Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

HIGHLAND CREEK WATERSHED
HYDROLOGIC MODEL UPDATE

Prepared for:
TORONTO AND REGION CONSERVATION AUTHORITY
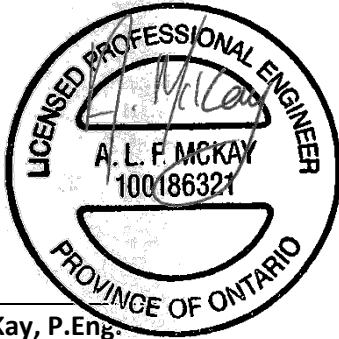
Prepared by:
MATRIX SOLUTIONS INC.

Version 2.0
May 2020
Guelph, Ontario

HIGHLAND CREEK WATERSHED

HYDROLOGIC MODEL UPDATE
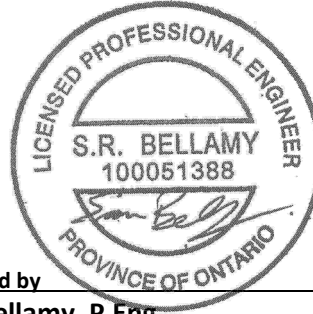
Prepared for Toronto and Region Conservation Authority, May 2020

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May 29, 2020

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May 29, 2020

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VERSION CONTROL

Version	Date	Issue Type	Filename	Description
V0.1	17-Feb-2020	Draft	27623-531 Highland Hydrologic Modelling Report R 2020-02-17 draft V0.1.docx	Issued to client for review
V1.0	23-Apr-2020	Final	27623-531 Highland Hydrologic Modelling Report R 2020-04-23 final V1.0.docx	Issued to client
V2.0	29-May-2020	Final	27623-531 Highland Hydrologic Modelling Report R 2020-05-29 final V2.0.docx	Issued to client

ACKNOWLEDGEMENTS

EXECUTIVE SUMMARY

Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc. to complete a comprehensive update to hydrologic and hydraulic modelling in the Highland Creek watershed. The objective of this study was to complete watershed-wide delineation of Regulatory floodplain limits using recent topographic and hydrologic data. To complete this objective, an up-to-date hydrologic model was developed to calculate peak flows throughout the watershed. The existing hydraulic model of the watershed was subsequently updated with the new peak flows as well as current topographic and survey data to generate water surface elevations and produce floodplain maps. This report documents the development and application of the hydrologic model.

Highland Creek has a drainage area of approximately 105 km^2, most of which is highly urbanized. There are 10 major subwatersheds with over 72 km of watercourses. Urbanization of the watershed began in the 1950s, expanding rapidly in a north-easterly direction through the 1960s and 1970s. Most of the watershed is drained through storm sewers with minimal attenuation from stormwater management (SWM) features. Several severe flood events have occurred in recent years, with the most significant occurring on August 19, 2005.

To initiate the project, background data was collected and reviewed including previously completed reports, flow and rainfall monitoring data, aerial imagery, SWM facility reports and GIS data to familiarize with the study area. The previous completed 2004 hydrology model and report (Aquafor Beech 2004) were reviewed to understand previous catchment parameterization, calibration approaches, and selection of design storm distributions. Data at flow monitoring locations were reviewed to determine monitoring duration and frequency as well as overlapping monitoring periods. Rainfall data from both TRCA and City of Toronto were summarized spatially to ensure a high density of rainfall input for the calibration and validation events. Soils data mapping showed most of the watershed classified as built-up area and more reliance water placed on the surficial geology mapping to characterize soils conditions. Land use mapping identified 19 different land use types within the watershed, with medium density residential, industrial, and recreational making up over 70% of the area.

PCSWMM was selected as the preferred modelling platform to represent the hydrologic processes within Highland Creek. The model platform integrates the full United States Environmental Protection Agency Storm Water Management Model Version 5.1 (EPA SWMM; EPA 2017) hydrology and hydraulics engine with a powerful GIS platform. PCSWMM was selected as it has built-in capability to represent the detailed hydrologic processes for each catchment, while also being able to represent a variety of SWM features and complex hydraulic routing.

