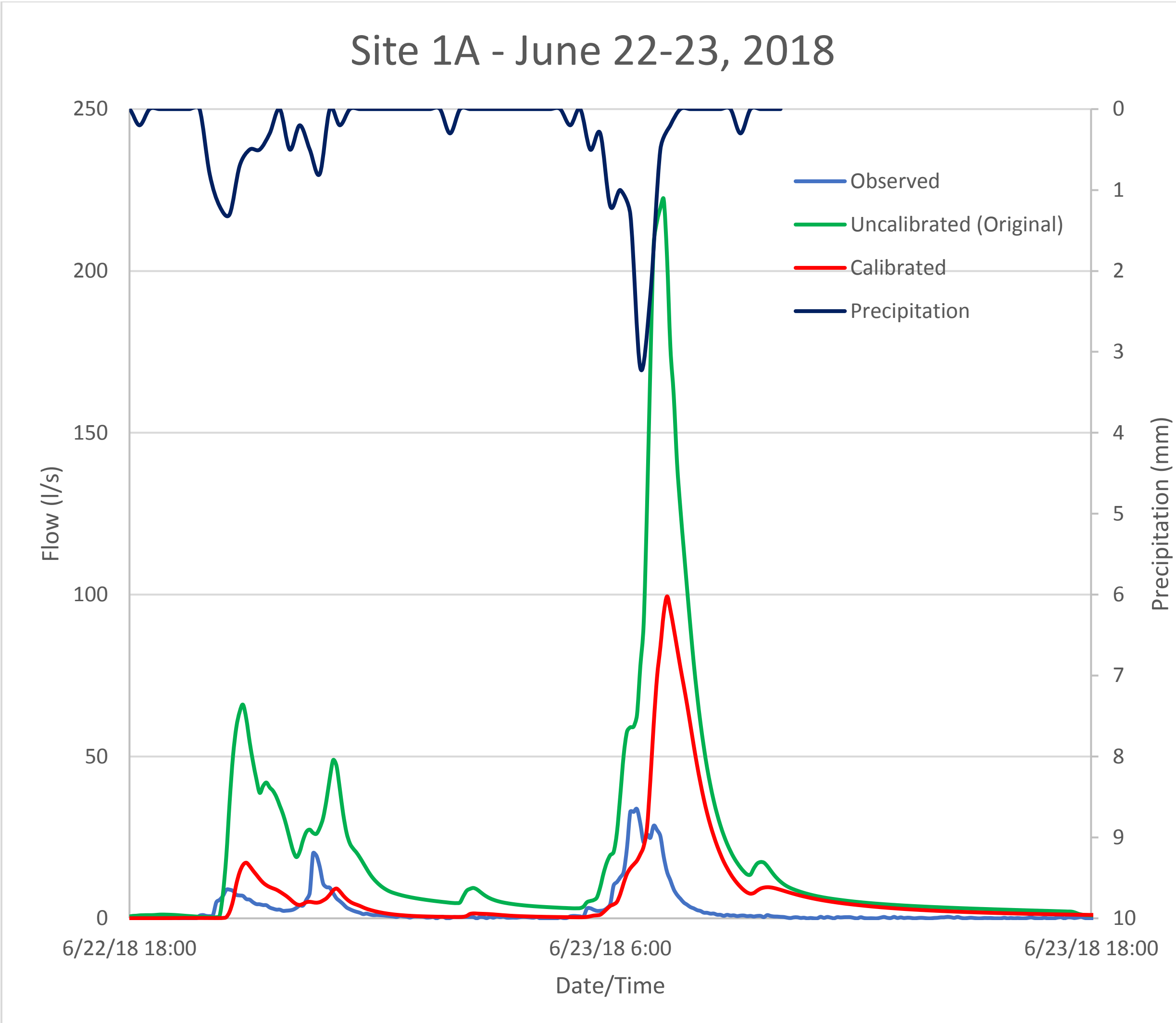
Trail crossing in Jerseyville Park experiencing scour pool incision and bank widening on downstream side. Gabion outfall compromised.

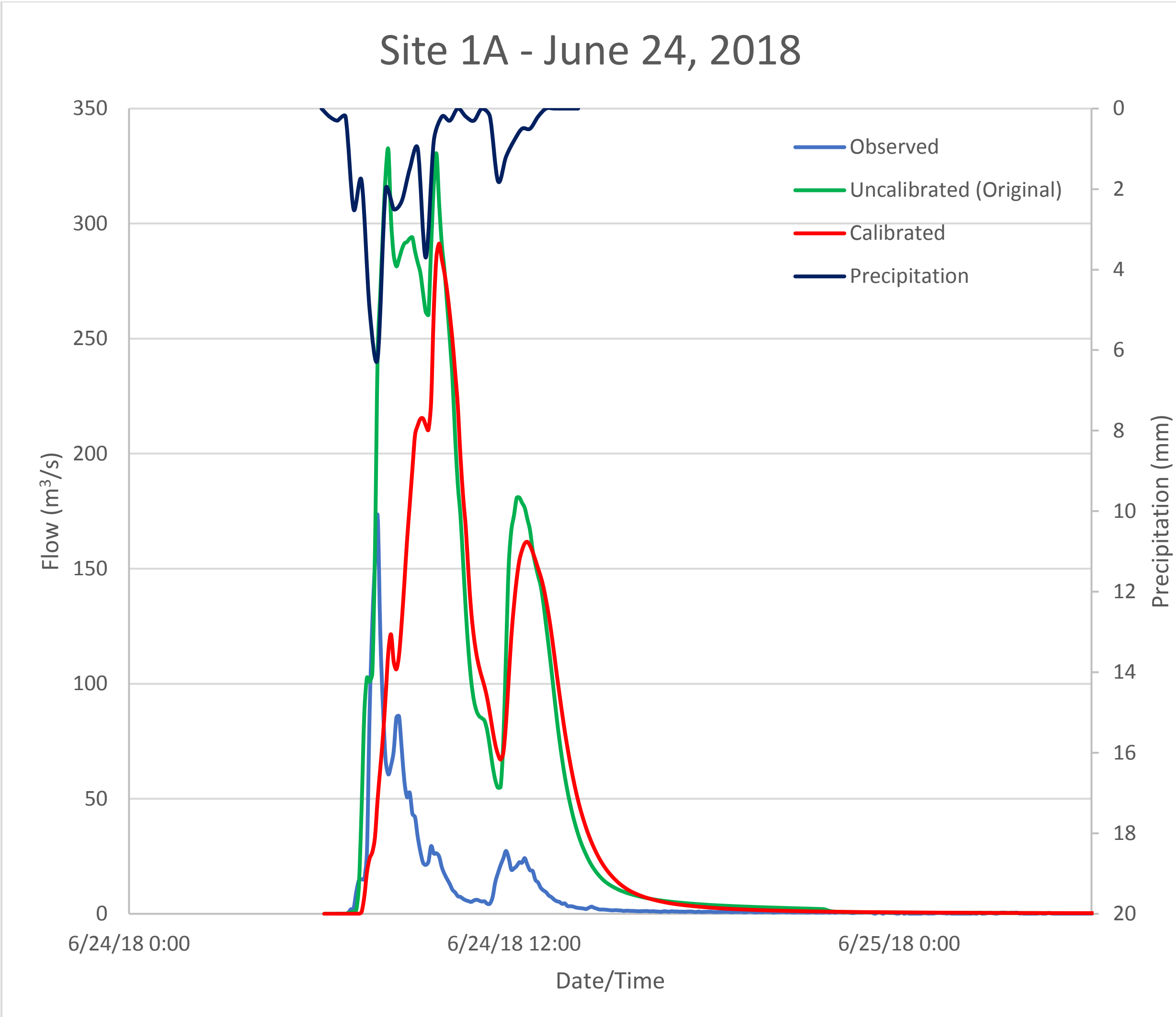
AquaLogic

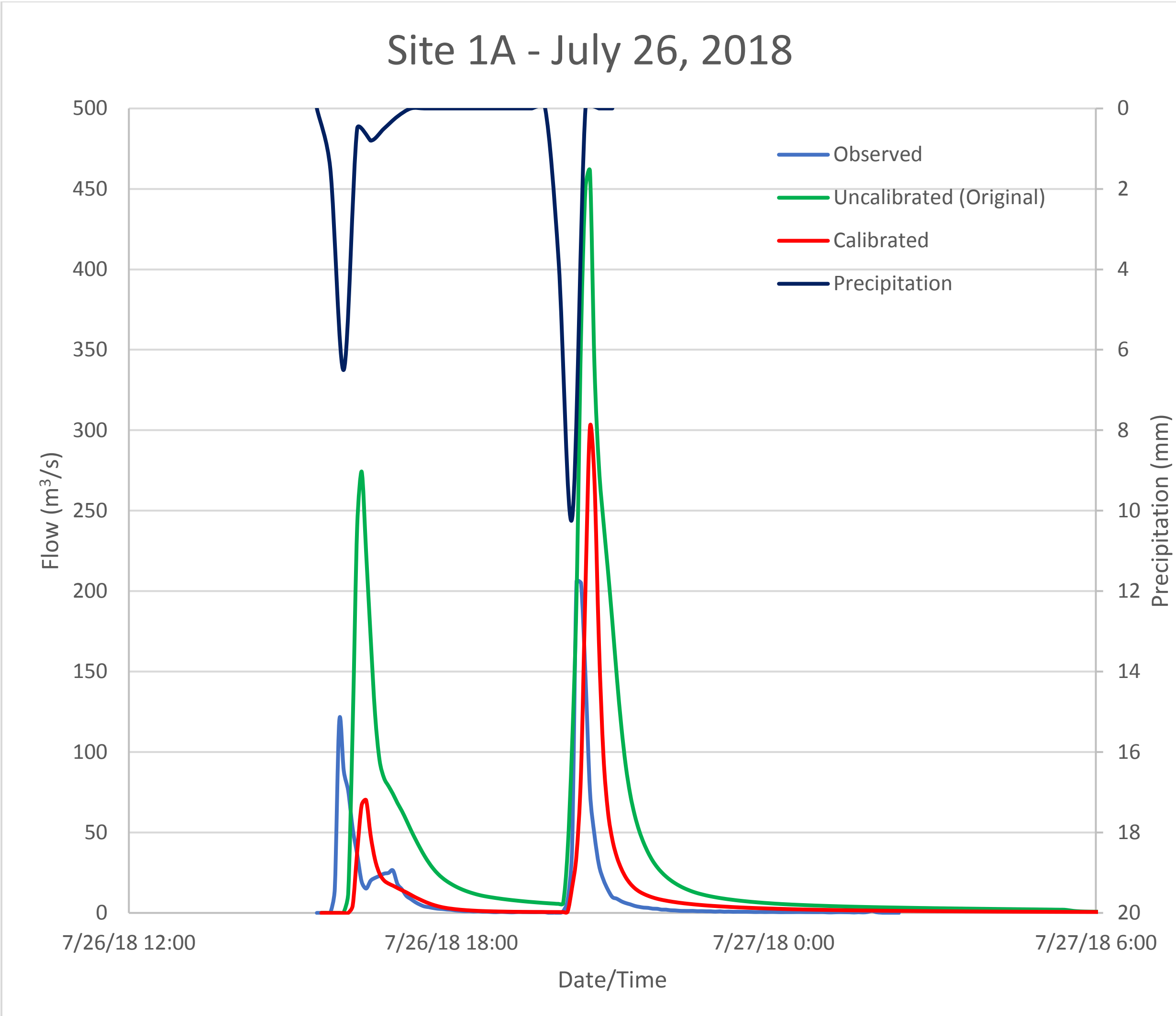
APPENDIX B

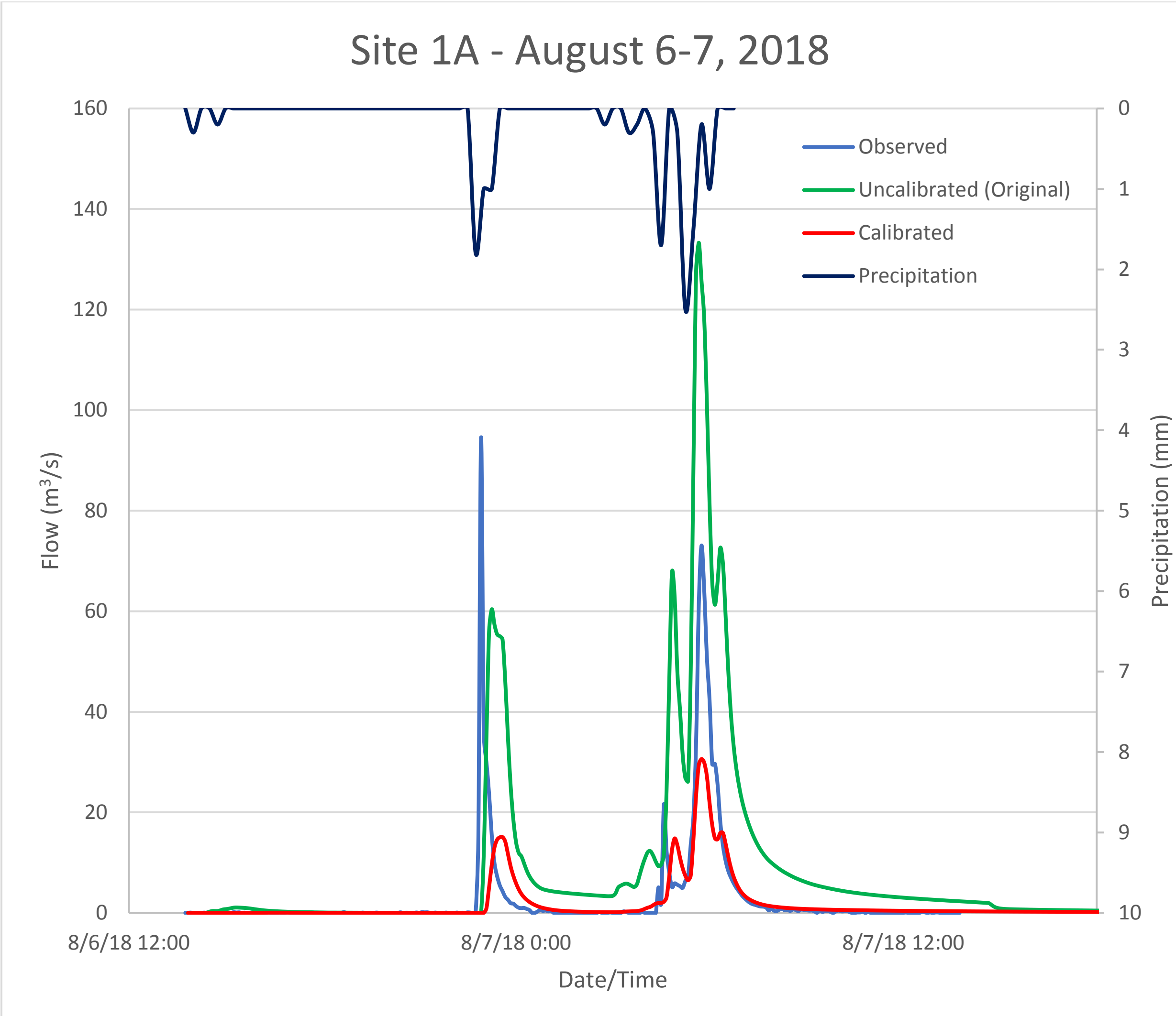
Model Calibration

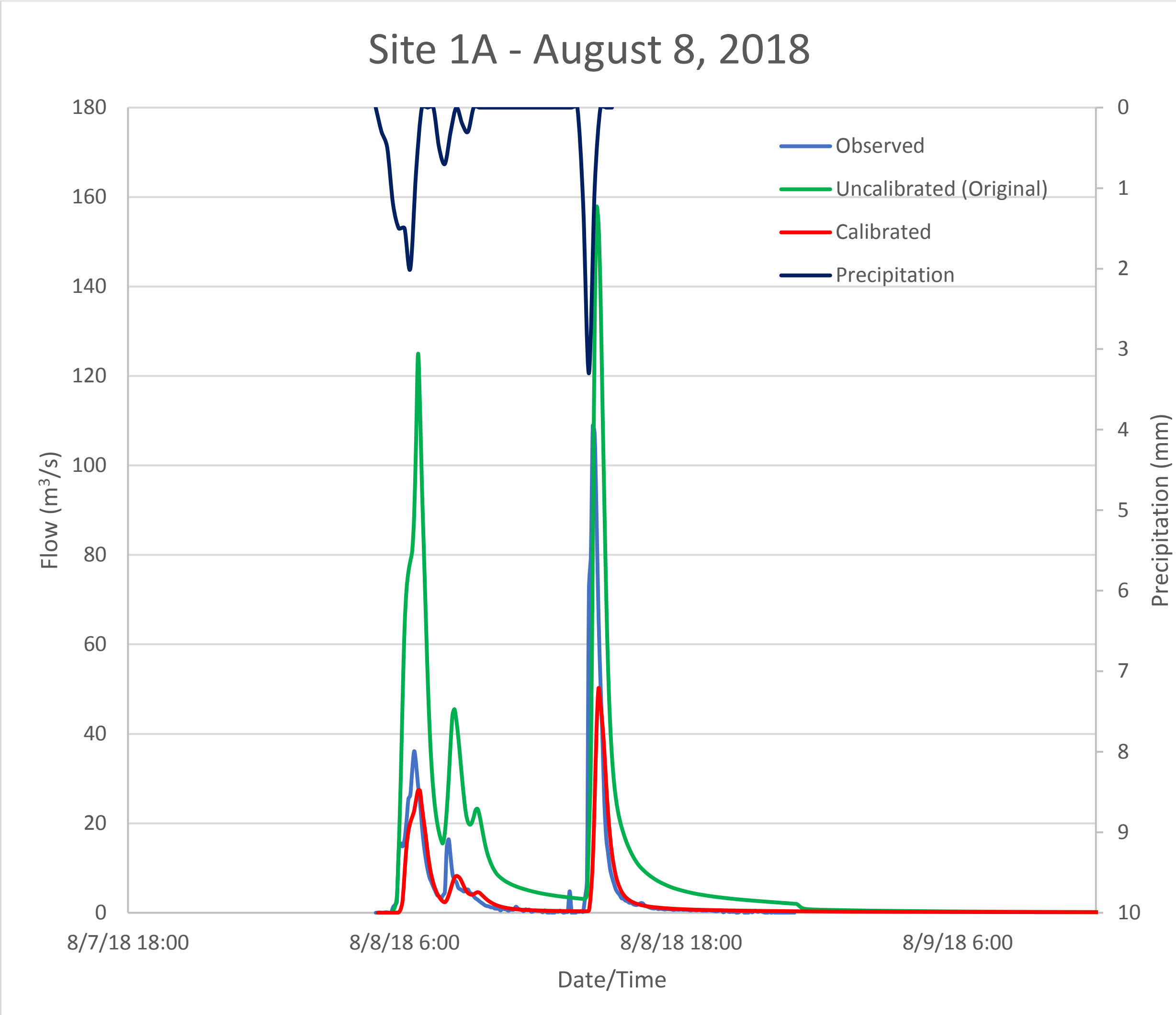

Site 1A - June 18, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (l/s)
Precipitation (mm)
300
250
200
150
100
50
0
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
6/18/2018 12:00
6/18/2018 18:00
6/19/2018 0:00
Date/Time

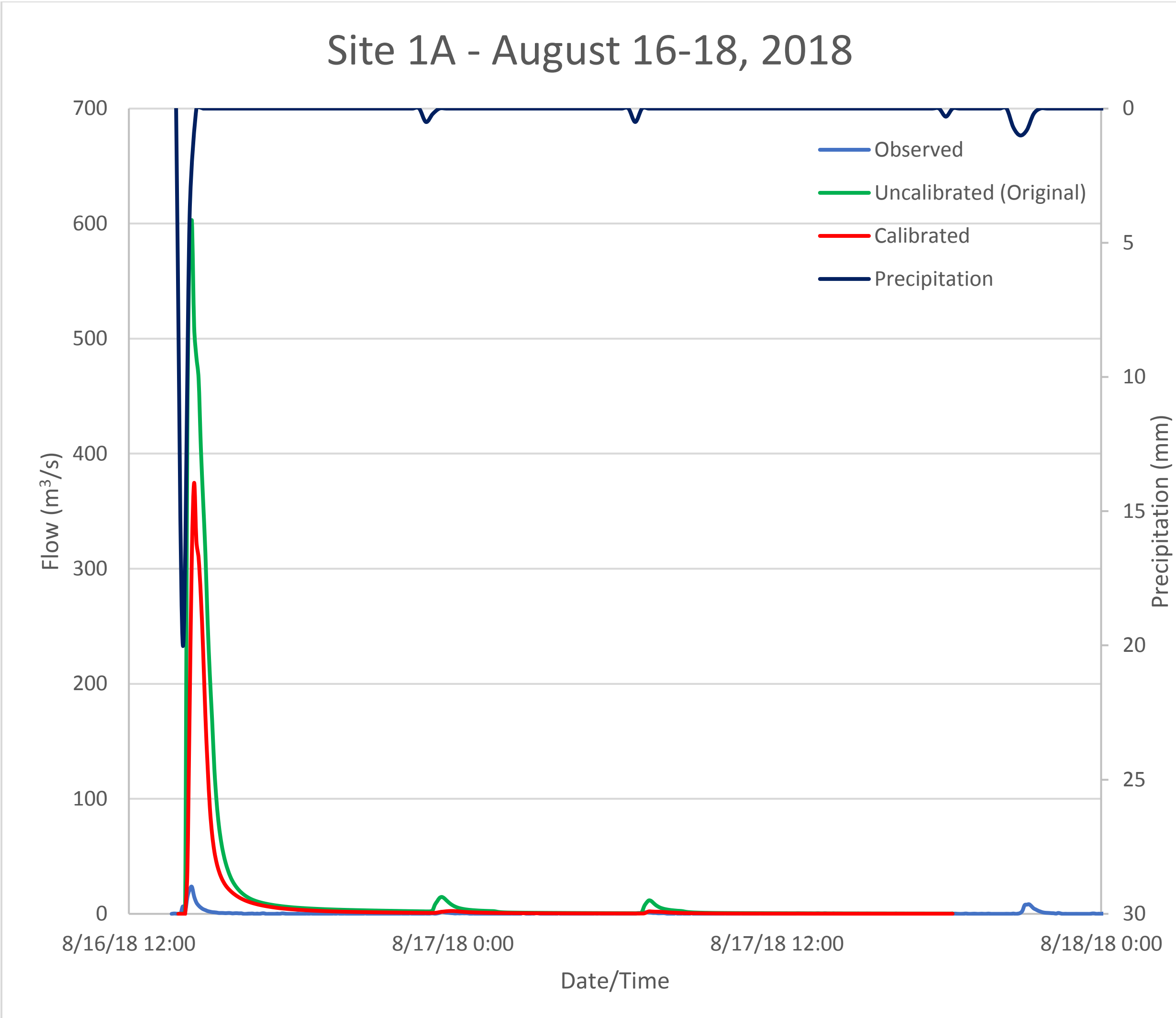

Site 1A - June 22-23, 2018
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
Flow (l/s)
Precipitation (mm)
Observed
Uncalibrated (Original)
Calibrated
Precipitation
6/22/18 18:00
6/23/18 6:00
6/23/18 18:00
Date/Time

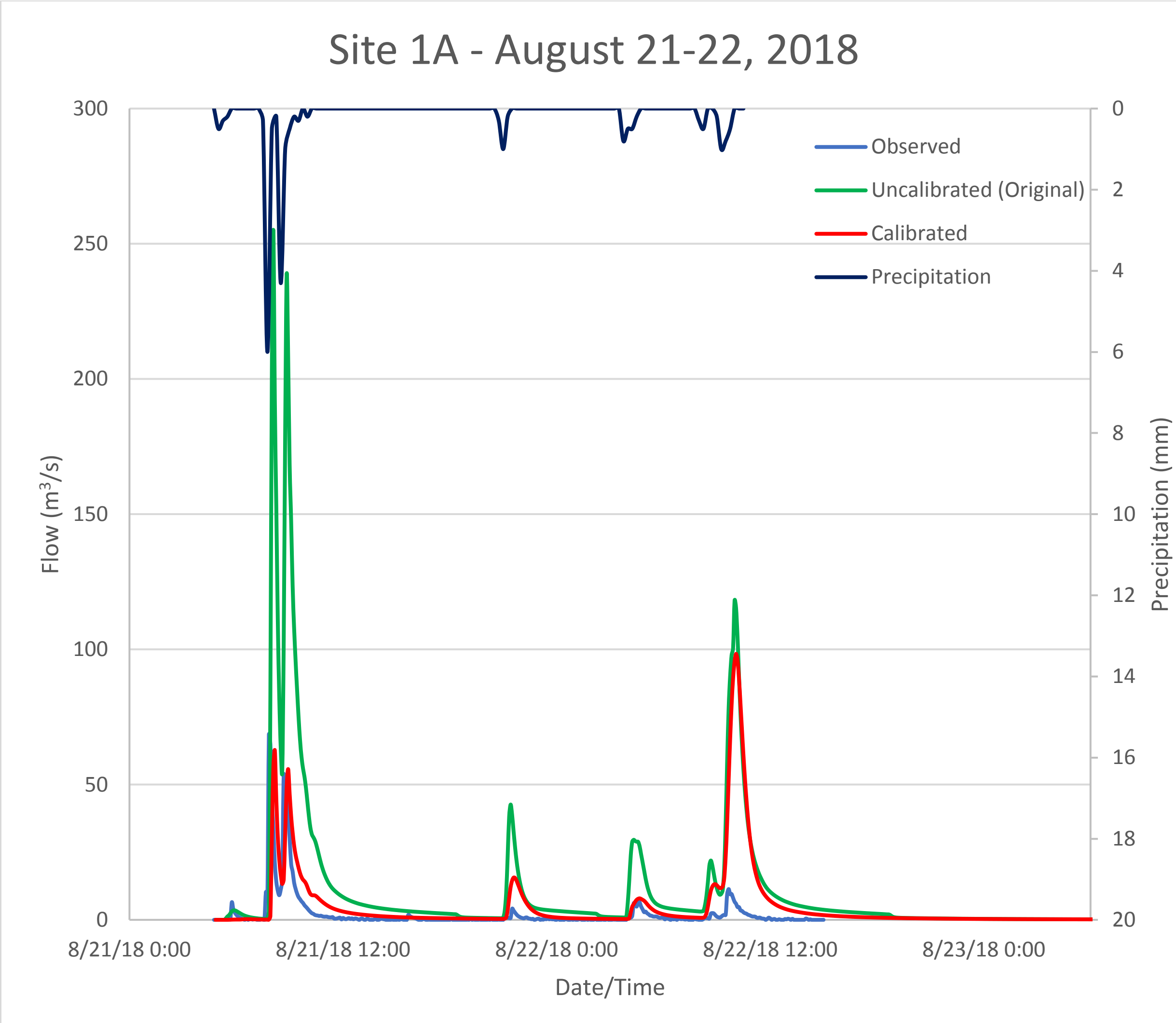

Site 1A - June 24, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
6/24/18 0:00
6/24/18 12:00
6/25/18 0:00
Date/Time

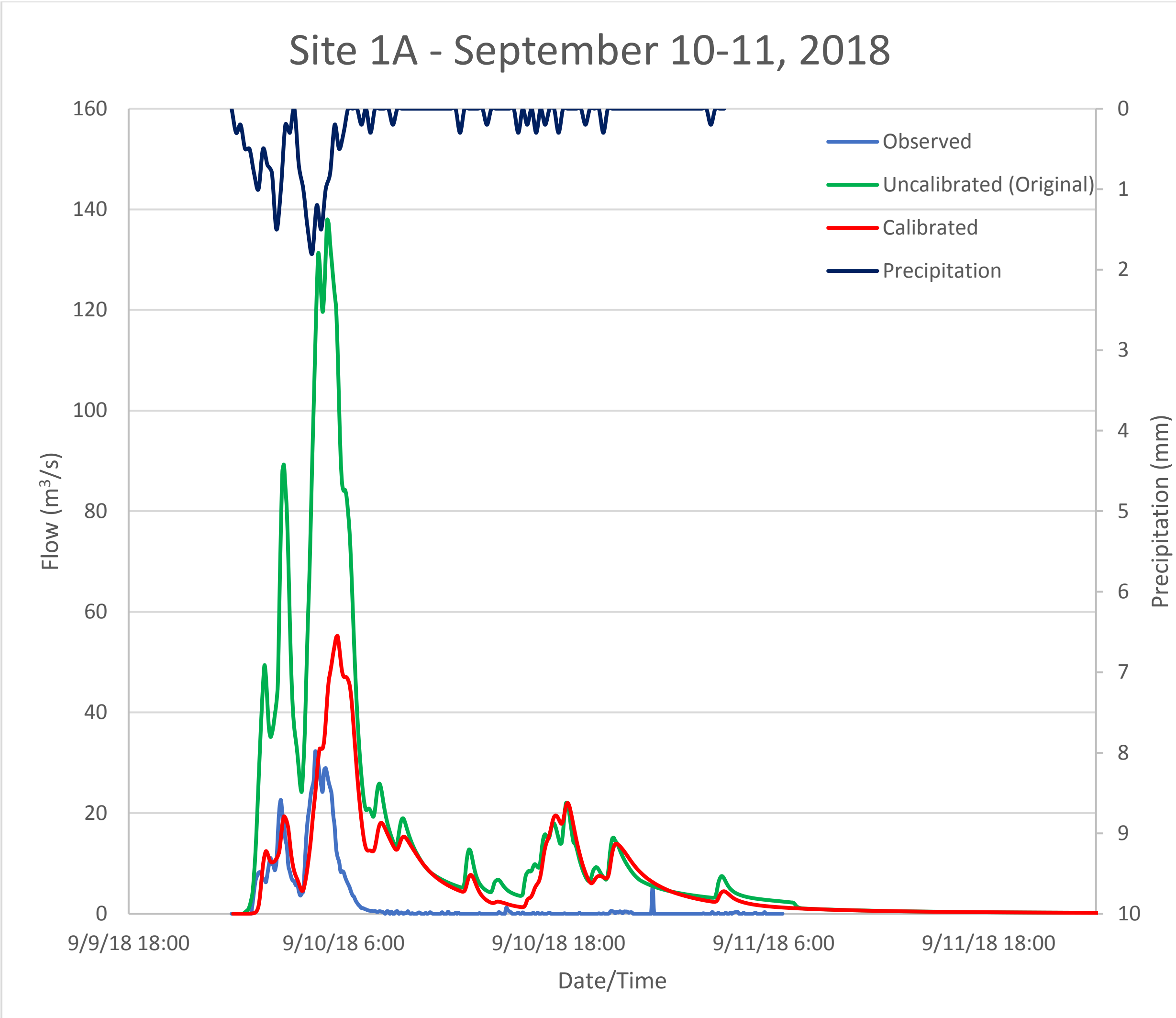

Site 1A - July 26, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
500
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
7/26/18 12:00
7/26/18 18:00
7/27/18 0:00
7/27/18 6:00
Date/Time

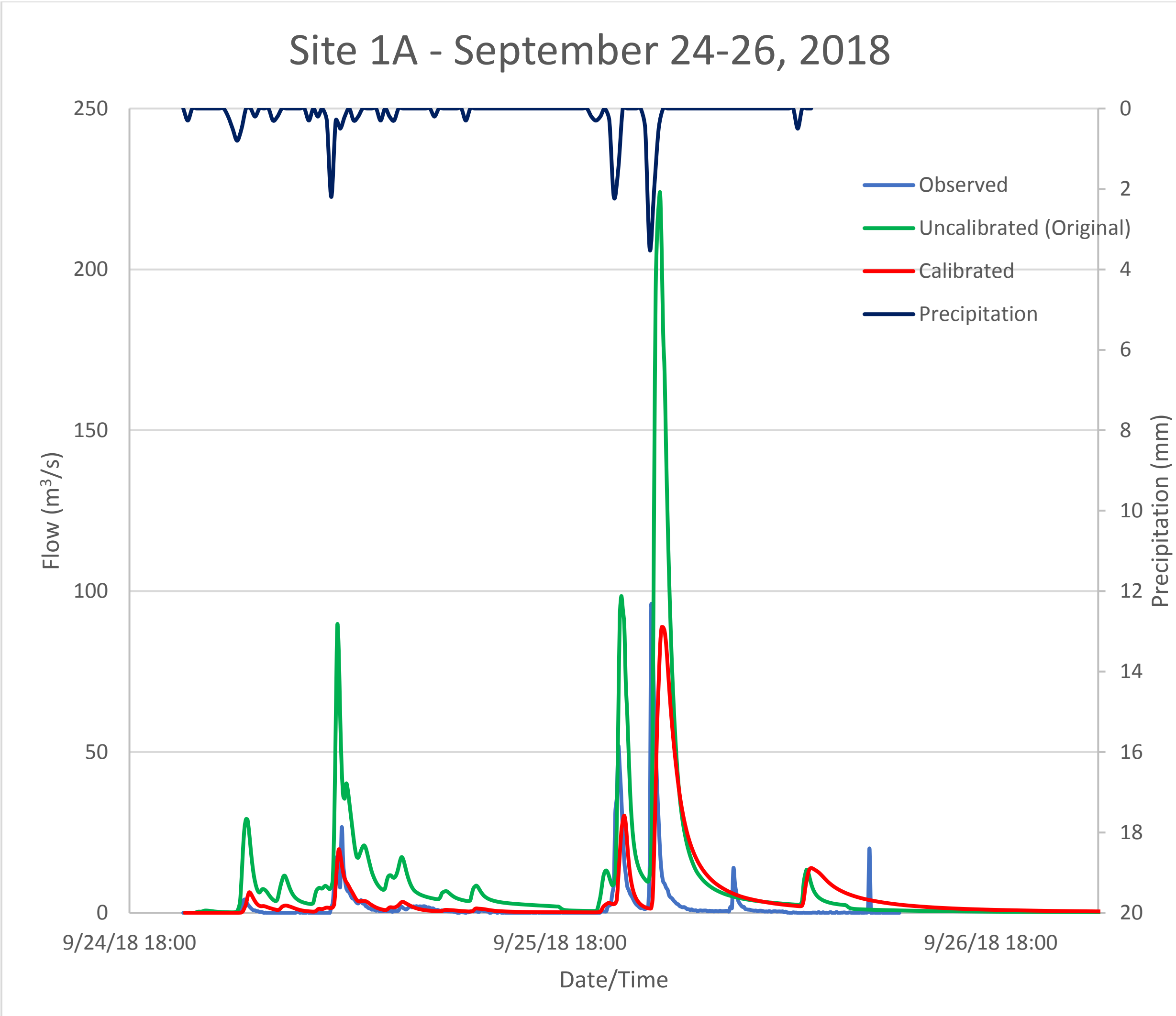

Site 1A - August 6-7, 2018
Flow (m³/s)
Precipitation (mm)
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
8/6/18 12:00
8/7/18 0:00
8/7/18 12:00

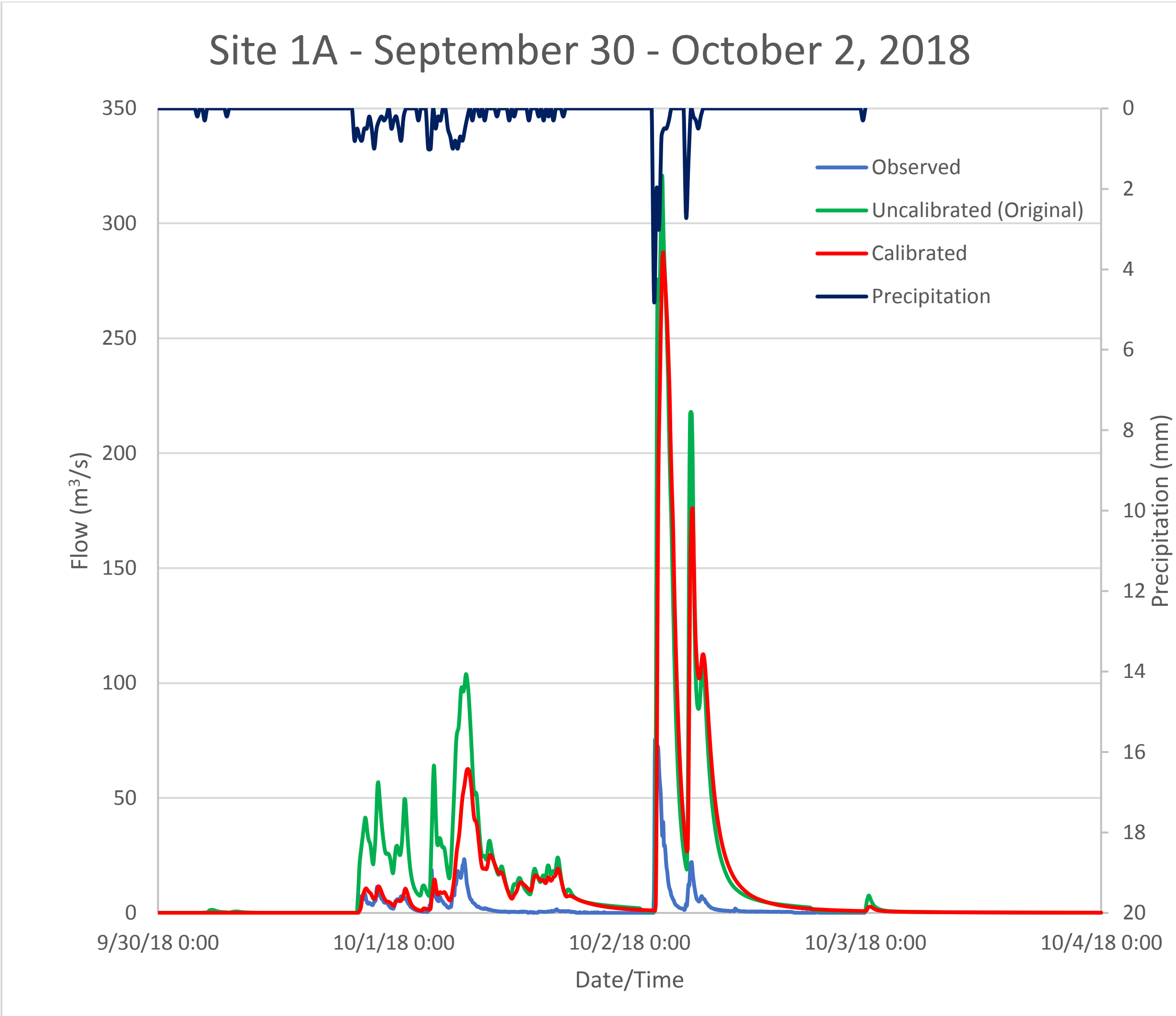

Site 1A - August 8, 2018
Flow (m^3/s)
Precipitation (mm)
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
6
7
8
9
10
8/7/18 18:00
8/8/18 6:00
8/8/18 18:00
8/9/18 6:00

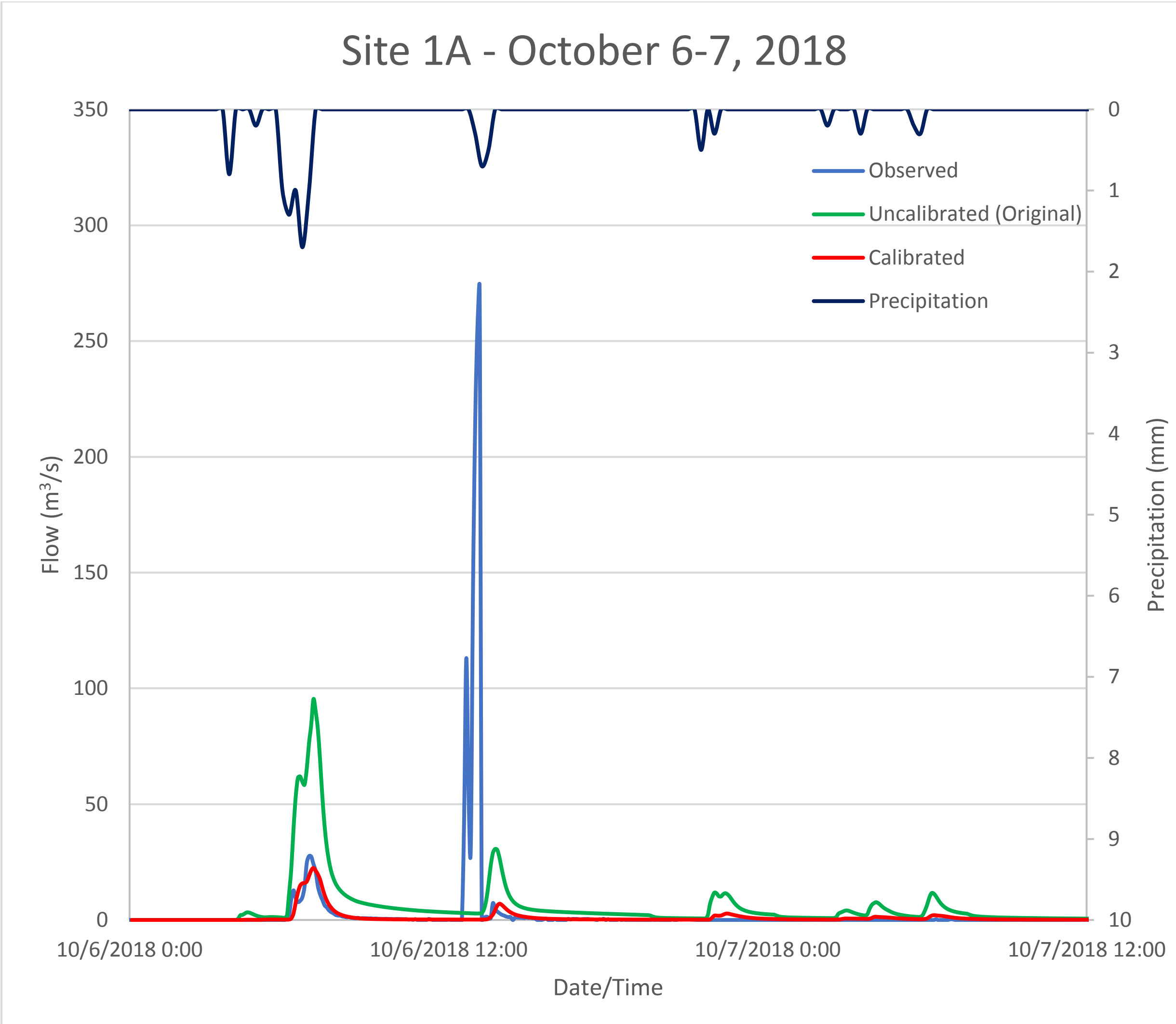

Site 1A - August 16-18, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m³/s)
Precipitation (mm)
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
8/16/18 12:00
8/17/18 0:00
8/17/18 12:00
8/18/18 0:00
Date/Time

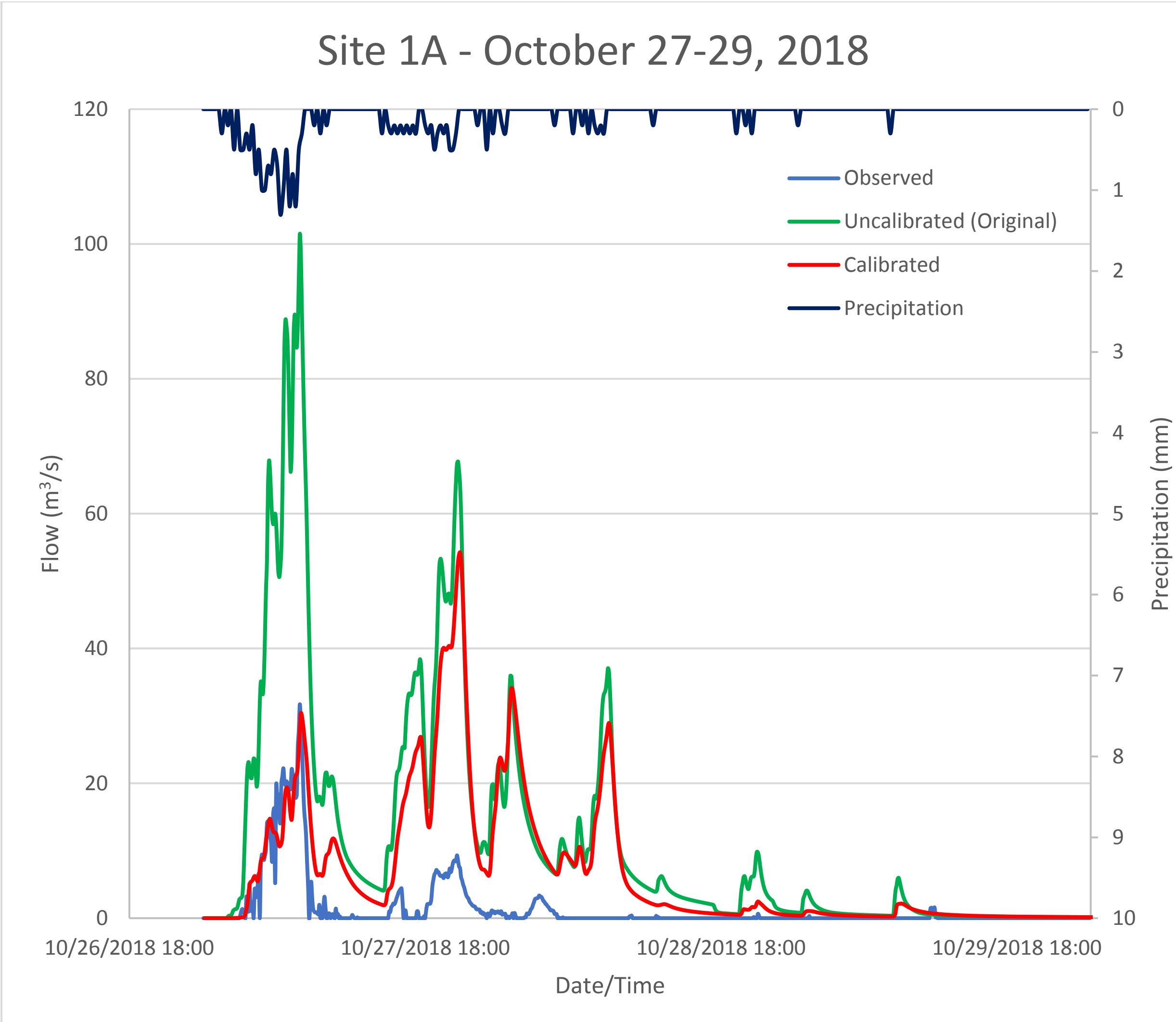

Site 1A - August 21-22, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m³/s)
Precipitation (mm)
Date/Time
8/21/18 0:00
8/21/18 12:00
8/22/18 0:00
8/22/18 12:00
8/23/18 0:00

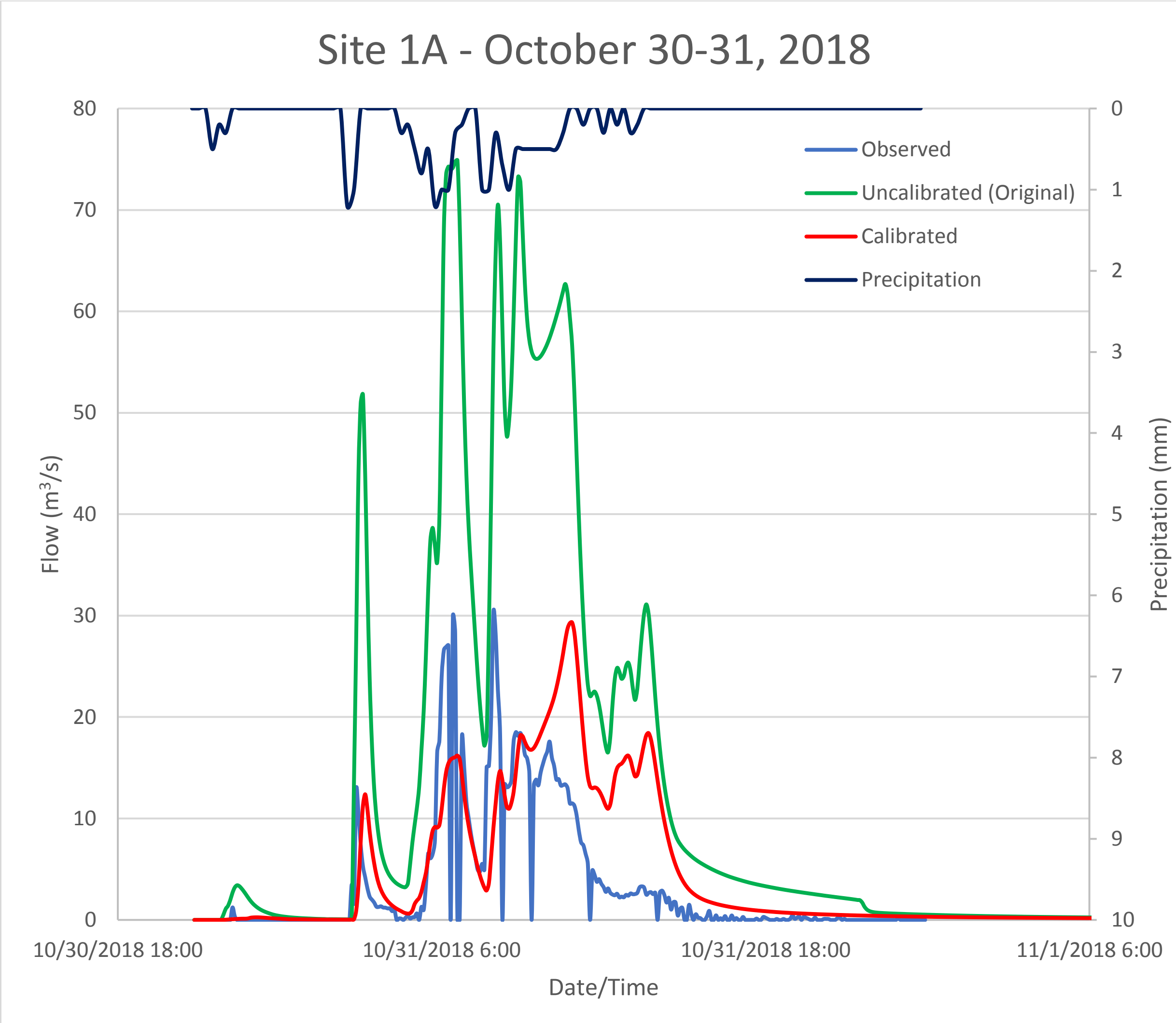

Site 1A - September 10-11, 2018
Flow (m3/s)
Precipitation (mm)
Date/Time
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
9/9/18 18:00
9/10/18 6:00
9/10/18 18:00
9/11/18 6:00
9/11/18 18:00
Observed
Uncalibrated (Original)
Calibrated
Precipitation