Model catchments were delineated for the Highland Creek watershed using the 2015 LiDAR. Initially, catchments were delineated at the upstream end of each watercourse, at confluences, at watercourse crossings, and for the 37 SWM facilities identified within the watershed. Catchments were refined to ensure that most catchments remained a reasonable size (between 2 and 150 ha) and that they

aligned with adjacent watershed boundaries (the Rouge and Don River watersheds). The final delineation resulted in 299 catchments with an average area of 35 ha.

Parameters for each catchment were defined from the background spatial datasets, literature values, and professional judgement based on knowledge of the watershed. Initial parameters values were calculated as follows and later refined during the calibration process:

- catchment area: defined through catchment delineation
- catchment flow length: defined by the longest overland flow path
- average catchment slope: defined by smoothed 2015 LiDAR raster
- percent impervious: defined by an aerial image raster analysis
- roughness coefficients for pervious and impervious areas: defined by land use and literature values
- depression storage for pervious and impervious areas: defined by land use and literature values
- soil infiltration parameters: Green and Ampt method defined by soils and surficial geology mapping
- channel routing: defined by simplified HEC-RAS model cross-sections; hydrologically significant structures were reviewed and added to the hydrologic model
- SWM facility parameterization: defined by information provided in the design reports

As per the TRCA guidelines, 10 high flow events were selected for model calibration and validation. Events selected for calibration/validation correspond with times where multiple rain gauges and flow monitoring gauges were recording. Emphasis was placed on events that resulted in the greatest peak flows, which occurred at both Water Survey of Canada flow gauges 02HC013 and 02HC058. Limited data was available for the TRCA HY034 flow gauge. Antecedent moisture conditions were determined for each event by reviewing the conditions 5 days prior to the event rainfall and were represented in the model by varying the initial moisture deficient soil parameter.

Several metrics were reviewed for each of the calibration and validation events simulated in the hydrologic model. Through the calibration processes and a review of the Water Survey of Canada rating curve development, it was determined that emphasis should be placed on the matching flows at 02HC058 over the downstream 02HC013 flow gauge as additional high-flow measurements had been taken to define the upper end of the rating curve. The resulting calibration achieved TRCA's criteria for matching peak flows and volumes for the required number of events at the 02HC058 flow gauge, while peak flows and volumes were generally overestimated at the 02HC013 flow gauge when compared to observed values. An additional small event analysis (i.e., less than the 2-year return period flow) was added to the analysis to further validate the results at the 02HC058 flow gauge. The August 19, 2005, event as also simulated in the model but could not be compared to observed flow data as none was recorded at the time of the event. Instead water level data at specific crossing locations were compared to measured high-water marks.

The 2- through 100-year, Regional, and 350-year design storm events were simulated to estimate return period and Regional storm event peak flows for input to the hydraulic model. As the Regional and 350-year flow estimates require that all SWM facilities and structures be removed, two PCSWMM models were developed with the calibrated hydrologic parameters. A PCSWMM model with SWM facilities and structures represented was used to simulate the 2- through 100-year design storm distributions, and a PCSWMM model without the SWM infrastructure pieces was used to simulate the Regional and 350-year events.

Nine different design storm distributions were simulated in the hydrologic model and compared to the flood frequency analysis completed for the 02HC058 and 02HC013 flow gauges. Matrix reviewed and discussed the result of the analysis with TRCA to determine what design storm would be most suitable. Ultimately the 1-hour Atmospheric Environmental Service was selected to represent the design storm flows in the Highland Creek, as it is applicable to urbanized watersheds and has a high-intensity and short-duration storm distribution similar to historical events.

To account for saturated conditions, the full 48 hyetograph of the Regional storm event (Hurricane Hazel) was simulated in the calibrated hydrologic model. Areal reduction factors were applied for the Regional storm using the equivalent circular area method. Peak flow results for both the 2- through 100-year design storms and Reginal storm were compared to the previous 2004 study (Aquafor Beech 2004). Diffferences in peak flow are largely due to refinements with the catchment delineation and the refined model parameterization. In general, the updated Regional flows are slightly lower (average 6% lower) than the previous 2004 models estimates.

A high level of care and professional judgement was used to calibrate and validate the Highland Creek hydrologic model to ensure the physical processes of infiltration, runoff, and routing were properly represented. As with any model, there are sources of inherit uncertainty whether that be in inputs, calibration parameters, or processes within the model themselves. Areas of potential uncertainty with the model, limitations of using the calibration hydrologic model and recommendations for improvements are provided to assist with future modelling efforts.

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1   INTRODUCTION

The Toronto and Region Conservation Authority (TRCA) retained Matrix Solutions Inc. to complete a comprehensive hydrologic and hydraulic model and floodplain mapping update for the Highland Creek watershed. To complete this objective, an up-to-date hydrologic model of the Highland Creek watershed was required to estimate Regional peak flows throughout the watershed, which was then input to an updated hydraulic model. The hydraulic model was then used to generated water surface elevations and subsequently produce floodplain maps. This report documents the development and application of the hydrologic model.

Hydrologic flow estimates were last updated in 2004 using the Visual OTTHYMO (Greenland International Consulting Inc. 2001) modelling software platform. To complete the 2019 hydrologic update, TRCA selected the PCSWMM (CHI 2019) modelling platform to simulate the hydrologic response of the Highland Creek watershed. The PCSWMM EPASWMM engine was developed to analyze runoff from urban areas and contains modelling capabilities to represent urban elements such as stormwater management (SWM) facilities, drainage system networks, and impervious catchments. Although the EPASWMM engine can also represent non-urban catchments, the hydrologic processes and parameters embedded in the model are tailored toward representing small urbanized catchments, such as Highland Creek.

PCSWMM has been used on a variety of projects throughout Ontario and Canada, including the latest hydrology updates for the Rouge (Wood 2018) and Don River (AECOM 2018) watersheds. Using PCSWMM to represent the hydrology of the Highland Creek watershed provides an opportunity to simulate rainfall-runoff interaction in a more detailed and comprehensive manner than the 2004 study. Additional meteorological and hydrometric data that has been collected since 2004 also provides several significant storm events that can be used to calibrate and validate the PCSWMM model. Overall, these refinements help provide a more reliable hydrologic model that is suitable for floodplain mapping.

This hydrology report outlines the hydrologic model development, parameterization, calibration, and validation results and Regional and design storm simulations results for the Highland Creek watershed.

1.1   Study Area and Watercourse Mapping

Highland Creek is a highly-urbanized system, with a drainage area of approximately 105 km^2. The watershed is almost entirely within the former City of Scarborough, with close to 90% of its area designated as urban land use and impervious coverage estimated at 53% of the basin area (McDonald 2011, Satgunarajah 2009, TRCA and City of Toronto 1999). Urbanization began in the 1950s, expanding rapidly in a northeasterly direction through the 1960s and 1970s, nearing its current urban form by the 1990s with some development and land use conversion occurring in subsequent years (McDonald 2011).

During urbanization, much of the upper reaches north of Highway 401 were channelized and lined with concrete or other engineered materials. The flow regime changed abruptly in the mid 1970s, losing seasonality and becoming flashier with measurable events throughout the year (McDonald 2011). Several severe flood events have occurred in recent years, with the most significant occurring on August 19, 2005.

The vast majority of the watershed is drained through storm sewers, with minimal attenuation from SWM features. Within Highland Creek, there are ten major subwatersheds with 21 watercourses which include:

- Bendale Branch including Bendale Branch Tributary 1, and Bendale Branch Tributary 2
- Centennial Creek including Centennial Creek Tributary
- Curran Hall Creek
- Dorset Park Branch including the Dorset Park Intercept
- East Highland Creek
- Ellesmere Ravine
- Malvern Branch including Malvern Branch Tributary
- Milliken Branch including Milliken Branch Tributary
- Thornton Creek including Thornton Creek Tributary
- West Highland Creek including West Highland Creek Tributary 1, and West Highland Creek Tributary 2
- Highland Creek (Main Branch)

Most watercourses drain from north to south and west to east through the watershed. In total, there are 72 km of mapped watercourses through the Highland Creek watershed. Mapped watercourses were provided by TRCA and are shown, along with the watershed boundary, on Figure 1.