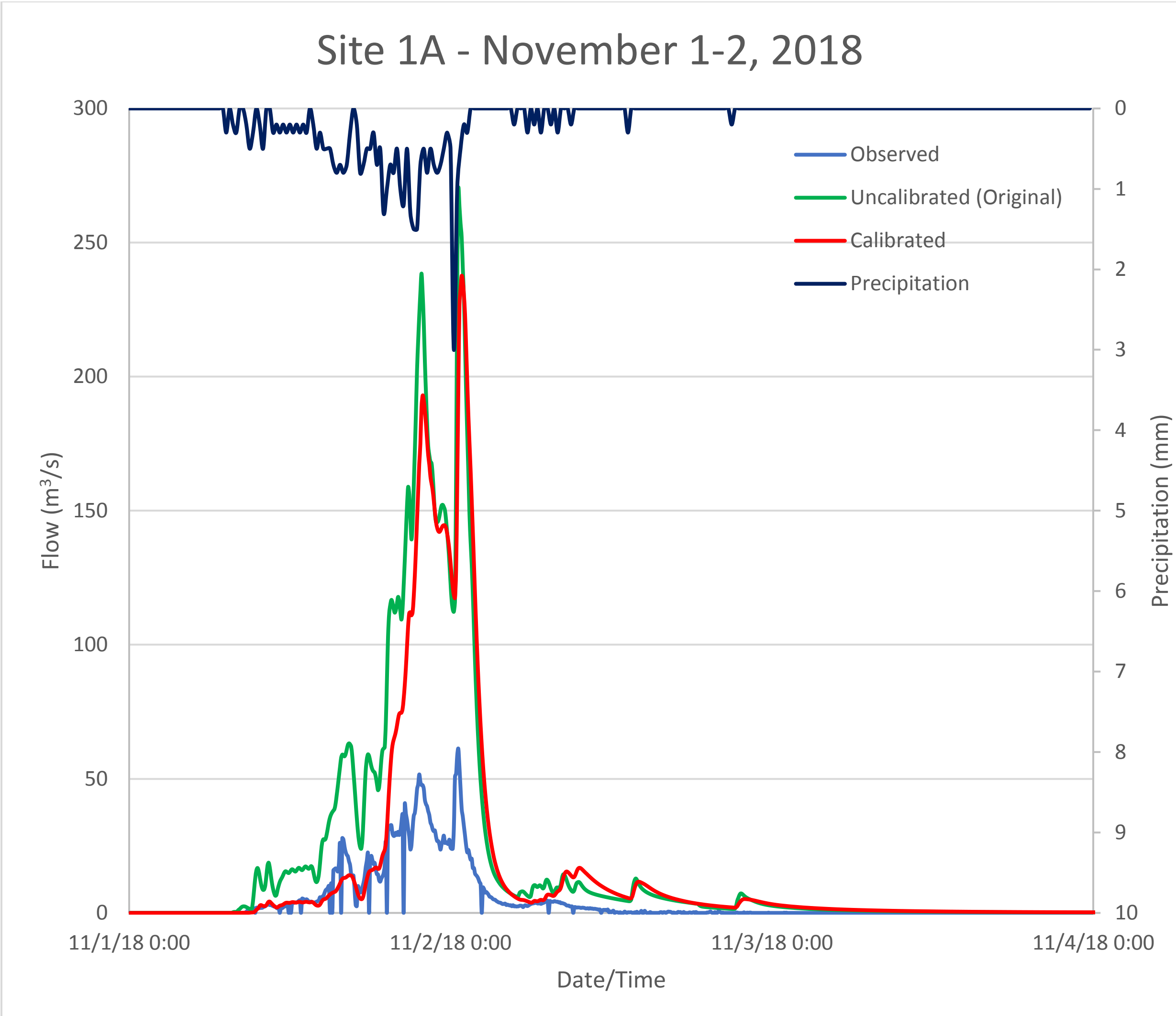

Site 1A - September 24-26, 2018
Flow (m³/s)
Precipitation (mm)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
9/24/18 18:00
9/25/18 18:00
9/26/18 18:00
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation

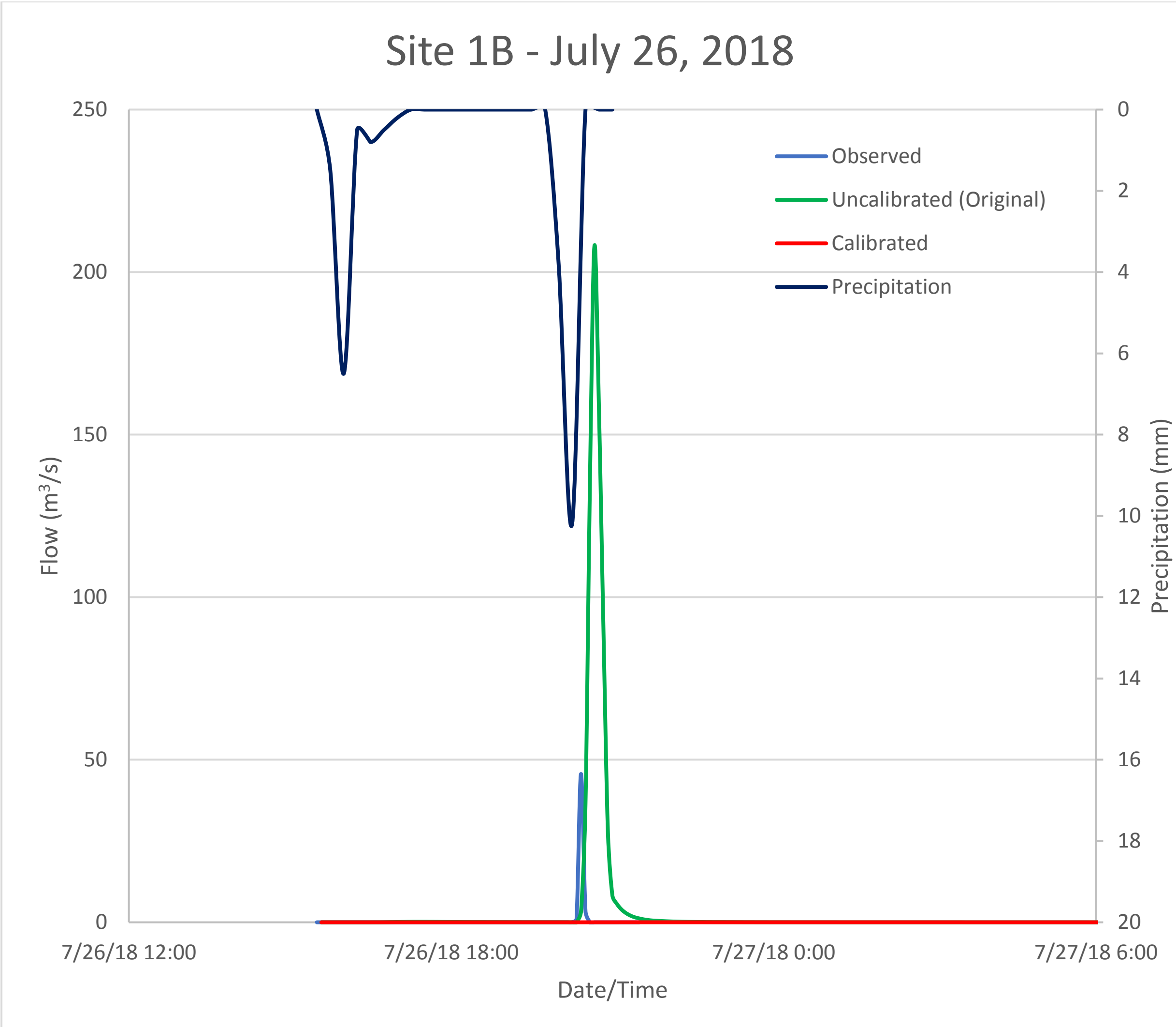

Site 1A - September 30 - October 2, 2018
Flow (m³/s)
Precipitation (mm)
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
9/30/18 0:00
10/1/18 0:00
10/2/18 0:00
10/3/18 0:00
10/4/18 0:00

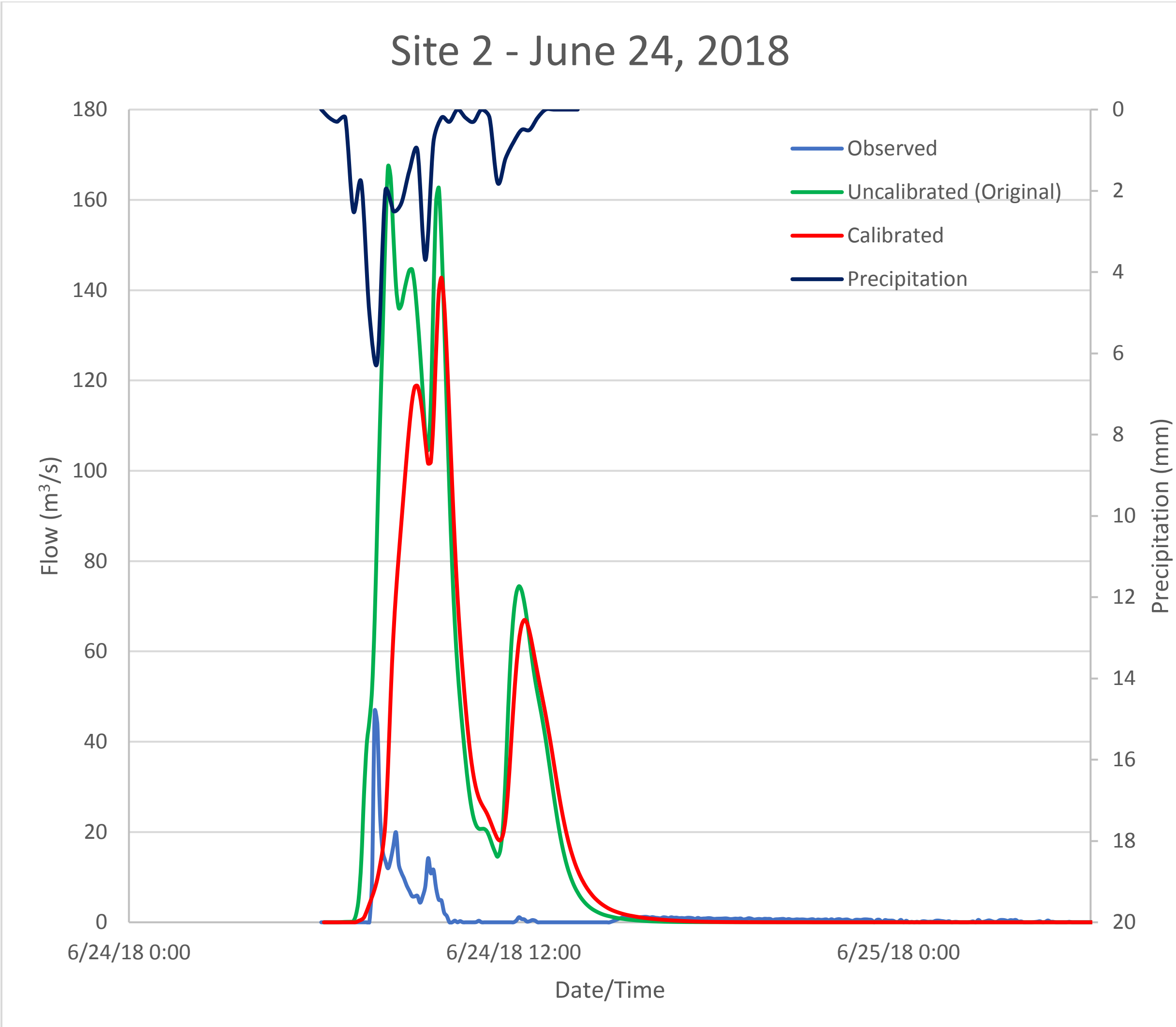

Site 1A - October 6-7, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m³/s)
Precipitation (mm)
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
10
10/6/2018 0:00
10/6/2018 12:00
10/7/2018 0:00
10/7/2018 12:00
Date/Time

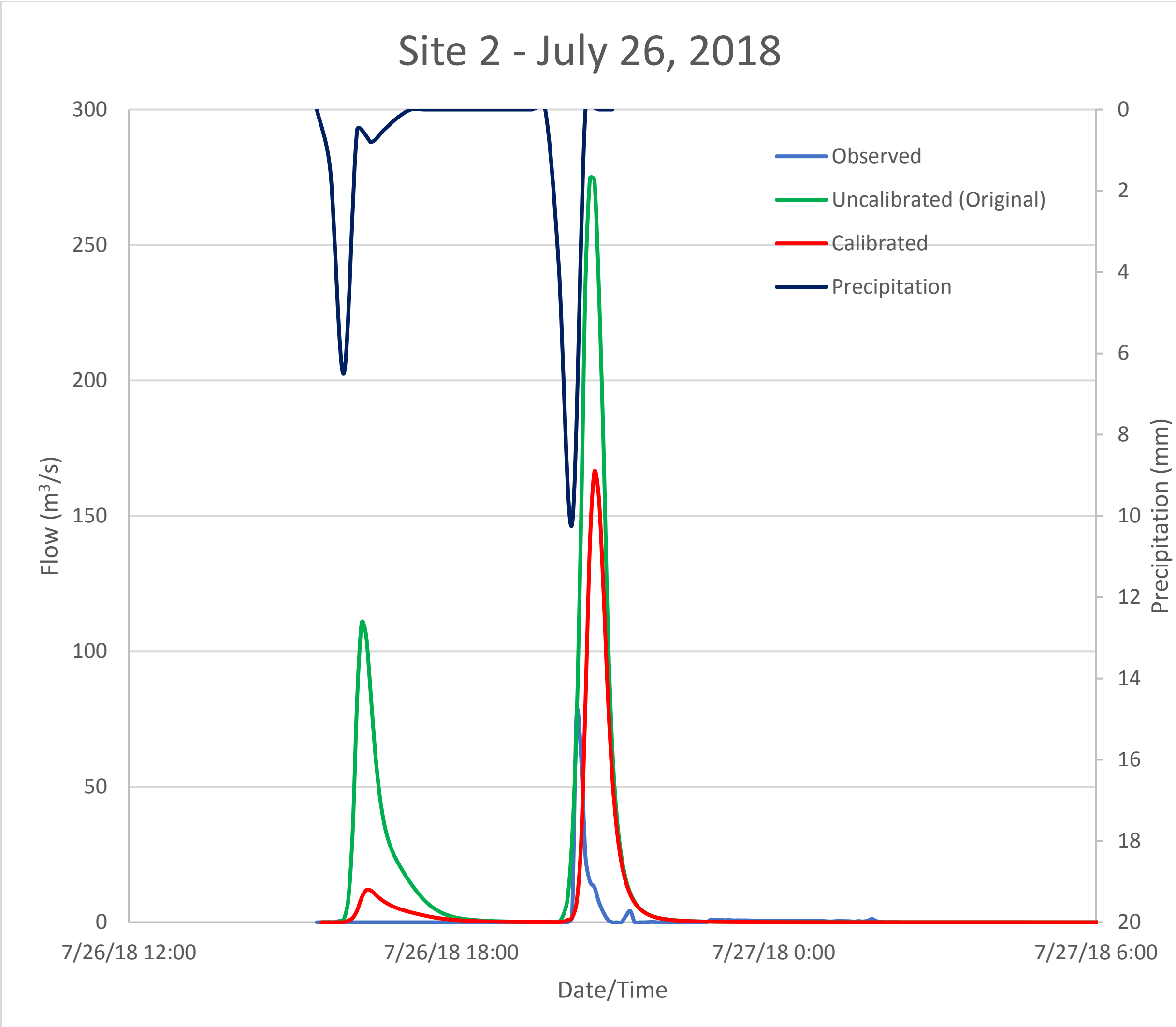

Site 1A - October 27-29, 2018
Flow (m^3/s)
Precipitation (mm)
Date/Time
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
10/26/2018 18:00
10/27/2018 18:00
10/28/2018 18:00
10/29/2018 18:00
Observed
Uncalibrated (Original)
Calibrated
Precipitation

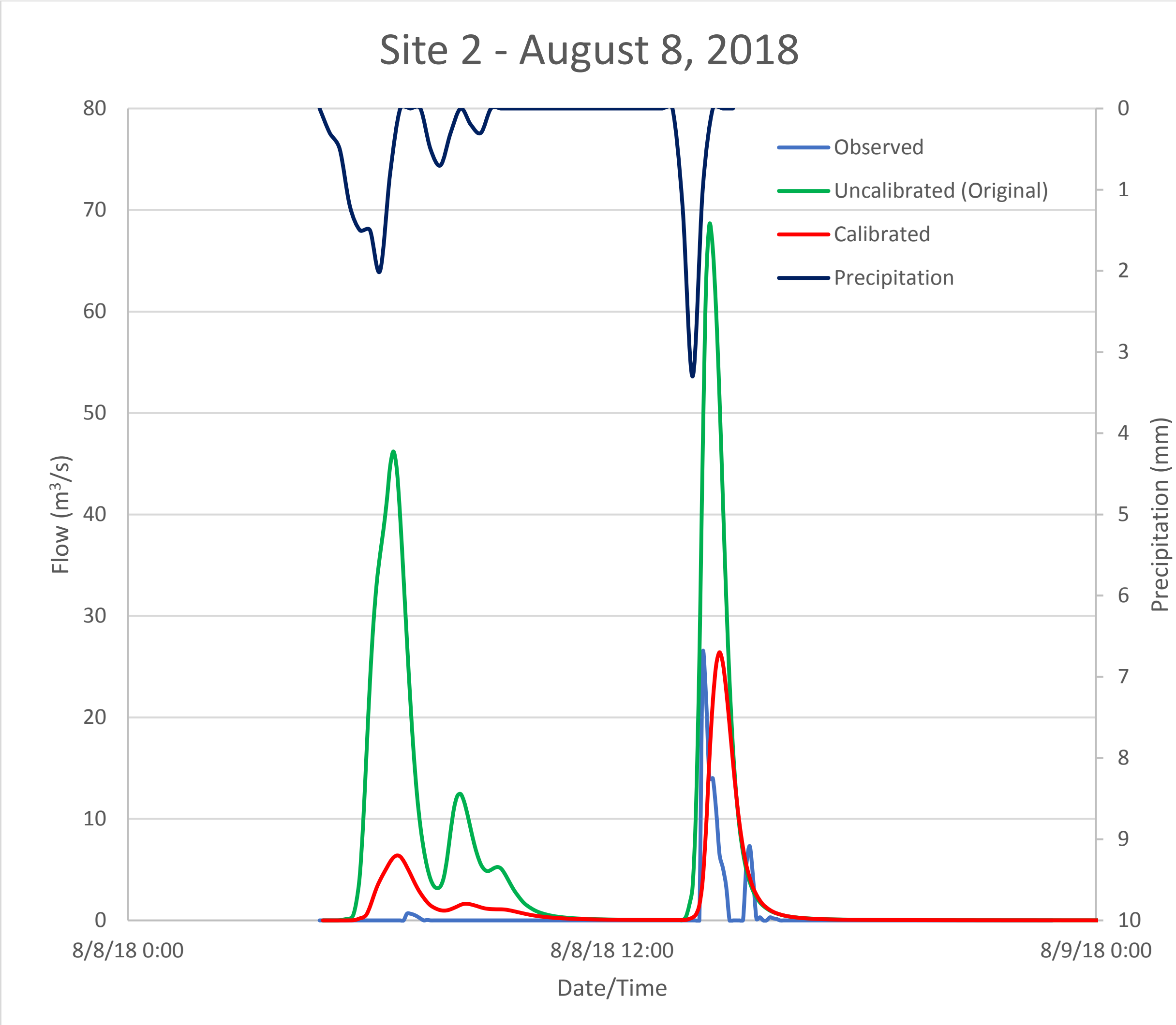

Site 1A - October 30-31, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
Date/Time
10/30/2018 18:00
10/31/2018 6:00
10/31/2018 18:00
11/1/2018 6:00
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
9

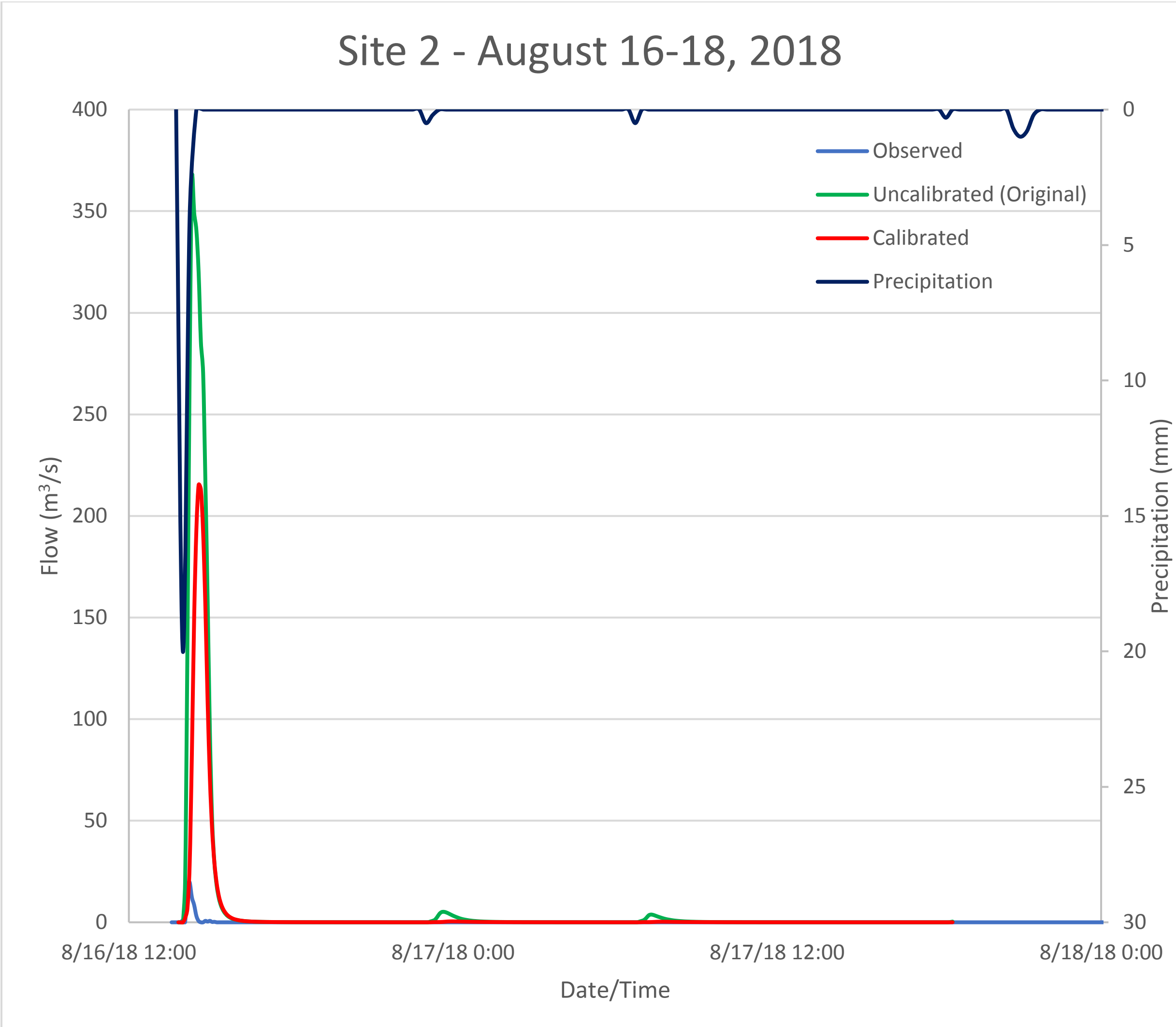

Site 1A - November 1-2, 2018
Flow (m³/s)
Precipitation (mm)
Date/Time
11/1/18 0:00
11/2/18 0:00
11/3/18 0:00
11/4/18 0:00
Observed
Uncalibrated (Original)
Calibrated
Precipitation

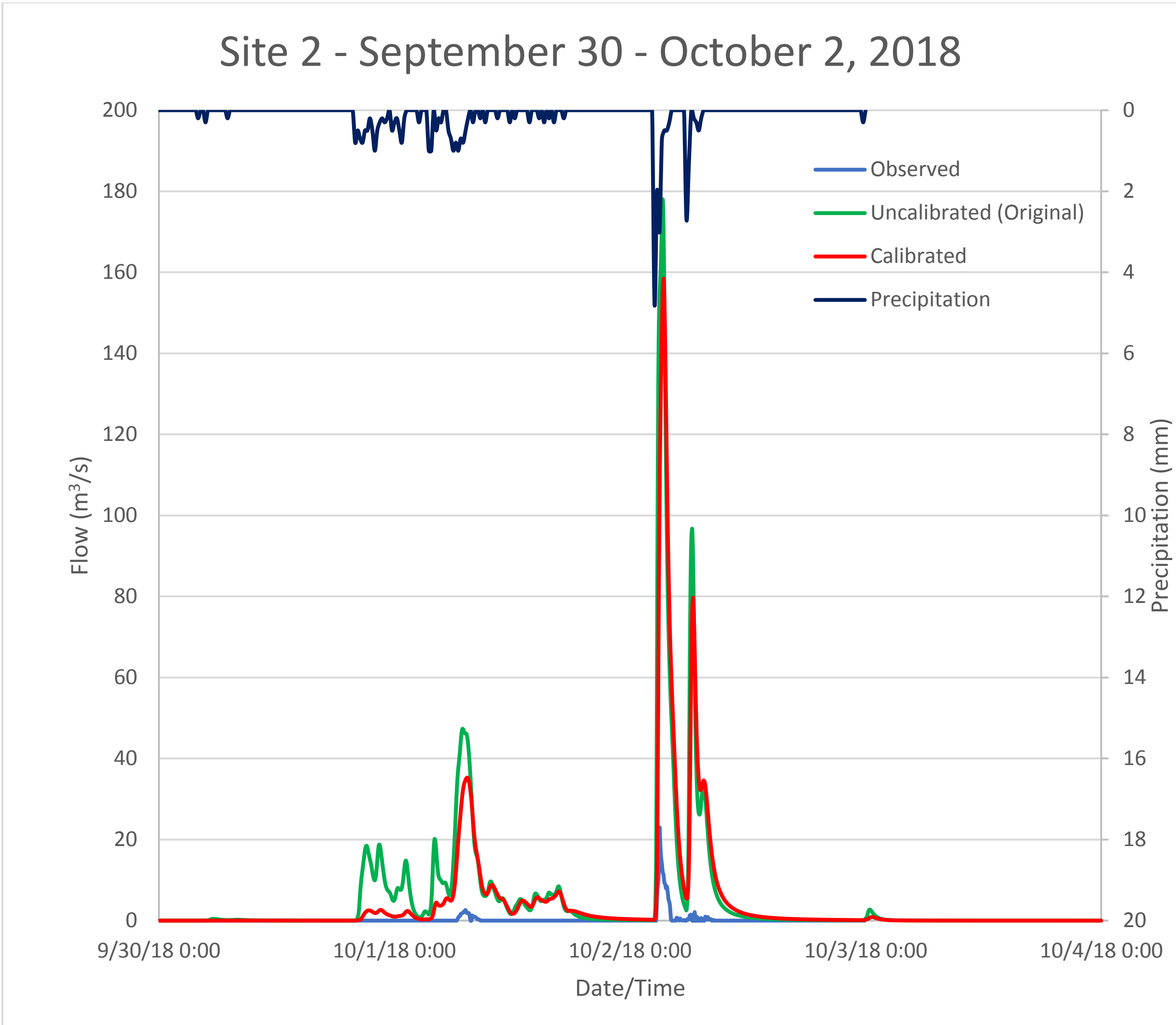

Site 1B - July 26, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
7/26/18 12:00
7/26/18 18:00
7/27/18 0:00
7/27/18 6:00
Date/Time

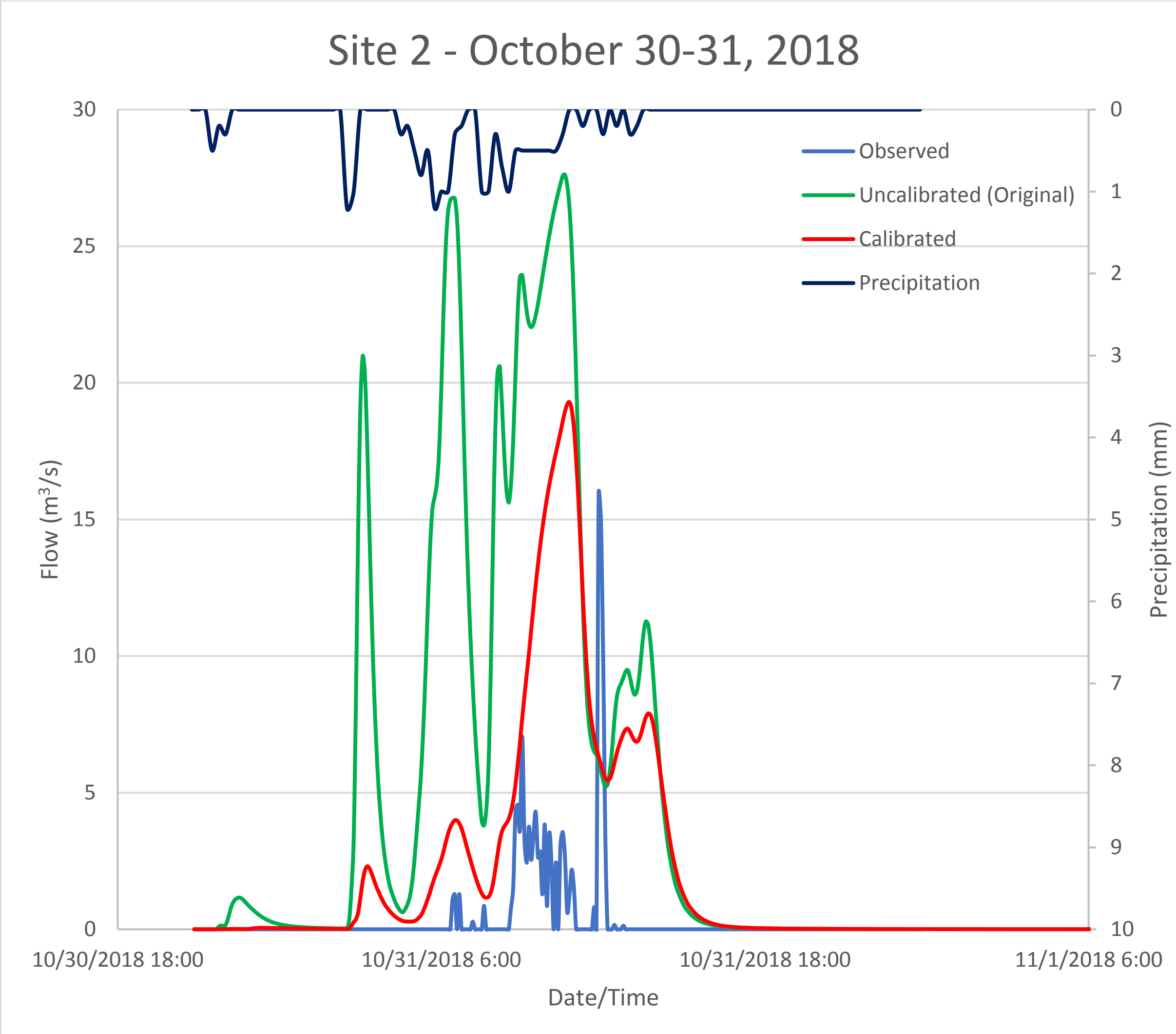

Site 2 - June 24, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
6/24/18 0:00
6/24/18 12:00
6/25/18 0:00
Date/Time

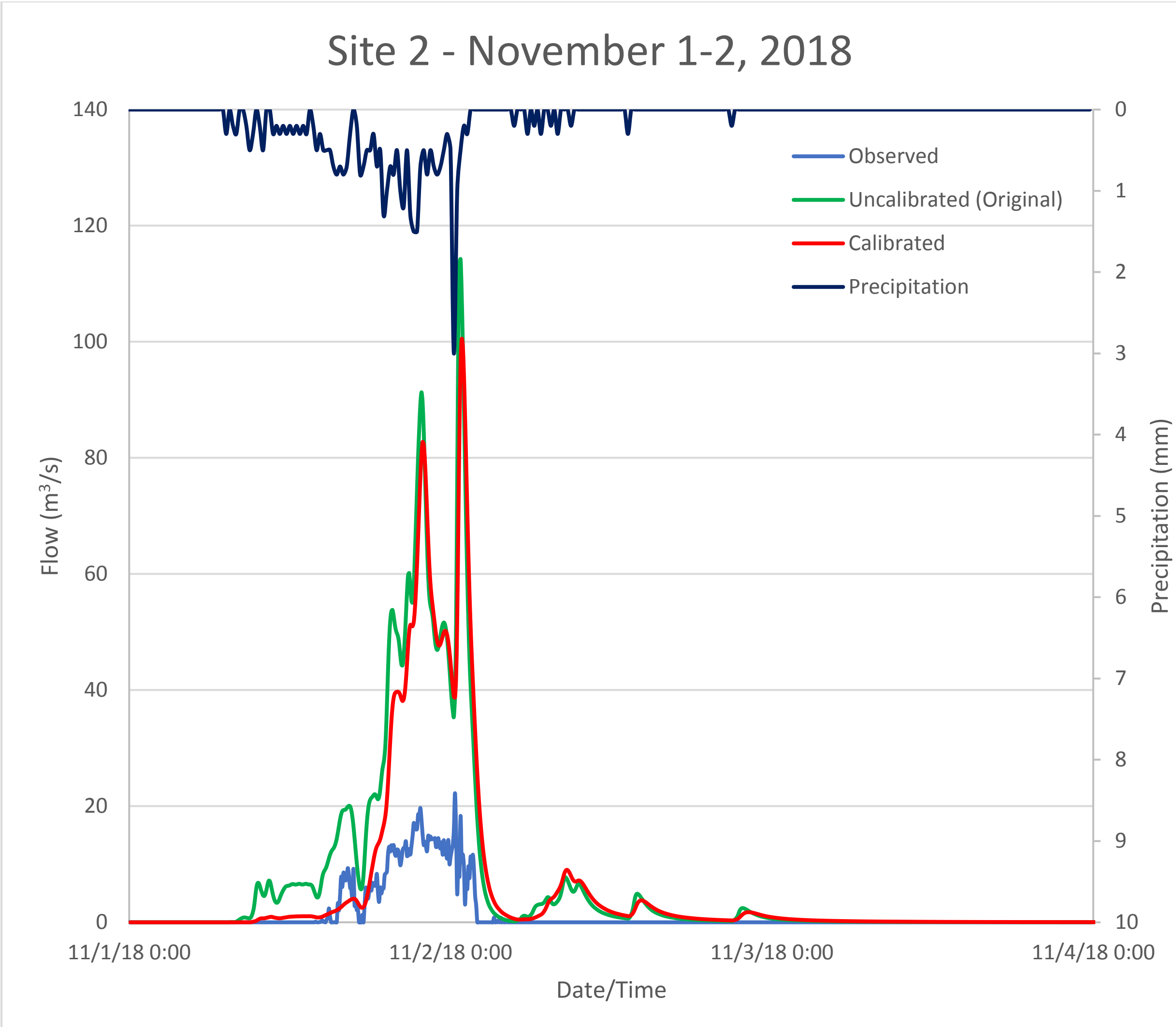

Site 2 - July 26, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
7/26/18 12:00
7/26/18 18:00
7/27/18 0:00
7/27/18 6:00
Date/Time

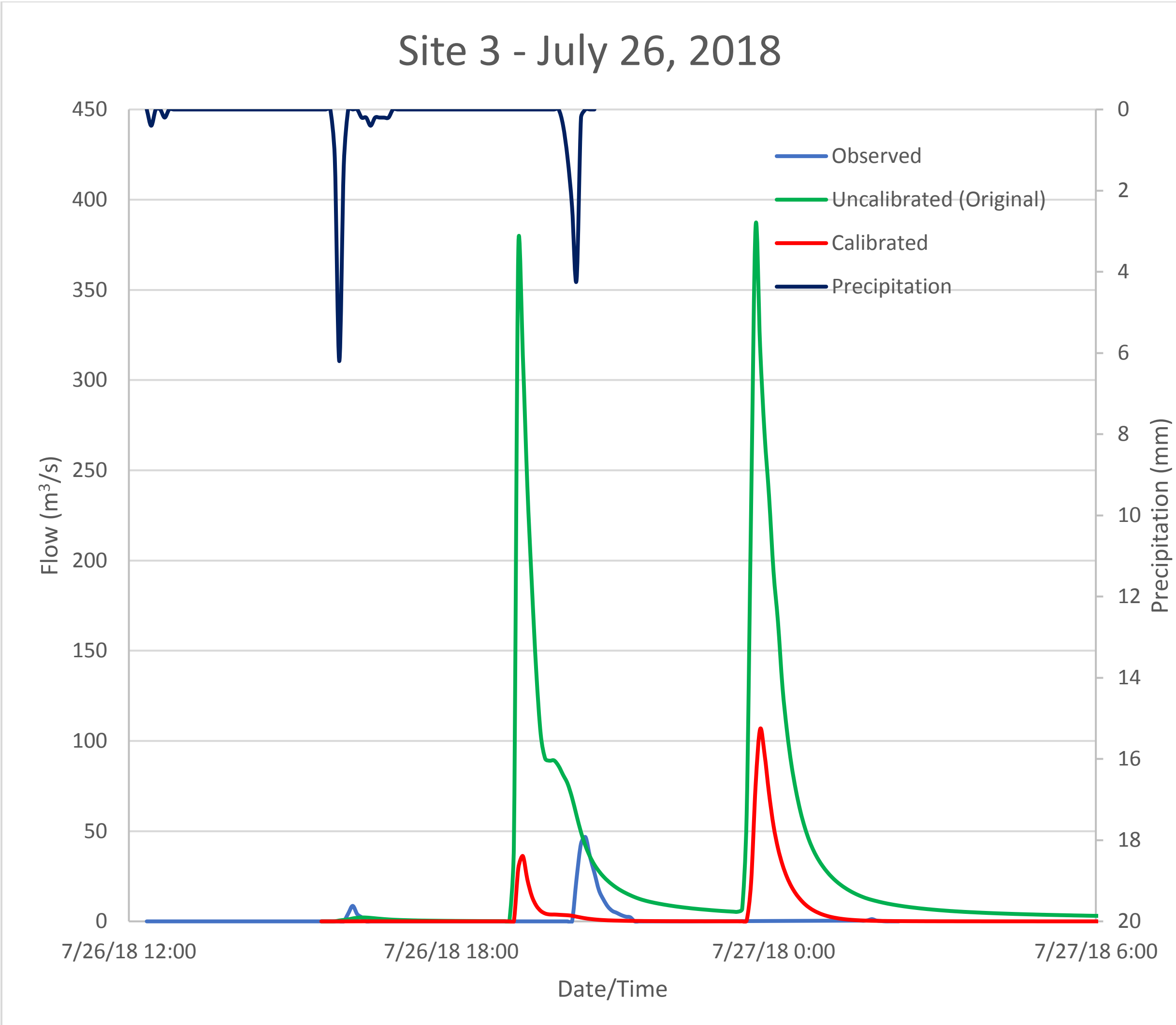

Site 2 - August 8, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m³/s)
Precipitation (mm)
0
10
20
30
40
50
60
70
80
1
2
3
4
5
6
7
8
9
8/8/18 0:00
8/8/18 12:00
8/9/18 0:00
Date/Time

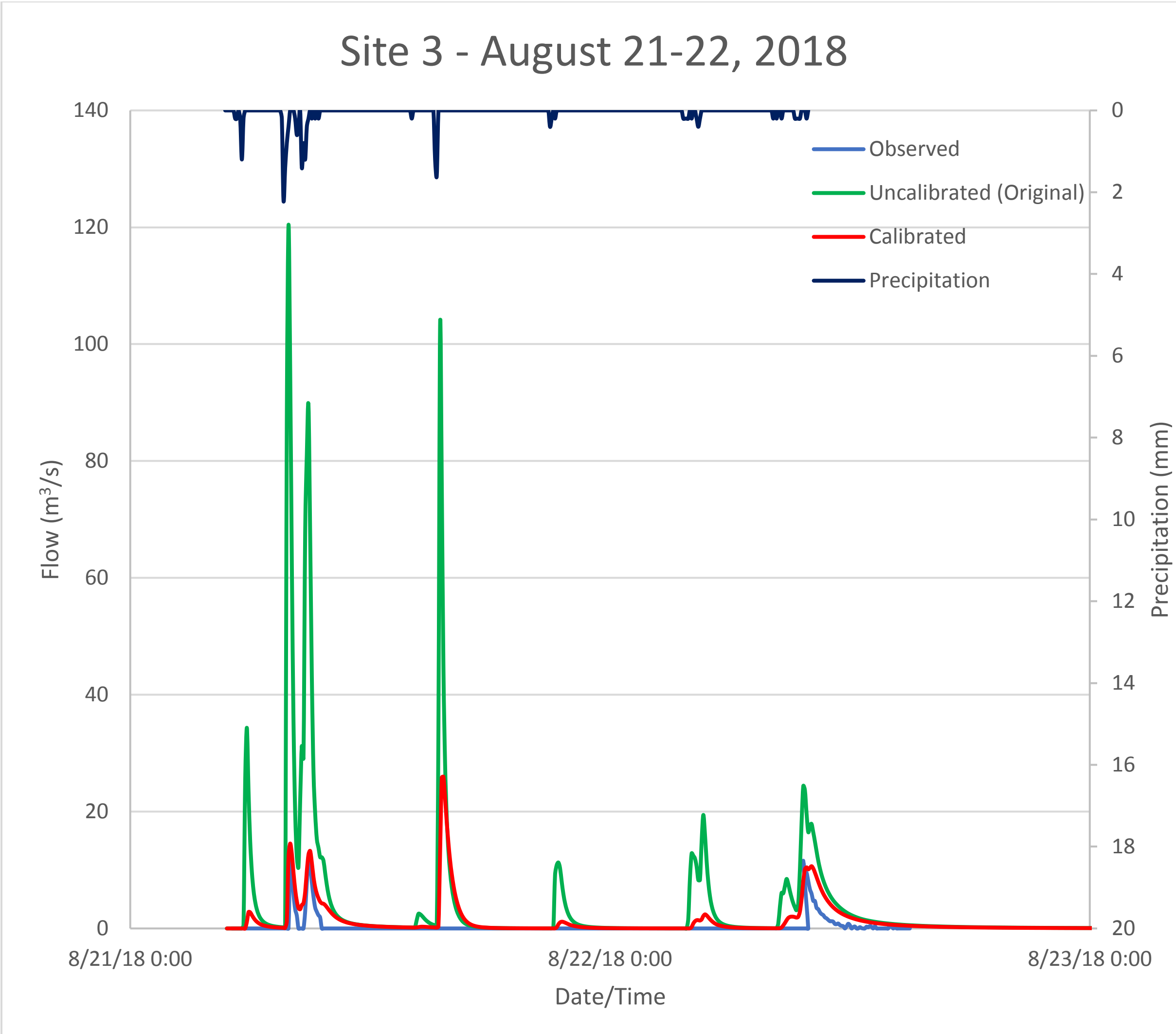

Site 2 - August 16-18, 2018
Flow (m³/s)
400
350
300
250
200
150
100
50
0
Precipitation (mm)
0
5
10
15
20
25
30
Observed
Uncalibrated (Original)
Calibrated
Precipitation
8/16/18 12:00
8/17/18 0:00
8/17/18 12:00
8/18/18 0:00
Date/Time


Site 2 - September 30 - October 2, 2018
Flow (m³/s)
Precipitation (mm)
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation
200
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
9/30/18 0:00
10/1/18 0:00
10/2/18 0:00
10/3/18 0:00
10/4/18 0:00


Site 2 - October 30-31, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
Date/Time
10/30/2018 18:00
10/31/2018 6:00
10/31/2018 18:00
11/1/2018 6:00
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8
9
10


Site 2 - November 1-2, 2018
140
120
100
80
60
40
20
0
Flow (m³/s)
0
1
2
3
4
5
6
7
8
9
10
Precipitation (mm)
11/1/18 0:00
11/2/18 0:00
11/3/18 0:00
11/4/18 0:00
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation


Site 3 - July 26, 2018
Flow (m³/s)
Precipitation (mm)
Date/Time
Observed
Uncalibrated (Original)
Calibrated
Precipitation
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20
7/26/18 12:00
7/26/18 18:00
7/27/18 0:00
7/27/18 6:00


Site 3 - August 21-22, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m3/s)
Precipitation (mm)
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14
16
18
20
8/21/18 0:00
8/22/18 0:00
8/23/18 0:00
Date/Time

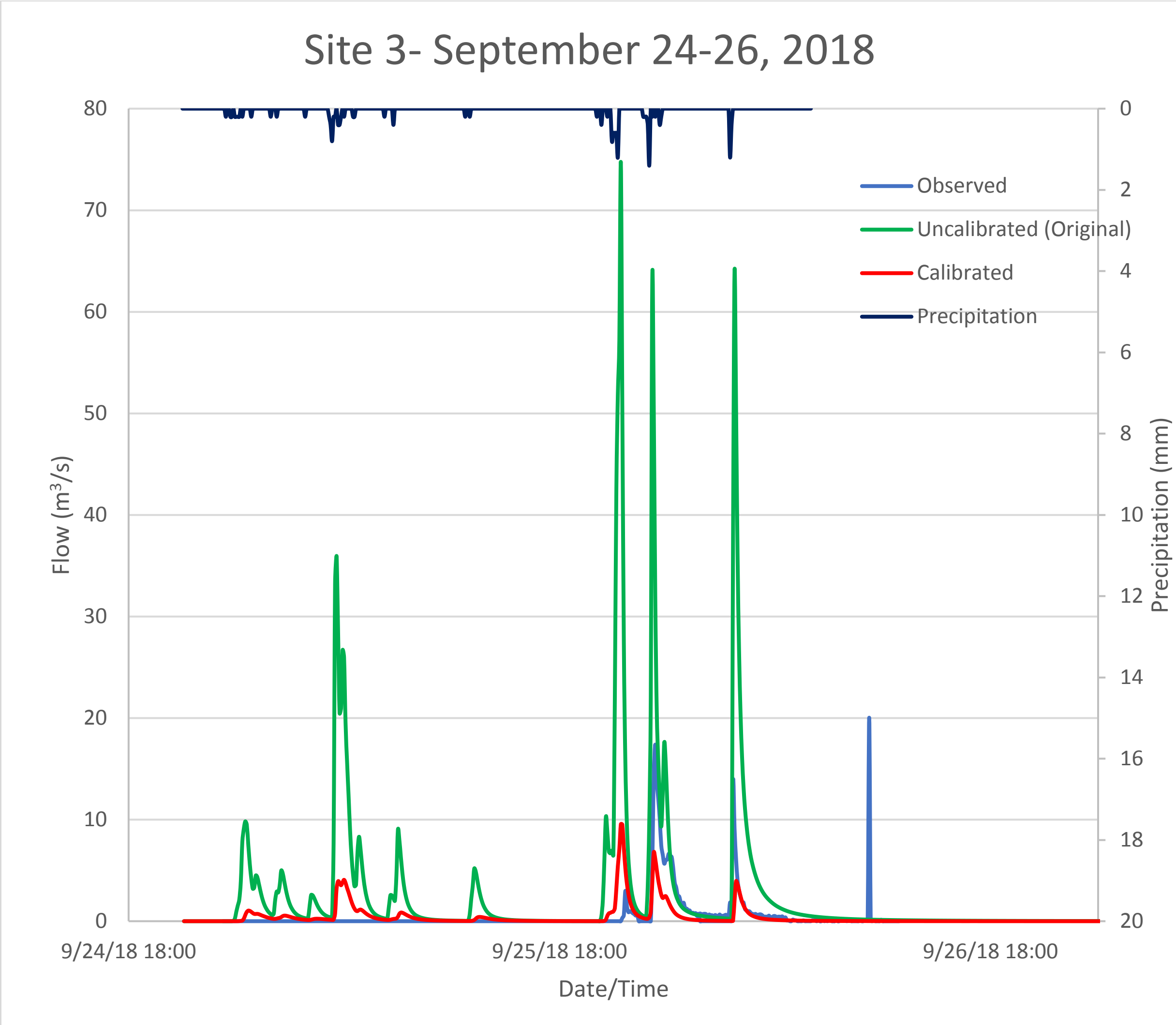

Site 3- September 24-26, 2018
Observed
Uncalibrated (Original)
Calibrated
Precipitation
Flow (m³/s)
Precipitation (mm)
Date/Time
9/24/18 18:00
9/25/18 18:00
9/26/18 18:00
0
10
20
30
40
50
60
70
80
2
4
6
8
12
14
16
18

Table B.1	Final Calibration Scatter Plot Data - Event Based - All Events						
Monitoring Location	Date	Volume (m^3)			Flow (l/s)		
		Observed	Uncalibrated (Original)	Calibrated	Observed	Uncalibrated (Original)	Calibrated
Site 1A	18-Jun-18	129	766	150	81	269	65
	22-Jun-18	243	1803	725	34	222	99
	24-Jun-18	762	4458	3548	173	332	291
	26-Jul-18	465	1903	655	206	461	302
	6-Aug-18	271	962	202	94	133	31
	8-Aug-18	399	1215	286	109	157	50
	16-Aug-18	136	3990	2289	24	602	375
	21-Aug-18	279	2076	903	68	255	98
	10-Sep-18	291	2284	1167	32	138	55
	24-Sep-18	355	1898	920	95	224	89
	30-Sep-18	653	5540	4409	74	321	287
	6-Oct-18	439	776	155	273	95	22
	27-Oct-18	377	3139	1834	32	101	54
	30-Oct-18	349	1636	563	30	75	29
	1-Nov-18	1206	5614	4418	61	270	238
Site 1B	26-Jul-18	15	209	0	46	208	0
Site 2	24-Jun-18	135	1743	1379	47	167	143
	26-Jul-18	70	757	324	77	275	166
	8-Aug-18	37	388	109	26	69	26
	16-Aug-18	20	1575	871	20	366	215
	30-Sep-18	67	1976	1631	23	178	158
	30-Oct-18	38	566	563	16	28	29
	1-Nov-18	375	1972	1640	22	114	100
Site 3	26-Jul-18	76	1712	231	47	385	106
	21-Aug-18	55	675	212	11	120	26
	24-Sep-18	80	527	74	20	75	10

Table B.2	Final Calibration Scatter Plot Data - Event Based - Screened						
Monitoring Location	Date	Volume (m^3)			Flow (l/s)		
		Observed	Uncalibrated (Original)	Calibrated	Observed	Uncalibrated (Original)	Calibrated
Site 1A	18-Jun-18	129	766	150	81	269	65
	22-Jun-18						
	24-Jun-18						
	26-Jul-18	465	1903	655	206	461	302
	6-Aug-18	271	962	202	94	133	31
	8-Aug-18	399	1215	286	109	157	50
	16-Aug-18						
	21-Aug-18						
	10-Sep-18						
	24-Sep-18						
	30-Sep-18						
	6-Oct-18						
	27-Oct-18						
	30-Oct-18	349	1636	563	30	75	29
	1-Nov-18						
Site 1B	26-Jul-18	15	209	0	46	208	0
Site 2	24-Jun-18						
	26-Jul-18	70	757	324	77	275	166
	8-Aug-18	37	388	109	26	69	26
	16-Aug-18						
	30-Sep-18						
	30-Oct-18						
	1-Nov-18						
Site 3	26-Jul-18	76	1712	231	47	385	106
	21-Aug-18	55	675	212	11	120	26
	24-Sep-18	80	527	74	20	75	10

Table B.3	Converted Soils from CN to Green and Ampt - Event Based - Screened						
Monitoring Location	Date	Volume (m^3)			Flow (l/s)		
		Observed	Uncalibrated (Original)	Calibrated	Observed	Uncalibrated (Original)	Calibrated
Site 1A	18-Jun-18	129	766	135	81	269	63
	22-Jun-18						
	24-Jun-18						
	26-Jul-18	465	1903	630	206	461	240
	6-Aug-18	271	962	169	94	133	27
	8-Aug-18	399	1215	215	109	157	37
	16-Aug-18						
	21-Aug-18						
	10-Sep-18						
	24-Sep-18						
	30-Sep-18						
	6-Oct-18						
	27-Oct-18						
	30-Oct-18	349	1636	257	30	75	15
	1-Nov-18						
Site 1B	26-Jul-18	15	209	0	46	208	0
Site 2	24-Jun-18						
	26-Jul-18	70	757	168	77	275	70
	8-Aug-18	37	388	55	26	69	7
	16-Aug-18						
	30-Sep-18						
	30-Oct-18						
	1-Nov-18						
Site 3	26-Jul-18	76	1712	102	47	385	33
	21-Aug-18	55	675	90	11	120	12
	24-Sep-18	80	527	73	20	75	8

Estimation of Green-Ampt Infiltration Parameters

(SWMM RUNOFF Variables SUCT, HYDCON, SMDMAX)

Provisional Values Suitable for Design Storm Events Where More Detailed Soils Data Is Not Available

USDA Soil Texture Classification	SUCT Avg. Capillary Suction		HYDCON Saturated Hydraulic Conductivity		SMDMAX Initial Moisture Deficit for Soil (Vol. of Air / Vol. of Voids, expressed as a fraction)	
	(in)	(mm)	(in/hr)	(mm/hr)	Moist Soil Climates (Eastern US)	Dry Soil Climates (Western US)
Sand	**1.95**	**49.5**	**9.27**	**235.6**	**.346**	**.404**
Loamy Sand	**2.41**	**61.3**	**2.35**	**59.8**	**.312**	**.382**
Sandy Loam	**4.33**	**110.1**	**0.86**	**21.8**	**.246**	**.358**
Loam	**3.50**	**88.9**	**0.52**	**13.2**	**.193**	**.346**
Silt Loam	**6.57**	**166.8**	**0.27**	**6.8**	**.171**	**.368**
Sandy Clay Loam	**8.60**	**218.5**	**0.12**	**3.0**	**.143**	**.250**
Clay Loam	**8.22**	**208.8**	**0.08**	**2.0**	**.146**	**.267**
Silty Clay Loam	**10.75**	**273.0**	**0.08**	**2.0**	**.105**	**.263**
Sandy Clay	**9.41**	**239.0**	**0.05**	**1.2**	**.091**	**.191**
Silty Clay	**11.50**	**292.2**	**0.04**	**1.0**	**.092**	**.229**
Clay	**12.45**	**316.3**	**0.02**	**0.6**	**.079**	**.203**

Notes:

1. These values are provisional, and are offered as reasonable parameters estimates for SWMM applications where more detailed soils information is not available. There is significant variance in these values; laboratory and field testing, sensitivity analysis, and calibration may be employed to improve upon these estimates.
2. Typically use USDA SCS (now NRCS) Soil Survey to determine Soil Texture. In these surveys, Saturated Hydraulic Conductivity is reported as Permeability . Use the values reported in the soil survey for permeability for **HYDCON**, rather than the **HYDCON** values listed in the table above. In the absence of a soil survey or more reliable information, the values listed above may be used.
3. Synthesized from *Handbook of Hydrology*, D.R. Maidment, Editor in Chief, McGraw-Hill, Inc., 1993, pp 5.1-5.39.

APPENDIX C

Existing Conditions Simulation

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S1_A1	A1	0.08	12	1.2	46.59	10	74.00	273.00	2.00	0.11
S10_A1	A1	0.24	72	4.5	37.09	10	74.00	273.00	2.00	0.11
S11_A1	A1	0.23	18	1.2	35.59	10	74.00	273.00	2.00	0.11
S12_A1	A1	0.31	72	4.5	40.59	10	74.00	273.00	2.00	0.11
S13_A1	A1	0.24	60	4.5	38.38	10	74.00	273.00	2.00	0.11
S14_A1	A1	0.09	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S15_A1	A1	0.20	72	4.5	43.10	10	74.00	273.00	2.00	0.11
S16_A1	A1	0.51	96	4.5	36.17	10	74.00	273.00	2.00	0.11
S17_A1	A1	0.05	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S18_A1	A1	0.19	24	3.0	52.89	10	74.00	273.00	2.00	0.11
S19_A1	A1	0.09	24	1.2	41.13	10	74.00	273.00	2.00	0.11
S2_A1	A1	0.02	12	1.2	52.88	10	74.00	273.00	2.00	0.11
S20_A1	A1	0.15	24	4.5	44.10	10	74.00	273.00	2.00	0.11
S21_A1	A1	0.05	12	1.2	50.63	10	74.00	210.92	5.78	0.14
S22_A1	A1	0.37	48	6.0	26.91	10	74.00	204.38	6.18	0.14
S23_A1	A1	1.14	180	6.0	25.87	10	74.00	212.60	5.67	0.13
S24_A1	A1	1.43	180	6.0	36.19	10	74.00	180.95	7.60	0.15
S25_A1	A1	0.74	108	6.0	30.87	10	74.00	180.95	7.60	0.15
S26_A1	A1	0.70	48	6.0	17.75	10	74.00	182.83	7.49	0.15
S27_A1	A1	0.34	18	3.0	52.89	10	74.00	273.00	2.00	0.11
S3_A1	A1	0.12	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S4_A1	A1	0.26	48	4.5	36.71	10	74.00	273.00	2.00	0.11
S5_A1	A1	0.30	48	4.5	41.37	10	74.00	273.00	2.00	0.11
S6_A1	A1	0.07	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S7_A1	A1	0.03	12	1.2	51.83	10	74.00	273.00	2.00	0.11
S8_A1	A1	0.34	72	4.5	33.59	10	74.00	273.00	2.00	0.11
S9_A1	A1	0.04	12	1.2	49.18	10	74.00	273.00	2.00	0.11
S1_A2	A2	0.06	12	1.2	51.15	10	74.00	273.00	2.00	0.11
S10_A2	A2	0.19	18	1.2	41.62	10	74.00	273.00	2.00	0.11
S11_A2	A2	0.11	30	1.2	49.66	10	74.00	273.00	2.00	0.11
S12_A2	A2	0.73	138	1.2	38.35	10	74.00	273.00	2.00	0.11
S13_A2	A2	0.36	24	1.2	49.72	10	74.00	273.00	2.00	0.11
S14_A2	A2	0.50	72	1.2	44.47	10	74.00	273.00	2.00	0.11
S15_A2	A2	0.10	12	1.2	49.71	10	74.00	273.00	2.00	0.11
S16_A2	A2	0.14	18	1.2	44.51	10	74.00	273.00	2.00	0.11

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S17_A2	A2	0.25	24	3.0	42.72	10	74.00	273.00	2.00	0.11
S18_A2	A2	0.55	90	2.4	40.61	10	74.00	273.00	2.00	0.11
S19_A2	A2	0.17	54	2.4	43.73	10	74.00	273.00	2.00	0.11
S2_A2	A2	0.13	12	1.2	50.62	10	74.00	273.00	2.00	0.11
S20_A2	A2	0.45	90	2.4	34.06	10	74.00	273.00	2.00	0.11
S21_A2	A2	0.69	90	2.4	38.61	10	74.00	273.00	2.00	0.11
S22_A2	A2	0.14	54	2.4	41.01	10	74.00	273.00	2.00	0.11
S23_A2	A2	0.25	48	3.0	40.17	10	74.00	273.00	2.00	0.11
S24_A2	A2	0.29	48	3.0	44.20	10	74.00	273.00	2.00	0.11
S25_A2	A2	0.19	18	1.2	43.90	10	74.00	273.00	2.00	0.11
S26_A2	A2	0.16	18	1.2	44.71	10	74.00	273.00	2.00	0.11
S27_A2	A2	0.08	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S28_A2	A2	2.42	180	6.0	24.80	10	74.00	200.74	6.40	0.14
S29_A2	A2	2.53	180	6.0	11.76	10	74.00	189.77	7.06	0.15
S3_A2	A2	0.07	12	1.2	50.39	10	74.00	273.00	2.00	0.11
S30_A2	A2	3.07	180	6.0	10.66	10	74.00	188.35	7.15	0.15
S31_A2	A2	0.09	18	1.2	45.94	10	74.00	273.00	2.00	0.11
S32_A2	A2	0.22	24	1.2	46.48	10	74.00	246.38	3.62	0.12
S33_A2	A2	0.28	72	1.2	40.46	10	74.00	273.00	2.00	0.11
S34_A2	A2	0.19	72	3.0	42.96	10	74.00	273.00	2.00	0.11
S35_A2	A2	0.36	72	3.0	40.00	10	74.00	273.00	2.00	0.11
S36_A2	A2	0.29	72	3.0	34.54	10	74.00	273.00	2.00	0.11
S37_A2	A2	0.34	72	3.0	45.49	10	74.00	273.00	2.00	0.11
S38_A2	A2	2.32	180	6.0	8.66	10	74.00	182.46	7.51	0.15
S39_A2	A2	0.04	12	1.2	49.16	10	74.00	273.00	2.00	0.11
S4_A2	A2	0.12	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S40_A2	A2	0.92	180	6.0	15.35	10	74.00	187.69	7.19	0.15
S41_A2	A2	0.09	24	1.2	51.52	10	74.00	273.00	2.00	0.11
S42_A2	A2	0.17	24	1.2	40.03	10	74.00	273.00	2.00	0.11
S43_A2	A2	0.37	96	6.0	34.07	10	74.00	217.26	5.39	0.13
S5_A2	A2	0.13	30	1.2	43.65	10	74.00	273.00	2.00	0.11
S6_A2	A2	0.09	30	1.2	47.91	10	74.00	273.00	2.00	0.11
S7_A2	A2	0.24	30	1.2	48.93	10	74.00	273.00	2.00	0.11
S8_A2	A2	0.38	84	1.2	42.49	10	74.00	273.00	2.00	0.11
S9_A2	A2	1.08	180	3.0	33.54	10	74.00	273.00	2.00	0.11

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S1_A3	A3	0.17	24	1.2	42.93	10	74.00	273.00	2.00	0.11
S2_A3	A3	0.05	18	1.2	43.08	10	74.00	273.00	2.00	0.11
S1_A4	A4	0.12	24	1.2	35.32	10	74.00	273.00	2.00	0.11
S10_A4	A4	0.03	12	1.2	36.13	10	74.00	273.00	2.00	0.11
S11_A4	A4	0.27	72	1.2	38.62	10	74.00	273.00	2.00	0.11
S12_A4	A4	0.21	24	1.2	44.97	10	74.00	273.00	2.00	0.11
S13_A4	A4	0.04	12	1.2	24.31	10	74.00	273.00	2.00	0.11
S14_A4	A4	0.15	18	1.2	44.81	10	74.00	273.00	2.00	0.11
S15_A4	A4	0.17	78	3.0	40.96	10	74.00	273.00	2.00	0.11
S16_A4	A4	0.30	78	3.0	45.31	10	74.00	273.00	2.00	0.11
S17_A4	A4	0.84	156	3.0	39.92	10	74.00	273.00	2.00	0.11
S18_A4	A4	0.16	18	1.2	42.00	10	74.00	273.00	2.00	0.11
S19_A4	A4	0.50	90	2.4	39.13	10	74.00	273.00	2.00	0.11
S2_A4	A4	0.03	12	1.2	42.53	10	74.00	273.00	2.00	0.11
S20_A4	A4	0.09	42	2.4	38.49	10	74.00	273.00	2.00	0.11
S21_A4	A4	0.13	66	3.0	49.27	10	74.00	273.00	2.00	0.11
S22_A4	A4	0.29	78	2.4	37.88	10	74.00	273.00	2.00	0.11
S23_A4	A4	0.09	24	3.0	54.71	10	74.00	273.00	2.00	0.11
S24_A4	A4	0.24	18	1.2	46.34	10	74.00	273.00	2.00	0.11
S25_A4	A4	0.05	12	3.0	46.19	10	74.00	273.00	2.00	0.11
S26_A4	A4	0.59	72	3.0	40.71	10	74.00	273.00	2.00	0.11
S27_A4	A4	0.16	42	3.0	36.91	10	74.00	273.00	2.00	0.11
S28_A4	A4	0.10	24	3.0	50.92	10	74.00	273.00	2.00	0.11
S29_A4	A4	0.20	60	3.0	35.51	10	74.00	273.00	2.00	0.11
S3_A4	A4	0.21	72	1.2	44.13	10	74.00	273.00	2.00	0.11
S30_A4	A4	0.30	120	3.0	39.35	10	74.00	239.12	4.06	0.12
S31_A4	A4	0.34	24	1.2	46.71	10	74.00	273.00	2.00	0.11
S32_A4	A4	0.27	24	1.2	45.08	10	74.00	250.21	3.39	0.12
S33_A4	A4	0.59	180	6.0	20.87	10	74.00	189.57	7.08	0.15
S34_A4	A4	0.73	180	6.0	14.53	10	74.00	182.84	7.49	0.15
S35_A4	A4	0.57	180	6.0	13.12	10	74.00	181.71	7.55	0.15
S36_A4	A4	0.27	96	6.0	11.95	10	74.00	180.95	7.60	0.15
S37_A4	A4	1.95	180	6.0	6.64	10	74.00	180.95	7.60	0.15
S38_A4	A4	0.64	138	3.0	36.76	10	74.00	265.97	2.43	0.11
S39_A4	A4	0.27	60	3.0	39.76	10	74.00	263.31	2.59	0.11

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S4_A4	A4	0.15	18	1.2	45.75	10	74.00	273.00	2.00	0.11
S40_A4	A4	0.15	30	1.2	53.79	10	74.00	273.00	2.00	0.11
S41_A4	A4	0.09	12	1.2	46.74	10	74.00	189.11	7.10	0.15
S42_A4	A4	0.12	18	1.2	41.93	10	74.00	186.19	7.27	0.15
S43_A4	A4	0.64	96	6.0	16.89	10	74.00	180.98	7.60	0.15
S44_A4	A4	0.18	24	1.2	43.34	10	74.00	185.76	7.31	0.15
S45_A4	A4	0.33	96	6.0	29.04	10	74.00	180.95	7.60	0.15
S46_A4	A4	0.77	96	6.0	19.09	10	74.00	180.95	7.60	0.15
S5_A4	A4	0.09	24	1.2	54.08	10	74.00	273.00	2.00	0.11
S6_A4	A4	0.22	18	1.2	44.49	10	74.00	273.00	2.00	0.11
S7_A4	A4	0.24	102	3.0	41.12	10	74.00	273.00	2.00	0.11
S8_A4	A4	0.07	24	1.2	43.65	10	74.00	273.00	2.00	0.11
S9_A4	A4	0.26	36	1.2	41.38	10	74.00	273.00	2.00	0.11
S1_A5	A5	0.38	48	1.2	51.86	10	74.00	273.00	2.00	0.11
S2_A5	A5	0.03	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S3_A5	A5	0.42	66	1.2	51.74	10	74.00	273.00	2.00	0.11
S4_A5	A5	0.49	108	1.2	51.27	10	74.00	265.04	2.48	0.11
S5_A5	A5	0.06	12	1.2	52.09	10	74.00	184.84	7.36	0.15
S6_A5	A5	0.85	54	6.0	52.08	10	74.00	185.94	7.30	0.15
S7_A5	A5	0.05	12	1.2	52.71	10	74.00	268.11	2.30	0.11
S8_A5	A5	0.29	48	1.2	51.54	10	74.00	272.97	2.00	0.11
S9_A5	A5	0.01	12	1.2	52.89	10	74.00	273.00	2.00	0.11
S1_A6	A6	1.07	132	6.0	37.33	10	74.00	180.95	7.60	0.15
S2_A6	A6	0.13	24	1.2	47.13	10	74.00	180.95	7.60	0.15
S3_A6	A6	0.83	120	4.5	38.53	10	74.00	180.95	7.60	0.15
S4_A6	A6	0.39	24	1.2	46.37	10	74.00	180.95	7.60	0.15
S5_A6	A6	0.15	18	1.2	45.68	10	74.00	180.95	7.60	0.15
S6_A6	A6	0.77	60	4.5	44.89	10	74.00	180.95	7.60	0.15
S1_B1	B1	0.38	60	1.2	40.75	10	62.00	191.55	11.90	0.18
S2_B1	B1	0.69	150	1.2	45.28	10	62.00	191.55	11.90	0.18
S3_B1	B1	0.08	12	1.2	49.91	10	62.00	191.55	11.90	0.18
S4_B1	B1	0.39	90	1.2	38.02	10	62.00	191.55	11.90	0.18
S5_B1	B1	0.19	24	1.2	46.50	10	62.00	191.55	11.90	0.18
S6_B1	B1	0.13	24	1.2	42.97	10	62.00	191.55	11.90	0.18
S7_B1	B1	0.40	60	1.2	39.29	10	62.00	191.55	11.90	0.18

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S1_B2	B2	0.13	24	1.2	49.28	10	70.93	173.14	8.11	0.17
S10_B2	B2	0.80	90	1.2	39.03	10	65.59	184.15	10.38	0.17
S11_B2	B2	0.33	72	1.2	42.98	10	62.52	190.49	11.68	0.18
S12_B2	B2	0.59	48	1.2	40.94	10	62.00	191.55	11.90	0.18
S13_B2	B2	0.28	24	1.2	50.68	10	62.00	191.55	11.90	0.18
S14_B2	B2	0.45	60	1.2	42.71	10	62.00	191.55	11.90	0.18
S15_B2	B2	0.33	24	1.2	43.06	10	72.75	169.38	7.33	0.17
S16_B2	B2	0.19	24	1.2	44.23	10	68.77	177.59	9.02	0.17
S17_B2	B2	0.17	24	1.2	49.60	10	62.00	191.55	11.90	0.18
S18_B2	B2	0.16	24	1.2	44.11	10	62.00	191.55	11.90	0.18
S19_B2	B2	0.43	24	1.2	50.84	10	62.00	191.55	11.90	0.18
S2_B2	B2	0.09	24	1.2	49.31	10	74.00	166.80	6.80	0.17
S20_B2	B2	0.16	24	1.2	44.35	10	62.00	191.55	11.90	0.18
S21_B2	B2	0.14	24	1.2	47.65	10	62.00	191.55	11.90	0.18
S22_B2	B2	0.24	24	1.2	47.26	10	62.00	191.55	11.90	0.18
S23_B2	B2	0.20	24	1.2	48.85	10	62.00	191.55	11.90	0.18
S24_B2	B2	0.95	120	1.2	39.40	10	62.00	191.55	11.90	0.18
S25_B2	B2	0.28	24	1.2	42.35	10	62.00	191.55	11.90	0.18
S26_B2	B2	0.85	150	1.2	37.99	10	62.00	191.55	11.90	0.18
S27_B2	B2	0.75	24	1.2	47.54	10	62.00	191.55	11.90	0.18
S28_B2	B2	0.43	24	1.2	45.97	10	62.00	191.55	11.90	0.18
S3_B2	B2	0.52	24	1.2	49.98	10	62.07	191.40	11.87	0.18
S4_B2	B2	0.24	24	1.2	47.14	10	66.22	182.84	10.11	0.17
S5_B2	B2	0.34	24	1.2	52.48	10	63.27	188.93	11.36	0.18
S6_B2	B2	0.26	48	1.2	44.86	10	62.21	191.12	11.81	0.18
S7_B2	B2	0.36	24	1.2	42.47	10	62.00	191.55	11.90	0.18
S8_B2	B2	0.06	18	1.2	51.78	10	66.60	182.07	9.95	0.17
S9_B2	B2	0.21	30	1.2	45.99	10	62.42	190.68	11.72	0.18
S1_B3	B3	0.10	12	1.2	43.84	10	62.00	191.55	11.90	0.18
S2_B3	B3	0.34	24	1.2	39.65	10	62.00	191.55	11.90	0.18
S3_B3	B3	0.22	36	1.2	42.88	10	62.00	191.55	11.90	0.18
S4_B3	B3	0.37	90	1.2	42.54	10	62.00	191.55	11.90	0.18
S5_B3	B3	0.49	24	1.2	27.12	10	62.00	191.55	11.90	0.18
S1_B4	B4	0.02	12	1.2	52.89	10	62.00	191.55	11.90	0.18
S10_B4	B4	0.52	24	1.2	47.47	10	62.00	191.55	11.90	0.18

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S2_B4	B4	0.05	12	1.2	45.02	10	62.00	191.55	11.90	0.18
S3_B4	B4	0.69	42	1.2	44.45	10	62.00	191.55	11.90	0.18
S4_B4	B4	0.14	24	1.2	47.81	10	62.00	191.55	11.90	0.18
S5_B4	B4	0.06	12	1.2	48.15	10	62.00	191.55	11.90	0.18
S6_B4	B4	0.45	60	1.2	36.14	10	62.00	191.55	11.90	0.18
S7_B4	B4	0.31	36	1.2	49.30	10	62.00	191.55	11.90	0.18
S8_B4	B4	0.14	24	1.2	48.29	10	62.00	191.55	11.90	0.18
S9_B4	B4	0.43	36	1.2	39.78	10	62.00	191.55	11.90	0.18
S1_B5	B5	0.16	24	1.2	44.06	10	62.00	191.55	11.90	0.18
S10_B5	B5	0.09	24	1.2	50.48	10	62.00	191.55	11.90	0.18
S11_B5	B5	0.04	24	1.2	45.88	10	62.00	191.55	11.90	0.18
S12_B5	B5	0.23	24	1.2	51.08	10	62.00	191.55	11.90	0.18
S13_B5	B5	0.24	24	1.2	48.78	10	62.00	191.55	11.90	0.18
S14_B5	B5	1.44	120	1.2	36.98	10	62.00	191.55	11.90	0.18
S15_B5	B5	0.44	24	1.2	46.23	10	62.00	191.55	11.90	0.18
S16_B5	B5	0.11	24	1.2	44.02	10	62.00	191.55	11.90	0.18
S17_B5	B5	0.26	24	1.2	43.10	10	62.00	191.55	11.90	0.18
S18_B5	B5	0.31	24	1.2	44.77	10	62.00	191.55	11.90	0.18
S19_B5	B5	0.28	24	1.2	48.07	10	62.00	191.55	11.90	0.18
S2_B5	B5	0.68	90	1.2	38.99	10	62.00	191.55	11.90	0.18
S20_B5	B5	0.31	24	1.2	53.47	10	62.00	191.55	11.90	0.18
S21_B5	B5	0.40	24	1.2	48.04	10	62.00	191.55	11.90	0.18
S22_B5	B5	1.67	120	1.2	35.39	10	62.00	191.55	11.90	0.18
S3_B5	B5	0.79	90	1.2	42.10	10	62.00	191.55	11.90	0.18
S4_B5	B5	0.09	24	1.2	47.58	10	62.00	191.55	11.90	0.18
S5_B5	B5	0.33	24	1.2	50.42	10	62.00	191.55	11.90	0.18
S6_B5	B5	0.31	24	1.2	52.59	10	62.00	191.55	11.90	0.18
S7_B5	B5	0.27	24	1.2	50.57	10	62.00	191.55	11.90	0.18
S8_B5	B5	0.01	12	1.2	52.89	10	62.00	191.55	11.90	0.18
S9_B5	B5	1.25	120	1.2	39.53	10	62.00	191.55	11.90	0.18
S1_B6	B6	0.06	12	1.2	53.72	10	68.64	177.86	9.08	0.17
S10_B6	B6	0.38	24	1.2	51.80	10	62.00	191.55	11.90	0.18
S11_B6	B6	0.22	24	1.2	52.03	10	62.00	191.55	11.90	0.18
S12_B6	B6	0.91	48	1.2	52.28	10	62.00	191.55	11.90	0.18
S13_B6	B6	0.03	12	1.2	52.43	10	62.00	191.55	11.90	0.18

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S2_B6	B6	0.03	12	1.2	44.08	10	62.92	189.66	11.51	0.18
S3_B6	B6	0.02	12	1.2	49.26	10	74.00	166.80	6.80	0.17
S4_B6	B6	0.08	12	1.2	36.45	10	72.94	168.98	7.25	0.17
S5_B6	B6	0.50	90	1.2	44.33	10	63.54	188.37	11.25	0.18
S6_B6	B6	0.11	30	1.2	35.74	10	74.00	166.80	6.80	0.17
S7_B6	B6	0.20	24	1.2	52.07	10	73.67	167.48	6.94	0.17
S8_B6	B6	0.29	24	1.2	51.98	10	70.46	174.11	8.31	0.17
S9_B6	B6	0.19	24	1.2	51.81	10	62.62	190.27	11.64	0.18
S1_B7	B7	0.41	24	1.2	42.34	10	62.00	191.55	11.90	0.18
S1_C1	C1	0.23	24	1.2	45.68	10	50.00	110.10	21.80	0.25
S10_C1	C1	0.43	24	1.2	47.09	10	50.00	110.10	21.80	0.25
S11_C1	C1	0.62	120	1.2	37.22	10	50.00	110.10	21.80	0.25
S12_C1	C1	0.36	24	1.2	50.11	10	50.00	110.10	21.80	0.25
S13_C1	C1	0.80	120	1.2	37.38	10	50.00	110.10	21.80	0.25
S14_C1	C1	0.39	60	1.2	52.93	10	50.00	110.10	21.80	0.25
S15_C1	C1	0.37	24	1.2	49.84	10	50.00	110.10	21.80	0.25
S16_C1	C1	0.27	24	1.2	50.17	10	50.00	110.10	21.80	0.25
S17_C1	C1	0.15	24	1.2	47.93	10	50.00	110.10	21.80	0.25
S18_C1	C1	0.98	138	1.2	35.26	10	50.00	110.10	21.80	0.25
S19_C1	C1	0.04	18	1.2	47.17	10	50.00	110.10	21.80	0.25
S2_C1	C1	0.19	24	1.2	46.31	10	50.00	110.10	21.80	0.25
S20_C1	C1	0.40	120	1.2	31.57	10	50.00	110.10	21.80	0.25
S21_C1	C1	0.29	24	1.2	45.86	10	50.00	110.10	21.80	0.25
S22_C1	C1	0.57	72	1.2	42.46	10	50.00	110.10	21.80	0.25
S23_C1	C1	0.28	24	1.2	50.46	10	50.00	110.10	21.80	0.25
S24_C1	C1	0.24	24	1.2	47.34	10	50.00	110.10	21.80	0.25
S3_C1	C1	0.12	24	1.2	43.90	10	50.00	110.10	21.80	0.25
S4_C1	C1	0.73	120	1.2	53.35	10	50.00	110.10	21.80	0.25
S5_C1	C1	1.63	138	1.2	37.56	10	50.00	110.10	21.80	0.25
S6_C1	C1	0.53	120	1.2	37.75	10	50.00	110.10	21.80	0.25
S7_C1	C1	0.26	24	1.2	43.81	10	50.00	110.10	21.80	0.25
S8_C1	C1	0.25	24	1.2	43.24	10	50.00	110.10	21.80	0.25
S9_C1	C1	0.38	24	1.2	46.25	10	50.00	110.10	21.80	0.25
S1_C2	C2	0.06	12	1.2	45.67	10	70.39	161.27	8.26	0.18
S10_C2	C2	0.30	24	3.6	49.12	10	52.79	124.49	17.99	0.23

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S11_C2	C2	0.14	24	1.2	52.31	10	50.00	110.10	21.80	0.25
S12_C2	C2	0.21	24	1.2	46.58	10	50.00	110.10	21.80	0.25
S13_C2	C2	0.26	48	1.2	49.28	10	50.00	110.10	21.80	0.25
S14_C2	C2	0.24	24	1.2	47.82	10	50.00	110.10	21.80	0.25
S15_C2	C2	0.22	66	1.2	35.99	10	50.00	110.10	21.80	0.25
S16_C2	C2	0.55	60	1.2	43.71	10	50.00	110.10	21.80	0.25
S17_C2	C2	0.26	42	1.2	50.15	10	50.00	110.10	21.80	0.25
S18_C2	C2	0.41	24	1.2	46.74	10	50.00	110.10	21.80	0.25
S19_C2	C2	0.18	24	1.2	42.61	10	55.50	138.45	14.30	0.21
S2_C2	C2	0.03	12	1.2	52.89	10	63.93	151.37	10.88	0.19
S20_C2	C2	0.55	72	3.6	44.24	10	52.02	120.49	19.05	0.23
S21_C2	C2	0.07	24	1.2	42.21	10	55.50	138.45	14.30	0.21
S22_C2	C2	0.43	60	1.2	44.89	10	50.84	114.42	20.66	0.24
S23_C2	C2	0.19	24	1.2	45.82	10	52.94	125.28	17.79	0.23
S24_C2	C2	0.06	24	1.2	47.67	10	50.00	110.10	21.80	0.25
S25_C2	C2	0.16	24	1.2	44.50	10	50.00	110.10	21.80	0.25
S26_C2	C2	0.09	24	1.2	44.14	10	50.00	110.10	21.80	0.25
S27_C2	C2	0.85	72	1.2	43.26	10	50.00	110.10	21.80	0.25
S28_C2	C2	0.21	24	1.2	46.53	10	50.00	110.10	21.80	0.25
S29_C2	C2	0.06	24	1.2	45.39	10	50.00	110.10	21.80	0.25
S3_C2	C2	0.24	24	1.2	54.63	10	66.64	155.52	9.79	0.19
S30_C2	C2	0.18	24	1.2	43.27	10	50.00	110.10	21.80	0.25
S31_C2	C2	0.30	42	1.2	46.77	10	50.00	110.10	21.80	0.25
S32_C2	C2	0.33	90	1.2	38.33	10	50.00	110.10	21.80	0.25
S33_C2	C2	0.29	24	1.2	51.69	10	50.00	110.10	21.80	0.25
S34_C2	C2	0.90	120	1.2	42.83	10	50.00	110.10	21.80	0.25
S35_C2	C2	0.45	24	1.2	47.77	10	50.00	110.10	21.80	0.25
S36_C2	C2	0.53	24	1.2	48.61	10	50.00	110.10	21.80	0.25
S37_C2	C2	0.23	42	1.2	63.23	10	50.00	110.10	21.80	0.25
S38_C2	C2	0.50	42	1.2	50.37	10	50.00	110.10	21.80	0.25
S4_C2	C2	0.65	72	6.0	43.14	10	57.47	141.47	13.50	0.21
S5_C2	C2	0.13	24	1.2	47.59	10	73.98	166.77	6.81	0.17
S6_C2	C2	0.54	96	6.0	37.26	10	63.23	150.29	11.17	0.19
S7_C2	C2	0.15	24	6.0	45.51	10	55.50	138.45	14.30	0.21
S8_C2	C2	0.25	24	6.0	49.05	10	55.50	138.45	14.30	0.21

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S9_C2	C2	0.57	96	1.2	37.62	10	53.76	129.46	16.68	0.22
S1_C3	C3	0.33	24	1.2	46.15	10	67.09	156.21	9.60	0.19
S10_C3	C3	0.70	78	1.2	41.16	10	50.00	110.10	21.80	0.25
S2_C3	C3	0.07	12	1.2	52.48	10	54.43	132.92	15.76	0.22
S3_C3	C3	0.81	96	6.0	41.40	10	59.38	144.40	12.73	0.20
S4_C3	C3	0.29	48	6.0	41.64	10	55.37	137.79	14.47	0.21
S5_C3	C3	0.21	24	1.2	54.74	10	55.21	136.94	14.70	0.21
S6_C3	C3	0.25	24	1.2	48.48	10	52.03	120.54	19.04	0.23
S7_C3	C3	0.20	30	1.2	47.68	10	50.00	110.10	21.80	0.25
S8_C3	C3	0.40	60	1.2	46.60	10	50.00	110.10	21.80	0.25
S9_C3	C3	0.36	60	1.2	41.16	10	50.00	110.10	21.80	0.25
S1_C4	C4	0.41	72	1.2	29.15	10	50.00	110.10	21.80	0.25
S10_C4	C4	0.23	24	1.2	47.03	10	50.00	110.10	21.80	0.25
S11_C4	C4	0.27	24	1.2	49.02	10	50.00	110.10	21.80	0.25
S12_C4	C4	0.32	36	1.2	56.94	10	50.00	110.10	21.80	0.25
S13_C4	C4	0.37	48	1.2	47.29	10	50.00	110.10	21.80	0.25
S2_C4	C4	1.24	72	1.2	36.10	10	50.00	110.10	21.80	0.25
S3_C4	C4	0.29	96	1.2	39.51	10	50.00	110.10	21.80	0.25
S5_C4	C4	0.59	96	1.2	39.82	10	50.00	110.10	21.80	0.25
S6_C4	C4	0.08	24	1.2	54.61	10	50.00	110.10	21.80	0.25
S7_C4	C4	0.15	36	1.2	50.96	10	50.00	110.10	21.80	0.25
S8_C4	C4	0.24	24	1.2	42.69	10	50.00	110.10	21.80	0.25
S9_C4	C4	0.14	24	1.2	44.88	10	50.00	110.10	21.80	0.25
S1_C5	C5	0.17	24	1.2	46.13	10	50.00	110.10	21.80	0.25
S2_C5	C5	0.10	18	1.2	51.45	10	50.00	110.10	21.80	0.25
S3_C5	C5	0.57	90	1.2	39.27	10	50.00	110.10	21.80	0.25
S4_C5	C5	0.60	120	1.2	36.25	10	50.00	110.10	21.80	0.25
S5_C5	C5	0.20	36	1.2	50.66	10	50.00	110.10	21.80	0.25
S6_C5	C5	0.34	84	1.2	39.25	10	50.00	110.10	21.80	0.25
S7_C5	C5	0.15	36	1.2	42.37	10	50.00	110.10	21.80	0.25
S1_C6	C6	0.15	18	1.2	47.80	10	54.13	131.38	16.17	0.22
S10_C6	C6	0.09	18	1.2	45.26	10	50.00	110.10	21.80	0.25
S11_C6	C6	0.30	36	1.2	50.89	10	50.00	110.10	21.80	0.25
S12_C6	C6	1.06	180	1.2	39.09	10	50.00	110.10	21.80	0.25
S2_C6	C6	0.98	120	1.2	45.29	10	50.82	114.30	20.69	0.24

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S3_C6	C6	0.10	18	1.2	46.62	10	55.50	138.45	14.30	0.21
S4_C6	C6	0.23	24	1.2	45.87	10	52.62	123.62	18.22	0.23
S5_C6	C6	0.01	18	1.2	52.89	10	55.50	138.45	14.30	0.21
S6_C6	C6	0.22	18	1.2	49.93	10	50.15	110.86	21.60	0.25
S7_C6	C6	0.19	24	1.2	47.16	10	50.00	110.10	21.80	0.25
S8_C6	C6	0.23	36	1.2	57.69	10	50.00	110.10	21.80	0.25
S9_C6	C6	0.07	18	1.2	48.33	10	50.00	110.10	21.80	0.25
S1_D1	D1	0.32	6	1.2	52.85	10	50.00	110.10	21.80	0.25
S10_D1	D1	0.39	72	1.2	45.03	10	50.00	110.10	21.80	0.25
S11_D1	D1	0.44	138	1.2	40.54	10	50.00	110.10	21.80	0.25
S12_D1	D1	0.28	60	1.2	38.03	10	50.00	110.10	21.80	0.25
S13_D1	D1	0.14	24	1.2	54.34	10	50.00	110.10	21.80	0.25
S14_D1	D1	0.48	24	1.2	49.60	10	50.00	110.10	21.80	0.25
S15_D1	D1	0.88	66	1.2	46.84	10	50.00	110.10	21.80	0.25
S16_D1	D1	0.13	24	1.2	46.01	10	50.00	110.10	21.80	0.25
S17_D1	D1	0.14	24	1.2	45.47	10	50.00	110.10	21.80	0.25
S18_D1	D1	0.23	24	1.2	49.74	10	50.00	110.10	21.80	0.25
S19_D1	D1	0.25	24	1.2	48.51	10	50.00	110.10	21.80	0.25
S2_D1	D1	0.44	18	1.2	52.21	10	50.00	110.10	21.80	0.25
S20_D1	D1	0.34	90	1.2	38.13	10	50.00	110.10	21.80	0.25
S21_D1	D1	0.15	24	1.2	50.13	10	50.00	110.10	21.80	0.25
S22_D1	D1	0.24	24	1.2	49.19	10	50.00	110.10	21.80	0.25
S23_D1	D1	0.26	24	1.2	48.56	10	50.00	110.10	21.80	0.25
S24_D1	D1	0.26	30	1.2	42.51	10	50.00	110.10	21.80	0.25
S25_D1	D1	0.27	24	1.2	47.46	10	50.00	110.10	21.80	0.25
S26_D1	D1	0.31	24	1.2	49.11	10	50.00	110.10	21.80	0.25
S27_D1	D1	0.36	24	1.2	55.53	10	50.00	110.10	21.80	0.25
S28_D1	D1	0.25	60	1.2	39.52	10	50.00	110.10	21.80	0.25
S29_D1	D1	0.74	54	1.2	45.41	10	50.00	110.10	21.80	0.25
S3_D1	D1	0.05	24	1.2	52.91	10	50.00	110.10	21.80	0.25
S30_D1	D1	0.87	84	1.2	39.86	10	50.00	110.10	21.80	0.25
S31_D1	D1	0.35	36	1.2	45.93	10	50.00	110.10	21.80	0.25
S32_D1	D1	0.80	72	1.2	44.69	10	50.00	110.10	21.80	0.25
S33_D1	D1	0.05	18	1.2	54.14	10	50.00	110.10	21.80	0.25
S34_D1	D1	0.43	132	1.2	46.64	10	50.53	112.84	21.08	0.24

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S35_D1	D1	0.17	24	1.2	51.85	10	53.15	126.36	17.50	0.22
S36_D1	D1	0.73	180	1.2	47.89	10	50.23	111.27	21.49	0.24
S37_D1	D1	0.49	24	1.2	51.16	10	50.00	110.10	21.80	0.25
S38_D1	D1	0.67	60	1.2	48.88	10	50.00	110.10	21.80	0.25
S39_D1	D1	0.15	24	1.2	52.54	10	50.00	110.10	21.80	0.25
S4_D1	D1	0.09	36	1.2	48.60	10	50.00	110.10	21.80	0.25
S40_D1	D1	0.25	24	1.2	53.30	10	50.00	110.10	21.80	0.25
S41_D1	D1	0.15	24	1.2	53.36	10	50.00	110.10	21.80	0.25
S42_D1	D1	0.70	180	1.2	38.49	10	50.00	110.10	21.80	0.25
S43_D1	D1	0.34	24	1.2	48.86	10	50.00	110.10	21.80	0.25
S44_D1	D1	0.51	60	1.2	50.42	10	50.00	110.10	21.80	0.25
S45_D1	D1	0.32	24	1.2	51.30	10	50.00	110.10	21.80	0.25
S46_D1	D1	0.15	24	1.2	49.34	10	50.00	110.10	21.80	0.25
S47_D1	D1	0.17	24	1.2	49.44	10	50.00	110.10	21.80	0.25
S48_D1	D1	0.37	24	1.2	46.64	10	50.00	110.10	21.80	0.25
S5_D1	D1	0.11	36	1.2	42.12	10	50.00	110.10	21.80	0.25
S6_D1	D1	0.15	24	1.2	54.51	10	50.00	110.10	21.80	0.25
S7_D1	D1	0.04	12	1.2	47.97	10	50.00	110.10	21.80	0.25
S8_D1	D1	0.06	36	1.2	40.91	10	50.00	110.10	21.80	0.25
S9_D1	D1	0.05	18	1.2	52.24	10	50.00	110.10	21.80	0.25
S1_D2	D2	0.19	24	1.2	47.80	10	50.00	110.10	21.80	0.25
S10_D2	D2	0.46	24	1.2	53.39	10	50.00	110.10	21.80	0.25
S11_D2	D2	0.38	48	1.2	43.58	10	50.00	110.10	21.80	0.25
S12_D2	D2	1.59	108	1.2	54.04	10	50.00	110.10	21.80	0.25
S13_D2	D2	1.06	108	1.2	56.70	10	50.00	110.10	21.80	0.25
S14_D2	D2	0.36	24	1.2	48.88	10	50.00	110.10	21.80	0.25
S15_D2	D2	0.32	24	1.2	48.15	10	50.00	110.10	21.80	0.25
S16_D2	D2	0.35	24	1.2	49.72	10	50.00	110.10	21.80	0.25
S17_D2	D2	0.31	24	1.2	46.47	10	50.00	110.10	21.80	0.25
S18_D2	D2	0.13	24	1.2	44.10	10	50.00	110.10	21.80	0.25
S19_D2	D2	0.78	60	1.2	44.21	10	50.00	110.10	21.80	0.25
S2_D2	D2	0.27	24	1.2	45.99	10	50.00	110.10	21.80	0.25
S20_D2	D2	0.53	60	1.2	47.96	10	50.00	110.10	21.80	0.25
S21_D2	D2	0.24	60	1.2	47.05	10	50.00	110.10	21.80	0.25
S22_D2	D2	0.88	60	1.2	46.13	10	50.00	110.10	21.80	0.25

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S23_D2	D2	0.19	24	1.2	50.13	10	50.00	110.10	21.80	0.25
S24_D2	D2	0.35	60	1.2	46.97	10	50.00	110.10	21.80	0.25
S25_D2	D2	0.26	60	1.2	55.60	10	50.00	110.10	21.80	0.25
S26_D2	D2	0.64	120	1.2	45.04	10	50.00	110.10	21.80	0.25
S27_D2	D2	0.17	24	1.2	40.93	10	50.00	110.10	21.80	0.25
S28_D2	D2	0.19	24	1.2	51.05	10	50.00	110.10	21.80	0.25
S29_D2	D2	0.41	60	1.2	49.45	10	50.00	110.10	21.80	0.25
S3_D2	D2	0.55	156	1.2	44.23	10	50.00	110.10	21.80	0.25
S30_D2	D2	0.19	24	1.2	45.22	10	50.00	110.10	21.80	0.25
S31_D2	D2	0.77	72	1.2	41.59	10	50.00	110.10	21.80	0.25
S32_D2	D2	0.11	24	1.2	46.84	10	50.00	110.10	21.80	0.25
S33_D2	D2	0.17	24	1.2	48.30	10	50.00	110.10	21.80	0.25
S34_D2	D2	0.19	24	1.2	50.44	10	50.00	110.10	21.80	0.25
S35_D2	D2	0.15	24	1.2	47.18	10	50.00	110.10	21.80	0.25
S36_D2	D2	0.70	54	1.2	43.28	10	50.00	110.10	21.80	0.25
S37_D2	D2	0.18	30	1.2	52.27	10	50.00	110.10	21.80	0.25
S38_D2	D2	0.23	24	1.2	49.24	10	50.00	110.10	21.80	0.25
S39_D2	D2	0.28	24	1.2	46.25	10	50.00	110.10	21.80	0.25
S4_D2	D2	0.27	24	1.2	48.16	10	50.00	110.10	21.80	0.25
S40_D2	D2	0.18	24	1.2	56.27	10	50.00	110.10	21.80	0.25
S41_D2	D2	0.19	24	1.2	52.87	10	50.00	110.10	21.80	0.25
S42_D2	D2	0.53	24	1.2	48.41	10	50.00	110.10	21.80	0.25
S43_D2	D2	0.20	24	1.2	50.35	10	50.00	110.10	21.80	0.25
S44_D2	D2	0.49	60	1.2	46.29	10	50.00	110.10	21.80	0.25
S45_D2	D2	0.38	24	1.2	45.09	10	50.00	110.10	21.80	0.25
S46_D2	D2	0.42	24	1.2	63.49	10	50.00	110.10	21.80	0.25
S47_D2	D2	0.21	48	1.2	44.05	10	50.00	110.10	21.80	0.25
S48_D2	D2	0.21	24	1.2	46.18	10	50.00	110.10	21.80	0.25
S49_D2	D2	0.32	24	1.2	51.61	10	50.00	110.10	21.80	0.25
S5_D2	D2	0.87	60	1.2	47.67	10	50.00	110.10	21.80	0.25
S50_D2	D2	0.37	24	1.2	48.25	10	50.00	110.10	21.80	0.25
S51_D2	D2	0.45	54	1.2	46.39	10	50.00	110.10	21.80	0.25
S52_D2	D2	0.68	54	1.2	47.78	10	50.00	110.10	21.80	0.25
S53_D2	D2	0.30	24	1.2	46.94	10	50.00	110.10	21.80	0.25
S6_D2	D2	0.14	24	1.2	45.79	10	50.00	110.10	21.80	0.25

Table C.1	**Existing Conditions Subcatchment Parameters**									
Subcatch Name	**Sub Network**	**Area (ha)**	**Flow Length (m)**	**Slope (%)**	**Imperv (%)**	**Depres Stor (mm)**	**CN**	**Suct Head (mm)**	**Conduct (mm/hr)**	**Init Def (frac.)**
S7_D2	D2	0.24	24	1.2	43.31	10	50.00	110.10	21.80	0.25
S8_D2	D2	1.58	180	1.2	57.55	10	50.00	110.10	21.80	0.25
S9_D2	D2	0.40	48	1.2	60.18	10	50.00	110.10	21.80	0.25
S1_D3	D3	0.15	12	1.2	53.95	10	50.00	110.10	21.80	0.25
S2_D3	D3	0.12	36	1.2	68.13	10	50.00	110.10	21.80	0.25
S3_D3	D3	0.39	24	1.2	59.92	10	50.00	110.10	21.80	0.25
S4_D3	D3	0.26	24	1.2	49.11	10	50.00	110.10	21.80	0.25
S5_D3	D3	0.19	24	1.2	52.55	10	50.00	110.10	21.80	0.25
S6_D3	D3	0.23	24	1.2	48.30	10	50.00	110.10	21.80	0.25
S1_E1	E1	0.10	21.6	1.2	44.15	10	50.00	110.10	21.80	0.25
S2_E1	E1	0.56	21.6	1.2	48.89	10	50.00	110.10	21.80	0.25
S3_E1	E1	0.16	20.4	1.2	48.11	10	50.00	110.10	21.80	0.25
S4_E1	E1	0.14	20.4	1.2	53.40	10	50.00	110.10	21.80	0.25
S1_E2	E2	1.44	92.4	1.2	37.89	10	50.00	110.10	21.80	0.25
S2_E2	E2	0.15	30	1.2	59.21	10	50.00	110.10	21.80	0.25
S3_E2	E2	0.10	25.2	1.2	41.39	10	50.00	110.10	21.80	0.25
S4_E2	E2	0.98	72	1.2	43.64	10	50.00	110.10	21.80	0.25
S5_E2	E2	0.38	26.4	1.2	51.24	10	50.00	110.10	21.80	0.25
S6_E2	E2	0.35	22.8	1.2	48.31	10	50.00	110.10	21.80	0.25
S7_E2	E2	0.34	24	1.2	47.47	10	50.00	110.10	21.80	0.25
S1_E3	E3	0.11	18	1.2	47.69	10	50.00	110.10	21.80	0.25
S2_E3	E3	0.45	21.6	1.2	51.17	10	50.00	110.10	21.80	0.25
S3_E3	E3	0.33	21.6	1.2	53.38	10	50.00	110.10	21.80	0.25
S1_E4	E4	1.53	144	1.2	29.99	10	50.00	110.10	21.80	0.25
S2_E4	E4	0.30	25.2	1.2	49.87	10	50.00	110.10	21.80	0.25
S3_E4	E4	0.56	28.8	1.2	37.65	10	50.00	110.10	21.80	0.25
S1_E5	E5	0.57	42	1.2	35.31	10	50.00	110.10	21.80	0.25
S2_E5	E5	0.15	30	1.2	47.66	10	50.00	110.10	21.80	0.25
S3_E5	E5	0.27	42	1.2	35.36	10	50.00	110.10	21.80	0.25
S4_E5	E5	0.08	30	1.2	48.83	10	50.00	110.10	21.80	0.25
S1_E6	E6	0.57	82.8	1.2	40.83	10	50.00	110.10	21.80	0.25
S2_E6	E6	0.48	48	1.2	44.09	10	50.00	110.10	21.80	0.25
S1_E7	E7	0.49	32.4	1.2	52.16	10	50.00	110.10	21.80	0.25
S10_E7	E7	1.61	162	1.2	31.97	10	50.00	110.10	21.80	0.25
S11_E7	E7	0.65	36	1.2	40.62	10	50.00	110.10	21.80	0.25

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S12_E7	E7	0.61	78	1.2	37.52	10	50.00	110.10	21.80	0.25
S13_E7	E7	0.45	78	1.2	40.15	10	50.00	110.10	21.80	0.25
S14_E7	E7	1.07	105.6	1.2	44.28	10	50.00	110.10	21.80	0.25
S15_E7	E7	0.58	30	1.2	39.80	10	50.00	110.10	21.80	0.25
S16_E7	E7	0.46	26.4	1.2	53.08	10	50.00	110.10	21.80	0.25
S17_E7	E7	0.34	26.4	1.2	45.32	10	50.00	110.10	21.80	0.25
S18_E7	E7	0.37	42	1.2	38.55	10	50.00	110.10	21.80	0.25
S19_E7	E7	0.62	78	1.2	36.11	10	50.00	110.10	21.80	0.25
S2_E7	E7	0.17	27.6	1.2	52.43	10	50.00	110.10	21.80	0.25
S20_E7	E7	1.44	102	1.2	44.39	10	50.00	110.10	21.80	0.25
S21_E7	E7	0.28	24	1.2	51.90	10	50.00	110.10	21.80	0.25
S22_E7	E7	0.35	24	1.2	51.90	10	50.00	110.10	21.80	0.25
S23_E7	E7	0.09	19.2	1.2	42.04	10	50.00	110.10	21.80	0.25
S24_E7	E7	0.16	20.4	1.2	53.02	10	50.00	110.10	21.80	0.25
S25_E7	E7	0.30	21.6	1.2	50.94	10	50.00	110.10	21.80	0.25
S26_E7	E7	0.12	25.2	1.2	47.59	10	50.00	110.10	21.80	0.25
S27_E7	E7	0.23	24	1.2	57.13	10	50.00	110.10	21.80	0.25
S28_E7	E7	0.20	26.4	1.2	54.33	10	50.00	110.10	21.80	0.25
S29_E7	E7	0.30	25.2	1.2	48.96	10	50.00	110.10	21.80	0.25
S3_E7	E7	0.54	38.4	1.2	48.79	10	50.00	110.10	21.80	0.25
S30_E7	E7	0.52	27.6	1.2	49.37	10	50.00	110.10	21.80	0.25
S31_E7	E7	1.40	90	1.2	38.10	10	50.00	110.10	21.80	0.25
S32_E7	E7	0.30	22.8	1.2	48.44	10	50.00	110.10	21.80	0.25
S33_E7	E7	0.42	30	1.2	43.95	10	50.00	110.10	21.80	0.25
S34_E7	E7	0.20	25.2	1.2	47.99	10	50.00	110.10	21.80	0.25
S35_E7	E7	0.17	31.2	1.2	43.81	10	50.00	110.10	21.80	0.25
S36_E7	E7	0.20	24	1.2	49.42	10	50.00	110.10	21.80	0.25
S37_E7	E7	0.14	25.2	1.2	50.69	10	50.00	110.10	21.80	0.25
S38_E7	E7	0.12	21.6	1.2	49.15	10	50.00	110.10	21.80	0.25
S39_E7	E7	0.18	30	1.2	53.89	10	50.00	110.10	21.80	0.25
S4_E7	E7	0.63	36	1.2	50.77	10	50.00	110.10	21.80	0.25
S40_E7	E7	0.81	88.8	1.2	36.78	10	50.00	110.10	21.80	0.25
S41_E7	E7	0.39	30	1.2	49.75	10	50.00	110.10	21.80	0.25
S42_E7	E7	0.31	27.6	1.2	50.11	10	50.00	110.10	21.80	0.25
S5_E7	E7	0.50	44.4	1.2	43.72	10	50.00	110.10	21.80	0.25