Easting (m)

Northing (m)

Highland Watershed
Water Body
Watercourse
Subwatershed
Bendale Branch - Reach 1
Bendale Branch - Reach 2
Bendale Branch - Reach 3
Bendale Trib 1
Bendale Trib 2
Centennial Creek - Reach 1
Centennial Creek - Reach 2
Centential Creek Trib
Curran Hall Creek
Dorset Park Branch - Reach 1
Dorset Park Branch - Reach 2
Dorset Park Intercept
East Highland Creek
Ellesmere Ravine
Highland Creek - Reach 1
Highland Creek - Reach 2
Highland Creek - Reach 3
Highland Creek - Reach 4
Highland Creek - Reach 5
Highland Trib 1
Malvern Branch - Reach 1
Malvern Branch - Reach 2
Malvern Branch Trib
Milliken Branch - Reach 1
Milliken Branch - Reach 2
Milliken Branch Trib
Thornton Creek - Reach 1
Thornton Creek - Reach 2
Thornton Trib
West Highland Creek - Reach 1
West Highland Creek - Reach 2
West Highland Creek - Reach 3
West Highland Creek - Reach 4
West Highland Trib 1
West Highland Trib 2

1:65,000
NAD 1983 UTM Zone 17N
metres
700   0   700   1,400

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Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Highland Creek Watershed and Mapped Watercourses

DRAFT

Date:	Project:	Submitter:	Reviewer:
June 2020	27623	A. McKay	S. Bellamy

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Figure 1

Map labels: Malvern Branch Trib, Malvern Branch, Milliken Branch Trib, Bendale Trib 1, Bendale Trib 2, Bendale Branch, Milliken Branch, Ellesmere Ravine, East Highland Creek, Highland Creek, Centennial Creek, Centennial Trib, Curran Hall Creek, West Highland Trib 2, West Highland Creek, Thornton Trib, Highland Trib 1, Thornton Creek, West Highland Trib 1, Dorset Park Branch, Dorset Park Intercept, Don River East Branch, Lake Ontario

1.2 Previous Hydrology Update (Aquafor Beech Limited)

The previous *Highland Creek Hydrology Update* was completed by Aquafor Beech Limited (2004). The purpose of the hydrology update was to "develop a flood management strategy to minimize the impact of future urban development." The hydrologic update involved the development and application of a numeric model, using the Visual OTTHYMO V2.0 code. The model was set up and parameterized as follows:

- 43 catchments ranging in size from 17 to 430 ha (see Figure 2)
- curve number (CN) parameterization derived from soil types, land cover mapping, and orthoimages; percent impervious was derived based on land use
- standard unit hydrographs to simulate runoff from urban catchments
- Nash unit hydrographs to simulate runoff from rural catchments
- channel routing using the variable storage coefficient method:

    + channel cross-section representation from HEC-2 hydraulic models
    + channel slopes from GIS

Calibration and verification of the 2004 hydrologic model was completed with the following exercises:

- Simulated flows were compared to observed flows at three locations: Water Survey of Canada (WSC) station 02HC013 and two monitoring gauges on West Highland Creek, which were privately operated from 1999 and 2000.

- Five calibration and two verification rainfall events were selected from 1995, 1996, 1999, and 2000. The events ranged from 14.3 to 73.0 mm.

- CN values were adjusted in the model to better match volumes between simulated and observed streamflow data.

- Roughness coefficients and channel routing elements were adjusted in the model to better match peak flows and timing between the simulated and observed streamflow data.