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S6_E7	E7	0.40	31.2	1.2	42.91	10	50.00	110.10	21.80	0.25
S7_E7	E7	2.39	182.4	1.2	32.76	10	50.00	110.10	21.80	0.25
S8_E7	E7	0.44	26.4	1.2	47.37	10	50.00	110.10	21.80	0.25
S9_E7	E7	0.42	27.6	1.2	55.83	10	50.00	110.10	21.80	0.25
S1_F1	F1	0.32	72	6.0	38.82	10	74.00	174.77	7.25	0.16
S1_F5	F1	0.12	30	1.2	43.66	10	74.00	180.95	7.60	0.15
S10_F1	F1	0.71	72	6.0	44.32	10	74.00	180.95	7.60	0.15
S11_F1	F1	0.78	30	2.4	47.26	10	72.95	177.85	8.22	0.15
S12_F1	F1	0.55	30	2.4	29.20	10	74.00	180.95	7.60	0.15
S13_F1	F1	0.22	30	2.4	44.75	10	74.00	180.95	7.60	0.15
S14_F1	F1	0.41	30	2.4	31.30	10	74.00	180.95	7.60	0.15
S15_F1	F1	0.51	30	2.4	42.64	10	74.00	180.95	7.60	0.15
S16_F1	F1	0.89	72	3.0	45.27	10	74.00	180.95	7.60	0.15
S17_F1	F1	0.83	30	2.4	37.68	10	74.00	180.95	7.60	0.15
S18_F1	F1	0.09	30	1.2	51.58	10	74.00	180.95	7.60	0.15
S19_F1	F1	0.23	30	1.2	52.45	10	74.00	180.39	7.57	0.15
S2_F1	F1	0.51	72	6.0	41.15	10	74.00	178.26	7.45	0.15
S20_F1	F1	0.09	30	1.2	52.02	10	74.00	180.95	7.60	0.15
S21_F1	F1	0.13	30	1.2	41.11	10	74.00	180.95	7.60	0.15
S22_F1	F1	0.22	30	1.2	41.04	10	74.00	180.95	7.60	0.15
S3_F1	F1	0.13	30	1.2	50.23	10	74.00	180.95	7.60	0.15
S4_F1	F1	0.31	30	2.4	44.47	10	74.00	196.51	6.65	0.14
S5_F1	F1	1.26	180	2.4	37.32	10	74.00	180.95	7.60	0.15
S6_F1	F1	0.23	30	1.2	49.22	10	74.00	180.95	7.60	0.15
S7_F1	F1	0.47	30	2.4	42.85	10	74.00	181.31	7.58	0.15
S8_F1	F1	0.75	168	2.4	28.75	10	74.00	180.95	7.60	0.15
S9_F1	F1	0.18	30	2.4	57.77	10	74.00	180.95	7.60	0.15
S1_F2	F2	0.93	108	1.2	23.35	10	74.00	242.32	3.54	0.12
S10_F2	F2	1.76	30	3.6	41.26	10	50.00	110.10	21.80	0.25
S11_F2	F2	1.14	108	6.0	38.28	10	52.61	117.80	20.26	0.24
S12_F2	F2	0.16	30	6.0	38.01	10	50.00	110.10	21.80	0.25
S13_F2	F2	0.28	30	4.8	44.77	10	50.86	112.63	21.29	0.24
S14_F2	F2	0.43	30	1.2	50.49	10	50.00	110.10	21.80	0.25
S2_F2	F2	0.93	108	1.2	38.41	10	74.00	254.33	3.14	0.11
S3_F2	F2	1.02	108	1.2	37.59	10	74.00	238.27	4.11	0.12

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S4_F2	F2	0.25	36	1.2	31.54	10	74.00	180.95	7.60	0.15
S5_F2	F2	1.61	156	6.0	35.19	10	62.70	147.58	14.29	0.20
S6_F2	F2	1.62	108	1.2	15.09	10	73.88	198.25	6.60	0.14
S7_F2	F2	0.23	30	1.2	26.22	10	69.19	166.75	10.45	0.17
S8_F2	F2	0.10	24	1.2	49.94	10	50.00	110.10	21.80	0.25
S9_F2	F2	0.80	30	1.2	45.64	10	50.00	110.10	21.80	0.25
S1_F3	F3	0.22	24	1.2	41.18	10	59.27	132.01	16.00	0.22
S2_F3	F3	0.49	36	1.2	46.61	10	50.00	110.10	21.80	0.25
S3_F3	F3	0.93	108	1.2	44.03	10	50.00	110.10	21.80	0.25
S1_F4	F4	0.10	24	1.2	54.10	10	74.00	172.27	7.11	0.16
S10_F4	F4	0.03	12	1.2	52.89	10	50.00	110.10	21.80	0.25
S11_F4	F4	0.17	30	1.2	39.86	10	50.00	110.10	21.80	0.25
S12_F4	F4	0.29	30	1.2	47.88	10	50.00	110.10	21.80	0.25
S13_F4	F4	0.35	42	1.2	37.20	10	50.00	110.10	21.80	0.25
S14_F4	F4	0.62	72	1.2	42.77	10	50.00	110.10	21.80	0.25
S15_F4	F4	0.27	30	1.2	45.09	10	50.00	110.10	21.80	0.25
S16_F4	F4	0.98	120	1.2	35.34	10	50.00	110.10	21.80	0.25
S17_F4	F4	0.28	30	1.2	36.01	10	50.00	110.10	21.80	0.25
S18_F4	F4	0.05	30	1.2	33.47	10	50.00	110.10	21.80	0.25
S19_F4	F4	0.32	30	1.2	46.33	10	50.00	110.10	21.80	0.25
S2_F4	F4	0.79	30	1.2	48.45	10	70.03	160.24	9.44	0.18
S20_F4	F4	0.17	30	1.2	42.76	10	50.00	110.10	21.80	0.25
S21_F4	F4	0.69	84	1.2	41.05	10	50.00	110.10	21.80	0.25
S22_F4	F4	0.17	30	1.2	45.48	10	50.00	110.10	21.80	0.25
S23_F4	F4	1.13	84	1.2	36.22	10	50.00	110.10	21.80	0.25
S24_F4	F4	0.24	30	1.2	41.99	10	50.00	110.10	21.80	0.25
S25_F4	F4	0.60	42	1.2	39.99	10	50.00	110.10	21.80	0.25
S26_F4	F4	0.42	30	1.2	46.76	10	50.00	110.10	21.80	0.25
S27_F4	F4	0.96	144	1.2	41.18	10	50.00	110.10	21.80	0.25
S28_F4	F4	0.53	96	1.2	44.17	10	50.00	110.10	21.80	0.25
S29_F4	F4	0.40	42	1.2	35.53	10	50.00	110.10	21.80	0.25
S3_F4	F4	0.29	30	1.2	47.81	10	74.00	173.11	7.16	0.16
S30_F4	F4	0.17	30	1.2	52.76	10	50.00	110.10	21.80	0.25
S31_F4	F4	0.32	30	1.2	52.43	10	50.00	110.10	21.80	0.25
S32_F4	F4	0.30	48	1.2	44.67	10	50.00	110.10	21.80	0.25

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S33_F4	F4	0.11	24	1.2	50.67	10	50.00	110.10	21.80	0.25
S34_F4	F4	0.13	24	1.2	45.85	10	50.00	110.10	21.80	0.25
S35_F4	F4	0.61	84	1.2	42.97	10	50.00	110.10	21.80	0.25
S36_F4	F4	0.14	30	1.2	46.38	10	50.00	110.10	21.80	0.25
S37_F4	F4	0.59	36	1.2	44.90	10	50.46	111.20	21.51	0.25
S38_F4	F4	0.76	36	1.2	49.60	10	58.91	131.15	16.23	0.22
S39_F4	F4	0.13	24	1.2	48.40	10	50.00	110.10	21.80	0.25
S4_F4	F4	0.18	30	1.2	49.72	10	74.00	180.95	7.60	0.15
S40_F4	F4	0.21	30	1.2	48.33	10	50.00	110.10	21.80	0.25
S41_F4	F4	0.40	96	1.2	41.22	10	50.00	110.10	21.80	0.25
S42_F4	F4	0.23	30	1.2	46.15	10	50.00	110.10	21.80	0.25
S43_F4	F4	0.62	48	1.2	47.57	10	50.00	110.10	21.80	0.25
S45_F4	F4	0.30	30	1.2	50.63	10	50.00	110.10	21.80	0.25
S46_F4	F4	0.45	96	1.2	40.26	10	50.00	110.10	21.80	0.25
S47_F4	F4	0.01	12	1.2	52.89	10	50.00	110.10	21.80	0.25
S5_F4	F4	0.11	30	1.2	50.71	10	71.57	173.78	9.04	0.16
S6_F4	F4	1.16	30	1.2	41.13	10	52.90	118.67	20.08	0.23
S7_F4	F4	0.18	30	1.2	43.17	10	55.29	125.73	18.67	0.23
S8_F4	F4	1.04	72	3.6	30.28	10	50.00	110.10	21.80	0.25
S9_F4	F4	0.08	30	1.2	41.12	10	50.00	110.10	21.80	0.25
S2_F5	F5	0.84	72	6.0	44.30	10	74.00	180.95	7.60	0.15
S3_F5	F5	0.20	30	6.0	44.92	10	74.00	180.95	7.60	0.15
S4_F5	F5	1.04	54	6.0	51.80	10	74.00	180.95	7.60	0.15
S5_F5	F5	0.93	42	1.2	44.19	10	74.00	180.95	7.60	0.15
S6_F5	F5	2.08	180	6.0	51.20	10	74.00	180.95	7.60	0.15
S1_G1	G1	0.99	48	1.2	46.40	10	50.00	110.10	21.80	0.25
S2_G1	G1	0.22	30	1.2	45.73	10	50.00	110.10	21.80	0.25
S3_G1	G1	0.16	30	1.2	45.93	10	50.00	110.10	21.80	0.25
S4_G1	G1	0.26	30	1.2	51.65	10	50.00	110.10	21.80	0.25
S5_G1	G1	0.24	30	1.2	43.94	10	50.00	110.10	21.80	0.25
S6_G1	G1	0.65	30	1.2	46.11	10	50.00	110.10	21.80	0.25
S7_G1	G1	0.74	36	1.2	43.45	10	50.00	110.10	21.80	0.25
S1_G2	G2	0.24	24	1.2	44.58	10	50.00	110.10	21.80	0.25
S1_G3	G3	0.09	12	1.2	51.63	10	50.00	110.10	21.80	0.25
S10_G3	G3	0.37	42	1.2	46.60	10	50.00	110.10	21.80	0.25

Table C.1	**Existing Conditions Subcatchment Parameters**									
Subcatch Name	**Sub Network**	**Area (ha)**	**Flow Length (m)**	**Slope (%)**	**Imperv (%)**	**Depres Stor (mm)**	**CN**	**Suct Head (mm)**	**Conduct (mm/hr)**	**Init Def (frac.)**
S11_G3	G3	0.40	42	1.2	39.59	10	50.00	110.10	21.80	0.25
S12_G3	G3	0.78	180	1.2	35.03	10	50.00	110.10	21.80	0.25
S13_G3	G3	1.24	180	1.2	37.75	10	50.00	110.10	21.80	0.25
S14_G3	G3	1.42	84	1.2	38.78	10	50.00	110.10	21.80	0.25
S15_G3	G3	0.51	24	1.2	46.99	10	50.00	110.10	21.80	0.25
S16_G3	G3	0.53	72	1.2	46.16	10	50.00	110.10	21.80	0.25
S17_G3	G3	0.34	30	1.2	44.77	10	50.00	110.10	21.80	0.25
S18_G3	G3	1.03	180	1.2	40.86	10	50.00	110.10	21.80	0.25
S19_G3	G3	0.99	180	1.2	35.91	10	50.00	110.10	21.80	0.25
S2_G3	G3	0.52	30	1.2	40.17	10	50.00	110.10	21.80	0.25
S20_G3	G3	1.22	144	1.2	39.87	10	50.00	110.10	21.80	0.25
S21_G3	G3	0.44	90	1.2	41.14	10	50.00	110.10	21.80	0.25
S3_G3	G3	0.74	24	1.2	45.96	10	50.00	110.10	21.80	0.25
S4_G3	G3	0.96	60	1.2	47.04	10	50.00	110.10	21.80	0.25
S5_G3	G3	0.24	42	1.2	47.92	10	50.00	110.10	21.80	0.25
S6_G3	G3	0.43	24	1.2	49.71	10	50.00	110.10	21.80	0.25
S7_G3	G3	0.78	24	1.2	49.56	10	50.00	110.10	21.80	0.25
S8_G3	G3	0.08	24	1.2	49.51	10	50.00	110.10	21.80	0.25
S9_G3	G3	0.15	42	1.2	46.26	10	50.00	110.10	21.80	0.25
S1_G4	G4	0.53	60	1.2	35.32	10	74.00	246.22	3.21	0.12
S10_G4	G4	0.48	60	1.2	41.16	10	74.00	273.00	2.00	0.11
S11_G4	G4	0.96	180	4.3	36.06	10	57.67	162.15	15.47	0.20
S12_G4	G4	0.25	48	3.0	41.40	10	54.30	139.28	18.25	0.22
S13_G4	G4	0.79	54	5.1	42.11	10	50.00	110.10	21.80	0.25
S14_G4	G4	1.72	114	5.1	35.07	10	50.00	110.10	21.80	0.25
S15_G4	G4	0.20	30	1.2	41.78	10	50.00	110.10	21.80	0.25
S16_G4	G4	0.25	48	3.0	41.62	10	50.00	110.10	21.80	0.25
S17_G4	G4	0.10	48	3.0	41.83	10	50.00	110.10	21.80	0.25
S18_G4	G4	1.23	138	5.1	36.70	10	50.00	110.10	21.80	0.25
S19_G4	G4	0.73	90	4.5	40.61	10	50.00	110.10	21.80	0.25
S2_G4	G4	0.28	36	1.2	42.13	10	74.00	273.00	2.00	0.11
S20_G4	G4	0.83	120	3.6	37.22	10	50.00	110.10	21.80	0.25
S21_G4	G4	0.40	30	2.7	41.34	10	50.00	110.10	21.80	0.25
S22_G4	G4	0.38	120	1.8	38.99	10	50.00	110.10	21.80	0.25
S23_G4	G4	0.13	24	1.2	46.22	10	50.00	110.10	21.80	0.25

Table C.1 Existing Conditions Subcatchment Parameters										
Subcatch Name	**Sub Network**	**Area (ha)**	**Flow Length (m)**	**Slope (%)**	**Imperv (%)**	**Depres Stor (mm)**	**CN**	**Suct Head (mm)**	**Conduct (mm/hr)**	**Init Def (frac.)**
S25_G4	G4	0.64	84	3.6	39.48	10	50.00	110.10	21.80	0.25
S26_G4	G4	1.24	72	3.6	40.89	10	50.00	110.10	21.80	0.25
S27_G4	G4	0.18	24	1.2	49.62	10	50.00	110.10	21.80	0.25
S28_G4	G4	0.27	42	1.8	52.14	10	50.00	110.10	21.80	0.25
S29_G4	G4	0.34	36	1.8	39.68	10	50.00	110.10	21.80	0.25
S3_G4	G4	0.55	30	1.2	45.54	10	74.00	273.00	2.00	0.11
S30_G4	G4	1.81	36	3.6	36.51	10	50.00	110.10	21.80	0.25
S31_G4	G4	0.56	30	1.2	45.02	10	50.00	110.10	21.80	0.25
S32_G4	G4	0.77	30	1.2	37.03	10	50.00	110.10	21.80	0.25
S33_G4	G4	0.52	30	1.2	43.68	10	50.00	110.10	21.80	0.25
S4_G4	G4	0.90	42	4.7	29.95	10	74.00	261.01	2.54	0.11
S5_G4	G4	0.49	78	6.0	20.00	10	74.00	270.36	2.12	0.11
S6_G4	G4	0.97	144	6.0	20.00	10	74.00	271.44	2.07	0.11
S7_G4	G4	0.26	120	6.0	20.29	10	74.00	273.00	2.00	0.11
S8_G4	G4	0.64	120	6.0	20.02	10	74.00	273.00	2.00	0.11
S9_G4	G4	0.48	96	6.0	29.51	10	69.31	241.16	5.87	0.13
S1_G5	G5	0.45	36	3.0	43.23	10	74.00	273.00	2.00	0.11
S10_G5	G5	0.89	96	6.0	36.83	10	73.74	271.26	2.21	0.11
S11_G5	G5	0.59	90	3.0	95.01	10	64.47	208.31	9.86	0.16
S12_G5	G5	0.34	60	4.8	61.69	10	50.00	110.10	21.80	0.25
S13_G5	G5	0.47	48	6.0	43.94	10	50.00	110.10	21.80	0.25
S14_G5	G5	0.14	60	4.8	50.93	10	50.00	110.10	21.80	0.25
S2_G5	G5	0.30	48	4.2	43.34	10	74.00	273.00	2.00	0.11
S3_G5	G5	0.22	36	4.2	34.69	10	74.00	273.00	2.00	0.11
S4_G5	G5	1.13	72	4.2	33.09	10	74.00	273.00	2.00	0.11
S5_G5	G5	0.70	72	3.3	42.60	10	74.00	273.00	2.00	0.11
S6_G5	G5	1.14	144	4.2	20.53	10	74.00	273.00	2.00	0.11
S7_G5	G5	0.22	48	1.2	43.48	10	74.00	273.00	2.00	0.11
S8_G5	G5	0.37	48	1.2	49.03	10	74.00	273.00	2.00	0.11
S9_G5	G5	0.31	36	6.0	48.98	10	64.75	210.23	9.63	0.16
S1_G6	G6	0.39	60	3.0	39.25	10	61.39	187.43	12.40	0.18
S10_G6	G6	0.19	30	1.2	46.87	10	50.00	110.10	21.80	0.25
S2_G6	G6	0.34	120	3.9	40.96	10	50.00	110.10	21.80	0.25
S3_G6	G6	0.51	144	3.9	41.11	10	50.00	110.10	21.80	0.25
S4_G6	G6	0.60	60	3.0	39.13	10	71.73	257.56	3.88	0.12

Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S5_G6	G6	0.56	180	3.9	40.54	10	50.00	110.10	21.80	0.25
S6_G6	G6	0.67	84	3.0	39.81	10	61.15	185.77	12.60	0.18
S7_G6	G6	0.31	36	3.9	47.44	10	50.00	110.10	21.80	0.25
S8_G6	G6	1.53	108	3.5	37.02	10	50.00	110.10	21.80	0.25
S9_G6	G6	0.85	96	5.0	42.80	10	50.00	110.10	21.80	0.25
S1_H1	H1	0.23	20.4	1.2	47.37	10	62.00	191.55	11.90	0.18
S10_H1	H1	0.83	35	1.5	34.95	10	64.95	166.80	6.80	0.17
S2_H1	H1	0.44	30	1.2	46.75	10	62.00	191.55	11.90	0.18
S3_H1	H1	0.26	24	1.2	48.84	10	63.85	189.01	11.38	0.18
S4_H1	H1	0.31	30	1.2	50.48	10	62.00	191.55	11.90	0.18
S5_H1	H1	0.74	60	1.2	41.60	10	72.77	176.75	8.85	0.17
S6_H1	H1	1.02	48	1.2	48.38	10	77.28	170.53	7.57	0.17
S7_H1	H1	0.58	48	1.2	47.62	10	65.69	186.48	10.86	0.18
S8_H1	H1	0.66	40	1.2	34.91	10	63.29	189.06	11.39	0.18
S9_H1	H1	0.68	60	1.0	28.56	10	66.23	174.28	8.34	0.17
S1_I1	I1	0.10	24	1.2	50.71	10	74.00	166.80	6.80	0.17
S2_I1	I1	0.46	48	3.6	42.02	10	74.00	242.15	3.39	0.12
S3_I1	I1	0.31	120	1.2	49.08	10	74.00	166.80	6.80	0.17
S4_I1	I1	0.44	72	1.2	37.88	10	74.00	231.38	3.88	0.13
S1_I2	I2	0.24	24	1.2	32.61	10	70.30	174.43	8.37	0.17
S2_I2	I2	0.35	30	1.2	42.76	10	74.00	166.80	6.80	0.17
S3_I2	I2	0.36	30	1.2	54.18	10	74.00	179.10	6.24	0.16
S4_I2	I2	0.44	30	1.2	50.73	10	74.00	217.29	4.52	0.14
S5_I2	I2	0.30	96	3.0	45.71	10	74.00	273.00	2.00	0.11
S1_I3	I3	0.46	78	2.4	41.02	10	74.00	273.00	2.00	0.11
S2_I3	I3	0.57	102	2.4	40.38	10	74.00	273.00	2.00	0.11
S3_I3	I3	0.83	102	2.1	45.46	10	74.00	273.00	2.00	0.11
S4_I3	I3	0.28	60	1.2	48.48	10	74.00	273.00	2.00	0.11
S5_I3	I3	1.54	132	2.4	31.50	10	74.00	273.00	2.00	0.11
S6_I3	I3	0.46	120	2.4	31.53	10	74.00	273.00	2.00	0.11
S1_I4	I4	0.47	78	1.2	45.02	10	74.00	273.00	2.00	0.11
S10_I4	I4	0.57	84	1.2	41.68	10	74.00	273.00	2.00	0.11
S11_I4	I4	0.40	72	4.8	40.46	10	74.00	273.00	2.00	0.11
S2_I4	I4	0.16	24	1.2	50.02	10	74.00	273.00	2.00	0.11
S3_I4	I4	0.14	48	4.5	53.11	10	74.00	273.00	2.00	0.11

Table C.1 Existing Conditions Subcatchment Parameters

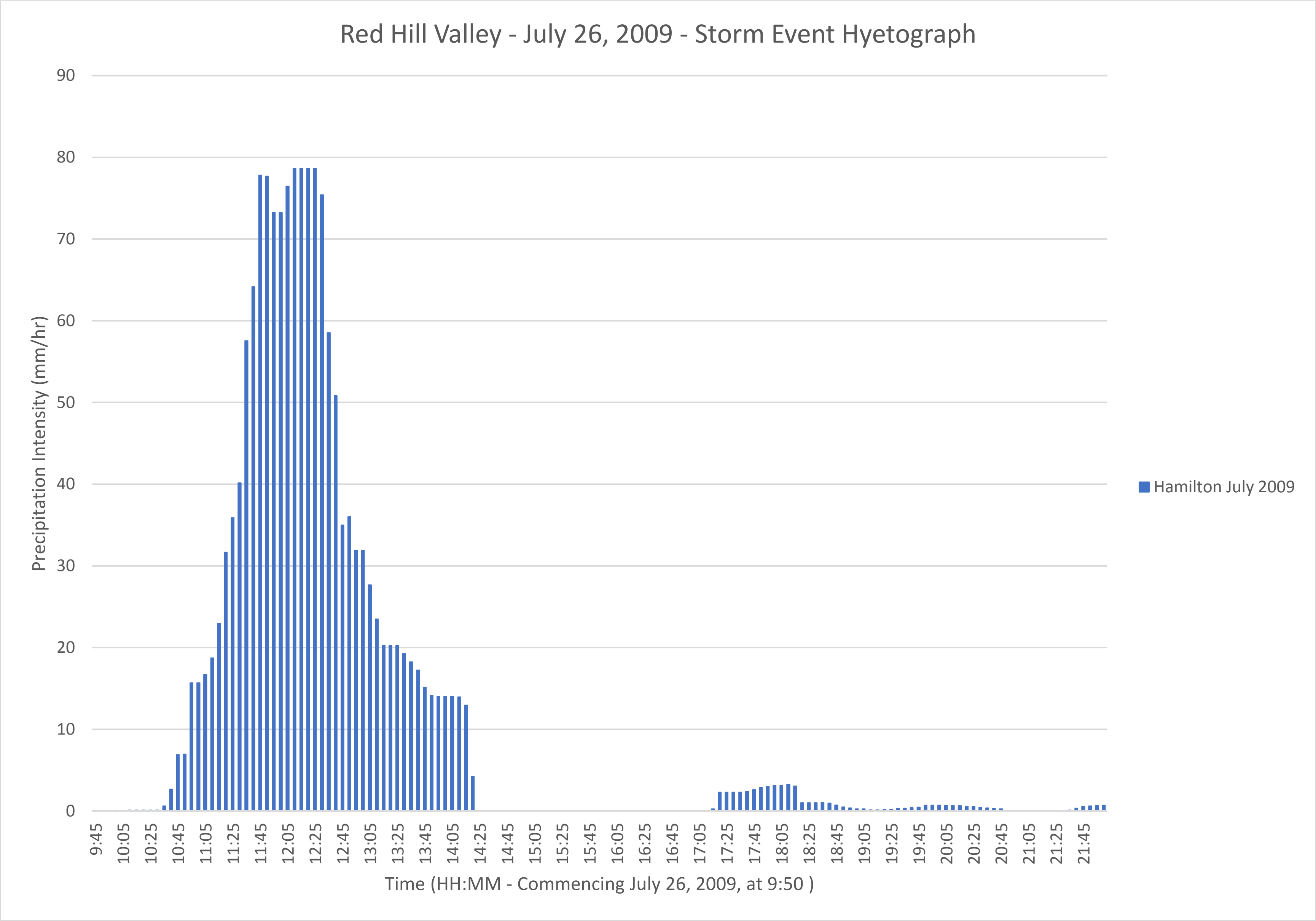
Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S4_I4	I4	0.45	72	4.5	44.45	10	74.00	273.00	2.00	0.11
S5_I4	I4	0.86	72	3.6	42.74	10	74.00	273.00	2.00	0.11
S6_I4	I4	0.35	60	4.5	45.60	10	74.00	273.00	2.00	0.11
S7_I4	I4	0.37	66	1.2	43.61	10	74.00	273.00	2.00	0.11
S8_I4	I4	2.20	126	2.9	70.44	10	74.00	273.00	2.00	0.11
S9_I4	I4	0.31	90	6.0	34.28	10	74.00	273.00	2.00	0.11
S1_J1	J1	0.38	60	1.2	48.03	10	50.00	110.10	21.80	0.25
S2_J1	J1	0.37	24	1.2	49.57	10	50.00	110.10	21.80	0.25
S3_J1	J1	1.02	78	1.2	39.76	10	50.00	110.10	21.80	0.25
S4_J1	J1	0.26	20.4	1.2	47.28	10	50.00	110.10	21.80	0.25
S5_J1	J1	0.70	70.8	1.2	43.42	10	50.00	110.10	21.80	0.25
S6_J1	J1	0.32	21	1.2	44.29	10	50.00	110.10	21.80	0.25
S7_J1	J1	0.36	42	1.2	45.13	10	50.00	110.10	21.80	0.25
S8_J1	J1	0.44	28.8	1.2	45.60	10	50.00	110.10	21.80	0.25
S1_J2	J2	0.96	144	1.2	48.30	10	50.00	110.10	21.80	0.25
S10_J2	J2	0.21	27.6	1.2	51.55	10	50.00	110.10	21.80	0.25
S11_J2	J2	0.79	192	1.2	41.15	10	50.00	110.10	21.80	0.25
S12_J2	J2	0.80	36	1.2	46.70	10	50.00	110.10	21.80	0.25
S13_J2	J2	0.43	26.4	1.2	43.62	10	50.00	110.10	21.80	0.25
S2_J2	J2	0.16	16.8	1.2	43.10	10	50.00	110.10	21.80	0.25
S3_J2	J2	0.14	19.2	1.2	43.96	10	50.00	110.10	21.80	0.25
S4_J2	J2	0.10	12	1.2	39.25	10	50.00	110.10	21.80	0.25
S5_J2	J2	0.84	168	1.2	41.98	10	50.00	110.10	21.80	0.25
S6_J2	J2	0.87	30	1.2	39.69	10	50.00	110.10	21.80	0.25
S7_J2	J2	0.52	24	1.2	46.31	10	50.00	110.10	21.80	0.25
S8_J2	J2	0.14	28.8	1.2	45.85	10	50.00	110.10	21.80	0.25
S9_J2	J2	0.17	24	1.2	48.60	10	50.00	110.10	21.80	0.25
S1_J3	J3	0.31	26.4	1.2	45.47	10	50.00	110.10	21.80	0.25
S2_J3	J3	0.22	30	1.2	52.47	10	50.00	110.10	21.80	0.25
S3_J3	J3	0.19	30	1.2	49.75	10	50.00	110.10	21.80	0.25
S4_J3	J3	0.13	18	1.2	42.49	10	50.00	110.10	21.80	0.25
S1_K1	K1	0.39	36	1.2	52.94	10	50.00	110.10	21.80	0.25
S2_K1	K1	0.17	22.8	1.2	65.82	10	50.00	110.10	21.80	0.25
S1_K2	K2	0.58	36	1.2	60.58	10	61.67	147.90	11.80	0.20
S2_K2	K2	0.83	36	1.2	58.88	10	58.13	142.47	13.24	0.20

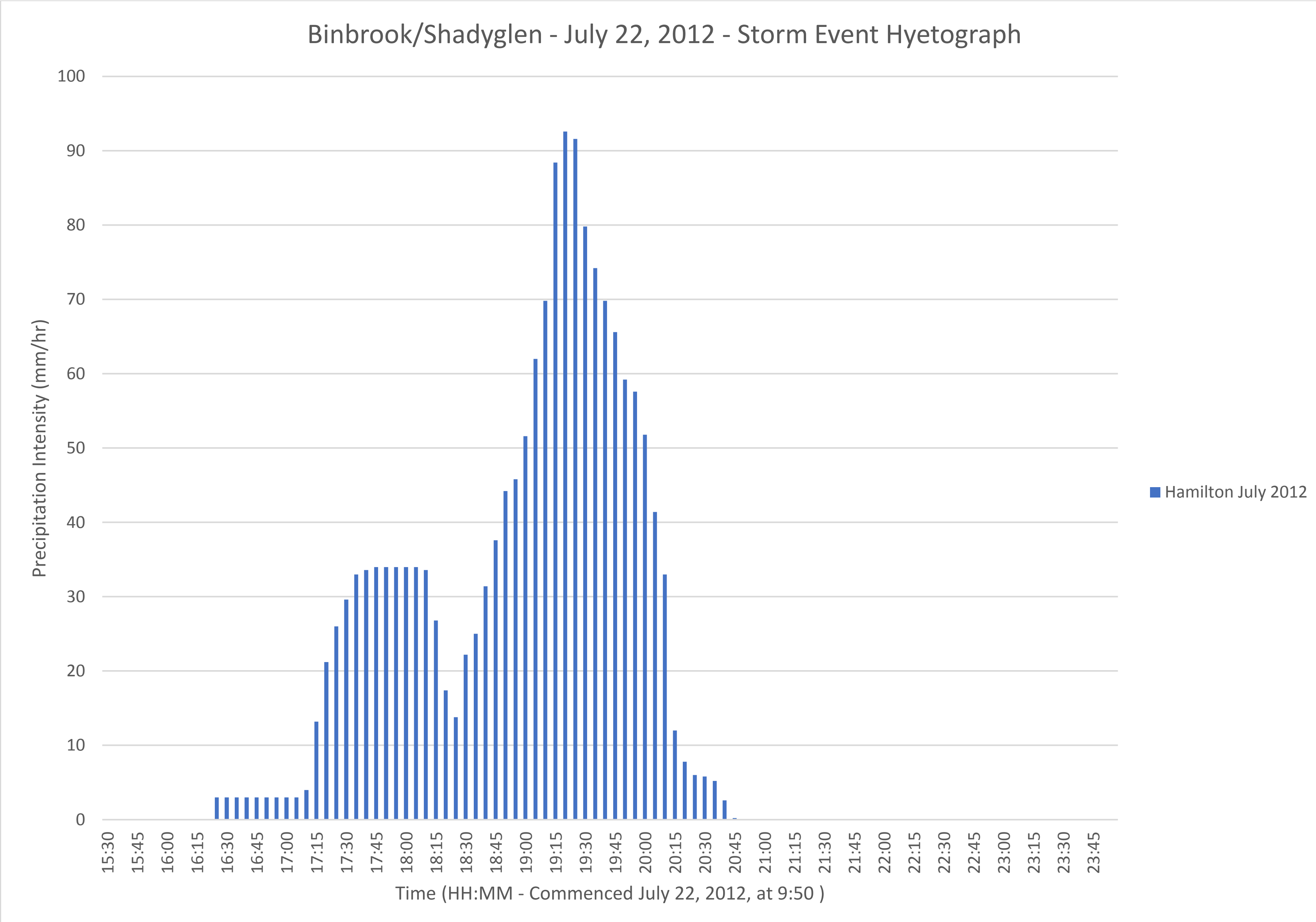
Table C.1 Existing Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Flow Length (m)	Slope (%)	Imperv (%)	Depres Stor (mm)	CN	Suct Head (mm)	Conduct (mm/hr)	Init Def (frac.)
S3_K2	K2	0.52	66	1.2	51.22	10	56.36	139.76	13.95	0.21
S4_K2	K2	0.56	33.6	1.2	42.81	10	55.50	138.45	14.30	0.21
S5_K2	K2	0.26	31.2	1.2	46.54	10	55.50	138.45	14.30	0.21
S6_K2	K2	0.29	31.2	1.2	43.61	10	55.50	138.45	14.30	0.21
S7_K2	K2	0.32	31.2	1.2	47.45	10	53.88	130.12	16.51	0.22
S8_K2	K2	0.60	60	1.2	43.80	10	50.00	110.10	21.80	0.25
S1_K3	K3	0.94	66	1.2	45.86	10	50.28	111.55	21.42	0.24
S10_K3	K3	0.68	72	1.2	44.37	10	50.00	110.10	21.80	0.25
S11_K3	K3	0.73	60	1.2	42.17	10	50.00	110.10	21.80	0.25
S12_K3	K3	0.27	48	1.2	47.35	10	50.00	110.10	21.80	0.25
S2_K3	K3	0.43	36	1.2	40.23	10	50.00	110.10	21.80	0.25
S3_K3	K3	0.12	36	1.2	35.52	10	50.00	110.10	21.80	0.25
S4_K3	K3	0.16	25.2	1.2	43.25	10	50.00	110.10	21.80	0.25
S5_K3	K3	0.23	26.4	1.2	42.55	10	50.00	110.10	21.80	0.25
S6_K3	K3	0.89	60	1.2	41.87	10	50.00	110.10	21.80	0.25
S7_K5	K3	0.57	60	1.2	36.39	10	50.00	110.10	21.80	0.25
S8_K3	K3	0.62	72	1.2	23.12	10	50.00	110.10	21.80	0.25
S9_K3	K3	0.40	60	1.2	42.44	10	50.00	110.10	21.80	0.25
S1_K4	K4	0.38	37.2	1.2	59.16	10	55.50	138.45	14.30	0.21
S2_K4	K4	0.59	16.8	1.2	65.84	10	53.82	129.76	16.60	0.22
S3_K4	K4	0.39	22.8	1.2	65.84	10	54.80	134.83	15.26	0.21
S4_K4	K4	0.14	22.8	1.2	65.84	10	50.00	110.10	21.80	0.25
S1_K5	K5	0.17	21.6	1.2	50.30	10	50.00	110.10	21.80	0.25
S2_K5	K5	0.28	18	1.2	51.37	10	50.00	110.10	21.80	0.25
S3_K5	K5	0.46	19.2	1.2	40.14	10	50.00	110.10	21.80	0.25
S4_K5	K5	0.56	60	1.2	48.40	10	50.00	110.10	21.80	0.25
S1_L1	L1	0.32	25.2	1.2	44.38	10	50.00	110.10	21.80	0.25
S2_L1	L1	0.27	20.4	1.2	46.31	10	50.00	110.10	21.80	0.25
S3_L1	L1	0.41	25.8	1.2	44.20	10	50.00	110.10	21.80	0.25
S4_L1	L1	0.35	24	1.2	47.23	10	50.00	110.10	21.80	0.25
S5_L1	L1	0.27	28.2	1.2	46.54	10	50.00	110.10	21.80	0.25
S6_L1	L1	0.21	24.48	1.2	51.41	10	50.00	110.10	21.80	0.25
S7_L1	L1	0.34	26.4	1.2	44.22	10	50.00	110.10	21.80	0.25
S8_L1	L1	0.37	27	1.2	46.97	10	50.00	110.10	21.80	0.25

Table C.2 External Area Subcatchment Parameters

Name	Area (ha)	Flow Length (m)		Slope (%)	Imperv. (%)	Curve Number	Suction Head (mm)	Conductivity (mm/hr)	Initial Deficit (frac.)
		Green-Ampt	Curve Number						
Ext_355_1	18.63	56.5	122	6.00	24.10	75.40	191.84	11.87	0.18
Ext_355_2	63.63	193	418	5.95	75.00	75.47	132.12	19.12	0.23
Ext_359_SWMF #23	8.22	78.7	212	3.61	27.30	81.47	271.28	2.11	0.11
Ext_360_SWMF #23	34.03	254.1	684	4.83	51.20	74.18	180.65	12.71	0.18
Ext_364_1	8.95	16.9	154	1.50	34.59	82.70	133.01	15.74	0.22
Ext_364_2	1.42	25	24	1.40	57.67	82.70	110.10	21.80	0.25
Ext_355	106.66	323.5	701	6.00	24.10	75.40	215.35	8.23	0.15
Ext_356	305.45	690	1495	5.00	0.00	63.40	218.78	7.07	0.14
Ext_357	450.46	818	1771	3.50	0.27	64.70	206.84	8.42	0.16
Ext_358	231.37	2210	5950	4.00	1.17	66.10	216.25	5.45	0.13
Ext_359	153.63	1471.2	3961	3.50	28.80	82.10	215.54	5.50	0.13
Ext_360	204.40	1526.5	4110	5.00	7.60	73.20	224.37	5.27	0.13
Ext_361	112.09	1325.9	3570	10.00	14.21	77.50	236.17	4.24	0.12
Ext_362	239.78	424.8	3860	1.00	2.18	64.60	132.45	15.89	0.22
Ext_363	111.24	377.1	3431	1.00	7.67	68.20	129.38	16.70	0.22
Ext_364	76.01	143.9	1310	1.50	34.59	82.70	125.44	17.74	0.23
Ext_365	58.35	182.3	1923	3.00	8.44	77.50	137.09	15.03	0.21
Ext_366	61.64	235.1	2471	2.00	23.52	80.90	139.35	15.50	0.21
Ext_367	105.58	201.4	2121	2.50	33.21	85.50	192.63	10.64	0.17
Ext_368	55.26	149.5	1373	2.00	42.84	89.60	209.52	8.98	0.16
Ext_369	105.62	853.1	2296	10.00	21.52	78.70	242.92	3.84	0.12
Ext_370	440.18	1337	6534	1.00	18.32	78.10	154.05	10.86	0.19
Ext_371	211.44	918	4488	1.00	44.24	88.30	153.04	12.29	0.20
Ext_372	117.56	831.7	4066	1.20	48.47	88.80	158.51	12.16	0.19
Ext_373	77.37	185.6	928	2.00	28.55	83.10	199.02	9.58	0.16
Ext_374	30.31	656.2	1767	10.00	15.35	96.50	241.52	3.92	0.12
Ext_375	129.98	1300	3500	8.00	4.00	68.80	210.99	5.77	0.14


Red Hill Valley - July 26, 2009 - Storm Event Hyetograph
Precipitation Intensity (mm/hr)
90
80
70
60
50
40
30
20
10
0
9:45
10:05
10:25
10:45
11:05
11:25
11:45
12:05
12:25
12:45
13:05
13:25
13:45
14:05
14:25
14:45
15:05
15:25
15:45
16:05
16:25
16:45
17:05
17:25
17:45
18:05
18:25
18:45
19:05
19:25
19:45
20:05
20:25
20:45
21:05
21:25
21:45
Time (HH:MM - Commencing July 26, 2009, at 9:50)
Hamilton July 2009


Binbrook/Shadyglen - July 22, 2012 - Storm Event Hyetograph
Precipitation Intensity (mm/hr)
0
10
20
30
40
50
60
70
80
90
100
15:30
15:45
16:00
16:15
16:30
16:45
17:00
17:15
17:30
17:45
18:00
18:15
18:30
18:45
19:00
19:15
19:30
19:45
20:00
20:15
20:30
20:45
21:00
21:15
21:30
21:45
22:00
22:15
22:30
22:45
23:00
23:15
23:30
23:45
Time (HH:MM - Commenced July 22, 2012, at 9:50)
Hamilton July 2012

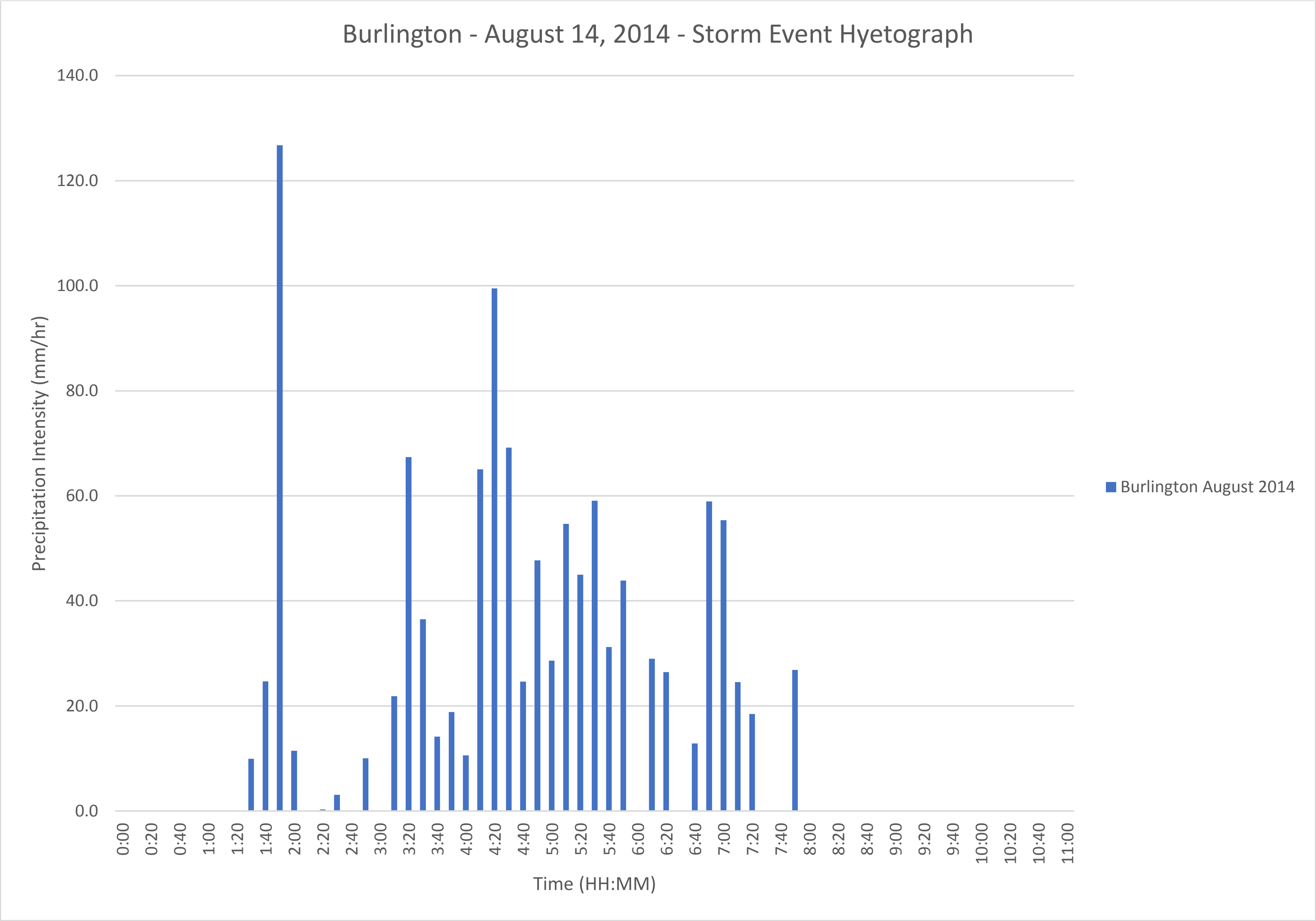

Burlington - August 14, 2014 - Storm Event Hyetograph
Precipitation Intensity (mm/hr)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
0:00 0:20 0:40 1:00 1:20 1:40 2:00 2:20 2:40 3:00 3:20 3:40 4:00 4:20 4:40 5:00 5:20 5:40 6:00 6:20 6:40 7:00 7:20 7:40 8:00 8:20 8:40 9:00 9:20 9:40 10:00 10:20 10:40 11:00
Time (HH:MM)
Burlington August 2014

Table C.3	Simulated Ditch System Performance of the Existing Conditions - 25 mm Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,207	0	0	100	0	0
	A2	2,713	0	0	100	0	0
	A3	150	0	0	100	0	0
	A4	2,273	0	0	100	0	0
	A5	427	0	0	100	0	0
	A6	41	0	0	100	0	0
B	B1	305	0	0	100	0	0
	B2	2,646	0	0	100	0	0
	B3	388	0	0	100	0	0
	B4	529	62	0	90	10	0
	B5	1,655	0	0	100	0	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	2,232	88	0	96	4	0
	C2	2,966	80	0	97	3	0
	C3	864	0	0	100	0	0
	C4	730	63	0	92	8	0
	C5	479	0	0	100	0	0
	C6	910	0	0	100	0	0
D	D1	4,199	0	0	100	0	0
	D2	5,259	218	0	96	4	0
	D3	458	0	0	100	0	0
E	E1	244	56	0	81	19	0
	E2	670	0	0	100	0	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	229	0	0	100	0	0
	E6	152	0	0	100	0	0
	E7	3,185	355	0	90	10	0
F	F1	1,892	0	0	100	0	0
	F2	1,695	0	0	100	0	0
	F3	300	0	0	100	0	0
	F4	3,825	168	18	95	4	0
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	2,325	56	0	98	2	0
	G4	2,759	0	0	100	0	0

Table C.3	Simulated Ditch System Performance of the Existing Conditions - 25 mm Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	G5	840	0	0	100	0	0
	G6	259	0	0	100	0	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	231	56	0	80	20	0
	I4	519	0	0	100	0	0
J	J1	799	0	0	100	0	0
	J2	1,209	0	0	100	0	0
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	1,015	0	0	100	0	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**58,792**	**1,239**	**18**	**98**	**2**	**0**

Table C.4	Simulated Ditch System Performance of the Existing Conditions - 2-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,173	34	0	97	3	0
	A2	2,630	83	0	97	3	0
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	350	77	0	82	18	0
	A6	41	0	0	100	0	0
B	B1	253	52	0	83	17	0
	B2	2,615	0	30	99	0	1
	B3	388	0	0	100	0	0
	B4	499	91	0	85	15	0
	B5	1,655	0	0	100	0	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	2,193	128	0	95	5	0
	C2	2,707	339	0	89	11	0

Table C.4	Simulated Ditch System Performance of the Existing Conditions - 2-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	479	0	0	100	0	0
	C6	841	70	0	92	8	0
D	D1	4,074	125	0	97	3	0
	D2	4,412	1,066	0	81	19	0
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	670	0	0	100	0	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	229	0	0	100	0	0
	E6	152	0	0	100	0	0
	E7	2,510	841	188	71	24	5
F	F1	1,868	25	0	99	1	0
	F2	1,646	49	0	97	3	0
	F3	217	83	0	72	28	0
	F4	3,115	813	83	78	20	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	1,925	457	0	81	19	0
	G4	2,677	82	0	97	3	0
	G5	840	0	0	100	0	0
	G6	224	36	0	86	14	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	231	56	0	80	20	0
	I4	501	17	0	97	3	0
J	J1	773	25	0	97	3	0
	J2	1,144	0	66	95	0	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	786	229	0	77	23	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0

Table C.4	Simulated Ditch System Performance of the Existing Conditions - 2-Year Storm Event					
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
L	L1	1,059	0	0	100	0	0
Total		**54,522**	**5,159**	**368**	**91**	**9**	**1**

Table C.5	Simulated Ditch System Performance of the Existing Conditions - 5-Year Storm Event						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	1,092	105	10	90	9	1
	A2	2,484	170	59	92	6	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	234	193	0	55	45	0
	A6	41	0	0	100	0	0
B	B1	253	52	0	83	17	0
	B2	2,372	205	69	90	8	3
	B3	388	0	0	100	0	0
	B4	490	85	16	83	14	3
	B5	1,505	103	47	91	6	3
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,946	374	0	84	16	0
	C2	2,404	642	0	79	21	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	407	21	51	85	4	11
	C6	841	70	0	92	8	0
D	D1	3,595	578	26	86	14	1
	D2	3,504	1,888	85	64	34	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	165	64	0	72	28	0
	E6	74	78	0	49	51	0
	E7	1,896	1,252	392	54	35	11
F	F1	1,781	111	0	94	6	0

Table C.5	Simulated Ditch System Performance of the Existing Conditions - 5-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	F2	1,507	188	0	89	11	0
	F3	217	83	0	72	28	0
	F4	2,965	963	83	74	24	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	1,504	789	88	63	33	4
	G4	2,118	628	14	77	23	0
	G5	840	0	0	100	0	0
	G6	190	70	0	73	27	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	440	79	0	85	15	0
J	J1	717	56	25	90	7	3
	J2	1,022	122	66	85	10	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	743	269	3	73	27	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**49,228**	**9,787**	**1,034**	**82**	**16**	**2**

Table C.6	Simulated Ditch System Performance of the Existing Conditions - 100-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	931	242	34	77	20	3
	A2	1,923	553	237	71	20	9
	A3	150	0	0	100	0	0
	A4	2,031	242	0	89	11	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17

Table C.6	Simulated Ditch System Performance of the Existing Conditions - 100-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	B2	1,926	651	69	73	25	3
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,075	484	96	65	29	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,357	772	192	58	33	8
	C2	1,440	1,604	2	47	53	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	315	0	164	66	0	34
	C6	610	301	0	67	33	0
D	D1	2,478	1,405	315	59	33	8
	D2	1,500	3,364	614	27	61	11
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,169	1,237	1,134	33	35	32
F	F1	1,487	314	91	79	17	5
	F2	873	756	67	51	45	4
	F3	217	83	0	72	28	0
	F4	1,832	1,802	377	46	45	9
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	724	1,570	88	30	66	4
	G4	1,597	955	206	58	35	7
	G5	717	123	0	85	15	0
	G6	135	57	67	52	22	26
H	H1	297	140	0	68	32	0
I	I1	385	0	0	100	0	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	167	290	62	32	56	12

Table C.6	**Simulated Ditch System Performance of the Existing Conditions - 100-Year Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
J	J1	426	321	51	53	40	6
	J2	887	196	126	73	16	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	497	338	0	60	40	0
	K3	516	407	93	51	40	9
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**35,684**	**20,213**	**4,152**	**59**	**34**	**7**

Table C.7	**Simulated Ditch System Performance of the Existing Conditions - 5-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	983	190	34	81	16	3
	A2	2,277	373	64	84	14	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,467	129	58	89	8	4
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,615	706	0	70	30	0
	C2	1,969	1,077	0	65	35	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,484	668	47	83	16	1
	D2	2,843	2,482	152	52	45	3
	D3	458	0	0	100	0	0

Table C.7 Simulated Ditch System Performance of the Existing Conditions - 5-Year CCDP CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,556	1,584	399	44	45	11
F	F1	1,541	326	25	81	17	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,499	1,429	83	62	36	2
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,263	1,030	88	53	43	4
	G4	2,033	692	33	74	25	1
	G5	748	92	0	89	11	0
	G6	135	90	34	52	35	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	73	62	74	14	12
J	J1	599	174	25	75	22	3
	J2	959	124	126	79	10	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**44,619**	**13,985**	**1,444**	**74**	**23**	**2**

Table C.8 Simulated Ditch System Performance of the Existing Conditions - 5-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	983	190	34	81	16	3
	A2	2,277	373	64	84	14	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,467	129	58	89	8	4
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,615	706	0	70	30	0
	C2	1,969	1,077	0	65	35	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,484	668	47	83	16	1
	D2	2,843	2,550	85	52	47	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,556	1,584	399	44	45	11
F	F1	1,541	326	25	81	17	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,499	1,429	83	62	36	2
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,263	1,030	88	53	43	4

Table C.8	**Simulated Ditch System Performance of the Existing Conditions - 5-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G4	2,033	692	33	74	25	1
	G5	748	92	0	89	11	0
	G6	135	90	34	52	35	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	73	62	74	14	12
J	J1	599	174	25	75	22	3
	J2	959	124	126	79	10	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**44,619**	**14,052**	**1,377**	**74**	**23**	**2**

Table C.9	**Simulated Ditch System Performance of the Existing Conditions - 5-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	1,036	137	34	86	11	3
	A2	2,431	224	59	90	8	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,467	133	54	89	8	3
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table C.9	**Simulated Ditch System Performance of the Existing Conditions - 5-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
C	C1	1,767	554	0	76	24	0
	C2	1,969	1,077	0	65	35	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	841	70	0	92	8	0
D	D1	3,568	584	47	85	14	1
	D2	3,165	2,228	85	58	41	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	141	88	0	62	38	0
	E6	74	78	0	49	51	0
	E7	1,651	1,490	399	47	42	11
F	F1	1,752	115	25	93	6	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,555	1,373	83	64	34	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	0	102	0	0	100	0
	G3	1,263	1,030	88	53	43	4
	G4	2,085	641	33	76	23	1
	G5	829	11	0	99	1	0
	G6	190	36	34	73	14	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	135	0	74	26	0
J	J1	652	121	25	82	15	3
	J2	994	150	66	82	12	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0

Table C.9 Simulated Ditch System Performance of the Existing Conditions - 5-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**46,309**	**12,494**	**1,246**	**77**	**21**	**2**

Table C.10 Simulated Ditch System Performance of the Existing Conditions - 100-Year CCDP CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	694	479	34	57	40	3
	A2	1,671	702	340	62	26	13
	A3	150	0	0	100	0	0
	A4	1,723	494	57	76	22	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,587	831	228	60	31	9
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,011	504	140	61	30	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	861	1,227	232	37	53	10
	C2	1,388	1,655	3	46	54	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	315	70	58	35	8
D	D1	2,165	1,675	359	52	40	9
	D2	1,086	2,726	1,667	20	50	30
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	337	311	22	50	46	3
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0

Table C.10	**Simulated Ditch System Performance of the Existing Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,385	1,707	13	39	48
F	F1	1,100	652	140	58	34	7
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,721	1,751	540	43	44	13
	F5	60	31	0	66	34	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,530	343	21	64	14
	G4	1,092	1,208	459	40	44	17
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	154	255	21	30	49
J	J1	129	458	212	16	57	27
	J2	687	346	176	57	29	15
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6
	K3	342	454	219	34	45	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**28,958**	**23,400**	**7,691**	**48**	**39**	**13**

Table C.11	**Simulated Ditch System Performance of the Existing Conditions - 100-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	931	242	34	77	20	3
	A2	1,823	583	307	67	22	11

Table C.11 Simulated Ditch System Performance of the Existing Conditions - 100-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	A3	150	0	0	100	0	0
	A4	1,825	391	57	80	17	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,740	678	228	66	26	9
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,041	518	96	63	31	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	943	1,186	192	41	51	8
	C2	1,427	1,616	3	47	53	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	350	34	58	38	4
D	D1	2,417	1,435	347	58	34	8
	D2	1,148	3,436	894	21	63	16
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	447	223	0	67	33	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	789	1,438	1,313	22	41	37
F	F1	1,301	451	140	69	24	7
	F2	660	897	139	39	53	8
	F3	217	83	0	72	28	0
	F4	1,721	1,840	450	43	46	11
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	632	1,557	193	27	65	8
	G4	1,357	1,045	357	49	38	13
	G5	717	42	81	85	5	10

Table C.11 Simulated Ditch System Performance of the Existing Conditions - 100-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	148	309	62	29	60	12
J	J1	326	343	129	41	43	16
	J2	704	380	126	58	31	10
	J3	334	15	0	96	4	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6
	K3	402	507	106	40	50	10
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**32,048**	**22,444**	**5,556**	**53**	**37**	**9**

Table C.12 Simulated Ditch System Performance of the Existing Conditions - 100-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	660	513	34	55	43	3
	A2	1,254	920	539	46	34	20
	A3	150	0	0	100	0	0
	A4	1,612	604	57	71	27	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,466	724	455	55	27	17
	B3	254	134	0	65	35	0
	B4	451	77	62	76	13	10
	B5	1,006	465	184	61	28	11
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,443	287	25	62	12
	C2	1,128	1,915	3	37	63	0

Table C.12 Simulated Ditch System Performance of the Existing Conditions - 100-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	510	247	153	56	27	17
D	D1	1,545	2,102	552	37	50	13
	D2	861	2,342	2,275	16	43	42
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	318	330	22	47	49	3
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,000	2,093	13	28	59
F	F1	854	660	379	45	35	20
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,555	1,746	711	39	44	18
	F5	44	16	31	49	17	34
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	263	1,577	541	11	66	23
	G4	882	981	896	32	36	32
	G5	638	108	94	76	13	11
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	206	180	0	53	47	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	73	157	288	14	30	56
J	J1	82	364	353	10	46	44
	J2	592	415	202	49	34	17
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	239	511	86	29	61	10
	K3	259	538	219	26	53	22
	K4	323	0	0	100	0	0

Table C.12	**Simulated Ditch System Performance of the Existing Conditions - 100-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**24,861**	**24,336**	**10,852**	**41**	**41**	**18**

Table C.13	**Simulated Ditch System Performance of the Existing Conditions - Hamilton 2009**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	892	281	34	74	23	3
	A2	1,823	583	307	67	22	11
	A3	150	0	0	100	0	0
	A4	1,793	454	26	79	20	1
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,654	764	228	63	29	9
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,011	504	140	61	30	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	969	1,160	192	42	50	8
	C2	1,431	1,613	3	47	53	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	350	34	58	38	4
D	D1	2,374	1,438	388	57	34	9
	D2	1,108	3,114	1,256	20	57	23
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	447	223	0	67	33	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	630	1,248	1,662	18	35	47

Table C.13 Simulated Ditch System Performance of the Existing Conditions - Hamilton 2009							
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
F	F1	1,301	451	140	69	24	7
	F2	660	897	139	39	53	8
	F3	217	83	0	72	28	0
	F4	1,721	1,751	540	43	44	13
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,486	387	21	62	16
	G4	1,479	923	357	54	33	13
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	292	117	21	56	23
J	J1	264	284	251	33	36	31
	J2	687	370	151	57	31	13
	J3	334	15	0	96	4	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6
	K3	342	454	219	34	45	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	1,059	0	0	100	0	0
Total		**31,385**	**21,743**	**6,920**	**52**	**36**	**12**

Table C.14 Simulated Ditch System Performance of the Existing Conditions - Stoney Creek 2012							
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	660	513	34	55	43	3
	A2	1,254	920	539	46	34	20
	A3	150	0	0	100	0	0
	A4	1,635	581	57	72	26	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0

Table C.14 Simulated Ditch System Performance of the Existing Conditions - Stoney Creek 2012

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
B	B1	110	144	52	36	47	17
	B2	1,466	812	367	55	31	14
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,006	509	140	61	31	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,443	287	25	62	12
	C2	1,251	1,792	3	41	59	0
	C3	528	336	0	61	39	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	315	70	58	35	8
D	D1	1,912	1,735	552	46	41	13
	D2	853	2,484	2,141	16	45	39
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	318	330	22	47	49	3
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,000	2,093	13	28	59
F	F1	981	652	259	52	34	14
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,555	1,867	589	39	47	15
	F5	44	47	0	49	51	0
G	G1	170	548	0	24	76	0
	G2	0	102	0	0	100	0
	G3	263	1,577	541	11	66	23
	G4	989	1,095	676	36	40	24
	G5	638	110	92	76	13	11
	G6	52	140	67	20	54	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0

Table C.14	Simulated Ditch System Performance of the Existing Conditions - Stoney Creek 2012						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	I4	110	120	288	21	23	56
J	J1	82	317	399	10	40	50
	J2	639	383	187	53	32	15
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	293	489	54	35	58	6
	K3	293	458	265	29	45	26
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**26,050**	**23,989**	**10,009**	**43**	**40**	**17**

Table C.15	Simulated Ditch System Performance of the Existing Conditions - Burlington 2014						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	983	190	34	81	16	3
	A2	1,923	553	237	71	20	9
	A3	150	0	0	100	0	0
	A4	2,097	176	0	92	8	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	50	52	67	16	17
	B2	1,926	651	69	73	25	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,291	268	96	78	16	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,423	706	192	61	30	8
	C2	1,827	1,217	2	60	40	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	2,519	1,334	347	60	32	8
	D2	1,553	3,188	737	28	58	13

Table C.15	**Simulated Ditch System Performance of the Existing Conditions - Burlington 2014**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	900	928	1,712	25	26	48
F	F1	1,541	289	62	81	15	3
	F2	1,040	636	20	61	37	1
	F3	217	83	0	72	28	0
	F4	1,894	1,630	487	47	41	12
	F5	91	0	0	100	0	0
G	G1	467	251	0	65	35	0
	G2	0	102	0	0	100	0
	G3	751	1,512	119	32	63	5
	G4	1,816	800	143	66	29	5
	G5	748	92	0	89	11	0
	G6	135	57	67	52	22	26
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	167	290	62	32	56	12
J	J1	377	248	174	47	31	22
	J2	816	267	126	67	22	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	643	192	0	77	23	0
	K3	456	340	219	45	34	22
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**37,578**	**17,418**	**5,052**	**63**	**29**	**8**

Location Map

Legend

Planning Units Boundary

Lands zoned Existing Residential "ER" Zone
Town of Ancaster Zoning By-law No.87-57

Hamilton
Planning & Economic Development Department

APPENDIX D

As of Right (Uncontrolled) Conditions Simulation

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	**Sub Network**	**Area (ha)**	**Imperviousness (%)**			**Pervious Depression Storage (mm)**	
			Ex Cond	**As of Right Cond**	**Difference**	**Ex Cond**	**As of Right Cond**
S1_A1	A1	0.08	46.59	58.69	12.10	10	1210
S10_A1	A1	0.24	37.09	67.47	30.38	10	1210
S11_A1	A1	0.23	35.59	62.44	26.85	10	1210
S12_A1	A1	0.31	40.59	70.10	29.51	10	1210
S13_A1	A1	0.24	38.38	62.48	24.10	10	1210
S14_A1	A1	0.09	52.89	52.89	0.00	10	10
S15_A1	A1	0.20	43.10	67.70	24.60	10	1210
S16_A1	A1	0.51	36.17	67.62	31.45	10	1210
S17_A1	A1	0.05	52.89	52.89	0.00	10	10
S18_A1	A1	0.19	52.89	52.89	0.00	10	10
S19_A1	A1	0.09	41.13	63.14	22.01	10	1210
S2_A1	A1	0.02	52.88	52.89	0.01	10	1210
S20_A1	A1	0.15	44.10	63.50	19.40	10	1210
S21_A1	A1	0.05	50.63	50.63	0.00	10	10
S22_A1	A1	0.37	26.91	37.28	10.37	10	1210
S23_A1	A1	1.14	25.87	41.27	15.40	10	1210
S24_A1	A1	1.43	36.19	36.19	0.00	10	10
S25_A1	A1	0.74	30.87	30.87	0.00	10	10
S26_A1	A1	0.70	17.75	20.41	2.66	10	1210
S27_A1	A1	0.34	52.89	52.89	0.00	10	10
S3_A1	A1	0.12	52.89	52.89	0.00	10	10
S4_A1	A1	0.26	36.71	66.45	29.74	10	1210
S5_A1	A1	0.30	41.37	69.02	27.65	10	1210
S6_A1	A1	0.07	52.89	52.89	0.00	10	10
S7_A1	A1	0.03	51.83	53.11	1.28	10	1210
S8_A1	A1	0.34	33.59	61.89	28.30	10	1210
S9_A1	A1	0.04	49.18	54.97	5.79	10	1210
S1_A2	A2	0.06	51.15	53.22	2.07	10	1210
S10_A2	A2	0.19	41.62	64.49	22.87	10	1210
S11_A2	A2	0.11	49.66	69.93	20.27	10	1210
S12_A2	A2	0.73	38.35	71.22	32.87	10	1210
S13_A2	A2	0.36	49.72	69.35	19.63	10	1210
S14_A2	A2	0.50	44.47	70.14	25.67	10	1210
S15_A2	A2	0.10	49.71	53.50	3.79	10	1210
S16_A2	A2	0.14	44.51	55.40	10.89	10	1210
S17_A2	A2	0.25	42.72	59.11	16.39	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S18_A2	A2	0.55	40.61	67.92	27.31	10	1210
S19_A2	A2	0.17	43.73	67.76	24.03	10	1210
S2_A2	A2	0.13	50.62	53.33	2.71	10	1210
S20_A2	A2	0.45	34.06	64.27	30.21	10	1210
S21_A2	A2	0.69	38.61	69.82	31.21	10	1210
S22_A2	A2	0.14	41.01	65.65	24.64	10	1210
S23_A2	A2	0.25	40.17	64.43	24.26	10	1210
S24_A2	A2	0.29	44.20	64.44	20.24	10	1210
S25_A2	A2	0.19	43.90	58.71	14.81	10	1210
S26_A2	A2	0.16	44.71	58.87	14.16	10	1210
S27_A2	A2	0.08	52.89	52.89	0.00	10	10
S28_A2	A2	2.42	24.80	35.43	10.63	10	1210
S29_A2	A2	2.53	11.76	15.28	3.52	10	1210
S3_A2	A2	0.07	50.39	53.37	2.98	10	1210
S30_A2	A2	3.07	10.66	14.95	4.29	10	1210
S31_A2	A2	0.09	45.94	62.30	16.36	10	1210
S32_A2	A2	0.22	46.48	63.26	16.78	10	1210
S33_A2	A2	0.28	40.46	64.98	24.52	10	1210
S34_A2	A2	0.19	42.96	70.73	27.77	10	1210
S35_A2	A2	0.36	40.00	69.72	29.72	10	1210
S36_A2	A2	0.29	34.54	64.32	29.78	10	1210
S37_A2	A2	0.34	45.49	74.41	28.92	10	1210
S38_A2	A2	2.32	8.66	11.21	2.55	10	1210
S39_A2	A2	0.04	49.16	53.60	4.44	10	1210
S4_A2	A2	0.12	52.89	52.89	0.00	10	10
S40_A2	A2	0.92	15.35	23.27	7.92	10	1210
S41_A2	A2	0.09	51.52	71.65	20.13	10	1210
S42_A2	A2	0.17	40.03	60.47	20.44	10	1210
S43_A2	A2	0.37	34.07	53.22	19.15	10	1210
S5_A2	A2	0.13	43.65	63.53	19.88	10	1210
S6_A2	A2	0.09	47.91	62.32	14.41	10	1210
S7_A2	A2	0.24	48.93	70.28	21.35	10	1210
S8_A2	A2	0.38	42.49	71.62	29.13	10	1210
S9_A2	A2	1.08	33.54	66.97	33.43	10	1210
S1_A3	A3	0.17	42.93	61.58	18.65	10	1210
S2_A3	A3	0.05	43.08	54.80	11.72	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S1_A4	A4	0.12	35.32	60.23	24.91	10	1210
S10_A4	A4	0.03	36.13	69.08	32.95	10	1210
S11_A4	A4	0.27	38.62	73.18	34.56	10	1210
S12_A4	A4	0.21	44.97	71.18	26.21	10	1210
S13_A4	A4	0.04	24.31	58.93	34.62	10	1210
S14_A4	A4	0.15	44.81	56.17	11.36	10	1210
S15_A4	A4	0.17	40.96	69.54	28.58	10	1210
S16_A4	A4	0.30	45.31	71.41	26.10	10	1210
S17_A4	A4	0.84	39.92	69.11	29.19	10	1210
S18_A4	A4	0.16	42.00	55.36	13.36	10	1210
S19_A4	A4	0.50	39.13	66.70	27.57	10	1210
S2_A4	A4	0.03	42.53	57.06	14.53	10	1210
S20_A4	A4	0.09	38.49	61.93	23.44	10	1210
S21_A4	A4	0.13	49.27	72.75	23.48	10	1210
S22_A4	A4	0.29	37.88	64.99	27.11	10	1210
S23_A4	A4	0.09	54.71	72.65	17.94	10	1210
S24_A4	A4	0.24	46.34	63.31	16.97	10	1210
S25_A4	A4	0.05	46.19	55.02	8.83	10	1210
S26_A4	A4	0.59	40.71	67.87	27.16	10	1210
S27_A4	A4	0.16	36.91	59.90	22.99	10	1210
S28_A4	A4	0.10	50.92	68.89	17.97	10	1210
S29_A4	A4	0.20	35.51	59.76	24.25	10	1210
S3_A4	A4	0.21	44.13	66.00	21.87	10	1210
S30_A4	A4	0.30	39.35	70.52	31.17	10	1210
S31_A4	A4	0.34	46.71	65.12	18.41	10	1210
S32_A4	A4	0.27	45.08	67.76	22.68	10	1210
S33_A4	A4	0.59	20.87	43.71	22.84	10	1210
S34_A4	A4	0.73	14.53	21.04	6.51	10	1210
S35_A4	A4	0.57	13.12	16.49	3.37	10	1210
S36_A4	A4	0.27	11.95	20.73	8.78	10	1210
S37_A4	A4	1.95	6.64	9.47	2.83	10	1210
S38_A4	A4	0.64	36.76	70.52	33.76	10	1210
S39_A4	A4	0.27	39.76	66.30	26.54	10	1210
S4_A4	A4	0.15	45.75	54.79	9.04	10	1210
S40_A4	A4	0.15	53.79	70.41	16.62	10	1210
S41_A4	A4	0.09	46.74	54.07	7.33	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S42_A4	A4	0.12	41.93	59.33	17.40	10	1210
S43_A4	A4	0.64	16.89	27.89	11.00	10	1210
S44_A4	A4	0.18	43.34	66.05	22.71	10	1210
S45_A4	A4	0.33	29.04	44.71	15.67	10	1210
S46_A4	A4	0.77	19.09	30.32	11.23	10	1210
S5_A4	A4	0.09	54.08	69.74	15.66	10	1210
S6_A4	A4	0.22	44.49	63.23	18.74	10	1210
S7_A4	A4	0.24	41.12	71.49	30.37	10	1210
S8_A4	A4	0.07	43.65	59.28	15.63	10	1210
S9_A4	A4	0.26	41.38	70.72	29.34	10	1210
S1_A5	A5	0.38	51.86	51.86	0.00	10	10
S2_A5	A5	0.03	52.89	52.89	0.00	10	10
S3_A5	A5	0.42	51.74	51.74	0.00	10	10
S4_A5	A5	0.49	51.27	51.27	0.00	10	10
S5_A5	A5	0.06	52.09	52.09	0.00	10	10
S6_A5	A5	0.85	52.08	52.08	0.00	10	10
S7_A5	A5	0.05	52.71	52.71	0.00	10	10
S8_A5	A5	0.29	51.54	51.54	0.00	10	10
S9_A5	A5	0.01	52.89	52.89	0.00	10	10
S1_A6	A6	1.07	37.33	37.33	0.00	10	10
S2_A6	A6	0.13	47.13	47.13	0.00	10	10
S3_A6	A6	0.83	38.53	38.53	0.00	10	10
S4_A6	A6	0.39	46.37	46.37	0.00	10	10
S5_A6	A6	0.15	45.68	45.68	0.00	10	10
S6_A6	A6	0.77	44.89	44.89	0.00	10	10
S1_B1	B1	0.38	40.75	52.17	11.42	10	1410
S2_B1	B1	0.69	45.28	59.13	13.85	10	1410
S3_B1	B1	0.08	49.91	49.91	0.00	10	10
S4_B1	B1	0.39	38.02	54.69	16.67	10	1410
S5_B1	B1	0.19	46.50	60.83	14.33	10	1410
S6_B1	B1	0.13	42.97	57.31	14.34	10	1410
S7_B1	B1	0.40	39.29	66.63	27.34	10	1410
S1_B2	B2	0.13	49.28	66.75	17.47	10	1410
S10_B2	B2	0.80	39.03	62.66	23.63	10	1410
S11_B2	B2	0.33	42.98	63.92	20.94	10	1410
S12_B2	B2	0.59	40.94	65.57	24.63	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S13_B2	B2	0.28	50.68	67.48	16.80	10	1410
S14_B2	B2	0.45	42.71	60.99	18.28	10	1410
S15_B2	B2	0.33	43.06	63.05	19.99	10	1410
S16_B2	B2	0.19	44.23	58.10	13.87	10	1410
S17_B2	B2	0.17	49.60	65.56	15.96	10	1410
S18_B2	B2	0.16	44.11	55.32	11.21	10	1410
S19_B2	B2	0.43	50.84	65.11	14.27	10	1410
S2_B2	B2	0.09	49.31	65.13	15.82	10	1410
S20_B2	B2	0.16	44.35	58.18	13.83	10	1410
S21_B2	B2	0.14	47.65	59.87	12.22	10	1410
S22_B2	B2	0.24	47.26	63.61	16.35	10	1410
S23_B2	B2	0.20	48.85	63.21	14.36	10	1410
S24_B2	B2	0.95	39.40	66.63	27.23	10	1410
S25_B2	B2	0.28	42.35	56.18	13.83	10	1410
S26_B2	B2	0.85	37.99	54.88	16.89	10	1410
S27_B2	B2	0.75	47.54	65.95	18.41	10	1410
S28_B2	B2	0.43	45.97	61.42	15.45	10	1410
S3_B2	B2	0.52	49.98	66.30	16.32	10	1410
S4_B2	B2	0.24	47.14	64.29	17.15	10	1410
S5_B2	B2	0.34	52.48	68.13	15.65	10	1410
S6_B2	B2	0.26	44.86	66.30	21.44	10	1410
S7_B2	B2	0.36	42.47	54.69	12.22	10	1410
S8_B2	B2	0.06	51.78	65.94	14.16	10	1410
S9_B2	B2	0.21	45.99	62.09	16.10	10	1410
S1_B3	B3	0.10	43.84	52.99	9.15	10	1410
S2_B3	B3	0.34	39.65	46.92	7.27	10	1410
S3_B3	B3	0.22	42.88	58.70	15.82	10	1410
S4_B3	B3	0.37	42.54	64.46	21.92	10	1410
S5_B3	B3	0.49	27.12	27.12	0.00	10	10
S1_B4	B4	0.02	52.89	52.89	0.00	10	10
S10_B4	B4	0.52	47.47	62.63	15.16	10	1410
S2_B4	B4	0.05	45.02	68.26	23.24	10	1410
S3_B4	B4	0.69	44.45	60.52	16.07	10	1410
S4_B4	B4	0.14	47.81	60.66	12.85	10	1410
S5_B4	B4	0.06	48.15	54.15	6.00	10	1410
S6_B4	B4	0.45	36.14	61.37	25.23	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S7_B4	B4	0.31	49.30	69.63	20.33	10	1410
S8_B4	B4	0.14	48.29	63.72	15.43	10	1410
S9_B4	B4	0.43	39.78	48.13	8.35	10	1410
S1_B5	B5	0.16	44.06	58.09	14.03	10	1410
S10_B5	B5	0.09	50.48	65.01	14.53	10	1410
S11_B5	B5	0.04	45.88	61.28	15.40	10	1410
S12_B5	B5	0.23	51.08	67.29	16.21	10	1410
S13_B5	B5	0.24	48.78	65.13	16.35	10	1410
S14_B5	B5	1.44	36.98	64.33	27.35	10	1410
S15_B5	B5	0.44	46.23	59.43	13.20	10	1410
S16_B5	B5	0.11	44.02	56.69	12.67	10	1410
S17_B5	B5	0.26	43.10	61.60	18.50	10	1410
S18_B5	B5	0.31	44.77	60.45	15.68	10	1410
S19_B5	B5	0.28	48.07	60.77	12.70	10	1410
S2_B5	B5	0.68	38.99	62.61	23.62	10	1410
S20_B5	B5	0.31	53.47	70.15	16.68	10	1410
S21_B5	B5	0.40	48.04	63.74	15.70	10	1410
S22_B5	B5	1.67	35.39	62.74	27.35	10	1410
S3_B5	B5	0.79	42.10	64.05	21.95	10	1410
S4_B5	B5	0.09	47.58	60.97	13.39	10	1410
S5_B5	B5	0.33	50.42	66.67	16.25	10	1410
S6_B5	B5	0.31	52.59	70.90	18.31	10	1410
S7_B5	B5	0.27	50.57	63.18	12.61	10	1410
S8_B5	B5	0.01	52.89	52.89	0.00	10	10
S9_B5	B5	1.25	39.53	66.86	27.33	10	1410
S1_B6	B6	0.06	53.72	59.85	6.13	10	1410
S10_B6	B6	0.38	51.80	51.80	0.00	10	10
S11_B6	B6	0.22	52.03	52.03	0.00	10	10
S12_B6	B6	0.91	52.28	52.28	0.00	10	10
S13_B6	B6	0.03	52.43	52.43	0.00	10	10
S2_B6	B6	0.03	44.08	63.04	18.96	10	1410
S3_B6	B6	0.02	49.26	52.68	3.42	10	1410
S4_B6	B6	0.08	36.45	51.90	15.45	10	1410
S5_B6	B6	0.50	44.33	59.97	15.64	10	1410
S6_B6	B6	0.11	35.74	51.82	16.08	10	1410
S7_B6	B6	0.20	52.07	52.25	0.18	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S8_B6	B6	0.29	51.98	51.98	0.00	10	10
S9_B6	B6	0.19	51.81	51.81	0.00	10	10
S1_B7	B7	0.41	42.34	47.84	5.50	10	1410
S1_C1	C1	0.23	45.68	54.29	8.61	10	1410
S10_C1	C1	0.43	47.09	62.34	15.25	10	1410
S11_C1	C1	0.62	37.22	61.11	23.89	10	1410
S12_C1	C1	0.36	50.11	64.37	14.26	10	1410
S13_C1	C1	0.80	37.38	64.46	27.08	10	1410
S14_C1	C1	0.39	52.93	65.32	12.39	10	1410
S15_C1	C1	0.37	49.84	65.99	16.15	10	1410
S16_C1	C1	0.27	50.17	64.68	14.51	10	1410
S17_C1	C1	0.15	47.93	62.76	14.83	10	1410
S18_C1	C1	0.98	35.26	62.05	26.79	10	1410
S19_C1	C1	0.04	47.17	55.76	8.59	10	1410
S2_C1	C1	0.19	46.31	59.29	12.98	10	1410
S20_C1	C1	0.40	31.57	55.57	24.00	10	1410
S21_C1	C1	0.29	45.86	57.45	11.59	10	1410
S22_C1	C1	0.57	42.46	62.87	20.41	10	1410
S23_C1	C1	0.28	50.46	66.73	16.27	10	1410
S24_C1	C1	0.24	47.34	62.87	15.53	10	1410
S3_C1	C1	0.12	43.90	58.58	14.68	10	1410
S4_C1	C1	0.73	53.35	67.24	13.89	10	1410
S5_C1	C1	1.63	37.56	60.53	22.97	10	1410
S6_C1	C1	0.53	37.75	61.90	24.15	10	1410
S7_C1	C1	0.26	43.81	58.99	15.18	10	1410
S8_C1	C1	0.25	43.24	59.77	16.53	10	1410
S9_C1	C1	0.38	46.25	61.58	15.33	10	1410
S1_C2	C2	0.06	45.67	52.47	6.80	10	1410
S10_C2	C2	0.30	49.12	64.58	15.46	10	1410
S11_C2	C2	0.14	52.31	67.95	15.64	10	1410
S12_C2	C2	0.21	46.58	60.54	13.96	10	1410
S13_C2	C2	0.26	49.28	68.11	18.83	10	1410
S14_C2	C2	0.24	47.82	62.53	14.71	10	1410
S15_C2	C2	0.22	35.99	53.73	17.74	10	1410
S16_C2	C2	0.55	43.71	62.81	19.10	10	1410
S17_C2	C2	0.26	50.15	67.94	17.79	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S18_C2	C2	0.41	46.74	63.85	17.11	10	1410
S19_C2	C2	0.18	42.61	56.39	13.78	10	1410
S2_C2	C2	0.03	52.89	52.89	0.00	10	10
S20_C2	C2	0.55	44.24	66.02	21.78	10	1410
S21_C2	C2	0.07	42.21	54.32	12.11	10	1410
S22_C2	C2	0.43	44.89	61.92	17.03	10	1410
S23_C2	C2	0.19	45.82	63.18	17.36	10	1410
S24_C2	C2	0.06	47.67	63.37	15.70	10	1410
S25_C2	C2	0.16	44.50	62.76	18.26	10	1410
S26_C2	C2	0.09	44.14	60.47	16.33	10	1410
S27_C2	C2	0.85	43.26	65.15	21.89	10	1410
S28_C2	C2	0.21	46.53	62.33	15.80	10	1410
S29_C2	C2	0.06	45.39	61.20	15.81	10	1410
S3_C2	C2	0.24	54.63	69.60	14.97	10	1410
S30_C2	C2	0.18	43.27	57.81	14.54	10	1410
S31_C2	C2	0.30	46.77	59.40	12.63	10	1410
S32_C2	C2	0.33	38.33	65.40	27.07	10	1410
S33_C2	C2	0.29	51.69	65.84	14.15	10	1410
S34_C2	C2	0.90	42.83	68.50	25.67	10	1410
S35_C2	C2	0.45	47.77	62.32	14.55	10	1410
S36_C2	C2	0.53	48.61	65.54	16.93	10	1410
S37_C2	C2	0.23	63.23	67.35	4.12	10	1410
S38_C2	C2	0.50	50.37	55.40	5.03	10	1410
S4_C2	C2	0.65	43.14	65.73	22.59	10	1410
S5_C2	C2	0.13	47.59	62.09	14.50	10	1410
S6_C2	C2	0.54	37.26	60.15	22.89	10	1410
S7_C2	C2	0.15	45.51	58.57	13.06	10	1410
S8_C2	C2	0.25	49.05	64.71	15.66	10	1410
S9_C2	C2	0.57	37.62	60.28	22.66	10	1410
S1_C3	C3	0.33	46.15	62.58	16.43	10	1410
S10_C3	C3	0.70	41.16	64.88	23.72	10	1410
S2_C3	C3	0.07	52.48	52.63	0.15	10	1410
S3_C3	C3	0.81	41.40	62.76	21.36	10	1410
S4_C3	C3	0.29	41.64	61.92	20.28	10	1410
S5_C3	C3	0.21	54.74	70.13	15.39	10	1410
S6_C3	C3	0.25	48.48	65.35	16.87	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	**Sub Network**	**Area (ha)**	**Imperviousness (%)**			**Pervious Depression Storage (mm)**	
			Ex Cond	**As of Right Cond**	**Difference**	**Ex Cond**	**As of Right Cond**
S7_C3	C3	0.20	47.68	62.21	14.53	10	1410
S8_C3	C3	0.40	46.60	56.38	9.78	10	1410
S9_C3	C3	0.36	41.16	61.54	20.38	10	1410
S1_C4	C4	0.41	29.15	42.68	13.53	10	1410
S10_C4	C4	0.23	47.03	64.95	17.92	10	1410
S11_C4	C4	0.27	49.02	64.56	15.54	10	1410
S12_C4	C4	0.32	56.94	73.05	16.11	10	1410
S13_C4	C4	0.37	47.29	60.71	13.42	10	1410
S2_C4	C4	1.24	36.10	59.52	23.42	10	1410
S3_C4	C4	0.29	39.51	65.76	26.25	10	1410
S5_C4	C4	0.59	39.82	63.85	24.03	10	1410
S6_C4	C4	0.08	54.61	69.52	14.91	10	1410
S7_C4	C4	0.15	50.96	70.17	19.21	10	1410
S8_C4	C4	0.24	42.69	53.80	11.11	10	1410
S9_C4	C4	0.14	44.88	56.80	11.92	10	1410
S1_C5	C5	0.17	46.13	56.19	10.06	10	1410
S2_C5	C5	0.10	51.45	61.79	10.34	10	1410
S3_C5	C5	0.57	39.27	60.40	21.13	10	1410
S4_C5	C5	0.60	36.25	61.91	25.66	10	1410
S5_C5	C5	0.20	50.66	64.06	13.40	10	1410
S6_C5	C5	0.34	39.25	65.30	26.05	10	1410
S7_C5	C5	0.15	42.37	56.13	13.76	10	1410
S1_C6	C6	0.15	47.80	52.53	4.73	10	1410
S10_C6	C6	0.09	45.26	58.81	13.55	10	1410
S11_C6	C6	0.30	50.89	67.31	16.42	10	1410
S12_C6	C6	1.06	39.09	58.48	19.39	10	1410
S2_C6	C6	0.98	45.29	68.42	23.13	10	1410
S3_C6	C6	0.10	46.62	52.45	5.83	10	1410
S4_C6	C6	0.23	45.87	62.43	16.56	10	1410
S5_C6	C6	0.01	52.89	52.89	0.00	10	10
S6_C6	C6	0.22	49.93	63.64	13.71	10	1410
S7_C6	C6	0.19	47.16	61.06	13.90	10	1410
S8_C6	C6	0.23	57.69	72.02	14.33	10	1410
S9_C6	C6	0.07	48.33	61.97	13.64	10	1410
S1_D1	D1	0.32	52.85	52.85	0.00	10	10
S10_D1	D1	0.39	45.03	59.51	14.48	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S11_D1	D1	0.44	40.54	56.67	16.13	10	1410
S12_D1	D1	0.28	38.03	51.43	13.40	10	1410
S13_D1	D1	0.14	54.34	62.31	7.97	10	1410
S14_D1	D1	0.48	49.60	58.72	9.12	10	1410
S15_D1	D1	0.88	46.84	59.81	12.97	10	1410
S16_D1	D1	0.13	46.01	55.82	9.81	10	1410
S17_D1	D1	0.14	45.47	56.26	10.79	10	1410
S18_D1	D1	0.23	49.74	59.26	9.52	10	1410
S19_D1	D1	0.25	48.51	59.09	10.58	10	1410
S2_D1	D1	0.44	52.21	61.75	9.54	10	1410
S20_D1	D1	0.34	38.13	52.27	14.14	10	1410
S21_D1	D1	0.15	50.13	59.57	9.44	10	1410
S22_D1	D1	0.24	49.19	57.89	8.70	10	1410
S23_D1	D1	0.26	48.56	57.98	9.42	10	1410
S24_D1	D1	0.26	42.51	55.38	12.87	10	1410
S25_D1	D1	0.27	47.46	57.24	9.78	10	1410
S26_D1	D1	0.31	49.11	58.63	9.52	10	1410
S27_D1	D1	0.36	55.53	65.85	10.32	10	1410
S28_D1	D1	0.25	39.52	51.76	12.24	10	1410
S29_D1	D1	0.74	45.41	59.59	14.18	10	1410
S3_D1	D1	0.05	52.91	60.52	7.61	10	1410
S30_D1	D1	0.87	39.86	54.47	14.61	10	1410
S31_D1	D1	0.35	45.93	56.24	10.31	10	1410
S32_D1	D1	0.80	44.69	58.52	13.83	10	1410
S33_D1	D1	0.05	54.14	60.65	6.51	10	1410
S34_D1	D1	0.43	46.64	51.60	4.96	10	1410
S35_D1	D1	0.17	51.85	51.85	0.00	10	10
S36_D1	D1	0.73	47.89	55.69	7.80	10	1410
S37_D1	D1	0.49	51.16	60.65	9.49	10	1410
S38_D1	D1	0.67	48.88	61.74	12.86	10	1410
S39_D1	D1	0.15	52.54	60.71	8.17	10	1410
S4_D1	D1	0.09	48.60	59.67	11.07	10	1410
S40_D1	D1	0.25	53.30	62.70	9.40	10	1410
S41_D1	D1	0.15	53.36	59.16	5.80	10	1410
S42_D1	D1	0.70	38.49	56.18	17.69	10	1410
S43_D1	D1	0.34	48.86	57.70	8.84	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S44_D1	D1	0.51	50.42	59.87	9.45	10	1410
S45_D1	D1	0.32	51.30	61.49	10.19	10	1410
S46_D1	D1	0.15	49.34	55.61	6.27	10	1410
S47_D1	D1	0.17	49.44	54.38	4.94	10	1410
S48_D1	D1	0.37	46.64	56.08	9.44	10	1410
S5_D1	D1	0.11	42.12	54.38	12.26	10	1410
S6_D1	D1	0.15	54.51	63.92	9.41	10	1410
S7_D1	D1	0.04	47.97	50.96	2.99	10	1410
S8_D1	D1	0.06	40.91	54.62	13.71	10	1410
S9_D1	D1	0.05	52.24	57.98	5.74	10	1410
S1_D2	D2	0.19	47.80	56.52	8.72	10	1410
S10_D2	D2	0.46	53.39	54.30	0.91	10	1410
S11_D2	D2	0.38	43.58	55.05	11.47	10	1410
S12_D2	D2	1.59	54.04	55.09	1.05	10	1410
S13_D2	D2	1.06	56.70	62.29	5.59	10	1410
S14_D2	D2	0.36	48.88	58.21	9.33	10	1410
S15_D2	D2	0.32	48.15	57.47	9.32	10	1410
S16_D2	D2	0.35	49.72	60.17	10.45	10	1410
S17_D2	D2	0.31	46.47	54.99	8.52	10	1410
S18_D2	D2	0.13	44.10	52.09	7.99	10	1410
S19_D2	D2	0.78	44.21	59.40	15.19	10	1410
S2_D2	D2	0.27	45.99	54.55	8.56	10	1410
S20_D2	D2	0.53	47.96	62.22	14.26	10	1410
S21_D2	D2	0.24	47.05	59.00	11.95	10	1410
S22_D2	D2	0.88	46.13	60.77	14.64	10	1410
S23_D2	D2	0.19	50.13	59.16	9.03	10	1410
S24_D2	D2	0.35	46.97	60.97	14.00	10	1410
S25_D2	D2	0.26	55.60	67.97	12.37	10	1410
S26_D2	D2	0.64	45.04	60.54	15.50	10	1410
S27_D2	D2	0.17	40.93	51.11	10.18	10	1410
S28_D2	D2	0.19	51.05	60.37	9.32	10	1410
S29_D2	D2	0.41	49.45	63.11	13.66	10	1410
S3_D2	D2	0.55	44.23	55.71	11.48	10	1410
S30_D2	D2	0.19	45.22	53.41	8.19	10	1410
S31_D2	D2	0.77	41.59	56.41	14.82	10	1410
S32_D2	D2	0.11	46.84	54.37	7.53	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	**Sub Network**	**Area (ha)**	**Imperviousness (%)**			**Pervious Depression Storage (mm)**	
			Ex Cond	**As of Right Cond**	**Difference**	**Ex Cond**	**As of Right Cond**
S33_D2	D2	0.17	48.30	57.84	9.54	10	1410
S34_D2	D2	0.19	50.44	60.91	10.47	10	1410
S35_D2	D2	0.15	47.18	55.50	8.32	10	1410
S36_D2	D2	0.70	43.28	58.36	15.08	10	1410
S37_D2	D2	0.18	52.27	62.65	10.38	10	1410
S38_D2	D2	0.23	49.24	58.73	9.49	10	1410
S39_D2	D2	0.28	46.25	55.79	9.54	10	1410
S4_D2	D2	0.27	48.16	56.21	8.05	10	1410
S40_D2	D2	0.18	56.27	65.63	9.36	10	1410
S41_D2	D2	0.19	52.87	63.08	10.21	10	1410
S42_D2	D2	0.53	48.41	59.39	10.98	10	1410
S43_D2	D2	0.20	50.35	60.14	9.79	10	1410
S44_D2	D2	0.49	46.29	61.07	14.78	10	1410
S45_D2	D2	0.38	45.09	53.63	8.54	10	1410
S46_D2	D2	0.42	63.49	65.72	2.23	10	1410
S47_D2	D2	0.21	44.05	55.96	11.91	10	1410
S48_D2	D2	0.21	46.18	55.94	9.76	10	1410
S49_D2	D2	0.32	51.61	58.18	6.57	10	1410
S5_D2	D2	0.87	47.67	62.46	14.79	10	1410
S50_D2	D2	0.37	48.25	55.96	7.71	10	1410
S51_D2	D2	0.45	46.39	61.16	14.77	10	1410
S52_D2	D2	0.68	47.78	61.87	14.09	10	1410
S53_D2	D2	0.30	46.94	56.16	9.22	10	1410
S6_D2	D2	0.14	45.79	52.14	6.35	10	1410
S7_D2	D2	0.24	43.31	52.81	9.50	10	1410
S8_D2	D2	1.58	57.55	61.72	4.17	10	1410
S9_D2	D2	0.40	60.18	60.18	0.00	10	10
S1_D3	D3	0.15	53.95	56.68	2.73	10	1410
S2_D3	D3	0.12	68.13	68.13	0.00	10	10
S3_D3	D3	0.39	59.92	62.93	3.01	10	1410
S4_D3	D3	0.26	49.11	56.85	7.74	10	1410
S5_D3	D3	0.19	52.55	62.54	9.99	10	1410
S6_D3	D3	0.23	48.30	57.57	9.27	10	1410
S1_E1	E1	0.10	44.15	57.31	13.16	10	1410
S2_E1	E1	0.56	48.89	66.86	17.97	10	1410
S3_E1	E1	0.16	48.11	63.48	15.37	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters

Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S4_E1	E1	0.14	53.40	65.44	12.04	10	1410
S1_E2	E2	1.44	37.89	64.04	26.15	10	1410
S2_E2	E2	0.15	59.21	76.73	17.52	10	1410
S3_E2	E2	0.10	41.39	58.79	17.40	10	1410
S4_E2	E2	0.98	43.64	71.03	27.39	10	1410
S5_E2	E2	0.38	51.24	66.82	15.58	10	1410
S6_E2	E2	0.35	48.31	64.40	16.09	10	1410
S7_E2	E2	0.34	47.47	65.84	18.37	10	1410
S1_E3	E3	0.11	47.69	48.91	1.22	10	1410
S2_E3	E3	0.45	51.17	65.98	14.81	10	1410
S3_E3	E3	0.33	53.38	71.77	18.39	10	1410
S1_E4	E4	1.53	29.99	52.45	22.46	10	1410
S2_E4	E4	0.30	49.87	66.90	17.03	10	1410
S3_E4	E4	0.56	37.65	49.73	12.08	10	1410
S1_E5	E5	0.57	35.31	59.31	24.00	10	1410
S2_E5	E5	0.15	47.66	66.99	19.33	10	1410
S3_E5	E5	0.27	35.36	52.31	16.95	10	1410
S4_E5	E5	0.08	48.83	64.55	15.72	10	1410
S1_E6	E6	0.57	40.83	64.60	23.77	10	1410
S2_E6	E6	0.48	44.09	64.85	20.76	10	1410
S1_E7	E7	0.49	52.16	52.16	0.00	10	10
S10_E7	E7	1.61	31.97	60.89	28.92	10	1410
S11_E7	E7	0.65	40.62	63.56	22.94	10	1410
S12_E7	E7	0.61	37.52	55.36	17.84	10	1410
S13_E7	E7	0.45	40.15	57.07	16.92	10	1410
S14_E7	E7	1.07	44.28	64.64	20.36	10	1410
S15_E7	E7	0.58	39.80	61.85	22.05	10	1410
S16_E7	E7	0.46	53.08	71.56	18.48	10	1410
S17_E7	E7	0.34	45.32	60.85	15.53	10	1410
S18_E7	E7	0.37	38.55	61.90	23.35	10	1410
S19_E7	E7	0.62	36.11	58.28	22.17	10	1410
S2_E7	E7	0.17	52.43	52.69	0.26	10	1410
S20_E7	E7	1.44	44.39	61.78	17.39	10	1410
S21_E7	E7	0.28	51.90	69.05	17.15	10	1410
S22_E7	E7	0.35	51.90	69.51	17.61	10	1410
S23_E7	E7	0.09	42.04	54.43	12.39	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S24_E7	E7	0.16	53.02	69.14	16.12	10	1410
S25_E7	E7	0.30	50.94	65.44	14.50	10	1410
S26_E7	E7	0.12	47.59	63.38	15.79	10	1410
S27_E7	E7	0.23	57.13	65.78	8.65	10	1410
S28_E7	E7	0.20	54.33	74.36	20.03	10	1410
S29_E7	E7	0.30	48.96	67.09	18.13	10	1410
S3_E7	E7	0.54	48.79	55.40	6.61	10	1410
S30_E7	E7	0.52	49.37	67.70	18.33	10	1410
S31_E7	E7	1.40	38.10	64.57	26.47	10	1410
S32_E7	E7	0.30	48.44	64.17	15.73	10	1410
S33_E7	E7	0.42	43.95	63.26	19.31	10	1410
S34_E7	E7	0.20	47.99	61.83	13.84	10	1410
S35_E7	E7	0.17	43.81	63.29	19.48	10	1410
S36_E7	E7	0.20	49.42	64.13	14.71	10	1410
S37_E7	E7	0.14	50.69	66.52	15.83	10	1410
S38_E7	E7	0.12	49.15	66.16	17.01	10	1410
S39_E7	E7	0.18	53.89	74.46	20.57	10	1410
S4_E7	E7	0.63	50.77	58.52	7.75	10	1410
S40_E7	E7	0.81	36.78	63.64	26.86	10	1410
S41_E7	E7	0.39	49.75	70.35	20.60	10	1410
S42_E7	E7	0.31	50.11	67.86	17.75	10	1410
S5_E7	E7	0.50	43.72	65.56	21.84	10	1410
S6_E7	E7	0.40	42.91	62.93	20.02	10	1410
S7_E7	E7	2.39	32.76	61.69	28.93	10	1410
S8_E7	E7	0.44	47.37	65.19	17.82	10	1410
S9_E7	E7	0.42	55.83	68.53	12.70	10	1410
S1_F1	F1	0.32	38.82	54.66	15.84	10	1210
S1_F5	F1	0.12	43.66	71.16	27.50	10	1210
S10_F1	F1	0.71	44.32	64.69	20.37	10	1210
S11_F1	F1	0.78	47.26	67.85	20.59	10	1210
S12_F1	F1	0.55	29.20	61.45	32.25	10	1210
S13_F1	F1	0.22	44.75	68.14	23.39	10	1210
S14_F1	F1	0.41	31.30	63.54	32.24	10	1210
S15_F1	F1	0.51	42.64	62.86	20.22	10	1210
S16_F1	F1	0.89	45.27	64.48	19.21	10	1210
S17_F1	F1	0.83	37.68	69.78	32.10	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S18_F1	F1	0.09	51.58	62.42	10.84	10	1210
S19_F1	F1	0.23	52.45	74.15	21.70	10	1210
S2_F1	F1	0.51	41.15	62.27	21.12	10	1210
S20_F1	F1	0.09	52.02	52.02	0.00	10	10
S21_F1	F1	0.13	41.11	41.11	0.00	10	10
S22_F1	F1	0.22	41.04	41.04	0.00	10	10
S3_F1	F1	0.13	50.23	62.45	12.22	10	1210
S4_F1	F1	0.31	44.47	59.97	15.50	10	1210
S5_F1	F1	1.26	37.32	65.89	28.57	10	1210
S6_F1	F1	0.23	49.22	68.41	19.19	10	1210
S7_F1	F1	0.47	42.85	62.98	20.13	10	1210
S8_F1	F1	0.75	28.75	60.95	32.20	10	1210
S9_F1	F1	0.18	57.77	79.56	21.79	10	1210
S1_F2	F2	0.93	23.35	34.71	11.36	10	1210
S10_F2	F2	1.76	41.26	58.30	17.04	10	1210
S11_F2	F2	1.14	38.28	66.07	27.79	10	1210
S12_F2	F2	0.16	38.01	65.15	27.14	10	1210
S13_F2	F2	0.28	44.77	65.36	20.59	10	1210
S14_F2	F2	0.43	50.49	68.06	17.57	10	1210
S2_F2	F2	0.93	38.41	62.46	24.05	10	1210
S3_F2	F2	1.02	37.59	56.95	19.36	10	1210
S4_F2	F2	0.25	31.54	62.93	31.39	10	1210
S5_F2	F2	1.61	35.19	65.33	30.14	10	1210
S6_F2	F2	1.62	15.09	15.41	0.32	10	1210
S7_F2	F2	0.23	26.22	45.99	19.77	10	1210
S8_F2	F2	0.10	49.94	53.22	3.28	10	1210
S9_F2	F2	0.80	45.64	66.65	21.01	10	1210
S1_F3	F3	0.22	41.18	66.23	25.05	10	1210
S2_F3	F3	0.49	46.61	67.11	20.50	10	1210
S3_F3	F3	0.93	44.03	60.12	16.09	10	1210
S1_F4	F4	0.10	54.10	64.88	10.78	10	1210
S10_F4	F4	0.03	52.89	52.89	0.00	10	10
S11_F4	F4	0.17	39.86	60.98	21.12	10	1210
S12_F4	F4	0.29	47.88	66.66	18.78	10	1210
S13_F4	F4	0.35	37.20	60.65	23.45	10	1210
S14_F4	F4	0.62	42.77	66.62	23.85	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S15_F4	F4	0.27	45.09	62.69	17.60	10	1210
S16_F4	F4	0.98	35.34	67.58	32.24	10	1210
S17_F4	F4	0.28	36.01	57.28	21.27	10	1210
S18_F4	F4	0.05	33.47	54.94	21.47	10	1210
S19_F4	F4	0.32	46.33	68.28	21.95	10	1210
S2_F4	F4	0.79	48.45	66.87	18.42	10	1210
S20_F4	F4	0.17	42.76	60.55	17.79	10	1210
S21_F4	F4	0.69	41.05	68.56	27.51	10	1210
S22_F4	F4	0.17	45.48	66.68	21.20	10	1210
S23_F4	F4	1.13	36.22	67.80	31.58	10	1210
S24_F4	F4	0.24	41.99	60.36	18.37	10	1210
S25_F4	F4	0.60	39.99	72.13	32.14	10	1210
S26_F4	F4	0.42	46.76	63.59	16.83	10	1210
S27_F4	F4	0.96	41.18	70.66	29.48	10	1210
S28_F4	F4	0.53	44.17	67.35	23.18	10	1210
S29_F4	F4	0.40	35.53	67.08	31.55	10	1210
S3_F4	F4	0.29	47.81	66.40	18.59	10	1210
S30_F4	F4	0.17	52.76	68.95	16.19	10	1210
S31_F4	F4	0.32	52.43	73.62	21.19	10	1210
S32_F4	F4	0.30	44.67	68.98	24.31	10	1210
S33_F4	F4	0.11	50.67	71.55	20.88	10	1210
S34_F4	F4	0.13	45.85	66.77	20.92	10	1210
S35_F4	F4	0.61	42.97	56.25	13.28	10	1210
S36_F4	F4	0.14	46.38	53.59	7.21	10	1210
S37_F4	F4	0.59	44.90	66.60	21.70	10	1210
S38_F4	F4	0.76	49.60	73.45	23.85	10	1210
S39_F4	F4	0.13	48.40	63.83	15.43	10	1210
S4_F4	F4	0.18	49.72	68.33	18.61	10	1210
S40_F4	F4	0.21	48.33	68.24	19.91	10	1210
S41_F4	F4	0.40	41.22	68.40	27.18	10	1210
S42_F4	F4	0.23	46.15	70.06	23.91	10	1210
S43_F4	F4	0.62	47.57	67.88	20.31	10	1210
S45_F4	F4	0.30	50.63	74.74	24.11	10	1210
S46_F4	F4	0.45	40.26	65.43	25.17	10	1210
S47_F4	F4	0.01	52.89	52.89	0.00	10	10
S5_F4	F4	0.11	50.71	62.69	11.98	10	1210

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S6_F4	F4	1.16	41.13	67.26	26.13	10	1210
S7_F4	F4	0.18	43.17	64.69	21.52	10	1210
S8_F4	F4	1.04	30.28	62.46	32.18	10	1210
S9_F4	F4	0.08	41.12	61.38	20.26	10	1210
S2_F5	F5	0.84	44.30	59.93	15.63	10	1210
S3_F5	F5	0.20	44.92	52.41	7.49	10	1210
S4_F5	F5	1.04	51.80	51.80	0.00	10	10
S5_F5	F5	0.93	44.19	44.19	0.00	10	10
S6_F5	F5	2.08	51.20	51.20	0.00	10	10
S1_G1	G1	0.99	46.40	53.13	6.73	10	1410
S2_G1	G1	0.22	45.73	64.57	18.84	10	1410
S3_G1	G1	0.16	45.93	65.38	19.45	10	1410
S4_G1	G1	0.26	51.65	72.49	20.84	10	1410
S5_G1	G1	0.24	43.94	63.66	19.72	10	1410
S6_G1	G1	0.65	46.11	64.34	18.23	10	1410
S7_G1	G1	0.74	43.45	63.51	20.06	10	1410
S1_G2	G2	0.24	44.58	57.74	13.16	10	1410
S1_G3	G3	0.09	51.63	67.51	15.88	10	1410
S10_G3	G3	0.37	46.60	66.16	19.56	10	1410
S11_G3	G3	0.40	39.59	63.10	23.51	10	1410
S12_G3	G3	0.78	35.03	35.34	0.31	10	1410
S13_G3	G3	1.24	37.75	59.57	21.82	10	1410
S14_G3	G3	1.42	38.78	65.53	26.75	10	1410
S15_G3	G3	0.51	46.99	64.21	17.22	10	1410
S16_G3	G3	0.53	46.16	62.62	16.46	10	1410
S17_G3	G3	0.34	44.77	44.77	0.00	10	10
S18_G3	G3	1.03	40.86	40.86	0.00	10	10
S19_G3	G3	0.99	35.91	61.49	25.58	10	1410
S2_G3	G3	0.52	40.17	42.23	2.06	10	1410
S20_G3	G3	1.22	39.87	43.41	3.54	10	1410
S21_G3	G3	0.44	41.14	41.14	0.00	10	10
S3_G3	G3	0.74	45.96	67.50	21.54	10	1410
S4_G3	G3	0.96	47.04	70.10	23.06	10	1410
S5_G3	G3	0.24	47.92	70.64	22.72	10	1410
S6_G3	G3	0.43	49.71	65.84	16.13	10	1410
S7_G3	G3	0.78	49.56	68.10	18.54	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S8_G3	G3	0.08	49.51	64.49	14.98	10	1410
S9_G3	G3	0.15	46.26	67.33	21.07	10	1410
S1_G4	G4	0.53	35.32	51.24	15.92	10	1410
S10_G4	G4	0.48	41.16	60.74	19.58	10	1410
S11_G4	G4	0.96	36.06	64.12	28.06	10	1410
S12_G4	G4	0.25	41.40	61.80	20.40	10	1410
S13_G4	G4	0.79	42.11	63.82	21.71	10	1410
S14_G4	G4	1.72	35.07	61.53	26.46	10	1410
S15_G4	G4	0.20	41.78	60.65	18.87	10	1410
S16_G4	G4	0.25	41.62	62.80	21.18	10	1410
S17_G4	G4	0.10	41.83	60.24	18.41	10	1410
S18_G4	G4	1.23	36.70	49.41	12.71	10	1410
S19_G4	G4	0.73	40.61	64.35	23.74	10	1410
S2_G4	G4	0.28	42.13	59.03	16.90	10	1410
S20_G4	G4	0.83	37.22	38.90	1.68	10	1410
S21_G4	G4	0.40	41.34	62.47	21.13	10	1410
S22_G4	G4	0.38	38.99	52.18	13.19	10	1410
S23_G4	G4	0.13	46.22	61.43	15.21	10	1410
S25_G4	G4	0.64	39.48	63.69	24.21	10	1410
S26_G4	G4	1.24	40.89	45.92	5.03	10	1410
S27_G4	G4	0.18	49.62	65.90	16.28	10	1410
S28_G4	G4	0.27	52.14	72.89	20.75	10	1410
S29_G4	G4	0.34	39.68	62.40	22.72	10	1410
S3_G4	G4	0.55	45.54	65.25	19.71	10	1410
S30_G4	G4	1.81	36.51	52.72	16.21	10	1410
S31_G4	G4	0.56	45.02	64.79	19.77	10	1410
S32_G4	G4	0.77	37.03	58.39	21.36	10	1410
S33_G4	G4	0.52	43.68	51.30	7.62	10	1410
S4_G4	G4	0.90	29.95	49.55	19.60	10	1410
S5_G4	G4	0.49	20.00	20.00	0.00	10	10
S6_G4	G4	0.97	20.00	20.00	0.00	10	10
S7_G4	G4	0.26	20.29	22.67	2.38	10	1410
S8_G4	G4	0.64	20.02	20.17	0.15	10	1410
S9_G4	G4	0.48	29.51	56.39	26.88	10	1410
S1_G5	G5	0.45	43.23	43.23	0.00	10	10
S10_G5	G5	0.89	36.83	36.83	0.00	10	10

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S11_G5	G5	0.59	95.01	95.01	0.00	10	10
S12_G5	G5	0.34	61.69	61.69	0.00	10	10
S13_G5	G5	0.47	43.94	64.83	20.89	10	1410
S14_G5	G5	0.14	50.93	52.98	2.05	10	1410
S2_G5	G5	0.30	43.34	43.34	0.00	10	10
S3_G5	G5	0.22	34.69	34.69	0.00	10	10
S4_G5	G5	1.13	33.09	33.09	0.00	10	10
S5_G5	G5	0.70	42.60	42.60	0.00	10	10
S6_G5	G5	1.14	20.53	20.53	0.00	10	10
S7_G5	G5	0.22	43.48	50.72	7.24	10	1410
S8_G5	G5	0.37	49.03	72.86	23.83	10	1410
S9_G5	G5	0.31	48.98	69.66	20.68	10	1410
S1_G6	G6	0.39	39.25	61.29	22.04	10	1410
S10_G6	G6	0.19	46.87	63.30	16.43	10	1410
S2_G6	G6	0.34	40.96	67.73	26.77	10	1410
S3_G6	G6	0.51	41.11	60.94	19.83	10	1410
S4_G6	G6	0.60	39.13	59.06	19.93	10	1410
S5_G6	G6	0.56	40.54	60.08	19.54	10	1410
S6_G6	G6	0.67	39.81	57.07	17.26	10	1410
S7_G6	G6	0.31	47.44	61.77	14.33	10	1410
S8_G6	G6	1.53	37.02	40.49	3.47	10	1410
S9_G6	G6	0.85	42.80	58.80	16.00	10	1410
S1_H1	H1	0.23	47.37	63.99	16.62	10	1110
S10_H1	H1	0.83	34.95	34.95	0.00	10	10
S2_H1	H1	0.44	46.75	64.79	18.04	10	1110
S3_H1	H1	0.26	48.84	66.86	18.02	10	1110
S4_H1	H1	0.31	50.48	68.76	18.28	10	1110
S5_H1	H1	0.74	41.60	62.10	20.50	10	1110
S6_H1	H1	1.02	48.38	54.71	6.33	10	1110
S7_H1	H1	0.58	47.62	66.40	18.78	10	1110
S8_H1	H1	0.66	34.91	49.53	14.62	10	1110
S9_H1	H1	0.68	28.56	43.78	15.22	10	1110
S1_I1	I1	0.10	50.71	64.40	13.69	10	1110
S2_I1	I1	0.46	42.02	61.05	19.03	10	1110
S3_I1	I1	0.31	49.08	69.72	20.64	10	1110
S4_I1	I1	0.44	37.88	58.35	20.47	10	1110

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S1_I2	I2	0.24	32.61	41.38	8.77	10	1110
S2_I2	I2	0.35	42.76	55.20	12.44	10	1110
S3_I2	I2	0.36	54.18	66.95	12.77	10	1110
S4_I2	I2	0.44	50.73	66.57	15.84	10	1110
S5_I2	I2	0.30	45.71	63.68	17.97	10	1110
S1_I3	I3	0.46	41.02	59.80	18.78	10	1110
S2_I3	I3	0.57	40.38	60.49	20.11	10	1110
S3_I3	I3	0.83	45.46	59.23	13.77	10	1110
S4_I3	I3	0.28	48.48	66.17	17.69	10	1110
S5_I3	I3	1.54	31.50	40.40	8.90	10	1110
S6_I3	I3	0.46	31.53	42.74	11.21	10	1110
S1_I4	I4	0.47	45.02	64.39	19.37	10	1110
S10_I4	I4	0.57	41.68	61.37	19.69	10	1110
S11_I4	I4	0.40	40.46	60.19	19.73	10	1110
S2_I4	I4	0.16	50.02	61.21	11.19	10	1110
S3_I4	I4	0.14	53.11	67.81	14.70	10	1110
S4_I4	I4	0.45	44.45	60.23	15.78	10	1110
S5_I4	I4	0.86	42.74	59.01	16.27	10	1110
S6_I4	I4	0.35	45.60	64.35	18.75	10	1110
S7_I4	I4	0.37	43.61	61.46	17.85	10	1110
S8_I4	I4	2.20	70.44	81.03	10.59	10	1110
S9_I4	I4	0.31	34.28	55.59	21.31	10	1110
S1_J1	J1	0.38	48.03	57.73	9.70	10	1410
S2_J1	J1	0.37	49.57	58.20	8.63	10	1410
S3_J1	J1	1.02	39.76	60.90	21.14	10	1410
S4_J1	J1	0.26	47.28	61.19	13.91	10	1410
S5_J1	J1	0.70	43.42	45.17	1.75	10	1410
S6_J1	J1	0.32	44.29	59.27	14.98	10	1410
S7_J1	J1	0.36	45.13	45.13	0.00	10	10
S8_J1	J1	0.44	45.60	61.74	16.14	10	1410
S1_J2	J2	0.96	48.30	58.72	10.42	10	1410
S10_J2	J2	0.21	51.55	63.32	11.77	10	1410
S11_J2	J2	0.79	41.15	64.91	23.76	10	1410
S12_J2	J2	0.80	46.70	59.87	13.17	10	1410
S13_J2	J2	0.43	43.62	51.39	7.77	10	1410
S2_J2	J2	0.16	43.10	53.36	10.26	10	1410

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S3_J2	J2	0.14	43.96	54.64	10.68	10	1410
S4_J2	J2	0.10	39.25	39.25	0.00	10	10
S5_J2	J2	0.84	41.98	64.99	23.01	10	1410
S6_J2	J2	0.87	39.69	58.51	18.82	10	1410
S7_J2	J2	0.52	46.31	60.17	13.86	10	1410
S8_J2	J2	0.14	45.85	60.49	14.64	10	1410
S9_J2	J2	0.17	48.60	63.59	14.99	10	1410
S1_J3	J3	0.31	45.47	61.30	15.83	10	1410
S2_J3	J3	0.22	52.47	66.26	13.79	10	1410
S3_J3	J3	0.19	49.75	57.44	7.69	10	1410
S4_J3	J3	0.13	42.49	53.69	11.20	10	1410
S1_K1	K1	0.39	52.94	52.94	0.00	10	10
S2_K1	K1	0.17	65.82	65.82	0.00	10	10
S1_K2	K2	0.58	60.58	60.58	0.00	10	10
S2_K2	K2	0.83	58.88	58.88	0.00	10	10
S3_K2	K2	0.52	51.22	51.22	0.00	10	10
S4_K2	K2	0.56	42.81	51.15	8.34	10	1210
S5_K2	K2	0.26	46.54	63.19	16.65	10	1210
S6_K2	K2	0.29	43.61	58.40	14.79	10	1210
S7_K2	K2	0.32	47.45	64.38	16.93	10	1210
S8_K2	K2	0.60	43.80	64.43	20.63	10	1210
S1_K3	K3	0.94	45.86	62.83	16.97	10	1210
S10_K3	K3	0.68	44.37	67.86	23.49	10	1210
S11_K3	K3	0.73	42.17	61.89	19.72	10	1210
S12_K3	K3	0.27	47.35	66.22	18.87	10	1210
S2_K3	K3	0.43	40.23	59.68	19.45	10	1210
S3_K3	K3	0.12	35.52	48.00	12.48	10	1210
S4_K3	K3	0.16	43.25	58.82	15.57	10	1210
S5_K3	K3	0.23	42.55	58.47	15.92	10	1210
S6_K3	K3	0.89	41.87	62.18	20.31	10	1210
S7_K5	K3	0.57	36.39	55.21	18.82	10	1210
S8_K3	K3	0.62	23.12	36.90	13.78	10	1210
S9_K3	K3	0.40	42.44	64.09	21.65	10	1210
S1_K4	K4	0.38	59.16	59.16	0.00	10	10
S2_K4	K4	0.59	65.84	65.84	0.00	10	10
S3_K4	K4	0.39	65.84	65.84	0.00	10	10

Table D.1 As of Right Conditions Subcatchment Parameters							
Subcatch Name	Sub Network	Area (ha)	Imperviousness (%)			Pervious Depression Storage (mm)	
			Ex Cond	As of Right Cond	Difference	Ex Cond	As of Right Cond
S4_K4	K4	0.14	65.84	65.84	0.00	10	10
S1_K5	K5	0.17	50.30	63.83	13.53	10	1210
S2_K5	K5	0.28	51.37	65.95	14.58	10	1210
S3_K5	K5	0.46	40.14	47.03	6.89	10	1210
S4_K5	K5	0.56	48.40	68.66	20.26	10	1210
S1_L1	L1	0.32	44.38	57.71	13.33	10	1210
S2_L1	L1	0.27	46.31	57.26	10.95	10	1210
S3_L1	L1	0.41	44.20	58.63	14.43	10	1210
S4_L1	L1	0.35	47.23	60.07	12.84	10	1210
S5_L1	L1	0.27	46.54	61.11	14.57	10	1210
S6_L1	L1	0.21	51.41	63.45	12.04	10	1210
S7_L1	L1	0.34	44.22	57.73	13.51	10	1210
S8_L1	L1	0.37	46.97	61.05	14.08	10	1210

Table D.1	Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 25 mm Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,197	10	0	99	1	0
	A2	2,713	0	0	100	0	0
	A3	150	0	0	100	0	0
	A4	2,273	0	0	100	0	0
	A5	427	0	0	100	0	0
	A6	41	0	0	100	0	0
B	B1	305	0	0	100	0	0
	B2	2,615	30	0	99	1	0
	B3	388	0	0	100	0	0
	B4	499	91	0	85	15	0
	B5	1,655	0	0	100	0	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	2,232	88	0	96	4	0
	C2	2,875	171	0	94	6	0
	C3	794	69	0	92	8	0
	C4	730	63	0	92	8	0
	C5	479	0	0	100	0	0
	C6	910	0	0	100	0	0
D	D1	4,199	0	0	100	0	0
	D2	5,259	218	0	96	4	0
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	670	0	0	100	0	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	229	0	0	100	0	0
	E6	152	0	0	100	0	0
	E7	2,981	503	55	84	14	2
F	F1	1,892	0	0	100	0	0
	F2	1,646	49	0	97	3	0
	F3	217	83	0	72	28	0
	F4	3,280	676	56	82	17	1
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	2,069	312	0	87	13	0

Table D.1 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 25 mm Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	G4	2,677	82	0	97	3	0
	G5	840	0	0	100	0	0
	G6	224	36	0	86	14	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	231	56	0	80	20	0
	I4	501	17	0	97	3	0
J	J1	799	0	0	100	0	0
	J2	1,144	66	0	95	5	0
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	880	135	0	87	13	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**57,078**	**2,860**	**111**	**95**	**5**	**0**

Table D.2 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 2-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,112	95	0	92	8	0
	A2	2,561	124	27	94	5	1
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	350	77	0	82	18	0
	A6	41	0	0	100	0	0
B	B1	253	52	0	83	17	0
	B2	2,508	107	30	95	4	1
	B3	388	0	0	100	0	0
	B4	490	101	0	83	17	0
	B5	1,505	150	0	91	9	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table D.2 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 2-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
C	C1	1,946	374	0	84	16	0
	C2	2,404	642	0	79	21	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	428	51	0	89	11	0
	C6	841	70	0	92	8	0
D	D1	3,940	259	0	94	6	0
	D2	3,791	1,686	0	69	31	0
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	165	64	0	72	28	0
	E6	74	78	0	49	51	0
	E7	2,114	1,034	392	60	29	11
F	F1	1,868	25	0	99	1	0
	F2	1,507	188	0	89	11	0
	F3	217	83	0	72	28	0
	F4	2,965	963	83	74	24	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	1,504	836	41	63	35	2
	G4	2,238	508	14	81	18	0
	G5	840	0	0	100	0	0
	G6	190	70	0	73	27	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	440	79	0	85	15	0
J	J1	773	0	25	97	0	3
	J2	1,022	122	66	85	10	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0

Table D.2 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 2-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	K3	743	269	3	73	27	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**50,712**	**8,655**	**681**	**84**	**14**	**1**

Table D.3 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,056	117	34	87	10	3
	A2	2,447	207	59	90	8	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	234	193	0	55	45	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,457	140	58	88	8	4
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,615	706	0	70	30	0
	C2	1,876	1,170	0	62	38	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,568	584	47	85	14	1
	D2	3,165	2,228	85	58	41	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0

Table D.3 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	E5	141	88	0	62	38	0
	E6	74	78	0	49	51	0
	E7	1,556	1,459	525	44	41	15
F	F1	1,625	242	25	86	13	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,417	1,511	83	60	38	2
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,160	1,134	88	49	48	4
	G4	2,033	692	33	74	25	1
	G5	748	92	0	89	11	0
	G6	169	57	34	65	22	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	135	0	74	26	0
J	J1	692	82	25	87	10	3
	J2	994	89	126	82	7	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**45,360**	**13,252**	**1,436**	**76**	**22**	**2**

Table D.4 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	931	242	34	77	20	3
	A2	1,856	551	307	68	20	11

Table D.4 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	A3	150	0	0	100	0	0
	A4	2,005	268	0	88	12	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,832	586	228	69	22	9
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,041	474	140	63	29	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	928	1,201	192	40	52	8
	C2	1,427	1,616	3	47	53	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	349	36	58	38	4
D	D1	2,417	1,435	347	58	34	8
	D2	1,148	3,533	797	21	64	15
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	447	223	0	67	33	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	630	1,303	1,606	18	37	45
F	F1	1,458	344	91	77	18	5
	F2	660	897	139	39	53	8
	F3	217	83	0	72	28	0
	F4	1,721	1,788	502	43	45	13
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,593	280	21	67	12
	G4	1,508	894	357	55	32	13
	G5	717	123	0	85	15	0

Table D.4	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G6	106	85	67	41	33	26
H	H1	180	257	0	41	59	0
I	I1	329	56	0	85	15	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	148	309	62	29	60	12
J	J1	359	310	129	45	39	16
	J2	779	304	126	64	25	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	441	394	0	53	47	0
	K3	402	484	130	40	48	13
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**32,605**	**21,723**	**5,721**	**54**	**36**	**10**

Table D.5	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	983	190	34	81	16	3
	A2	2,206	436	71	81	16	3
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,122	455	69	80	17	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,327	232	96	80	14	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,529	705	86	66	30	4
	C2	1,827	1,217	2	60	40	0

Table D.5	Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year CCDP CC Storm Event						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	2,908	1,229	62	69	29	1
	D2	1,981	3,254	243	36	59	4
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,356	1,393	790	38	39	22
F	F1	1,541	326	25	81	17	1
	F2	1,012	663	20	60	39	1
	F3	217	83	0	72	28	0
	F4	1,934	1,701	377	48	42	9
	F5	91	0	0	100	0	0
G	G1	467	251	0	65	35	0
	G2	0	102	0	0	100	0
	G3	784	1,509	88	33	63	4
	G4	1,965	672	122	71	24	4
	G5	748	92	0	89	11	0
	G6	135	57	67	52	22	26
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	246	211	62	47	41	12
J	J1	536	238	25	67	30	3
	J2	945	139	126	78	11	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	643	119	73	77	14	9
	K3	617	306	93	61	30	9
	K4	323	0	0	100	0	0

Table D.5	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**40,325**	**17,095**	**2,628**	**67**	**28**	**4**

Table D.6	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	983	190	34	81	16	3
	A2	2,158	484	71	80	18	3
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,054	522	69	78	20	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,325	235	96	80	14	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,529	705	86	66	30	4
	C2	1,827	1,217	2	60	40	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	2,908	1,229	62	69	29	1
	D2	1,981	3,254	243	36	59	4
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0

Table D.6 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	E7	1,356	1,393	790	38	39	22
F	F1	1,541	326	25	81	17	1
	F2	1,012	663	20	60	39	1
	F3	217	83	0	72	28	0
	F4	1,934	1,701	377	48	42	9
	F5	91	0	0	100	0	0
G	G1	467	251	0	65	35	0
	G2	0	102	0	0	100	0
	G3	784	1,509	88	33	63	4
	G4	1,965	672	122	71	24	4
	G5	748	92	0	89	11	0
	G6	135	57	67	52	22	26
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	246	211	62	47	41	12
J	J1	536	237	25	67	30	3
	J2	945	139	126	78	11	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	716	119	0	86	14	0
	K3	603	320	93	59	31	9
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**40,268**	**17,226**	**2,555**	**67**	**29**	**4**

Table D.7 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	983	190	34	81	16	3
	A2	2,228	422	64	82	16	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0

Table D.7	Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year UWO CC Storm Event						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,194	383	69	83	14	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,327	232	96	80	14	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,550	771	0	67	33	0
	C2	1,827	1,219	0	60	40	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,331	806	62	79	19	1
	D2	2,383	2,851	243	44	52	4
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,405	1,345	790	40	38	22
F	F1	1,541	326	25	81	17	1
	F2	1,179	496	20	70	29	1
	F3	217	83	0	72	28	0
	F4	2,393	1,299	320	60	32	8
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,086	1,207	88	46	51	4
	G4	2,033	604	122	74	22	4
	G5	748	92	0	89	11	0
	G6	135	90	34	52	35	13
H	H1	437	0	0	100	0	0

Table D.7	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 5-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	246	211	62	47	41	12
J	J1	640	133	25	80	17	3
	J2	959	124	126	79	10	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0
	K3	617	340	59	61	33	6
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**42,707**	**15,005**	**2,336**	**71**	**25**	**4**

Table D.8	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	694	479	34	57	40	3
	A2	1,487	832	395	55	31	15
	A3	150	0	0	100	0	0
	A4	1,681	535	57	74	24	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,572	707	367	59	27	14
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,006	499	150	61	30	9
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,443	287	25	62	12
	C2	1,128	1,915	3	37	63	0
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0

Table D.8 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year CCDP CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	C5	315	83	81	66	17	17
	C6	510	247	153	56	27	17
D	D1	1,996	1,651	552	48	39	13
	D2	898	2,376	2,204	16	43	40
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	318	330	22	47	49	3
	E3	265	35	24	82	11	8
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,000	2,093	13	28	59
F	F1	981	771	140	52	41	7
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,437	1,794	780	36	45	19
	F5	60	31	0	66	34	0
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	263	1,577	541	11	66	23
	G4	989	1,059	711	36	38	26
	G5	715	44	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	120	288	21	23	56
J	J1	82	430	286	10	54	36
	J2	605	403	202	50	33	17
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	350	432	54	42	52	6
	K3	259	538	219	26	53	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0

Table D.8	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
Total		**26,349**	**23,702**	**9,998**	**44**	**39**	**17**

Table D.9	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	931	242	34	77	20	3
	A2	1,776	598	340	65	22	13
	A3	150	0	0	100	0	0
	A4	1,723	494	57	76	22	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,587	831	228	60	31	9
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,008	507	140	61	31	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	861	1,188	271	37	51	12
	C2	1,304	1,740	3	43	57	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	315	70	58	35	8
D	D1	2,272	1,581	347	54	38	8
	D2	1,148	2,849	1,481	21	52	27
	D3	458	0	0	100	0	0
E	E1	107	194	0	36	64	0
	E2	337	311	22	50	46	3
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	495	1,296	1,749	14	37	49
F	F1	1,189	563	140	63	30	7

Table D.9 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	F2	641	915	139	38	54	8
	F3	133	166	0	45	55	0
	F4	1,569	1,903	540	39	47	13
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,451	422	21	61	18
	G4	1,092	1,208	459	40	44	17
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	148	253	117	29	49	23
J	J1	163	439	196	20	55	25
	J2	687	381	141	57	32	12
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6
	K3	293	503	219	29	50	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	1,059	0	0	100	0	0
Total		**29,728**	**22,858**	**7,463**	**50**	**38**	**12**

Table D.10 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	660	513	34	55	43	3
	A2	1,254	856	604	46	32	22
	A3	150	0	0	100	0	0
	A4	1,531	584	158	67	26	7
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0

Table D.10 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
B	B1	110	144	52	36	47	17
	B2	1,466	713	467	55	27	18
	B3	254	134	0	65	35	0
	B4	451	77	62	76	13	10
	B5	1,006	343	306	61	21	18
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,335	395	25	58	17
	C2	979	1,943	124	32	64	4
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0
	C5	266	132	81	56	27	17
	C6	419	255	237	46	28	26
D	D1	1,491	1,957	751	36	47	18
	D2	816	2,268	2,394	15	41	44
	D3	402	56	0	88	12	0
E	E1	58	242	0	19	81	0
	E2	265	351	55	39	52	8
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	416	1,031	2,093	12	29	59
F	F1	854	631	408	45	33	22
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,210	1,838	964	30	46	24
	F5	44	0	47	49	0	51
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	200	1,517	664	8	64	28
	G4	813	903	1,043	29	33	38
	G5	638	108	94	76	13	11
	G6	52	119	89	20	46	34
H	H1	78	359	0	18	82	0
I	I1	206	180	0	53	47	0
	I2	523	19	0	97	3	0

Table D.10	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - 100-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	I3	191	97	0	66	34	0
	I4	73	157	288	14	30	56
J	J1	57	248	494	7	31	62
	J2	449	530	230	37	44	19
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	239	511	86	29	61	10
	K3	190	560	265	19	55	26
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	897	161	0	85	15	0
Total		**23,469**	**23,958**	**12,622**	**39**	**40**	**21**

Table D.11	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Hamilton 2009 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	864	310	34	72	26	3
	A2	1,776	630	307	65	23	11
	A3	150	0	0	100	0	0
	A4	1,723	494	57	76	22	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,587	759	300	60	29	11
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,006	509	140	61	31	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	861	1,084	375	37	47	16
	C2	1,286	1,757	3	42	58	0
	C3	658	205	0	76	24	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	231	153	58	25	17

Table D.11 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Hamilton 2009 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
D	D1	2,231	1,429	539	53	34	13
	D2	1,001	2,677	1,800	18	49	33
	D3	402	56	0	88	12	0
E	E1	134	166	0	45	55	0
	E2	337	311	22	50	46	3
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,067	2,025	13	30	57
F	F1	1,189	563	140	63	30	7
	F2	641	915	139	38	54	8
	F3	133	166	0	45	55	0
	F4	1,555	1,863	593	39	46	15
	F5	60	31	0	66	34	0
G	G1	170	548	0	24	76	0
	G2	0	102	0	0	100	0
	G3	509	1,451	422	21	61	18
	G4	1,176	1,124	459	43	41	17
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	120	288	21	23	56
J	J1	153	375	271	19	47	34
	J2	639	404	166	53	33	14
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	350	432	54	42	52	6
	K3	293	503	219	29	50	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**28,951**	**22,294**	**8,803**	**48**	**37**	**15**

Table D.12	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Stoney Creek 2012 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	660	513	34	55	43	3
	A2	1,254	884	576	46	33	21
	A3	150	0	0	100	0	0
	A4	1,635	581	57	72	26	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,466	812	367	55	31	14
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,006	435	214	61	26	13
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	528	1,372	421	23	59	18
	C2	1,084	1,960	3	36	64	0
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	510	247	153	56	27	17
D	D1	1,743	1,905	552	42	45	13
	D2	764	2,279	2,434	14	42	44
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	318	330	22	47	49	3
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	333	1,014	2,193	9	29	62
F	F1	981	660	252	52	35	13
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,387	1,661	964	35	41	24
	F5	44	16	31	49	17	34
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	200	1,428	753	8	60	32

Table D.12 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Stoney Creek 2012 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	G4	882	981	896	32	36	32
	G5	638	110	92	76	13	11
	G6	52	119	89	20	46	34
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	120	288	21	23	56
J	J1	57	276	465	7	35	58
	J2	473	468	268	39	39	22
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	293	489	54	35	58	6
	K3	231	457	328	23	45	32
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**24,712**	**23,543**	**11,794**	**41**	**39**	**20**

Table D.13 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Burlington 2014 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	931	242	34	77	20	3
	A2	1,923	484	307	71	18	11
	A3	150	0	0	100	0	0
	A4	2,005	268	0	88	12	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	50	52	67	16	17
	B2	1,914	573	159	72	22	6
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,135	380	140	69	23	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table D.13 Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Burlington 2014 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
C	C1	1,388	741	192	60	32	8
	C2	1,614	1,429	3	53	47	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	2,425	1,235	539	58	29	13
	D2	1,375	3,281	822	25	60	15
	D3	458	0	0	100	0	0
E	E1	194	106	0	65	35	0
	E2	463	207	0	69	31	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	699	1,020	1,820	20	29	51
F	F1	1,487	343	62	79	18	3
	F2	800	828	67	47	49	4
	F3	217	83	0	72	28	0
	F4	1,714	1,737	560	43	43	14
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,486	387	21	62	16
	G4	1,525	959	275	55	35	10
	G5	748	92	0	89	11	0
	G6	106	85	67	41	33	26
H	H1	297	140	0	68	32	0
I	I1	385	0	0	100	0	0
	I2	536	5	0	99	1	0
	I3	191	97	0	66	34	0
	I4	167	290	62	32	56	12
J	J1	341	261	196	43	33	25
	J2	796	262	151	66	22	13
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	643	192	0	77	23	0

Table D.13	**Simulated Ditch System Performance for the Uncontrolled As of Right Conditions - Burlington 2014 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	K3	456	340	219	45	34	22
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**35,016**	**18,823**	**6,210**	**58**	**31**	**10**

APPENDIX E

As-of-Right (Controlled) Conditions Simulation

Table E.1	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 25 mm Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	1,207	0	0	100	0	0
	A2	2,713	0	0	100	0	0
	A3	150	0	0	100	0	0
	A4	2,273	0	0	100	0	0
	A5	427	0	0	100	0	0
	A6	41	0	0	100	0	0
B	B1	305	0	0	100	0	0
	B2	2,646	0	0	100	0	0
	B3	388	0	0	100	0	0
	B4	529	62	0	90	10	0
	B5	1,655	0	0	100	0	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	2,232	88	0	96	4	0
	C2	2,966	80	0	97	3	0
	C3	864	0	0	100	0	0
	C4	730	63	0	92	8	0
	C5	479	0	0	100	0	0
	C6	910	0	0	100	0	0
D	D1	4,199	0	0	100	0	0
	D2	5,259	218	0	96	4	0
	D3	458	0	0	100	0	0
E	E1	244	56	0	81	19	0
	E2	670	0	0	100	0	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	229	0	0	100	0	0
	E6	152	0	0	100	0	0
	E7	3,185	355	0	90	10	0
F	F1	1,892	0	0	100	0	0
	F2	1,695	0	0	100	0	0
	F3	300	0	0	100	0	0
	F4	3,747	247	18	93	6	0
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	2,325	56	0	98	2	0

Table E.1	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 25 mm Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G4	2,759	0	0	100	0	0
	G5	840	0	0	100	0	0
	G6	259	0	0	100	0	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	231	56	0	80	20	0
	I4	519	0	0	100	0	0
J	J1	799	0	0	100	0	0
	J2	1,209	0	0	100	0	0
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	1,015	0	0	100	0	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**58,713**	**1,317**	**18**	**98**	**2**	**0**

Table E.2	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 2-Year Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	1,173	34	0	97	3	0
	A2	2,630	83	0	97	3	0
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	350	77	0	82	18	0
	A6	41	0	0	100	0	0
B	B1	253	52	0	83	17	0
	B2	2,615	0	30	99	0	1
	B3	388	0	0	100	0	0
	B4	499	91	0	85	15	0
	B5	1,655	0	0	100	0	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table E.2	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 2-Year Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
C	C1	2,193	128	0	95	5	0
	C2	2,567	479	0	84	16	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	479	0	0	100	0	0
	C6	841	70	0	92	8	0
D	D1	4,074	125	0	97	3	0
	D2	4,412	1,066	0	81	19	0
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	621	49	0	93	7	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	209	20	0	91	9	0
	E6	152	0	0	100	0	0
	E7	2,510	935	94	71	26	3
F	F1	1,892	0	0	100	0	0
	F2	1,646	49	0	97	3	0
	F3	217	83	0	72	28	0
	F4	3,115	813	83	78	20	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	1,925	457	0	81	19	0
	G4	2,677	82	0	97	3	0
	G5	840	0	0	100	0	0
	G6	224	36	0	86	14	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	501	17	0	97	3	0
J	J1	773	25	0	97	3	0
	J2	1,144	0	66	95	0	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0

Table E.2	Simulated Ditch System Performance for the Controlled As of Right Conditions - 2-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	K3	786	229	0	77	23	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**54,297**	**5,478**	**274**	**90**	**9**	**0**

Table E.3	Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,112	95	0	92	8	0
	A2	2,489	166	59	92	6	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	234	193	0	55	45	0
	A6	41	0	0	100	0	0
B	B1	253	52	0	83	17	0
	B2	2,372	205	69	90	8	3
	B3	388	0	0	100	0	0
	B4	490	85	16	83	14	3
	B5	1,505	150	0	91	9	0
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,860	374	86	80	16	4
	C2	2,268	778	0	74	26	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	407	21	51	85	4	11
	C6	841	70	0	92	8	0
D	D1	3,595	578	26	86	14	1
	D2	3,504	1,888	85	64	34	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0

Table E.3 Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	E5	165	64	0	72	28	0
	E6	74	78	0	49	51	0
	E7	2,084	1,064	392	59	30	11
F	F1	1,781	111	0	94	6	0
	F2	1,507	188	0	89	11	0
	F3	217	83	0	72	28	0
	F4	2,965	963	83	74	24	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	102	0	0	100	0	0
	G3	1,504	836	41	63	35	2
	G4	2,118	628	14	77	23	0
	G5	840	0	0	100	0	0
	G6	190	70	0	73	27	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	440	79	0	85	15	0
J	J1	717	56	25	90	7	3
	J2	1,022	122	66	85	10	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	743	269	3	73	27	0
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**49,219**	**9,813**	**1,016**	**82**	**16**	**2**

Table E.4 Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	931	242	34	77	20	3
	A2	1,923	553	237	71	20	9

Table E.4 Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	A3	150	0	0	100	0	0
	A4	2,097	176	0	92	8	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,926	651	69	73	25	3
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,200	359	96	73	22	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,453	676	192	63	29	8
	C2	1,440	1,604	2	47	53	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	610	301	0	67	33	0
D	D1	2,478	1,405	315	59	33	8
	D2	1,572	3,291	614	29	60	11
	D3	458	0	0	100	0	0
E	E1	194	106	0	65	35	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	1,222	1,184	1,134	35	33	32
F	F1	1,487	343	62	79	18	3
	F2	873	756	67	51	45	4
	F3	217	83	0	72	28	0
	F4	1,784	1,778	450	44	44	11
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	724	1,570	88	30	66	4
	G4	1,669	935	155	60	34	6
	G5	717	123	0	85	15	0

Table E.4	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G6	135	57	67	52	22	26
H	H1	297	140	0	68	32	0
I	I1	385	0	0	100	0	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	167	290	62	32	56	12
J	J1	426	321	51	53	40	6
	J2	904	180	126	75	15	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	497	338	0	60	40	0
	K3	516	407	93	51	40	9
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**36,248**	**19,738**	**4,062**	**60**	**33**	**7**

Table E.5	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	983	190	34	81	16	3
	A2	2,431	224	59	90	8	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,467	133	54	89	8	3
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table E.5	Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year CCDP CC Storm Event						
Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
C	C1	1,615	706	0	70	30	0
	C2	1,969	1,077	0	65	35	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,484	668	47	83	16	1
	D2	2,843	2,550	85	52	47	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	141	88	0	62	38	0
	E6	74	78	0	49	51	0
	E7	1,622	1,518	399	46	43	11
F	F1	1,752	115	25	93	6	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,417	1,511	83	60	38	2
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,086	1,207	88	46	51	4
	G4	2,033	692	33	74	25	1
	G5	748	92	0	89	11	0
	G6	169	57	34	65	22	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	73	62	74	14	12
J	J1	599	174	25	75	22	3
	J2	959	124	126	79	10	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0

Table E.5 Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year CCDP CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**44,865**	**13,815**	**1,368**	**75**	**23**	**2**

Table E.6 Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year MTO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	983	190	34	81	16	3
	A2	2,431	224	59	90	8	2
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,467	133	54	89	8	3
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,615	706	0	70	30	0
	C2	1,969	1,077	0	65	35	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,484	668	47	83	16	1
	D2	2,843	2,550	85	52	47	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0

Table E.6	Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year MTO CC Storm Event						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	E5	141	88	0	62	38	0
	E6	74	78	0	49	51	0
	E7	1,622	1,518	399	46	43	11
F	F1	1,752	115	25	93	6	1
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,417	1,511	83	60	38	2
	F5	91	0	0	100	0	0
G	G1	604	114	0	84	16	0
	G2	0	102	0	0	100	0
	G3	1,086	1,207	88	46	51	4
	G4	2,085	641	33	76	23	1
	G5	748	92	0	89	11	0
	G6	169	57	34	65	22	13
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	73	62	74	14	12
J	J1	599	174	25	75	22	3
	J2	959	124	126	79	10	10
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	784	51	0	94	6	0
	K3	710	260	46	70	26	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**44,916**	**13,764**	**1,368**	**75**	**23**	**2**

Table E.7 Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year UWO CC Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	1,092	81	34	90	7	3
	A2	2,459	170	83	91	6	3
	A3	150	0	0	100	0	0
	A4	2,228	45	0	98	2	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	102	0	67	33	0
	B2	2,299	277	69	87	10	3
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,505	96	54	91	6	3
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,723	598	0	74	26	0
	C2	1,969	984	93	65	32	3
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	3,568	584	47	85	14	1
	D2	3,165	2,228	85	58	41	2
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	599	71	0	89	11	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	141	88	0	62	38	0
	E6	74	78	0	49	51	0
	E7	1,651	1,490	399	47	42	11
F	F1	1,781	111	0	94	6	0
	F2	1,245	450	0	73	27	0
	F3	217	83	0	72	28	0
	F4	2,555	1,373	83	64	34	2
	F5	91	0	0	100	0	0
G	G1	718	0	0	100	0	0
	G2	0	102	0	0	100	0
	G3	1,294	1,000	88	54	42	4

Table E.7	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 5-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G4	2,085	661	14	76	24	0
	G5	829	11	0	99	1	0
	G6	190	70	0	73	27	0
H	H1	437	0	0	100	0	0
I	I1	385	0	0	100	0	0
	I2	541	0	0	100	0	0
	I3	191	97	0	66	34	0
	I4	384	135	0	74	26	0
J	J1	652	121	25	82	15	3
	J2	994	150	66	82	12	5
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	835	0	0	100	0	0
	K3	743	226	46	73	22	5
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**46,397**	**12,367**	**1,285**	**77**	**21**	**2**

Table E.8	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	694	479	34	57	40	3
	A2	1,640	678	395	60	25	15
	A3	150	0	0	100	0	0
	A4	1,723	494	57	76	22	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,587	759	300	60	29	11
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,006	509	140	61	31	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table E.8	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
C	C1	861	1,188	271	37	51	12
	C2	1,304	1,740	3	43	57	0
	C3	528	251	85	61	29	10
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	315	70	58	35	8
D	D1	1,996	1,800	403	48	43	10
	D2	1,045	2,611	1,821	19	48	33
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	337	311	22	50	46	3
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,322	1,771	13	37	50
F	F1	1,010	743	140	53	39	7
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,555	1,825	632	39	45	16
	F5	60	31	0	66	34	0
G	G1	170	548	0	24	76	0
	G2	0	102	0	0	100	0
	G3	263	1,669	449	11	70	19
	G4	989	1,208	562	36	44	20
	G5	715	44	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	120	288	21	23	56
J	J1	82	438	278	10	55	35
	J2	687	320	202	57	26	17
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	350	432	54	42	52	6

Table E.8	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year CCDP CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	K3	293	503	219	29	50	22
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**27,602**	**23,815**	**8,631**	**46**	**40**	**14**

Table E.9	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	931	242	34	77	20	3
	A2	1,823	583	307	67	22	11
	A3	150	0	0	100	0	0
	A4	1,982	265	26	87	12	1
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,740	747	159	66	28	6
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,041	474	140	63	29	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	928	1,186	207	40	51	9
	C2	1,427	1,616	3	47	53	0
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	315	70	58	35	8
D	D1	2,415	1,438	347	58	34	8
	D2	1,148	3,436	894	21	63	16
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	447	223	0	67	33	0

Table E.9	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year MTO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	630	1,561	1,349	18	44	38
F	F1	1,350	452	91	71	24	5
	F2	660	897	139	39	53	8
	F3	133	166	0	45	55	0
	F4	1,721	1,788	502	43	45	13
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,649	224	21	69	9
	G4	1,357	1,045	357	49	38	13
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	148	253	117	29	49	23
J	J1	359	310	129	45	39	16
	J2	687	396	126	57	33	10
	J3	334	15	0	96	4	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6
	K3	402	484	130	40	48	13
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	1,059	0	0	100	0	0
Total		**31,857**	**22,490**	**5,701**	**53**	**37**	**9**

Table E.10	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	660	513	34	55	43	3
	A2	1,254	884	576	46	33	21
	A3	150	0	0	100	0	0
	A4	1,531	620	122	67	27	5
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,466	713	467	55	27	18
	B3	254	134	0	65	35	0
	B4	451	77	62	76	13	10
	B5	1,006	373	276	61	23	17
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,424	306	25	61	13
	C2	979	2,064	3	32	68	0
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0
	C5	266	132	81	56	27	17
	C6	510	247	153	56	27	17
D	D1	1,491	2,156	552	36	51	13
	D2	816	2,268	2,394	15	41	44
	D3	402	56	0	88	12	0
E	E1	58	242	0	19	81	0
	E2	265	351	55	39	52	8
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	447	1,000	2,093	13	28	59
F	F1	854	631	408	45	33	22
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,301	1,838	873	32	46	22
	F5	44	16	31	49	17	34
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	263	1,454	664	11	61	28

Table E.10	**Simulated Ditch System Performance for the Controlled As of Right Conditions - 100-Year UWO CC Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G4	813	1,050	896	29	38	32
	G5	638	108	94	76	13	11
	G6	52	140	67	20	54	26
H	H1	78	359	0	18	82	0
I	I1	206	180	0	53	47	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	73	157	288	14	30	56
J	J1	57	314	428	7	39	54
	J2	488	492	230	40	41	19
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	239	511	86	29	61	10
	K3	190	560	265	19	55	26
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	897	161	0	85	15	0
Total		**23,785**	**24,571**	**11,693**	**40**	**41**	**19**

Table E.11	**Simulated Ditch System Performance for the Controlled As of Right Conditions - Hamilton 2009 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	931	242	34	77	20	3
	A2	1,890	517	307	70	19	11
	A3	150	0	0	100	0	0
	A4	2,005	268	0	88	12	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	168	85	52	55	28	17
	B2	1,740	747	159	66	28	6
	B3	365	23	0	94	6	0
	B4	451	123	16	76	21	3
	B5	1,011	504	140	61	30	8
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0

Table E.11 Simulated Ditch System Performance for the Controlled As of Right Conditions - Hamilton 2009 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
C	C1	969	1,119	232	42	48	10
	C2	1,346	1,613	87	44	53	3
	C3	723	141	0	84	16	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	526	350	34	58	38	4
D	D1	2,374	1,296	530	57	31	13
	D2	1,108	3,330	1,040	20	61	19
	D3	458	0	0	100	0	0
E	E1	165	135	0	55	45	0
	E2	447	223	0	67	33	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	630	1,226	1,683	18	35	48
F	F1	1,350	402	140	71	21	7
	F2	660	897	139	39	53	8
	F3	217	83	0	72	28	0
	F4	1,652	1,799	560	41	45	14
	F5	91	0	0	100	0	0
G	G1	241	477	0	34	66	0
	G2	0	102	0	0	100	0
	G3	509	1,451	422	21	61	18
	G4	1,508	894	357	55	32	13
	G5	717	42	81	85	5	10
	G6	106	85	67	41	33	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	154	255	21	30	49
J	J1	264	272	263	33	34	33
	J2	687	370	151	57	31	13
	J3	334	15	0	96	4	0
K	K1	121	0	0	100	0	0
	K2	407	374	54	49	45	6

Table E.11 Simulated Ditch System Performance for the Controlled As of Right Conditions - Hamilton 2009 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	K3	342	454	219	34	45	22
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**31,798**	**21,146**	**7,104**	**53**	**35**	**12**

Table E.12 Simulated Ditch System Performance for the Controlled As of Right Conditions - Stoney Creek 2012 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
A	A1	660	513	34	55	43	3
	A2	1,254	884	576	46	33	21
	A3	150	0	0	100	0	0
	A4	1,635	581	57	72	26	2
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	110	144	52	36	47	17
	B2	1,466	812	367	55	31	14
	B3	357	31	0	92	8	0
	B4	451	123	16	76	21	3
	B5	1,006	435	214	61	26	13
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	591	1,335	395	25	58	17
	C2	1,084	1,960	3	36	64	0
	C3	463	400	0	54	46	0
	C4	641	152	0	81	19	0
	C5	315	83	81	66	17	17
	C6	510	247	153	56	27	17
D	D1	1,743	1,905	552	42	45	13
	D2	816	2,268	2,394	15	41	44
	D3	402	56	0	88	12	0
E	E1	80	220	0	27	73	0
	E2	318	330	22	47	49	3
	E3	265	59	0	82	18	0
	E4	288	0	0	100	0	0

Table E.12	**Simulated Ditch System Performance for the Controlled As of Right Conditions - Stoney Creek 2012 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	E5	47	182	0	21	79	0
	E6	74	78	0	49	51	0
	E7	416	958	2,166	12	27	61
F	F1	981	771	140	52	41	7
	F2	600	957	139	35	56	8
	F3	133	166	0	45	55	0
	F4	1,437	1,702	873	36	42	22
	F5	44	16	31	49	17	34
G	G1	107	611	0	15	85	0
	G2	0	102	0	0	100	0
	G3	200	1,517	664	8	64	28
	G4	882	981	896	32	36	32
	G5	638	110	92	76	13	11
	G6	52	140	67	20	54	26
H	H1	78	359	0	18	82	0
I	I1	293	92	0	76	24	0
	I2	523	19	0	97	3	0
	I3	191	97	0	66	34	0
	I4	110	120	288	21	23	56
J	J1	57	314	428	7	39	54
	J2	492	515	202	41	43	17
	J3	288	61	0	83	17	0
K	K1	121	0	0	100	0	0
	K2	293	489	54	35	58	6
	K3	259	492	265	26	48	26
	K4	323	0	0	100	0	0
	K5	530	30	0	95	5	0
L	L1	943	116	0	89	11	0
Total		**25,007**	**23,820**	**11,221**	**42**	**40**	**19**

Table E.13	**Simulated Ditch System Performance for the Controlled As of Right Conditions - Burlington 2014 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
A	A1	931	242	34	77	20	3
	A2	1,923	484	307	71	18	11

Table E.13 Simulated Ditch System Performance for the Controlled As of Right Conditions - Burlington 2014 Storm Event

Network	Sub-Network	Performance by Length (m)			Performance by Length (%)		
		Within Ditch	Within ROW	Beyond ROW	Within Ditch	Within ROW	Beyond ROW
	A3	150	0	0	100	0	0
	A4	2,031	242	0	89	11	0
	A5	138	289	0	32	68	0
	A6	41	0	0	100	0	0
B	B1	203	50	52	67	16	17
	B2	1,914	594	138	72	22	5
	B3	365	23	0	94	6	0
	B4	490	85	16	83	14	3
	B5	1,291	268	96	78	16	6
	B6	31	0	0	100	0	0
	B7	80	0	0	100	0	0
C	C1	1,403	725	192	60	31	8
	C2	1,632	1,413	2	54	46	0
	C3	723	141	0	84	16	0
	C4	699	94	0	88	12	0
	C5	397	0	81	83	0	17
	C6	757	153	0	83	17	0
D	D1	2,478	1,334	388	59	32	9
	D2	1,513	3,228	737	28	59	13
	D3	458	0	0	100	0	0
E	E1	233	67	0	78	22	0
	E2	491	179	0	73	27	0
	E3	289	35	0	89	11	0
	E4	288	0	0	100	0	0
	E5	102	127	0	44	56	0
	E6	74	78	0	49	51	0
	E7	773	992	1,775	22	28	50
F	F1	1,487	343	62	79	18	3
	F2	800	828	67	47	49	4
	F3	217	83	0	72	28	0
	F4	1,714	1,758	540	43	44	13
	F5	91	0	0	100	0	0
G	G1	467	251	0	65	35	0
	G2	0	102	0	0	100	0
	G3	536	1,459	387	22	61	16
	G4	1,669	884	206	60	32	7
	G5	748	92	0	89	11	0

Table E.13	**Simulated Ditch System Performance for the Controlled As of Right Conditions - Burlington 2014 Storm Event**						
Network	**Sub-Network**	**Performance by Length (m)**			**Performance by Length (%)**		
		Within Ditch	**Within ROW**	**Beyond ROW**	**Within Ditch**	**Within ROW**	**Beyond ROW**
	G6	135	57	67	52	22	26
H	H1	297	140	0	68	32	0
I	I1	385	0	0	100	0	0
	I2	536	5	0	99	1	0
	I3	191	97	0	66	34	0
	I4	167	290	62	32	56	12
J	J1	352	273	174	44	34	22
	J2	796	262	151	66	22	13
	J3	349	0	0	100	0	0
K	K1	121	0	0	100	0	0
	K2	643	192	0	77	23	0
	K3	456	340	219	45	34	22
	K4	323	0	0	100	0	0
	K5	560	0	0	100	0	0
L	L1	1,059	0	0	100	0	0
Total		**35,999**	**18,300**	**5,750**	**60**	**30**	**10**

APPENDIX F

Implementation Considerations Report

CITY OF HAMILTON

IMPLEMENTATION CONSIDERATIONS OF ON-SITE CONTROLS FOR RURALLY-SERVICED EXISTING RESIDENTIAL NEIGHBOURHOODS IN ANCASTER

APRIL 06, 2023

IMPLEMENTATION CONSIDERATIONS FOR ON-SITE CONTROLS FOR RURALLY-SERVICED EXISTING RESIDENTIAL NEIGHBOURHOODS IN ANCASTER

CITY OF HAMILTON

PROJECT NO.: TPB178165
DATE: APRIL 06, 2023

WSP E&I LIMITED CANADA
3450 HARVESTER RD,
BURLINGTON, ON
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1 INTRODUCTION

1.1 BACKGROUND

The City of Hamilton (the City) retained WSP E&I Canada Limited (WSP; formerly Wood Environment & Infrastructure Solutions Canada Limited) to prepare the Detailed Drainage Assessment Study of Rurally-Serviced Existing Residential Neighbourhoods in the Community of Ancaster. The Phase 2 Summary Report includes an assessment of rurally-serviced areas within the Community of Ancaster, with the objective to analyze and assess the potential for impacts on flooding, and to a lesser extent erosion and water quality.

The premise of that study relates to the development trends in various high-value ‘desirable’ neighbourhoods across Hamilton, whereby severances and the redevelopment of lots has been leading to increased lot coverage, thereby affecting the performance of existing drainage systems, particularly in those areas serviced by ditches (rural or semi-urban drainage systems). Lands within these areas have seen building coverage shift to the maximum allowable by planning policy (35 %), however notably, this only accounts for the portion of land occupied by the buildings and primary accessories / structures and does not include any other impervious areas, such as driveways, walkways, and patios, which have also seen a trend to significantly increase and thereby further cover lot areas with hard surfaces. Based upon the assessment of the rurally-serviced Study Area and the analytical modelling conducted, significant potential increases in both peak flows and runoff volumes would be anticipated, depending on the extent of coverage, location within the development area and intensity of the storm.

The study area limits included all of the Existing Residential (ER) neighbourhoods in the Community of Ancaster with rural drainage servicing (i.e. roadside ditching), related to the Level of Service (LOS) associated with these drainage systems and the expected impacts of re-development/intensification to maximum “as of right” limits. The study assessed the impacts of re-development, and developed a plan to mitigate these potential impacts, and advanced an associated implementation strategy.

The mitigation plan recommended private property side source controls to address the drainage impacts from intensification and severances, including the following preferred measures:

- Permeable Pavement (Paving Stones and/or Permeable Surfaces - Driveway Areas)
- Bioretention Areas
- Enhanced Grassed Swales and Bioswales
- Sub-surface infiltration areas (open-bottom chambers, soakaway pits, etcetera)

1.2 IMPLEMENTATION CONSIDERATIONS

This Technical Memorandum has been prepared to provide additional detail and clarity around the available implementation approaches for onsite stormwater management (SWM) measures. A review of policy and legislation at the Provincial and municipal level has been completed to inform the City on the potential implementation approaches for source controls on private property.

Recent and emerging changes to Provincial legislation (e.g, Bill 23) have resulted in modifications to the implementation tools and legal mechanisms available to the City for requiring private onsite controls; these modifications, as well as an assessment of alternative implementation tools are described in Section 2.0.

A best practices review has also been completed (ref. Section 3.0) of other municipalities and conservation authorities in Ontario and across Canada with respect to onsite SWM to further identify implementation considerations appropriate for the City of Hamilton.

Section 4.0 provides a summary of municipal by-laws and policy with potential for onsite control implementation within the community of Ancaster, including the potential creation of a new policy implemented through existing municipal by-laws, as well as next steps regarding consultation with City staff and legal counsel to determine the viability of the potential implementation mechanisms and their alignment with the City's overall approach to responding to Bill 23.

2 LEGISLATIVE REVIEW

Numerous policies and legislative requirements for stormwater management are embedded in the legislation and policies at the Provincial and municipal levels. The legislation review has documented the relevant legislation which is considered to guide and direct the actions of the City in delivering stormwater management services, including the City's ability to require onsite controls on private property. Considerations for implementation have been provided for each review document in order to identify potential legislative tools/legal mechanisms to implement the preferred measures of onsite controls in the Community of Ancaster in the City of Hamilton.

Table 1: Provincial and Municipal Document Review

Provincial	
Policies	Provincial Policy Statement (2020)
	A Place to Grow: Growth Plan for the Greater Golden Horseshoe (2020)
Legislation	Bill 109: More Homes for Everyone Act (2022)
	Bill 23: More Homes Built Faster (2022)
	Planning Act (1990)
	Municipal Act (2001)
	Ontario Water Resources Act (1990)
	Drainage Act (1990)
Guidance	MECP Consolidated Linear Infrastructure Permissions Approach Environmental Compliance Approval (2022)
	MECP Interpretive Bulletin (2015)
	Draft MECP Low Impact Development Stormwater Management Guidance Manual (2022)
	Draft MECP Subwatershed Planning Guide (2022)
	MECP Municipal Wastewater and Stormwater Management in Ontario Discussion Paper (2022)
Municipal	
Policies	Urban Hamilton Official Plan (2022)
	Airport Employment Growth District (AEGD) Wastewater System Capacity Allocation Policy (2020)
By-laws	Comprehensive Zoning By-law No. 05-200 (2005)
	Site Plan Control By-law No. 15-176 (2015) and Application Process
	Site Alteration By-law No. 19-286 (2019)
	Building Permit By-law No. 15-058 (2015) Application Requirements and Process
	Ancaster Zoning By-law No. 87-57 (1987)
	Property Standards By-law No. 10-221 (2010)
	Sewer and Drain By-law No. 06-026 (2006)
	Sewer Use By-law No. 14-900 (2014)
Guidance	Green Standards and Guidelines (Under Development)
	Comprehensive Development Guidelines and Financial Policies Manual (2019)
	Complete Streets Design Guidelines (2022)

2.1 PROVINCIAL POLICY

2.1.1 PROVINCIAL POLICY STATEMENT (2020)

The Provincial Policy Statement (PPS) (2020) provides policy direction and sets the framework for regulating land use planning and development, to protect resources of Provincial interest, public health and safety, and the quality of the natural and built environment.

The PPS provides policy directions regarding the management of infrastructure and notes that it should be efficiently provided, prepare for the impacts due to climate change, and optimize existing infrastructure. The PPS identifies that planning authorities should promote green infrastructure to complement grey infrastructure as well as support land use and development patterns that promote design which considers the mitigating effects of vegetation and green infrastructure.

Section 1.6.6.7 of the PPS identifies that planning for stormwater management shall:

> a) be integrated with planning for sewage and water services and ensure that systems are optimized, feasible, and financially viable over the long term;
>
> b) minimize, or, where possible, prevent increases in contaminant loads;
>
> c) minimize erosion and changes in water balance, and prepare for the impacts of a changing climate through the effective management of stormwater, including the use of green infrastructure;
>
> d) mitigate risks to human health, safety, property, and the environment;
>
> e) maximize the extent and function of vegetative and pervious surfaces; and
>
> f) promote stormwater management best practices, including stormwater attenuation and reuse, water conservation and efficiency, and low impact development.

The PPS identifies actions that planning authorities must undertake to protect, improve or restore the quality and quantity of water, including planning at the watershed scale, preparing for climate change, restricting development as required, and minimizing stormwater volumes and contaminant loads.

In addition, Section 4.7 of the PPS provides considerations for approvals under the Planning Act and other Provincial legislation:

> In addition to land use approvals under the *Planning Act*, *infrastructure* may also require approval under other legislation and regulations. An environmental assessment process may require new infrastructure and existing infrastructure modifications under applicable legislation. Wherever possible and practical, approvals under the *Planning Act* and other legislation or regulations should be integrated provided the intent and requirements of both processes are met.

Onsite Control Implementation Considerations

The PPS requires municipalities to effectively manage stormwater, minimize contaminant loads and erosion, and promote onsite controls on private property. Planning decisions are generally required to be consistent with the PPS, and therefore the PPS provides justification for a municipality to request/require onsite controls, however it does not identify specific implementation measures, nor does it represent a legal implementation mechanism.

2.1.2 A PLACE TO GROW: GROWTH PLAN FOR THE GREATER GOLDEN HORSESHOE (2020)

A Place to Grow: Growth Plan for the Greater Golden Horseshoe (Growth Plan) (2019) provides direction on growth and development within the Greater Golden Horseshoe (GGH), while supporting the economy, protecting the environment, and improving quality of life. In the context of stormwater management, the Growth Plan recommends that municipalities develop stormwater master plans and further recommends that development proposals be supported by stormwater management plans.

Specific policies within Section 3 of the Growth Plan focus on infrastructure to support growth in the GGH, with Section 3.2.7 providing policies on stormwater management. The following specific policies are considered of relevance:

> **3.2.7.1** Municipalities will develop stormwater master plans or equivalent for serviced settlement areas that:
>
> > d) examine the cumulative environmental impacts of stormwater from existing and planned development, including an assessment of how extreme weather events will exacerbate these impacts and the identification of appropriate adaptation strategies;
> >
> > e) incorporate appropriate low impact development and green infrastructure;
> >
> > f) identify the need for stormwater retrofits, where appropriate;
>
> **3.2.7.2** Proposals for large-scale development proceeding by way of a secondary plan, plan of subdivision, vacant land plan of condominium or site plan will be supported by a stormwater management plan or equivalent, that:
>
> > a) is informed by a subwatershed plan or equivalent;
> >
> > b) incorporates an integrated treatment approach to minimize stormwater flows and reliance on stormwater ponds, which includes appropriate low impact development and green infrastructure;
> >
> > c) establishes planning, design, and construction practices to minimize vegetation removal, grading and soil compaction, sediment erosion, and impervious surfaces; and
> >
> > d) aligns with the stormwater master plan or equivalent for the settlement area, where applicable.

Onsite Control Implementation Considerations

The Growth Plan, similar to the PPS, provides clear direction for municipalities to encourage onsite controls (e.g, LID and GI), however does not provide any implementation mechanisms.

2.2 PROVINCIAL LEGISLATION

The Province has recently enacted significant modifications to key pieces of legislation in Ontario, with additional changes anticipated. Ontario Bill 109 and Ontario Bill 23 identify the modifications to several of these core pieces of legislation which relate to development planning and municipal administration.

2.2.1 BILL 109: MORE HOMES FOR EVERYONE ACT (2022)

The Province enacted Bill 109 – *More Homes For Everyone Act* (Bill 109) in April 2022. The Act is based on the premise that reduced housing affordability is a result of insufficient housing supply. The objective of the Act is to reduce “red tape”, streamlining both the development approvals process and review timelines. The Act includes modifications to the following Provincial Acts: Planning Act, Development Charges Act, New Home Construction Licensing Act, Ontario New Home Warranties Plan Act and City of Toronto Act.

Bill 109 includes the following new requirements:

- Municipalities to partially or fully refund Site Plan Control (SPC) & Zoning By-law Amendment (ZBL-A) application fees which do not receive a decision within the allocated timeframe.
    - 60 – 120 days for SPC review
    - 120 – 240 days for ZBL-A and OPA review
- SPC decisions have been delegated to City planning staff rather than City Council (City Council was previously the approving body).
- New Community Infrastructure and Housing Accelerator tool – allows City Council to request the Minster make a decision on a planning matter, which would not need to comply with policy (similar to Ministerial Zoning Orders).
- Requires public reporting on development applications, approvals and other financial matters.
- Requires Community Benefit Charges By-laws be reviewed every 5 years.
- Ministerial discretion to refer all Official Plan matters to Ontario Land Tribunal (OLT).

Onsite Control Implementation Considerations

The refunding of application fees based on review timelines may influence a municipality's decision or policy to review certain applications to avoid financial penalties, particularly those that add effort to the City's current processes.

2.2.2 BILL 23: MORE HOMES BUILT FASTER (2022)

The Province enacted Bill 23 – *More Homes Built Faster Act* in November 2022. Similar to Bill 109, Bill 23 is based on the premise that reduced housing affordability is a result of insufficient housing supply. The objective of the Act is to reduce development application requirements to reduce the timelines and costs of developments and increase the number of homes being built in Ontario.

Bill 23 includes significant modifications to the following Provincial Acts: Planning Act, Conservation Authorities Act, Development Charges Act, Municipal Act, New Home Construction Licensing Act, Ontario Heritage Act, Ontario Land Tribunal Act, Ontario Underground Infrastructure Notification System Act, City of Toronto Act, and Supporting Growth and Housing in York and Durham Regions Act. Included below are summaries of the relevant acts and changes which would potentially affect the planning process in Ontario, and subsequently have impacts within Ancaster.

Conservation Authority Act (1990)

The Conservation Authority Act, administered by the Ministry of Natural Resources and Forestry (MNRF), "provides the organization and delivery of programs and services that further the conservation, restoration, development and management of natural resources and watersheds in Ontario" (Section 0.1). The following change, among others, has been made to the Conservation Authority Act through Bill 23:

- Conservation Authorities may not provide a program or service related to reviewing and commenting on certain matters (i.e., comments are restricted to items that affect unstable soil or bedrock, and exclude comments related to pollution prevention and the conservation of land).

Development Charges Act (1997)

The Development Charges Act authorizes a municipality to impose development charges through a by-law to pay for increased capital costs required from the increased needs for servicing that arise from development to the area for which the by-law applies. The following changes, among others, have been made to the Development Charges Act through Bill 23:

- Exemptions / restrictions from Development Charges for the creation of affordable / attainable residential units, non-profit housing developments and for inclusionary zoning residential units.
- Restrictions on items that can be charged through Development Charges (e.g. certain studies).

Changes to the Planning Act enacted through Bill 23 are identified in Section 2.2.3.

2.2.3 PLANNING ACT (1990)

The Planning Act (1990) sets out rules for land use planning in Ontario and provides the basis for policy tools that can be used by a municipality to make local planning decisions, including Official Plans, Zoning By-laws, Site Plan Control (SPC), and Plans of Subdivision. SPC is of specific relevance as this authorizes a municipality to examine the design and technical aspects of a proposed development to ensure it is attractive and compatible with the surrounding area, and contributes to the economic, social, and environmental vitality of the City.

Ontario Bill 23 – *More Homes for Everyone Act* includes the following amendments to the Planning Act, among others:

- Minister may amend an Official Plan if the plan is likely to adversely affect a matter of Provincial interest.
- Residential developments of 10 units or less are no longer subject to Site Plan Control.
- The exterior design of a building is no longer subject to Site Plan Control.
- Restrictions on the amount of park land dedication requirements.
- Restrictions on the amount of community benefit charge requirements.
- Conservation Authorities and select Upper-tier Municipalities are no longer able to participate in planning processes, including the appeal process, with exceptions.

<u>Onsite Control Implementation Considerations</u>

Bill 23 has significantly reduced the scope of Site Plan Control (SPC), reducing the ability of a municipality to require SPC applications for developments of 10 residential units or less. As the primary form of development in the Community of Ancaster is through severances and redevelopment of single-family dwellings, these developments are no longer subject to SPC, and accordingly SPC is no longer an available mechanism for the implementation of onsite SWM.

Prior to the enactment of Bill 23, SPC would have been the preferred implementation mechanism, as the Planning Act enabled a municipality to designate all or any part of the municipality as SPC Area. Historically, this would have allowed the City to enact a policy which required that all development within the Community of Ancaster be subject to SPC, and furthermore, that all development applications meet specified onsite control requirements. As this implementation mechanism is no longer applicable, additional Provincial and municipal policies and legislation have been reviewed to identify an alternative implementation mechanism.

2.2.4 MUNICIPAL ACT (2001)

The Municipal Act (2001) outlines the extent of powers and duties, organizations, and structure, of municipalities in Ontario. The Municipal Act authorizes municipalities to pass by-laws, implement programs, provide services and actions pertaining to stormwater, for the purposes of preventing damage to property resulting from flooding, and protection and conservation of the environment. It authorizes entry to land for inspection, testing and sampling of discharge for the same reason.

The Municipal Act authorizes a municipality to pass by-laws respecting the protection or conservation of the environment that requires buildings to be constructed in accordance with provisions of the Ontario Building Code, which includes the power to require green roofs or alternative roof surfaces that achieve similar levels of performance. These policies are highlighted below:

> **97.1 (1)** Without limiting sections 9, 10 and 11, those sections authorize a local municipality to pass a by-law respecting the protection or conservation of the environment that requires buildings to be constructed in accordance with provisions of the building code under the *Building Code Act, 1992* that are prescribed under that Act, subject to such conditions and limits as may be prescribed under that Act. 2017, c. 10, Sched. 1, s.
>
> > **(3)** Without limiting sections 9, 10 and 11, the power described in subsection (1) includes the power to require the construction of green roofs or of alternative roof surfaces that achieve similar levels of performance to green roofs. 2017, c. 10, Sched. 1, s. 5.

Additionally, the Municipal Act authorizes a municipality to regulate/require a permit for all movement of topsoil except for activities which are a condition of approval for Site Plan, Plan of Subdivision, Consent, a Development Permit or as an incidental part of drain construction under the Drainage Act.

> **142** (2) Without limiting sections 9, 10 and 11, a local municipality may,
>
> (a) prohibit or regulate the placing or dumping of fill;
>
> (b) prohibit or regulate the removal of topsoil;
>
> (c) prohibit or regulate the alteration of the grade of the land;
>
> (d) require that a permit be obtained for the placing or dumping of fill, the removal of topsoil or the alteration of the grade of the land; and
>
> (e) impose conditions to a permit, including requiring the preparation of plans acceptable to the municipality relating to grading, filling or dumping, the removal of topsoil and the rehabilitation of the site. 2006, c. 32, Sched. A, s. 76 (1).
>
> **(5)** A by-law passed under this section does not apply to,
>
> (a) activities or matters undertaken by a municipality or a local board of a municipality;
>
> (b) the placing or dumping of fill, removal of topsoil or alteration of the grade of land imposed after December 31, 2002 as a condition to the approval of a site plan, a plan of subdivision or a consent under section 41, 51 or 53, respectively, of the *Planning Act* or as a requirement of a site plan agreement or subdivision agreement entered into under those sections;
>
> (c) the placing or dumping of fill, removal of topsoil or alteration of the grade of land imposed after December 31, 2002 as a condition to a development permit authorized by regulation made under section 70.2 of the *Planning Act* or as a requirement of an agreement entered into under that regulation;
>
> (g) the placing or dumping of fill, removal of topsoil or alteration of the grade of land undertaken as an incidental part of drain construction under the *Drainage Act* or the *Tile Drainage Act*. 2001, c. 25, s. 142 (5); 2002, c. 17, Sched. A, s. 30 (2, 3)

<u>Onsite Control Implementation Considerations</u>

The Municipal Act provides the Municipality the authority to regulate the movement of topsoil for by-laws not listed such as the Site Alteration By-law. A further discussion on Municipal By-laws can be found in Section 2.4 of this Technical Memorandum.

2.2.5 ONTARIO WATER RESOURCES ACT (1990)

The Ontario Water Resources Act (OWRA, RSO 1990 and amendments) prohibits activities that introduce pollutants into natural waterbodies, such as creeks, rivers and lakes: "Every person that discharges or causes or permits the discharge of any material of any kind into or in any waters ... that may impair the quality of the water… is guilty of an offence" (Section 16.(1)).

The OWRA gives the Ontario Ministry of the Environment, Conservation and Parks (MECP) the authority to regulate water supply, sewage disposal and to control sources of water pollution, which includes surface waters and groundwater in Ontario. The MECP issues Environmental Compliance Approvals under Section 53 of the OWRA for the treatment and disposal of sewage by municipal and private systems. Stormwater is defined as "sewage" under the OWRA.

Current practices demonstrate that although regulatory agencies (e.g., MECP, MNRF, and Conservation Authorities) encourage retrofit controls, they have not enforced a formal requirement. However, a formal obligation for retrofit controls could potentially be applied through the discretionary powers of MECP using the relevant sections of the OWRA if it could be demonstrated that lack of controls would conform with the above-noted definition.

Onsite Control Implementation Considerations

The preceding approach may be challenging to justify and apply and is not a common approach with respect to private on-site controls. It is considered that this approach may have limited viability for the current intent. Notwithstanding it is understood that the City of Ottawa has applied Section 53 of the OWRA to implement private on-site LIDs and thus may merit further consideration.

2.2.6 DRAINAGE ACT (1990)

The Ontario Drainage Act (1990) allows municipalities to collect funds to make minor improvements, such as deepening, widening, or extending a drain to an outlet. Municipal drain assessments are only intended for water quantity works (i.e., to provide conveyance capacity to the drainage outlet) with costs apportioned based on drainage area and runoff. Water quality/source water improvement projects, planning studies, and other (typically) urban drainage issues generally fall under the OWRA (ref.2.1.5) rather than Drainage Act.

Onsite Control Implementation Considerations
The Drainage Act has been used for some urban drainage works and is currently being considered by MECP for this purpose through pilot initiatives advanced by the Credit Valley Conservation related to the aggregation of communal Low Impact Development Best Management Practices (2022 – Draft). The principle is based on using the Act to formalize the definition of communal drainage works which are constructed on private properties in an "aggregated" form. The Drainage Act through its Petitions and an Engineer's Report would allow the municipality to implement, access and maintain the on-site drainage features in perpetuity.

2.3 PROVINCIAL GUIDANCE

2.3.1 MECP MUNICIPAL WASTEWATER AND STORMWATER MANAGEMENT IN ONTARIO DISCUSSION PAPER (2022)

The MECP prepared the Municipal Wastewater and Stormwater Management in Ontario Discussion Paper in 2022 to stimulate discussion and seek feedback on potential policy approaches for a variety of topics related to wastewater, stormwater management, and water conservation. The Paper recognizes a need for change and identifies there is currently no comprehensive environmental protection policy led by the MECP to provide clear guidance for stormwater management or encourage the use of green stormwater infrastructure. The Paper suggests solutions to modernize stormwater management in Ontario such as performance measures that provide an outcome-based approach for managing stormwater management systems. Examples of practices that should be implemented include requiring on-going inspection and maintenance of infrastructure and managing stormwater through green stormwater infrastructure/LID in combination with conventional stormwater management.

Onsite Control Implementation Considerations

The Paper encourages the use of onsite controls, however, recognizes the lack of direction and guidance for its implementation on private property. It is anticipated following the consultation period, clearer policy direction to improve municipal wastewater and stormwater will be provided.

2.3.2 DRAFT MECP SUBWATERSHED PLANNING GUIDE (2022)

The MECP prepared a Draft Subwatershed Planning Guide (2022) to support cohesive stormwater management throughout the Province as well as updating current guidance from 1993 around Subwatershed Planning.

This Guide was prepared in order to serve as a method for implementing land use policies related to watershed and subwatershed planning in coordination with planning for water, wastewater and storm water servicing, water resources, drinking water source protection and climate change resilience. The document provides details to guide municipalities in creating subwatershed plans that algin with the goals and objectives of other Provincial plans.

> **1.2** this guide promotes consistent application of Provincial policies and programs and offers a valuable administrative, planning, and technical framework for:
>
> - Protecting, improving, or restoring the quality and quantity of water in a watershed.
> - Mitigating potential risk to drinking water sources.
> - Mitigating potential risk to public health or safety or of property damage from flooding and other natural hazards and the impacts of a changing climate.
> - Clarifying roles and responsibilities among municipalities, Provincial ministries, and conservation authorities.

The Guide does not provide specific guidance related to onsite controls, however, does identify LID BMPs as stormwater management strategy a municipality should consider when preparing the implementation and management strategies section of their subwatershed plans.

> **3.3.3** Any environmental assessment and/or master planning processes that are required for water, wastewater or stormwater infrastructure within the subwatershed area should be aligned with the findings and recommendations of the subwatershed plan… Various management practices are outlined to guide how the following (in many cases related) matters will be addressed;
>
> - Low impact development best practices

Onsite Control Implementation Considerations

Once finalized, it is anticipated that the guide will outline roles and responsibilities amongst different agencies, recommended steps, approaches, and best practices for undertaking subwatershed planning, and key technical tools to support subwatershed planning, among other considerations.

2.3.3 MECP INTERPRETIVE BULLETIN (2015)

In 2015, the MECP, then known as the Ministry of the Environment and Climate Change, released the *Interpretation Bulletin: Ontario Ministry of Environment and Climate Change Expectations Re: Stormwater Management* to outline the Ministry's emphasis on source control measures to replicate a site's natural hydrology and provide further guidance for stormwater management plans and practices.

The 2015 MECP Interpretation Bulletin was subsequently updated by the Consolidated Linear Infrastructure Permission Approach (CLI) Environmental Compliance Approval (ECA). The 2015 Interpretation Bulletin however remains relevant to municipalities specifically to encourage LID measures to be implemented on sites not subject to the CLI ECA.

The Bulletin states that conventional stormwater management practices can allow precipitation runoff to convey contaminants into natural ecosystems, reducing the water quality of streams, fish and wildlife habitat, and other aquatic resources. To maintain water quality, MECP emphasized an approach to control precipitation where it falls by employing techniques for LID, such as lot level and conveyance measures. LID techniques can be applied to reduce the volume of runoff from urban areas and help maintain the hydrologic cycle, an important aspect of development as urbanization increases throughout Ontario. Furthermore, as climate change continues to impact municipalities, newly constructed stormwater management facilities are expected to perform under conditions substantially different than historically.

Prior to the CLI ECA, natural hydrology as part of the performance criteria was not directly reflected in the Environmental Compliance Approval (ECA) applications submitted to MECP for stormwater management systems. As noted above, the 2015 MECP Interpretation Bulletin, encouraged ECA applicants to use LID practices and to arrange pre-consultation sessions with MECP, relevant approving municipalities, and local conservation authorities, allowing opportunities for the incorporation of LID practices to be considered early in the development process during the watershed and subwatershed planning phase, as opposed to during the detailed stormwater management plan submission. The new CLI ECA process requires the foregoing as part of the system performance criteria and applicants "must" consider LID practices as part of the recommended stormwater management controls.

The principles for LID stormwater management practices are outlined in the Ontario Environmental Protection Act (EPA); Ontario Water Resources Act; Water Management Policies, Guidelines, Provincial Water Quality Objectives (PWQO) of the Ministry of the Environment and Climate Change (also referred to as the "Blue Book"); and Stormwater Management Planning and Design Manual published in March 2003. Since 2015, MECP has expected that stormwater management plans will follow findings of any watershed, subwatershed, and/or environmental management plans and apply LID practices to maintain the natural hydrologic cycle as much as possible.

2.3.4 MECP CONSOLIDATED LINEAR INFRASTRUCTURE PERMISSIONS APPROACH ENVIRONMENTAL COMPLIANCE APPROVAL (2022)

The MECP as of 2022 has adopted a process termed the "Consolidated Linear Infrastructure Permission Approach (CLI)" to replace the Provincial environmental compliance approvals (ECA) framework for low-risk municipal stormwater management projects. Instead of ECAs for individual stormwater management projects, a single collective CLI ECA will be issued for all of a municipality's stormwater management works. The purpose of the CLI ECA is to reduce administration and provide consistent regulatory requirements in Ontario. The MECP will also be phasing out the Transfer of Review Program with municipalities that have agreements with the Province.

Stormwater management infrastructure listed within the municipality's CLI ECA will be subject to the same MECP requirements. For SWM infrastructure renewal, alterations that do not meet the requirement for preauthorization (not meeting the conditions in Schedule D of the CLI ECA SWM template) would require an application for amendment to be approved by the MECP.

The City of Hamilton, under the CLI approach, is responsible for ensuring that third parties (e.g. developers) meet the design criteria of the CLI ECA in designing and constructing stormwater management infrastructure. Should a project being proposed by a third-party deviate from the design criteria including stormwater management criteria outlined in the CLI ECA template, an amendment to the CLI ECA to the MECP would be required to receive approval and thereby amend the City's CLI ECA.

Onsite Control Implementation Considerations

The City of Hamilton CLI application is required to be reviewed by WSP in order to determine whether potential implementation measures are available through this application process to require onsite controls within the Community of Ancaster.

2.3.5 DRAFT MECP LOW IMPACT DEVELOPMENT STORMWATER MANAGEMENT GUIDANCE MANUAL (2022)

The Government of Ontario prepared the DRAFT Low Impact Development Stormwater Management Guidance Manual (2022) (LID Guidance Manual) to guide practitioners in the planning, design and implementation of LID methods to protect waterways and water quality, reduce flood risks and potential for damage, and increase resilience to climate change events throughout the Province of Ontario. This manual encourages innovative practices, designs, and technologies for LID, as well as early adoption within the development process.

The LID Guidance Manual provides performance guidance on Runoff Volume Control Targets using the 90th percentile precipitation event where the rainfall amount ranges based on local precipitation patterns throughout Ontario. The Manual states that Stormwater management measures should be used in a hierarchical approach starting with target runoff retention followed by LID feature filtration and then conventional stormwater management. The purpose for these guidelines is to provide flexible guidance for municipalities, developers, and other interested parties to apply its direction in order to implement green infrastructure and practices that infiltrate, evapotranspire, and/or harvest and reuse stormwater.

2.4 MUNICIPAL POLICIES

2.4.1 URBAN HAMILTON OFFICIAL PLAN

The City of Hamilton Urban Official Plan (UHOP) (2013) provides policy direction and guidance on the management of communities, land use changes and physical development over the next 30 years. The City has recently undergone a Municipal Comprehensive Review (MCR), a required process for the municipality to update policies and guidelines in their Official Plan. Policies related to LID have been updated during the MCR process to further encourage green infrastructure and sustainability. On January 10, 2023, the UHOP was updated to include policies from Official Plan Amendment (OPA) 167, which was approved by the Province on November 4, 2022.

Below includes a review of the UHOP policies which provide direction for the use of LID and green infrastructure on private property, as well as implementation guidance.

Chapter B of the UHOP details policies that strive to create complete communities that are healthy, diverse, and vibrant. Section 3 of the UHOP focuses on the quality of life and providing direction on the creation of complete communities that have access to a mix of jobs, local services and shops, and housing and community facilities. Section 3.1 focuses on improving its economy and provides policies to strengthen the City's economic competitiveness, prosperity and resilience. Policies relevant to this Study include:

> **B.3.1.1** The City shall strengthen its economy by:
>
> > b) preparing a new comprehensive Zoning By-law to implement the policies of the Official Plan;

Section 3.2 includes polices related to housing with the goal of providing a sufficient supply of housing within a range of housing types, forms, tenures, densities, affordability levels, and housing with support services. Policies related to source control on private property include:

> **B.3.2.1.7** Promote subdivision design and building orientation to maximize energy efficiency and conservation, improve air quality, reduce greenhouse gas emissions, promote green infrastructure and preserve and/or enhance natural features.
>
> **B.3.2.4.7** The construction of new buildings and the retrofitting of the existing building stock shall be encouraged to utilize locally sourced materials and to incorporate water conservation and energy efficiency techniques, the expansion of district energy generation, and renewable energy systems, through the policies of the Plan and other strategies.

Section 3.3 provides detailed polices related to urban design, and the physical form of the urban areas in the City. Policies in this section promote environmental sustainability, as outlined in the following sections:

> **B. 3.3.1.5** Ensure that new development is compatible with and enhances the character of the existing environment and locale.
>
> **B. 3.3.1.6** Create places that are adaptable and flexible to accommodate future demographic and environmental changes, including the impacts of a changing climate.
>
> **B. 3.3.1.7** Promote development and spaces that respect natural processes and features and contribute to environmental sustainability.
>
> **B. 3.3.1.10** Create urban places and spaces that improve air quality and are resistant to the impacts of climate change.
>
> **B.3.3.2.1** The physical design of a site shall:
>
> > b) enhance the function of the applicable urban structure element described in Section E.2.0 – Urban Structure; and,
> >
> > c) be in accordance with the applicable policies of Chapter E – Urban Systems and Designations, secondary plans, specific design studies and other plans or studies that make specific design recommendations;
>
> **B. 3.3.2.2** The principles in Policies B.3.3.2.3 through B.3.3.2.10 inclusive, shall apply to all development and redevelopment, where applicable.
>
> **B.3.3.2.4** Quality spaces physically and visually connect the public and private realms. Public and private development and redevelopment should create quality spaces by:
>
> > a) organizing space in a logical manner through the design, placement, and construction of new buildings, streets, structures, and landscaping;
> >
> > f) including transitional areas between the public and private spaces where possible through use of features such as landscaping, planters, porches, canopies, and/or stairs;
>
> **B.3.3.2.8** Urban design should promote the reduction of greenhouse gas emissions, ability to adapt to the impacts of a changing climate now and in the future, and protect and enhance the natural urban environment by:

b) integrating, protecting, and enhancing environmental features and landscapes, including existing topography, forest and vegetative cover, green spaces and corridors through building and site design;

c) encouraging on-site storm water management and infiltration through the use of techniques and technologies, including storm water management ponds, green roofs, and vegetated swales;

B.3.3.10.8 Parking lots shall be paved with hard surfaces to reduce dust and promote improved air quality. The use of permeable pavement systems or other low impact development practices is encouraged for storm water management, when technically possible.

B.3.3.13 The policies of this section shall be implemented through mechanisms such as zoning, plans of subdivision and condominium, site plan control, site plan guidelines, and urban design guidelines as specified in Chapter F – Implementation.

B.3.3.14 The City, as owners of many public buildings and places, shall apply the design policies of this Section and other sections of this Plan when planning for and developing new, and making improvements to, streets, public spaces, community facilities, and infrastructure.

Section 3.7 of Chapter B focuses on improving human and environmental health and protection of the global climate through energy efficiency, environmental design, green infrastructure, and renewable and alternative energy systems. Relevant policies include:

B.3.7.2 The City shall prepare for the impacts of a changing climate by encouraging energy efficient and environmental designed development and redevelopment through:

a) approval of planning applications, including applications for zoning by-law amendments, site plan approval, and plans of subdivision or condominium, as appropriate;

j) water and storm water conservation/management practices and low impact development techniques, such as green roofs, water recycling systems, urban storm water swales, etc.;

n) other environmental development standards that encourage energy efficiency and environmental design as contained in the City's approved engineering policies and standards and master planning studies, and are supported by the City's financial incentive programs;

B.3.7.3 The City shall develop and update Sustainable Building and Development Guidelines, including a development review checklist, to promote energy efficient development and redevelopment proposals, and implement the Guidelines through the development approvals process.

Chapter E of the UHOP aims to provide direction for growth and development within Hamilton's urban areas. Section 3 of this chapter provides polices for lands designated as 'neighbourhoods'. The intent of this designation is to describe neighbourhood functions, identify appropriate scales of development and design requirements for various land uses. According to the UHOP Urban Land Use Designations, lands within Ancaster are designated as "Neighbourhood" or "Mixed Use – Medium Density".

Section 3.2 provides general polices for lands within the neighbourhoods designation.

E.3.2.7 The City shall require quality urban and architectural design. Development of lands within the Neighbourhoods designation shall be designed to be safe, efficient, pedestrian oriented, and attractive, and shall comply with the following criteria:

e) Development shall comply with Section B.3.3 – Urban Design Policies and all other applicable policies;

Section 3.5 provides specific polices for medium density residential areas:

E.3.5.1 Medium density residential areas are characterized by multiple dwelling forms on the periphery of neighbourhoods in proximity to major or minor arterial roads, or within the interior of neighbourhoods fronting on collector roads.

The UHOP identifies "multiple dwelling" as "a building or part thereof containing five or more dwelling units. Examples of such dwellings include block townhouse dwellings, stacked townhouse dwellings, street townhouse dwellings fronting onto a condominium road, and apartment dwellings"

E.3.5.8 For medium density residential uses, the maximum height shall be six storeys, but the height may be increased to 12 storeys without an amendment to this Plan, provided the Applicant demonstrates that:

b) the development shall incorporate sustainable building and design principles including but not limited to the use of locally sourced and/or recycled materials, water conservation, energy efficiency techniques, and low impact development approaches;

v) incorporate sustainable building and design principles including but not limited to use of locally sourced and/or recycled materials, water conservation and energy efficiently techniques and low impact development approaches;

Section 4.6 provides specific polices for areas with Mixed Use - Medium Density designations:

E.4.6.8 Additional height up to a total of 12 storeys may be permitted without an amendment to this Plan, provided the applicant demonstrates;

b) The development shall incorporate sustainable building and design principles including but not limited to use of locally sourced and/ or recycled materials, water conservation and energy efficiently techniques and low impact development approaches:

Chapter F of the UHOP provides polices and describes tools and guidelines to support the effective implementation and monitor the successes of specific policies in the Plan.

Section 1 of this chapter identifies specific tools for the implementation of the Planning Act. Section 1.6 details of a development permit system as an implementation tool, which is intended to be a flexible planning tool combining zoning, site plan control and minor variance into one process.

F.1.6.1 The City may investigate the development of a development permit system for use in specific geographic areas of the City;

Section 1.7 provides policies on site plan control, which can be used as a means for encouraging well-designed functional and accessible development in Hamilton.

F.1.7.1 Site plan control shall be used to achieve the following planning objectives:

a) minimize the impact of development on adjacent properties;

d) enhance the public realm and create a functional and distinctive streetscape through high quality building design;

f) integrate ecologically important features into site designs to protect and enhance their functions;

F.1.7.2 Council shall use the powers of site plan control to implement certain aspects of this Plan. Accordingly, the entire area within the City of Hamilton Planning Area shall be established as a proposed Site Plan Control Area.

F.1.7.3 Council may establish the classes of development that are subject to site plan control, and those which are exempt, in a by-law.

F.1.7.5 To achieve the objectives in Policy F.1.7.1, the City shall, as part of the site plan approval:

b) require sustainable design elements within an adjoining City right-of-way, including, without limitation, trees, landscaping, permeable paving materials, street furniture, curb ramps, waste and recycling containers and bicycle parking facilities be provided;

F.1.7.6 To City shall establish and update Site Plan Guidelines to indicate the City's design preferences and expectations for site development.

Section 1.19 of chapter F provides polices related to applicated requirements and formal consultation. Subsection F.1.19.1 identifies information and materials required to deem applications for Official Plan Amendments, Zoning By-law amendments, draft plan of subdivision, and site plan complete.

F.1.19.9 The City shall establish guidelines for the other information and materials identified in Policy F.19.6, to provide direction regarding the intended content and scope of such other information and materials.

Section 3 outlines other implementation tools to guide decision making such as plans and studies. Section 3.1.6 details for watershed and sub-watershed plans.

F.3.1.6.2 Once a Watershed or Sub-watershed plan is endorsed by City Council and approved by the relevant Conservation Authority, the City shall implement its recommendations through:

a) amendments to the Official Plan, as appropriate;

c) zoning By-law amendments;

d) conditions of approval for new developments;

F.3.1.6.3 Recommendations from approved watershed and subwatershed plans shall be implemented by future amendments to this Plan, including secondary plans and/or conditions or criteria identified through the review of development applications.

Section 3.2 identifies Council adopted guidelines and technical studies provide guidance for the preparation of studies. Relevant to this Study include:

F. 3.2.6.1 Proponents of development applications may be required to prepare a Design Report to indicate how the proposal is consistent with the design principles and policies identified in throughout this Plan and any applicable existing design guidelines.

F.3.2.6.2 The need and scope for the preparation of a Design Report shall be determined by the City during the formal consultation stage of the development review process and submitted as part of an application in accordance with Section F.1.19.5. The specific requirements of the Urban Design Report shall be reflective of individual applications and determined on a case-by-case basis.

F.3.2.8.1 Council has adopted Site Plan Guidelines to encourage a high quality of building and site design. These Guidelines shall be used by proponents and professionals when preparing site plans. The Site Plan Guidelines indicate the City's design preferences and expectation for site development. The City shall revise the Site Plan Guidelines from time to time.

F.3.2.9.1 Proponents of development applications may be required to prepare an Energy and Environmental Assessment Report to indicate how the proposal incorporates environmental and sustainable design features and practices, such as active transportation, energy efficiency through building and site design, and water conservation and is consistent with the principles and policies identified in Section B.3.7 – Energy and Environmental Design and other applicable policies in Chapter E – Urban Systems and Designations.

F.3.2.12 Other Technical Studies 3.2.12.1 In addition to the studies identified in Section F.1.19 – Complete Application Requirements and Formal Consultation, and Sections F.3.2.1 to F.3.2.9, inclusive, the City may require technical studies to be submitted as part of the Planning Act, R.S.O., 1990 c. P.13 process. Prior to submission of these technical studies, consultation shall be required with City staff to confirm the contents for and the criteria to be used in the technical studies.

Onsite Control Implementation Considerations

Policies identified within Chapter's B and E encourage sustainable management techniques such as LID through onsite control, however, does not provide a mechanism for how this can be required by developers. Chapter F does provide implementation mechanisms, for on-site controls in Ancaster, however due to Bill 23, implementation is limited outside of the use of SPC.

2.5 MUNICIPAL BY-LAWS

2.5.1 COMPREHENSIVE ZONING BY-LAW NO. 05-200 (2005)

The Comprehensive Zoning By-law (2005) is the primary tool used to regulate use of all land within the City, both rural and urban. It establishes permitted uses and location of structures within specific properties. The Comprehensive Zoning By-law notes that adequate storm and sanitary sewer systems should be provided in all existing or new developments. Further, if a development is proposed adjacent to an environmental feature, an environmental impact statement may be necessary for the development of an area, and Section 7 of the Zoning By-law provides requirements related to hazard lands. This by-law applies to all applications, including building permits.

The sections outlining these aspects are as follows:

Section 4: General Provisions
4.22 Adequate Services

Except for Section 4.15 – Model Homes in Draft Plans of Subdivision, no buildings or structures may be erected, used or occupied unless:

i) adequate watermains, storm and sanitary sewer systems are existing or have been provided for in a binding and secured development agreement and all regulatory approvals have been received to the satisfaction of the General Manager of Planning and Economic Development Department and/or his or her designate; or,

ii) For lands in a Rural zone,

1) An approved waste disposal and water supply systems to sustain the use of land for buildings shall be provided and maintained to the satisfaction of the Chief Building Official; and,

2) All regulatory approvals have been received to the satisfaction of the General Manager of the Planning and Economic Development Department and/or his or her designate.

4.30 Environmental Impact Statement (EIS)

An EIS may be required where development is proposed in or adjacent to an environmental feature in order to ensure that the environmental feature is appropriately protected against the impacts of development. Accordingly, an EIS may be required for development proposed on lands zoned P6, P7 and P8 as well as development proposed within 120 metres of natural features.

<u>Onsite Control Implementation Considerations</u>

The Zoning By-law Adequate Services policies require that no buildings or structures be developed without adequate storm services. While "adequate" is not defined in the Comprehensive Zoning By-law (or the Urban Hamilton Official Plan), this clause could serve as a basis to require onsite controls in the Community of Ancaster in order to provide "adequate" storm servicing in this area. A requirement for onsite controls rooted in the Zoning By-law would allow for this requirement to be applicable to Building Permits.

The majority of other City by-laws, as they relate to onsite controls, are only applicable to development regulated through the Planning Act (e.g., SPC, Plans of Subdivision and Minor Variance). Accordingly, this clause within the Zoning By-law represents one of the potential implementation mechanisms available to require onsite controls within the Community of Ancaster.

2.5.2 SITE PLAN CONTROL BY-LAW NO. 15-176 (2015) AND APPLICATION PROCESS

Section 41 of the Planning Act enables the City to designate the whole or part of Hamilton as Site Plan Control (SPC) Area. The Hamilton Official Plans describe the SPC area and policies related to SPC. The City of Hamilton Site Plan Control (SPC) By-law is a process which specifies site requirements for any development that is less than ten units. Due to Bill 23, SPC is no longer a tool that is available to be used throughout municipalities in Ontario. However, components relating to drainage can still be enforced through following the process outlined within the onsite stormwater management Hamilton Site Plan Application requirements that each development is required to follow. If the Site Plan Control By-law becomes available for the City to utilize, the following sections would be relevant for the Ancaster area:

Site Plan Control By-law

3.0 No person shall undertake any development in the site plan control area unless:

3.1 Council of the City or persons to whom authority has been delegated has approved of the following:

3.1.2 drawings showing plan, elevation and cross-section views for each building to be erected, including any residential building containing more than 2 dwellings units, which are sufficient to display:

3.1.2.5 the sustainable design elements on any adjoining highway under the City's jurisdiction, including without limitation trees, shrubs, hedges, plantings or other ground cover, permeable paving materials, street furniture, curb ramps, waste and recycling containers and bicycle parking facilities; and,

4.0 As a condition of approval of the plans and drawings referred to in Section 3.0, the City may require the owner to enter into an agreement or undertaking with the City imposing any conditions permitted by Section 41 of the Planning Act.5.0 Notice of any agreement or undertaking entered into under clause 4.0 above may be registered against the land to which it applies and the municipality may enforce the provisions thereof against the owner and, subject to the provisions of the Registry Act and the Land Titles Act, any and all subsequent owners of the land.

8.0 Subject to Section 9.0 below, the provisions of this by-law do not apply to:

8.1 any single detached dwelling, duplex dwelling or semi-detached dwelling;

8.2 any building accessory to the uses described in paragraph 8.1 above;

8.3 any street townhouse building with a registered plan of subdivision for which the subdivision agreement is in full force and effect; and

8.4 any agricultural building or structure.

9.0 Notwithstanding Section 8.0 above, the provisions of this by-law shall apply to the following:

9.1 any buildings or structures, including accessory buildings and structures, decks, and additions to existing buildings, situated Adjacent to or within a Core Area(s), except for single detached, duplex, semi-detached or street townhouse dwellings located within a plan of subdivision or plan of condominium draft approved after January 1,2013,
9.2 any single detached dwelling, duplex dwelling and semi-detached dwelling forming part of the zero lot line development shown on the map attached to and forming part of this by-law as Schedule “A”
9.3 any single detached dwelling, duplex dwelling and semi-detached dwelling situated to the east and west of Beach Boulevard as shown on the map attached to and forming part of this by-law as Schedule “B”;
9.4 any single detached dwellings, duplex dwellings and semi-detached, dwellings, including accessory buildings and structures, decks, and additions, forming part of a linked housing or similar innovative house grouping development as described in the City's Official Plans, any approved Neighbourhood Plan or any other planning policy document approved by the City. Any development proposing to locate multiple single, semi or duplex dwellings on a single parcel of land is hereby deemed to be an innovative house grouping development within the meaning of this clause 9.4,

Site Plan Application Requirements
4. Minimum Grading Information
- Location of all existing and proposed catch basins, swales, retaining walls, berms, accesses
- Preliminary stormwater management detail as applicable must be submitted, i.e. location and types of storage facilities, etc. (shown conceptually

Onsite Control Implementation Considerations

The City’s SPC By-law currently does not apply to single detached dwellings, duplex dwellings and semi-detached dwellings, with the exception of the dwellings specified in Section 9.0 that are located within the areas specified in Appendix A. Prior to the enactment of Bill 23, an additional clause could have been added to Section 9.0 of the SPC By-law, structured similarly to Sections 9.2 and 9.3, identifying that any dwellings located within a Schedule C (i.e. the Community of Ancaster) would be subject to SPC.

As Bill 23 now restricts SPC to only developments of greater than 10 units, this approach and utilizing the SPC By-law to implement onsite controls within the Community of Ancaster is no longer an available mechanism.

2.5.3 *“EXISTING RESIDENTIAL” ZONED LANDS IN ANCASTER BY-LAW NO. 18-104 (2018)*

The Site Plan Control By-law (No. 15-176), described in Section 2.5.2, was amended in April 2018 to modify regulations within “Lands Located in Certain Residential Areas of Ancaster”. Section 9.3 of the by-law was deleted and replaced with the following:

9.3 any single detached dwelling, duplex dwelling and semi-detached dwelling, including accessory buildings and structures, decks, and additions, for lands located:
(i) east and west of Beach Boulevard, as shown on the maps attached to and forming part of this by-law as Schedules "B1" to “B3”;
(ii) in certain residential areas of Ancaster, as shown on the maps attached to and forming part of this by-law as Schedules "C1" to “C13”.”

Transition
11.1 Building Permit applications received by the City before April 26, 2018 are not subject to Section 9.3 (ii) of this By-law, provided the Building Permit is issued within 6 months of the effective date of this By-law.

11.2 Site Plan Control for the lands described in Section 9.3 (ii) shall not come into effect until April 26, 2018.

Onsite Control Implementation Considerations

The Zoning By-law was previously revised to require development within Ancaster to be subject to Site Plan Control. It is WSP's understanding that this requirement is no longer in place; further discussions with the City recommended to confirm. Nonetheless, the limitations for requiring SPC for developments of 10 units or less currently apply as a result of Bill 23.

2.5.4 SITE ALTERATION BY-LAW NO. 19-286 (2019)

The Site Alteration By-law (2019) applies to activities related to the addition or removal of topsoil and grading, excluding these activities that are included/associated with other development application processes, such as the Site Plan Control and Building Permit processes (with other exceptions). The objective of the Site Alteration By-law is that when any site alteration occurs, there should be no adverse impacts to surface water drainage, groundwater, water, infrastructure, buildings, or any other structures. An inspector may also enter on land to inspect and confirm compliance with the By-law and agreement, among other documents. The following sections of the Site Alteration By-law are considered relevant:

Purposes

2. The purposes of this By-law are,

(a) to control and regulate site alteration on lands within the City of Hamilton;

(b) to ensure site alteration is undertaken for necessary or beneficial purposes, not primarily for financial gain;

(c) to minimize adverse impacts on infrastructure, environment and community in respect of site alteration undertakings; and

(d) to promote and protect agricultural resources.

Statutory Exemptions

5. (1) This By-law does not apply to site alteration undertaken,

(a) as a condition to the approval of or a condition of or a requirement of any of the following, imposed after December 31, 2002 pursuant to the Planning Act:

(i) a site plan or site plan agreement under section 41;

(ii) a plan of subdivision or a subdivision agreement under section 51;

(iii) a consent under section 53;

(iv) a development permit or agreement under a regulation made under section 70.2;

(e) as an incidental part of drain construction under the Drainage Act or the Tile Drainage Act;

Rural Area Exceptions from Permit Requirement

(2) Despite subsection 11(1), no permit is required for site alteration undertaken in the Rural Area,

(a) for the purposes of improving site drainage or soil quality provided that:

(i) the site alteration involves a maximum of 500 cubic metres of fill or topsoil, which may include imported fill or topsoil only from within the City of Hamilton;

(ii) the Director is notified of the intended site alteration at least 48 hours in advance of commencing site alteration; and

(iii) this exception may be used only once with respect to a property, and otherwise a permit is required.

General Conditions

26) No person shall undertake site alteration or cause site alteration to be undertaken except in accordance with the following conditions:

(g) site alteration shall not cause adverse impacts, on the site or any other lands, on any of the following:

(i) surface water drainage;
(ii) groundwater or a water source intended for agricultural use or human consumption;
(iii) bodies of water or watercourses;
(iv) private, municipal or utility infrastructure;
(v) buildings or other structures;

Exceptions from Permit Requirement

7(1) Despite subsection 11(1), no permit is required for site alteration undertaken,

(a) for the purposes of lawn maintenance, landscaping or gardening, provided that:

(i) the depth of fill deposited on the site does not exceed 15 centimetres at any location;
(ii) there is no change in the location, direction or rate of drainage to neighbouring properties; and
(iii) there is no change or blockage of any swale.

(b) for the installation of a pool where a permit has been issued pursuant to By-law No. 16-184, provided that:

(i) any previously approved grading plan is maintained or if there is no previously approved grading plan applicable to the property, a minimum 60-centimetre strip of undisturbed ground remains along the rear and side property lines within the rear yard; and
(ii) any retaining walls are limited to 0.5 metres in height, measured from existing ground elevations.

(c) incidental to the construction of a building for which a building permit has been issued by the Chief Building Official, provided that the accompanying application provides sufficient information for the Chief Building Official to determine that such site alteration conforms with this By-law

Permit Required

11 (1) No person shall undertake site alteration or cause site alteration to be undertaken unless a site alteration permit has been issued to undertake such site alteration.

Criteria

11(4) In considering whether to issue a site alteration permit, the Director shall have regard to,

(e) any effects on ground and surface water resources;
(f) any effects on drainage;
(g) if the use of the site is residential, whether the proposed site alteration complies with the City's Lot Grading Policy, Criteria and Standards;
(i) any effects on the environment;
(j) any planning and land use considerations;
(k) any effects on nearby communities;
(l) any comments provided by external bodies or agencies;
(n) the suitability of the proposed construction site control and security measures;

<u>Onsite Control Implementation Considerations</u>

The Site Alteration By-law applies to activities related to the movement of topsoil and grading, however does not apply to those activities which are associated with an undertaking that is subject to other development approvals through the Planning Act, or regulated through the Drainage Act. As works regulated through the Site Alteration By-law shall have regard to any effects on drainage as well as on ground and surface water resources, the Site Alteration Permit process could be utilized to require onsite controls within the Ancaster Community.

2.5.5 BUILDING PERMIT BY-LAW NO. 15-058 (2015) APPLICATION REQUIREMENTS AND PROCESS

For any building permit plans submitted within the City of Hamilton, they must demonstrate conformity with the Ontario Building Code (OBC), the Zoning By-law and "any other applicable law". With the exception of grading, this by-law is limited to the OBC. Each plan should also detail any municipal services on site, including water and piping, which directly relate to the drainage characteristics of the site. The site plan for a building permit should also conform to the Planning Act. The relevant sections from the Building Permit By-law are the following:

5 Plans and Specifications
5.1(2) Every applicant shall furnish as part of the application:

(a) sufficient plans, specifications, documents and other information, including design calculations, to enable the Chief Building Official to determine whether the proposed construction, demolition, or change of use conforms to the Act, the Building Code and any other applicable law; and

(b) a site plan referenced to a current plan of survey certified by a registered Ontario Land Surveyor and a certified copy of such a survey shall be filed with the municipality unless this requirement is waived in writing because the Chief Building Official in his or her opinion is able, without having a current plan of survey, to determine whether the proposed work conforms to the Act, the Building Code and any other applicable law. Such site plan shall include:

(i) the lot size and dimensions of the property;
(ii) all setbacks from existing and proposed buildings to property boundaries and to each other;
(iii) the proposed lot coverage;
(iv) the existing and finished grades and first floor elevations referenced to an established datum at or adjacent to the site in respect of which the application is made; and
(v) all existing rights-of-way, easements and municipal services.

<u>Onsite Control Implementation Considerations</u>

Site plans submitted as part of Building Permit applications are required to include the existing and finished grading, as well as conform with the Zoning By-law and "any other applicable law". Grading requirements are not sufficiently broad to allow for the inclusion of onsite control requirements, however the need to comply with the Zoning By-law and "any other applicable law" provides a potential mechanism to require onsite controls through the Zoning By-law as identified in Section 2.5.1, or through other applicable law as identified in Section 2.5.

2.5.6 ANCASTER ZONING BY-LAW NO. 87-57 (2022)

The Zoning By-law for the former Town of Ancaster has been consolidated into the City Zoning By-law. The requirement that development include and maintain adequate services specifically to storm systems has been carried over from this by-law. Further, this by-law stipulates that structures should not be constructed on any lands with environmental issues such as poor drainage or unstable lands, consistent with Section 28 of the Conservation Authorities Act. The following sections of the Ancaster Zoning By-law are relevant:

7.14 Parking and Loading

Permanently maintained off-street parking and loading facilities shall be provided for every building or structure erected for, altered for, or converted to, any use permitted in any Zone, and the required facilities shall be provided at the time of construction, alteration or conversion.

(xiii) All parking areas required for the accommodation of more than two vehicles shall be constructed with a stable surface of concrete or asphalt, shall have adequate drainage and shall be permanently maintained.

7.19 Hazard Lands

No building or structure shall be erected on lands that have inherent environmental hazards such as flood susceptibility, poor drainage, marshy or swamp conditions, erosion and unstable soils as delineated in an Ontario Regulation under Section 28 of the Conservation Authorities Act, R.S.O. 1980, as amended, unless such building or structure is approved and any required permit is issued by the Conservation Authority having jurisdiction.

General Provisions

7.29 Adequate Services (06-038)

Except for Section 7.27 - Model Homes in Draft Plans of Subdivision, no buildings or structures may be erected, used or occupied unless:

i. adequate watermains, storm and sanitary sewer systems are existing or have been provided for in a binding and secured development agreement and all regulatory approvals have been received to the satisfaction of the General Manager of the Planning and Economic Development Department and/or his or her designate; or
ii. where such services are not required or contemplated, an approved waste disposal system and potable water supply to sustain the use of land for buildings or structures are existing or have been provided for to the satisfaction of the Chief Building Official and all regulatory approvals have been received to the satisfaction of the General Manager of the Planning and Economic Development Department and/or his or her designate; and

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(1) Prior to the erection of any permitted building, a Fill, Construction and Alteration to Waterways Permit shall be obtained from the Grand River Conservation Authority, where required by the said Authority; and
(2) That the Holding “H” only be lifted upon:
    (i) the determination of adequate setback limits have been established for the protection of the wetlands and watercourses and stormwater management has been approved, to the satisfaction of the Grand River Conservation Authority, as it applies only to the use of the elementary school; and

Onsite Control Implementation Considerations

The Ancaster Zoning By-law has been incorporated into the Zoning By-law; accordingly, implementation considerations are identified in Section 2.5.1.

2.5.7 PROPERTY STANDARDS BY-LAW NO. 10-221 (2010)

Within the Property Standards By-law, stormwater is defined as “water that is discharged from a surface as a result of rainfall, snowmelt, snowfall or other precipitation”. The main provision within this by-law is to prevent stormwater from damaging property or adjacent property. As new development is built, it should comply with the components of this by-law to prevent any on-site drainage issues for the property owner and neighbourhood. The relevant sections of the by-law are as follows:

Storm Water, Etc.

21(1) Storm water, including storm water discharged from a roof, shall be drained so as to prevent recurrent standing water, erosion or other damage on the property or on an adjoining property. [As Amended: By-law 13-127, s.2]
21(2) Discharge from a sump pump or an air conditioner shall not be permitted to discharge on adjoining property, a sidewalk, road allowance or stairway.
21(3) An eavestrough or downspout shall be maintained:
(a) watertight and free from leaks;
(b) free from any obstructions;
(c) in a stable condition, securely fastened to the building or structure it drains; and
(d) so as to properly perform its intended function.

Onsite Control Implementation Considerations

The Property Standards By-law requires that stormwater must not damage property or adjacent property. This provides a basis for establishing a policy that requires development within the Community of Ancaster include onsite controls, which is then implemented through the Property Standards By-law.

2.5.8 SEWER AND DRAIN BY-LAW NO. 06-022 (2006)

The Sewer and Drain By-law By-law regulates the use and construction of sewers and drains in Hamilton. The relevant sections of this by-law are the following:

Parking Area Drainage

9. The Owner of a parking area for vehicles that is not contained within a building shall ensure that such parking area is drained by Catchbasins, Storm Sewer Laterals and/or other appropriate Stormwater drainage systems, in such manner as is approved by the General Manager of Public Works.

Miscellaneous Prohibitions

Obstructing Watercourses

13. (1) No person shall obstruct, allow the obstruction of or maintain any obstruction in any open or closed drainage facility or natural watercourse.
(2) The City may by a notice in writing, require the Owner of the lands or any other person, obstructing or allowing the obstruction of or maintaining the obstruction of any drainage facility or natural watercourse, to do within a specified time all such work as the City determines is necessary to remove the obstruction as specified in the said notice.

Damaging or Obstructing Sewer

(3) No person shall do anything likely to damage or obstruct any part of the Sewage Works of the City.

Onsite Control Implementation Considerations

The Sewer and Drain By-law focuses on the connection to municipal infrastructure, rather than the management of water onsite, and accordingly does not represent a clear legislative mechanism to require onsite controls.

2.5.9 SEWER USE BY-LAW NO. 14-900 (2014)

The Sewer Use By-law outlines the manner in which water is drained or discharged into the sanitary, storm and combined sewer systems in the City. There are specific prohibitions on the type of materials which could be discharged, and it does not include chemical or industrial materials to reduce the amount of pollution within the storm sewer system. Permits are also required to discharge certain materials. The relevant sections are the following:

Discharges to Sewer Works

4. 1 No person shall, directly or indirectly, discharge or permit the discharge of matter into a sewer works or into a connection to a sewer works where to do so may result in:

(a) a health or safety hazard to a person authorized by the General Manager to work on the sewer works, including but not limited to a person authorized to inspect, operate, maintain or repair the sewer works;
(b) an offence under any federal or Provincial legislation, including but not limited to, the Ontario Water Resources Act, the Environmental Protection Act, the Fisheries Act or a regulation there under;
(c) failure of biosolids from a sewage treatment facility to meet the requirements set out in the Nutrient Management Act, 2002 or a regulation thereunder;
(d) interference with the proper operation or maintenance of the sewer works;
(e) interference with any treatment process at a sewage treatment facility;
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(f) a hazard to or harm of any person, animal, property or vegetation;
(g) impairment of the quality of the water in any watercourse;
(h) solid or viscous substances in a quantity or of such size as to be capable of causing obstruction to the flow in the sewer works;
(i) an offensive odour to emanate from the sewer works, including but not limited to sewage containing hydrogen sulphide, carbon disulphide, or other reduced sulphur compounds, amines or ammonia in such quantity as may cause an offensive odour;
(j) damage to the sewer works; or
(k) failure of any discharge from the sewer works to comply with the requirements of an environmental compliance approval or with federal or Provincial legislation.

Discharges to Storm Sewers

4.7 No Person shall, directly or indirectly, Discharge or permit the Discharge of Matter into a Storm Sewer or into a Connection to a Storm Sewer where the Discharge:

(a) contains Sewage;
(b) contains Contact Cooling Water;
(c) contains Oil and Grease (Mineral/Synthetic) which causes a visible film, sheen or discolouration on the water's surface;
(d) contains any raw material, intermediate product, finished product, by-product or waste product of an Industrial process;
(e) contains paint or organic solvent;
(f) contains liquid or solid Matter generated by carpet or furniture cleaning that is collected in a holding tank;
(g) exceeds of any one or more of the limits for any one or more of the parameters in Schedule C;
(h) contains Blowdown Water; or,
(i) contains water originating from Construction Dewatering. (Substituted 22-103)

4.8 Despite subsection 4.7(g), 4.7(h) and 4.7(i) a Person may Discharge or permit the Discharge of Matter into a Storm Sewer or into a Connection to a Storm Sewer where the Discharge:

(a) exceeds of any one or more of the limits for any one or more of the parameters in Schedule C, where:

(i) the Discharge is in accordance with a valid environmental compliance approval, order, or an approval, licence or permit issued pursuant to the Environmental Protection Act or Ontario Water Resources Act which expressly allows the Discharge;
(ii) a copy of the environmental compliance approval, order or an approval, licence or permit referred to in subsection 4.8(a)(i) has been provided to the General Manager;
(iii) the Discharge complies with a valid Sewer Discharge Permit; and
(iv) all fees required under the Sewer Discharge Permit are paid;

(b) contains Blowdown Water, where:
(i) the Discharge is in accordance with a valid environmental compliance approval, order or an approval, licence or permit issued pursuant to the Environmental Protection Act or Ontario Water Resources Act which expressly allows the Discharge;
(ii) a copy of the environmental compliance approval, order or an approval, licence or permit referred to in subsection 4.8(b)(i) has been provided to the General Manager;
(iii) the Discharge complies with a valid Sewer Discharge Permit; and
(iv) all fees required under the Sewer Discharge Permit are paid; or,

(c) contains water originating from Construction Dewatering activities, where:
(i) the Discharge complies with a valid Sewer Discharge Permit; and
(ii) all fees required under the Sewer Discharge Permit are paid. (Substituted 22-103

Sewer Use By-law Assessment Reports and Water Balance Studies

5.1 If required by written notice from an Officer, the owner or occupier of a premises shall complete and submit to the Officer:
(a) a Sewer Use By-law Assessment Report, no more than 60 days after delivery of the written notice;
(b) a Water Balance Study, prepared, signed and stamped by a qualified professional engineer licenced under the Professional Engineers Act, no more than six months after delivery of the written notice, except where an extension to the six months deadline is granted in writing by an Officer.

5.2 Where a change occurs in the information contained in a Sewer Use By-law Assessment
Report or Water Balance Study, the owner or occupier of a premises shall submit to the Officer, no more than 30 days after the change:
(a) information and documentation regarding the change; or
(b) where the Officer determines it is necessary to do so, a new or updated Sewer Use By-law Assessment Report or Water Balance Study, as required.

Onsite Control Implementation Considerations

The Sewer Use By-law focuses on the connection to municipal infrastructure, rather than the management of water onsite and eventual discharge to municipal ditch systems and eventually storm sewer systems, and accordingly does not represent a clear legislative mechanism to require onsite controls. Furthermore, the Sewer Use By-law requirements relating to discharges to storm sewers pertain to water quality as opposed to water quantity. While not specifically pertaining to discharges to municipal storm infrastructure (i.e. ditch systems), the Sewer Use By-law does include water quantity and water budget regulations, and therefore could be further assessed to determine potential for water quantity requirements (i.e. onsite control requirements) within the Community of Ancaster.

2.6 MUNICIPAL GUIDANCE

2.6.1 GREEN STANDARDS AND GUIDELINES (UNDER DEVELOPMENT)

The City has retained WSP to support the preparation of the City's Green Standards and Guidelines (GSG) which are currently under development and anticipated for completion in 2023. The GSG will create a guideline that tailors to the specific needs and conditions within the city, the applicable watershed and sub watersheds, and area specific stormwater management criteria. These guidelines will work in unison with other City initiatives such as the Climate Action Strategy, to mitigate and adapt the city to the effects of climate change. The GSG will provide developers with a decision methodology and implementation consideration to inform development applications. This decision methodology/matrix will allow development proponents to systematically evaluate development applications to identify best management practice options and onsite control requirements.

Onsite Control Implementation Considerations

Implementation considerations for onsite controls within the Community of Ancaster will inform the implementation mechanism for the City-wide GSG onsite controls.

2.6.2 AIRPORT EMPLOYMENT GROWTH DISTRICT (AEGD) WASTEWATER SYSTEM CAPACITY ALLOCATION POLICY (2020)

The City of Hamilton, as the Development Approval Authority, determines and allocates wastewater conveyance and treatment capacity for all approved development. Development approvals cannot and should not be granted or development rights conferred upon a property without receiving servicing allocation, particularly wastewater capacity allocation. This policy notes that where there is limited wastewater capacity available, as in the AEGD, policies and guidelines for the allocation of this capacity are necessary to "provide a consistent, fair, equitable and financially sustainable process" in which wastewater capacity can be managed and aligned with the City's growth strategy and priorities.

Hamilton City Council through the adoption of the Term of Council Priorities, Economic Development Action Plan, Official Plan, annual budgets and other City policy, has provided the framework and guiding principles in determining the capacity allocation priorities. Priorities such as Economic Prosperity and Growth, Clean and Green, and Built Environment and Infrastructure are key in establishing these priorities.

The AEGD Wastewater Capacity Allocation Policy includes the following articles:

- Purpose and Intent;
- City of Hamilton's Role in Determining Wastewater Capacity Allocation;
- Infrastructure Sustainability Criteria;
- Considerations and Requirements;
- Wastewater Capacity Allocation Confirmation Letter from City;
- Public Interest Projects;
- Revocation of Wastewater Capacity Allocation; and
- Municipal Control;

The long-term servicing strategy for the AEGD is set out in the Water and Wastewater Master Plans which were approved as part of the Ontario Municipal Board decision. These Master Plans are comprised of two Servicing Phases. The development of the Phase One Servicing Area was based on existing Municipal water and wastewater servicing infrastructure provisions at the time of the AEGD approval. Phase Two Servicing Area is dependent on the extension of the Dickenson Road Wastewater Trunk Sewer project.

While there is minimal residential development within the AEGD, the following sections are considered relevant to stormwater management:

Article 1 – The City's Role in Determining Wastewater Capacity Allocation

1. The City, as the provider and operator of the wastewater treatment and conveyance system is the owner of the system capacity. As such, the City approves wastewater system capacity (conveyance and treatment) based on the assigned population densities of the area and a per capita per day value of water consumption plus an infiltration index.

2. The City, as the approval authority, grants wastewater system capacity allocation to lands through approval of development applications regulated by the Planning Act, a change of use through a building permit application, or application for servicing permit.

3. In consultation with the development community, the City administers a Staging of Development Program in accordance with the Urban Hamilton Official Plan (Chapter F, Section 3.6) for development proposals including those within the Catchment Area (see attached Appendix A).

4. The City determines the available wastewater system capacity on an on-going basis and grants available capacity in consultation with applicants / developers based on a set of sustainability criteria and other considerations and requirements which guide decisions on allocation.

Article 2 – Infrastructure Sustainability Criteria:

1. Infrastructure Sustainability Criteria, as defined below, will be used as a guide in determining the merits of allocating wastewater capacity in the Catchment Area by establishing if the development proposal:

a) Maintains and optimizes the use of existing City infrastructure;

b) Minimizes the cost for provision of new City infrastructure;

c) Facilitates the development of complete communities;

d) Supports other City policies such as the Corporate Strategic Plan to promote economic prosperity and growth; the Official Plan, the AEGD Secondary Plan, Zoning By-law, the Economic Development Strategy and all relevant Master Plans; and,

e) Demonstrates an ability to readily develop/proceed.

Article 3 – Considerations and Requirements

2. The Policy will generally apply to any development application that results in approval to physically develop or service land and/or reduces available wastewater system capacity. Applications such as Formal Consultation, Re-zoning and Official Plan Amendments would not qualify on their own for wastewater allocation under the Policy because these applications do not result in approval to physically develop or service land.

3. Allocation of capacity is premised on the basis that adequate downstream conveyance capacity availability has been verified to the satisfaction of the City.

4. A wastewater generation report must be submitted to support allocation of wastewater capacity. The report, including sanitary sewer capacity assessment calculations, shall be prepared based on the engineering parameters and methodologies specified in the City's Development Guidelines and Standards, Adequate Services By-law and Provincial regulations.

6. Additional wastewater capacity allocation (i.e. over and above the existing use) required for residential redevelopment / infill projects is generally limited to the as-of-right zoning designation of the property.

<u>Onsite Control Implementation Considerations</u>

The AEGD Wastewater System Capacity Allocation Policy provides a relevant example of a policy which allows the City to approve developments based on capacity allocation (for the case of Ancaster this would be storm capacity). There are however notable differences between this policy and the application to the preferred measures in Ancaster. Wastewater capacity allocation involves the connection to the municipal sewer system, while onsite controls do not involve the direct connection to the municipal storm system, resulting in reduced legislative justification for the City to regulate capacity, particularly to prohibit development if these capacity requirements are not met. Furthermore, the AEGD policy is only applicable to development applications regulated by the Planning Act, a change of use through a building permit application, or application for servicing permit. Following Bill 23, development as defined in the Planning Act has been redefined relative to SPC to greater than 10 residential units, which would not be applicable to the development in Ancaster. Further, residential redevelopment would not constitute a change of use through a building permit application.

Nonetheless, the AEGD policy does provide a relevant guide for a policy which requires development applications in a specified area within Hamilton to meet capacity requirements. A policy that regulates stormwater management capacity on site may be modelled after a similar structure, including the City's role in determining adequate storm servicing, identifying criteria for onsite controls (e.g. referencing the Ancaster Final Report recommendations and/or the City-wide GSG), and identifying additional considerations and requirements. This form of a policy however may be implemented through a different mechanism than the AEGD policy, such as through the aforementioned by-laws in Section 5.0.

2.6.3 COMPREHENSIVE DEVELOPMENT GUIDELINES AND FINANCIAL POLICIES MANUAL (2019)

The Comprehensive Development Guidelines and Financial Policies Manual (2019) details development engineering requirements in relation to:

- Subdivision and site plan process requirements;
- Sanitary sewers and wastewater treatment;
- Storm sewers and stormwater management;
- Watermains and water supply;
- Roadways, including asphalt pavement, curbs, subdrains, sidewalks, walkways, retaining walls, fencing and noise barriers;
- Tree planting and sodding of boulevards;
- Lot grading;
- Street lighting and municipal consent for construction of utilities; and
- Financial policies.

These engineering requirements should be followed during any new development process and comply with Provincial and municipal policies. Under this policy, building permits would only be issued after the Site Plan has been approved, as per:

B.6. Building Permits
Building permits will be issued after Site Plan Approval has been granted and may require the posting of securities. As part of the Concurrent Review Process, there is a waiver that must be signed, see Appendix N – Acknowledgement for Concurrent Building Permit Review Process. Refer to Submission Requirements and Application Form for Site Plan Control.

Further, the engineering requirements for site plan approval include stormwater management, noting that uncontrolled stormwater runoff may result in flooding, soil erosion, and pollution of watercourses. The general standards for stormwater management encourage utilizing on-site stormwater management through the following guidelines (B.8.9):

- Drainage must remain internal to the site unless otherwise approved.

- Every parking area, where storm sewers are available, shall be drained in accordance with Section 9 of By-Law No. 06-026.
- Townhouses, commercial and industrial buildings cannot connect roof leaders to the storm sewers unless the applicant provides a site design, including an appropriate Stormwater management study prepared by a qualified Engineer (City of Hamilton Site Plan Control, Draft Grading Plan Requirements)

Section G of this policy details stormwater management design characteristics and developed in cohesion with the Storm Drainage Policy, best management practices, and Provincial standards. The City supports the implementation of source controls where feasible, which would usually be determined in a Subwatershed Study or other form of Master Plan. However, if such studies do not exist or are not applicable to the proposed development, the Proponent shall consider the application of source controls as a BMP. Further, a Development Impact Monitoring Plan should be submitted and approved by the City, with optional input from the Conservation Authorities and Niagara Escarpment Commission. The purpose of the monitoring plan is to reduce or eliminate adverse impacts due to changes to runoff quality and quantity.

To manage flooding from new development or redeveloped areas, this policy has the following components in Section G.5.3.1:

- All newly developing or redeveloping areas must assess their potential impacts on local and regional flooding, mitigate accordingly. In areas where no watershed plan has been completed, it is the policy of the City of Hamilton to require that runoff peak flows are controlled to pre-development levels or less, unless the Proponent can demonstrate through appropriate modelling and analysis that uncontrolled flow will not cause detrimental impacts on flood conditions on downstream properties and watercourse systems. Before the City will accept any increase in runoff rates, it must also receive endorsement from the agencies having jurisdiction. In certain site-specific circumstances, the City may require that post development flows be controlled to less than pre-development levels. As such, discussion regarding the over-control of post development flows would be required with the City.
- Where Watershed Subwatershed or Master Drainage Plans have been completed, the Development Proponent will be required to comply with the recommendations of the specific plan. Any variations will need to be appropriately supported by detailed analysis and also be approved by any agencies having jurisdiction.

Alternatively, if on-site stormwater management cannot be provided by the Proponent, cash-in-lieu can be given towards off-site stormwater management infrastructure in a different area of the City. Usually this would only apply towards low sensitivity receiver, limited rehabilitation opportunities, and very small development or infill.

Onsite Control Implementation Considerations

The Comprehensive Development Guidelines and Financial Policies Manual provides significant guidance related to stormwater management, however primarily applies to SPC and Plans of Subdivision, and other development agreements specified in the Planning Act, providing limited legal mechanism to require onsite controls for single-unit dwellings within the Community of Ancaster.

2.6.4 COMPLETE STREETS DESIGN GUIDELINES (2022)

The Complete Streets Design Manual outlines the design, implementation, maintenance, and monitoring of Complete Liveable Better (CLB) Streets within the City. These streets are meant to enhance diversity of transportation modes throughout the roadway (e.g. bike lanes and sidewalks), improve road safety, and address transportation requirements of the neighbourhood.

Section 3.6.3 of the Complete Streets Design Manual focuses on stormwater management, including promoting low impact development features and managing stormwater closer to the source (on-site control). The manual argues that this would reduce runoff volume, erosion, flooding, and in turn, the impact on the storm sewer system.

Section 3.7.2 focuses on sewers, describing design components for storm sewers and sanitary sewers, while Section 3.7.3 describes watermains and water services. Both these sections emphasize proper maintenance of infrastructure to provide proper services and prevent issues from occurring. The importance of maintenance is also noted in the following section:

> **2.5.3 Maintenance Strategy**
> Plans for ongoing maintenance of the facility should be developed as part of the capital budget submission for the project. Operating costs, maintenance standards, and divisional responsibilities should be identified and included in the relevant operating budgets.

Regarding green infrastructure, the Street Element Condition Definitions (Section 2.2.11) provide a guideline to describe the relevant desired conditions per typology and to audit an existing street. Ratings for each element are graded from 1 to 5. The rating reflects the level of accommodation or level of service for that street element. For stormwater management, the focus is on low impact development, hence the rating system is as follows:

1	Street trees and stormwater management practices are not actively provided.
2	Design incorporates low impact development features where possible.
3	Design incorporates low impact development features where possible.
4	Design incorporates low impact development features.
5	Low impact development features incorporated in a comprehensive manner.

Section 2.2.3 from this policy include emphasizing the promotion of CLB Streets through the development process. Section 2.2.3 is the following:

2.2.3 Subdivision and Site Plans
Subdivision and site plans are typically part of development applications that City staff need to review and approve and are a key project input to the planning process. Since these types of plans will impact the street network for their corresponding areas, staff reviewing the plans should work to ensure that Complete Streets design principles are incorporated into the plans.

Onsite Control Implementation Considerations

The Complete Streets Guidelines provides relevant guidance for the format of onsite controls, however focuses on onsite controls within the municipal right-of-way rather than on private property and is focused on development applications such as subdivision and site plans.

3 BEST PRACTICES REVIEW

3.1 CITY OF TORONTO

3.1.1 TORONTO GREEN STANDARD (2021)

The City of Toronto identifies sustainable design requirements for new private and City-owned developments through the Toronto Green Standard (2021). This consists of 4 tiers of performance measures, Tier 1 as required through the planning approval process and Tiers 2 to 4 as high-level voluntary standards. Projects which demonstrate Tier 2 performance levels or above may be eligible for refunds on development charges. On June 11, 2021, the City of Toronto updated its Green Standards to Version 4 (TGS V4), which would be applied to all applications submitted under the Planning Act commencing May 1, 2022.

The TGS V4 identifies varying requirements for three types of development: low-rise residential development, mid-high rise residential and non-residential developments, and city agency, corporation & division-owned Facilities. Each include policies applicable to the type of development related to Air Quality, Building Energy, Emissions & Resilience, Water Quality & Efficiency, Ecology and Biodiversity, Waste & the Circular Economy. Requirements regarding onsite controls can be found in both the Water Quality & Efficiency and Ecology and Biodiversity Sections.

<u>Onsite Control Implementation Considerations</u>

The TGS V4 is applied to development applications submitted under the Planning Act. This would include SPC, Plan of Subdivision and ZBLA applications. Applicants are required to submit the TGS V4 checklist in order to render the application process complete. As discussed in Section 2.2.3, changes to the Planning Act enacted by Bill 23 limits the ability to require onsite controls through the SPC process.

3.2 CITY OF MISSISSAUGA

3.2.1 GREEN DEVELOPMENT STANDARDS (2012)

The Green Development Standards were released in 2012 to aid the City of Mississauga in achieving sustainability and environmental responsibility and as a response to the Green Development Strategy (2010). The Green Development Standards offer a variety of green practices including LID stormwater retention techniques, tree planting requirements, techniques to increase pedestrian and cycling comfort, exterior building design practices, and LEED (Leadership in Energy and Environmental Design) requirements.

<u>Onsite Control Implementation Considerations</u>

The Green Development Standards are implemented through the SPC process. Specific text within the Site Plan Application Process Guidelines identifies "A Green Development Standards Cover Letter indicating where Low Impact Development and other sustainable site and building features have been considered through site development **may be required** as part of the Site Plan Application process (34)." Though strongly encouraged, standards related to LID and onsite controls are not a specific requirement of SPC process. As discussed in Section 2.2.3, changes to the Planning Act brought by Bill 23 limit the ability to require onsite controls through the SPC process.

3.3 CITY OF OTTAWA

3.3.1 LOW IMPACT DEVELOPMENT TECHNICAL GUIDANCE REPORT (2021)

The City of Ottawa Low Impact Development Technical Guidance Report focuses on addressing issues with implementation of LID for sites constrained by clay soils, shallow bedrock, and high groundwater elevations, all of which are common conditions throughout the City of Ottawa. The document provides a description of the issues/constraints, rationale for LID measures in the settings described above, a review of technical issues and requirements, a process/approach for selection of LID measures in areas with constraints, and examples of LID implementation.

Onsite Control Implementation Considerations

The City of Ottawa aims to implement LID as part of new development, infill development, and linear reconstruction and retrofits, citing Section 53 of the OWRA as a permit approval mechanism.

> **53** (1) Subject to section 47.3 of the *Environmental Protection Act*, no person shall use, operate, establish, alter, extend or replace new or existing sewage works except under and in accordance with an environmental compliance approval.

3.3.2 HIGH PERFORMANCE DEVELOPMENT STANDARD (2022)

The High Performance Development Standard (HPDS) was approved by Ottawa City Council on April 13, 2022, with intended implementation of the Tier 1 standards in June 2023. Following a similar framework to the Toronto Green Standards (ref.3.1.1), the HPDS has been developed as a tiered system, with Tier 1 as mandatory metrics and Tiers 2-3 as voluntary. The HPDS has been phased in as of June 2022 but will not be required until June 2023. The only HPDS requirement that will apply to SPC applications related to onsite controls is green roofs, however it is possible additional requirements will be included in future versions.

Onsite Control Implementation Considerations

The main mechanism for implementation of the HPDS is through SPC and Plan of Subdivision. The application will include a HPDS checklist to be submitted as part of the application process.

3.4 CITY OF BARRIE

3.4.1 INFILTRATION LOW IMPACT DEVELOPMENT SCREENING PROCESS (N.D)

The Infiltration Low Impact Development Screening Process outlines a decision-making framework for the suitability of an infiltration LID feature. This document undertakes a three-step approach, in which the first step is to conduct a location suitability screening that considers drinking water vulnerable areas and water quality characteristics of the stormwater to be infiltrated, the second step to consult with the Infiltration LID Working Group, and finally the third step, to ensure federal, Provincial and municipal requirements are met. The Infiltration LID Screening Process does not identify specific types of LID practices to be used, rather it identifies the permissible sources where stormwater runoff may use infiltration-based practices. For example, the document identifies vegetated and rooftop runoff as permitted regardless of the land use activities proposed for the project site, however it does not permit pollution hot spot runoff (e.g. a gas station) to be directed to the infiltration LID facility.

Onsite Control Implementation Considerations

The City of Barrie implements LID practices through SPC process. The SPC application requires a stormwater management report, which must include:

- Outline of the operations, maintenance, and monitoring program for the stormwater management facilities, including Oil Grit Separators (OGS) and Low Impact Developments (LIDs)
- The inclusion of any low impact developments (LIDs) and their function (and included in the modelling) including relevant hydrologeological information

This in turn activates the Infiltration LID Screening Process to identify whether the site is applicable for the use of LID.

3.5 TOWN OF OAKVILLE

3.5.1 LIVEABLE BY DESIGN MANUAL (2017)

The Town of Oakville prepared the Livable by Design Manual (2017) to act as a framework for which development proposals will be evaluated. The Livable by Design Manual is comprised of three components which provide direction for design and development. This includes the Livable by Design Manual – Urban Design Direction for Oakville (Part A) (2014), Design Guidelines for Stable Residential Communities (Part B) (2013), and the Liveable by Design Manual – Site Design and Development Standards for Oakville (Part C) (2017).

Section 4 of the Livable by Design Manual – Urban Design Direction for Oakville (Part A) suggests integrating bio-retention swales in parking areas and incorporating permeable paving materials for the effective management of stormwater. The Design Guidelines for Stable Residential Communities (Part B) focuses on low-rise detached and semi-detached dwellings, with guidelines in Section 3 encouraging bioswales, rain gardens, and rainwater harvesting for LID on all new development. This document also encourages permeable paving materials on driveways and pedestrian areas for better management of stormwater run-off. The Liveable by Design Manual – Site Design and Development Standards for Oakville (Part C) provides specific standards for new developments. Section 2 encourages stormwater to be managed on-site by areas that can accommodate natural infiltration and decrease loads on municipal services.

Onsite Control Implementation Considerations

These documents apply to all development proposals subject to review and planning approval by the town, including OPA's, ZBLA's, Plans of Subdivision, SPC, Sign Variances and Committee of Adjustment applications, as permitted under the Planning Act. The main mechanism for implementation as identified within the three documents is the SPC process.

3.6 NIAGARA REGION

3.6.1 MODEL URBAN DESIGN GUIDELINES (2005)

The Niagara Region Model Urban Design Guidelines (2005) supports the implementation of their Smart Growth Initiative which aims to grow the region while balancing economic, social, and environmental needs. The Model Urban Design Guidelines provides design principles and specific guidelines for a range of development within the region. Section 4(g) encourages increasing permeable areas, implementing bioswales and drainage basis to collect stormwater runoff.

<u>Onsite Control Implementation Considerations</u>

The Model Urban Design Guidelines provides consistent development guidelines for all municipalities within the Niagara Region. As part of the Smart Growth Initiative, the Smart Growth Design Criteria Checklist, based on the Model Urban Design Guidelines, is used to assess a development application, such as SPC, for approval of the Development Charges Reduction Program.

4 CONCLUSION & NEXT STEPS

4.1 CHANGES IN PROVINCIAL LEGILSATION IMPACTING IMPLEMENTATION FEASIBILITY

Recent changes to Provincial legislation, particularly Bill 23 which has enacted modifications to a range of Provincial acts, notably the Planning Act, has impacted the implementation mechanisms available for onsite controls within the Community of Ancaster.

The changes to the Planning Act have significantly reduced the scope of Site Plan Control (SPC), reducing the ability of a municipality to require SPC applications for developments of 10 residential units or less. As the primary form of development in the Community of Ancaster is through severances and redevelopment of single unit dwellings, these developments are no longer subject to SPC, and accordingly SPC is no longer an available mechanism for the implementation of onsite SWM.

Prior to the enactment of Bill 23, SPC would have been the preferred implementation mechanism, as the Planning Act enabled a municipality to designate all or any part of the municipality as SPC Area. Historically, this would have allowed the City to enact a policy which required that all development within the Community of Ancaster be subject to SPC (which the City did previously enact through By-law 18-104 as summarized in Section 2.5.3), and furthermore, that all development applications meet specified onsite control requirements. As this implementation mechanism is no longer applicable, additional Provincial and municipal policies and legislation have been reviewed to identify an alternative implementation mechanism.

4.2 SUMMARY OF MUNICIPAL BY-LAWS AND POLICY WITH POTENTIAL FOR ONSITE CONTROL IMPLEMENTATION

AEGD Waster System Capacity Allocation Policy

Applicability of Existing Policy

The AEGD Wastewater System Capacity Allocation Policy provides a relevant example of a municipal policy which allows the City to approve development based on capacity allocation (for the case of Ancaster this would be storm capacity). There are however notable differences between this wastewater policy and the application to the preferred stormwater management onsite measures in Ancaster. Wastewater capacity allocation involves the connection to the municipal sewer system, while onsite controls do not involve a direct infrastructure connection to the municipal storm system, resulting in reduced legislative justification for the City to regulate capacity, particularly to prohibit development if these capacity requirements are not met.

Additionally, the AEGD policy is only applicable to development applications regulated by the Planning Act, a change of use through a building permit application, or application for servicing permit. Following Bill 23, development as defined in the Planning Act has been redefined relative to SPC to greater than 10 residential units, which would not be applicable to the form of development taking place in Ancaster. Further, residential redevelopment would not constitute a change of use through a building permit application.

Recommendations to Further Determine Feasibility

The AEGD Wastewater System Capacity Allocation Policy does provide a relevant guide for a policy which requires development applications in a specified area within Hamilton to meet capacity requirements. A policy that regulates stormwater management capacity onsite could be modelled following a similar structure, such as a “Community of Ancaster Stormwater Management Onsite Controls Policy”. This policy could contain the following sections/considerations:

- Define the City's role in determining what constitutes adequate site servicing, including:
  - Define which forms of development are subject to the policy. Given the new definition of development within SPC to be limited to developments of 10 units or greater, identify which forms of development will be subject to the policy (i.e., identifying an avenue if possible to include severances and redevelopment as these are the primary forms of development within Ancaster resulting in drainage impacts) and which forms of development may be exempt. Identify which development application processes and municipal by-laws the policy will be implemented through (e.g., Zoning By-law, Site Alteration By-law, etc., as expanded upon below).
  - Define "adequate servicing" in the context of storm servicing in the Community of Ancaster.
    - Add reference to the Zoning By-law Adequate Services policies that require that no buildings or structures be developed without adequate storm services.
    - Definition may consider the following: Adequate Servicing means designing and constructing source controls which meet the design capacity requirements for the applicable drainage network, based on the storm event criteria and desired level of service, to prevent additional impacts to flooding, erosion and water quality.
- Provide rationale of why the City is requiring this policy, including:
  - Alignment with municipal and Provincial policy (e.g., PPS, OP, etc.) to manage stormwater, minimize contaminant loads and erosion, and promote onsite controls on private property, among others.
  - Recommendation from the Detailed Drainage Assessment Study (Phase 2) of Rurally-Serviced Existing Residential Neighbourhoods in the Community of Ancaster to require source controls on private property. Recommendation is based on the need to reduce the impacts on flooding, as well as erosion and water quality, resulting from developing primarily in the form of severances and redevelopment that has been leading to an increase in lot coverage, thereby affecting the performance of existing drainage systems, particularly those areas serviced by ditches. Accordingly, the City needs the ability to manage peak flows and runoff volumes, which is most effectively done through source controls on private property.
- Identify criteria for onsite controls. Based on the Phase 2 Report, this may include:
  - Preferred onsite control measures:
    - Permeable Pavement (Paving Stones and/or Permeable Surfaces - Driveway Areas)
    - Bioretention Areas
    - Enhanced Grassed Swales and Bioswales
    - Sub-surface infiltration areas (open-bottom chambers, soakaway pits, etc.)
  - Management of 90 – 115 mm of rainfall per impervious hectare (900 – 1150 m^3 of runoff per impervious hectare), in order to provide control up to, and including, the 100-year storm event.
  - Required targets may vary by primary drainage network, reflecting the variability in surficial soils and topography.

- Considerations and Requirements:
  - Align with the following municipal or conservation authority documents:
    - The City's Comprehensive Development Guidelines and Financial Policies Manual (2019)
    - The City's Green Standards and Guidelines (GSG), which are currently under development.
    - Any future guidance as developed by the City or its partners (e.g., Hamilton Conservation Authority), such as a climate change study.
  - Submission of a Stormwater Management (SWM) Report, along with other supporting studies (specifically a geotechnical/hydro-geological assessment to confirm specific onsite conditions) to demonstrate the adequate conveyance/minimum onsite quantity is being managed.
  - Preference for measures to be constructed in front yard areas, where possible, for ease of access for inspection and future maintenance works.
  - Monitoring and maintenance requirements, such as responsible party and inspection frequency.

Zoning By-law

Applicability of Existing Policy

The Zoning By-law Adequate Services policies require that no buildings or structures be developed without adequate storm services. While "adequate" is not defined in the by-law, this clause could serve as a basis to require onsite controls in the Community of Ancaster in order to provide "adequate" storm servicing in this area. A requirement for onsite controls rooted in the Zoning By-law would allow for this requirement to be applicable to Building Permits.

The majority of other City by-laws, as they relate to onsite controls, are only applicable to development regulated through the Planning Act (e.g., SPC, Plans of Subdivision and Minor Variance). Accordingly, this clause within the Zoning By-law represents one of the potential implementation mechanisms available to require onsite controls within the Community of Ancaster.

Recommendations to Further Determine Feasibility

- Within the Zoning By-law Adequate Services clause, a requirement could be added that development must comply with the "Community of Ancaster Stormwater Management Onsite Controls Policy", specifically the definition of adequate services as they relate to stormwater management infrastructure within this area.
- Consider defining adequate services in the Zoning By-law Glossary, if appropriate, in recognition of the different definitions of what constitutes adequate services as they relate to different forms of infrastructure and geographical areas.

Site Plan Control By-law

Applicability of Existing Policy

The City's SPC By-law currently does not apply to single detached dwellings, duplex dwellings and semi-detached dwellings, with the exception of the dwellings specified in Section 9.0 that are located within the areas specified in Appendix A. Prior to the enactment of Bill 23, an additional clause could have been added to Section 9.0 of the SPC By-law, structured similarly to Sections 9.2 and 9.3, identifying that any dwellings located within a Schedule C (the Community of Ancaster) would be subject to SPC.

As Bill 23 now restricts SPC to only apply to developments of greater than 10 units, this approach and utilizing the SPC By-law to implement onsite controls within the Community of Ancaster is no longer an available mechanism.

Recommendations to Further Determine Feasibility

- SPC is not a viable implementation mechanism at this time. Should Provincial policy and legislation change, then the SPC By-law should be utilized as the primary implementation mechanism for onsite controls within Ancaster.

Site-Alteration By-law

Applicability of Existing Policy

The Site Alteration By-law applies to activities related to the movement of topsoil and grading, however, does not apply to these activities which are associated with an undertaking that is subject to other development approvals through the Planning Act, or regulated through the Drainage Act. As works regulated through the Site Alteration By-law shall have regard to any effects on drainage as well as on ground and surface water resources, the Site Alteration Permit process could be utilized to require onsite controls within the Ancaster Community.

Recommendations to Further Determine Feasibility

- A clause could be added to the General Conditions Section 26 (g) to provide additional clarity regarding what constitutes not causing adverse impacts as a result of site alteration, by adding a reference to the "Community of Ancaster Stormwater Management Onsite Controls Policy", stating that this policy must be complied with in the applicable geographical area.
- Should the "Community of Ancaster Stormwater Management Onsite Controls Policy" be successfully enforced through the Zoning By-law and/or Building Permit processes, in regards to development in the form of severances and redevelopment, then this policy would not be able to be applied through the Site Alteration By-law, as specified in Section 5.0 of the by-law.

Building Permit By-law

Applicability of Existing Policy

Site plans submitted as part of Building Permit applications are required to include the existing and finished grading, as well as conform with the Zoning By-law and "any other applicable law". Grading requirements are not sufficiently broad to allow for the inclusion of onsite control requirements, however the need to comply with the Zoning By-law and "any other applicable law" provides a potential mechanism to require onsite controls through the Zoning By-law as identified in Section 2.5.1, or through other applicable law as identified in Section 2.5.

Recommendations to Further Determine Feasibility

- Adding a reference within the Zoning By-law Adequate Services section to the "Community of Ancaster Stormwater Management Onsite Controls Policy" could provide a basis to enforce this policy through the building permit application process.
- Consideration could be given for the "Community of Ancaster Stormwater Management Onsite Controls Policy" to take the form of a by-law rather than a policy, in order for it to be considered applicable law and accordingly applicable to building permit applications. However, in light of recent Provincial policy and legislative changes, a by-law of this nature may not be justified as applicable law; further consultation is required with the City's legal counsel.

Property Standards By-law

Applicability of Existing Policy

The Property Standards By-law applies to new and existing development and requires that stormwater must not damage property or adjacent property, or cause erosion. This provides a potential basis for establishing a policy that requires development within Ancaster to include onsite controls, given the intent of the policy and onsite controls will be to prevent damage to adjacent property (i.e., through flooding) as well as prevent erosion. The by-law does not provide the necessary justification for the City to require onsite controls for the purpose of managing quantity discharged to the municipal storm system.

Recommendations to Further Determine Feasibility

- When reviewing development applications which are subject to the Property Standards By-law, municipal reviewers could apply the "Community of Ancaster Stormwater Management Onsite Controls Policy" in order to demonstrate that the applicant is in conformance with clauses identified in Section 21. The Property Standards By-law includes references to Provincial and municipal legislation (such as the Ontario Building Code, Ontario Heritage Act, and City User Fees and Charges By-law) however does not include reference to municipal policies; accordingly, discussion is required with the Planning and Economic Development department and other relevant City staff prior to adding a reference to this policy within the Property Standards By-law.

Sewer Use By-law

Applicability of Existing Policy

The Sewer Use By-law focuses on the connection to municipal infrastructure, rather than the management of water onsite and eventual discharge to municipal ditch systems and eventually storm sewer systems, and accordingly does not represent a clear legislative mechanism to require onsite controls. Furthermore, the Sewer Use By-law requirements relating to discharges to storm sewers pertain to water quality as opposed to water quantity.

Recommendations to Further Determine Feasibility

While not specifically pertaining to discharges to municipal storm infrastructure (i.e., ditch systems), the Sewer Use By-law does include water quantity and water budget requirements. Accordingly, the Sewer Use By-law could be further assessed to determine potential for water quantity requirements (i.e., onsite control requirements) within the Community of Ancaster.

4.3 ONSITE CONTROL IMPLEMENTATION IN OTHER MUNICIPALITIES

Historically, municipalities across Ontario have utilized the Site Plan Control process, enabled through the powers granted to municipalities through the Planning Act, to require onsite controls on private property. Given the recent changes to Provincial legislation, the identification of implementation tools for onsite controls outside the SPC process is an issue facing municipalities across Ontario.

4.4 NEXT STEPS

City staff may need to further review to better assess the potential application of existing municipal by-laws, as well as the creation of a new policy, in order to implement onsite controls within the Community of Ancaster. Next steps may include:

- Consultation with the broader group of City staff, particularly Planning & Economic Development, to discuss the viability of the implementation of a "Community of Ancaster Stormwater Management Onsite Control Policy", or a similar version of policy. Discussions should include how this policy would align with the City's overall response to Bill 23, including the implementation of other development application or infrastructure requirements on developments of 10 units or less.
- Review with the City's legal counsel regarding the legal basis for developing a policy based on adequate servicing, in light of Bill 23 restrictions on the SPC process and regulation of development. Review potential municipal by-laws which may be used as a mechanism to enforce the policy (e.g., Zoning By-law, Site Alteration By-law, Building Permit By-law, Property Standards By-law, and Sewer Use By-law).

Should changes occur to Provincial policy and legislative requirements, particularly related to limitations on the SPC process resulting from Bill 23, further review would be required, and if feasible the SPC By-law should be utilized as the primary implementation mechanism for onsite controls within the Community of Ancaster.

APPENDIX G

Limitations

Limitations

1. The work performed in the preparation of this report and the conclusions presented are subject to the following:
    a. The Standard Terms and Conditions which form a part of our Professional Services Contract;
    b. The Scope of Services;
    c. Time and Budgetary limitations as described in our Contract; and
    d. The Limitations stated herein.
2. No other warranties or representations, either expressed or implied, are made as to the professional services provided under the terms of our Contract, or the conclusions presented.
3. The conclusions presented in this report were based, in part, on visual observations of the Site and attendant structures. Our conclusions cannot and are not extended to include those portions of the Site or structures, which are not reasonably available, in WSP's opinion, for direct observation.
4. The environmental conditions at the Site were assessed, within the limitations set out above, having due regard for applicable environmental regulations as of the date of the inspection. A review of compliance by past owners or occupants of the Site with any applicable local, provincial or federal bylaws, orders-in-council, legislative enactments and regulations was not performed.
5. The Site history research included obtaining information from third parties and employees or agents of the owner. No attempt has been made to verify the accuracy of any information provided, unless specifically noted in our report.
6. Where testing was performed, it was carried out in accordance with the terms of our contract providing for testing. Other substances, or different quantities of substances testing for, may be present on-site and may be revealed by different or other testing not provided for in our contract.
7. Because of the limitations referred to above, different environmental conditions from those stated in our report may exist. Should such different conditions be encountered, WSP must be notified in order that it may determine if modifications to the conclusions in the report are necessary.
8. The utilization of WSP's services during the implementation of any remedial measures will allow WSP to observe compliance with the conclusions and recommendations contained in the report. WSP's involvement will also allow for changes to be made as necessary to suit field conditions as they are encountered.
9. This report is for the sole use of the party to whom it is addressed unless expressly stated otherwise in the report or contract. Any use which any third party makes of the report, in whole or the part, or any reliance thereon or decisions made based on any information or conclusions in the report is the sole responsibility of such third party. WSP accepts no responsibility whatsoever for damages or loss of any nature or kind suffered by any such third party as a result of actions taken or not taken or decisions made in reliance on the report or anything set out therein.
10. This report is not to be given over to any third party for any purpose whatsoever without the written permission of WSP.

11. Provided that the report is still reliable, and less than 12 months old, WSP will issue a third-party reliance letter to parties that the client identifies in writing, upon payment of the then current fee for such letters. All third parties relying on WSP's report, by such reliance agree to be bound by our proposal and WSP's standard reliance letter. WSP's standard reliance letter indicates that in no event shall WSP be liable for any damages, howsoever arising, relating to third-party reliance on WSP's report. No reliance by any party is permitted without such agreement.