The calibrated model was then used to simulate the 2- through 100-year design storms and the regulatory event (Hurricane Hazel). The 6-hour Atmospheric Environmental Service (AES) design storm distribution was selected to represent the design storms as it produced higher peak flows than the 12-hour AES distribution. Rainfall depths for the design storms were obtained from the Toronto Bloor Street intensity-duration-frequency (IDF) curves.
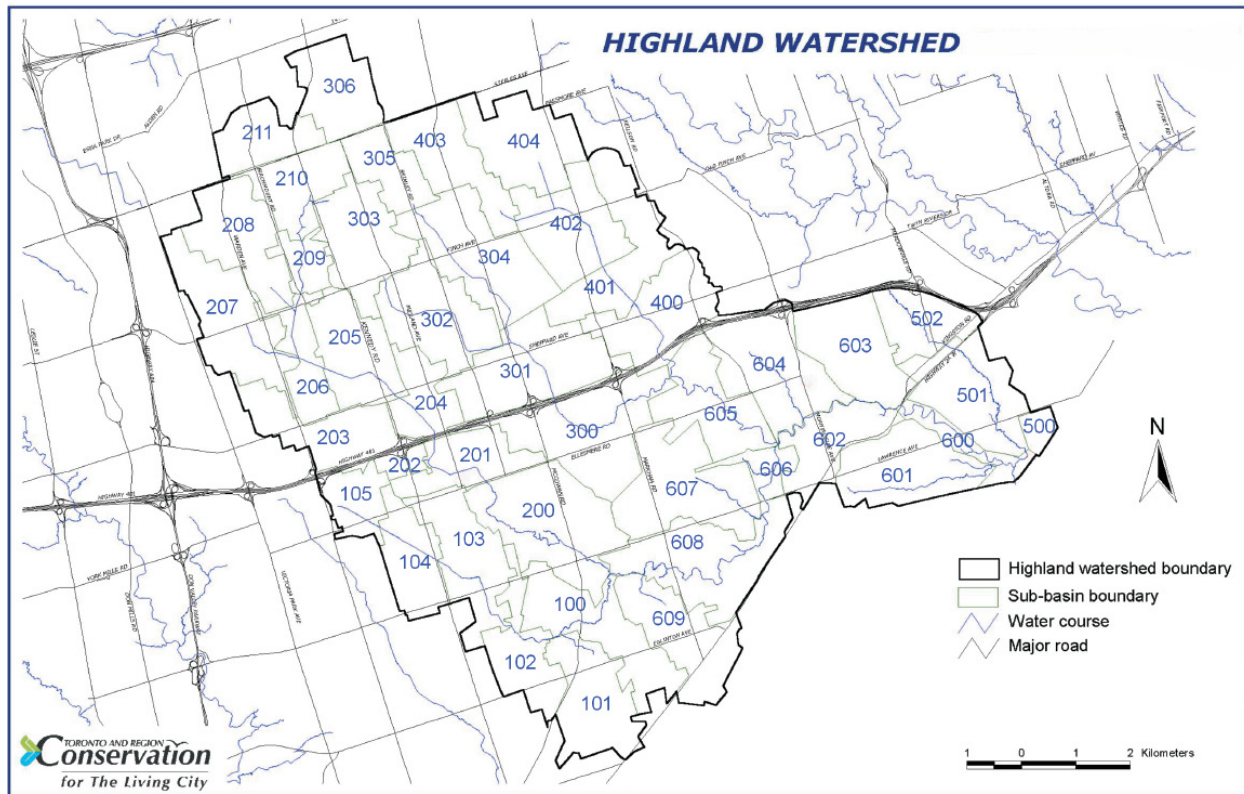
FIGURE 2   2004 Hydrology Model Catchment Boundaries (Aquafor Beech 2004)

The current study will improve upon the previous 2004 study through increased catchment discretization, refined of land cover and soils mapping, more detailed channel routing, and additional calibration to observed storm events.

2   MODEL DEVELOPMENT

The following section outlines the model development process and includes a summary of input data sources, model selection, catchment delineation, catchment parameterization, channel routing, SWM facility representation, and areas of special consideration.

2.1   Input Data Sources

Several data sources were used to develop, calibrate, and verify the hydrologic model. TRCA provided most data sources and supplemented with data available from the City of Toronto; Environment and Climate Change Canada (ECCC); and Ministry of the Environment, Conservation and Parks. A summary of data sources is listed in the following subsections.

2.1.1 Flow and Rainfall Data

Flow and rainfall data are critical datasets for a hydrologic model. Climate data is the main input that drives the runoff response and observed flow data is used to compare to the simulated flows and confirm the model is replicating observed conditions.

2.1.1.1 Flow Data

Three hydrometric (flow and water level) monitoring stations are located within the Highland Creek watershed. WSC operates two monitoring stations (IDs: 02HC058 and 02HC013) and TRCA operates one monitoring station (ID: HY034).

WSC monitoring station 02HC013 is located on the main branch of Highland Creek, downstream of the Ellesmere Tributary confluence near the Morningside Avenue bridge. The station was installed in 1969 and operated until 1998 when is was discontinued. The station was then re-established in 2005 after the August 19, 2005, event. WSC monitoring station 02HC058 was established in 2006 and is located on West Highland Creek, near the Bellamy Road bridge. The TRCA HY034 monitoring station was established in 2003 and flows are available from 2003 and 2007 and then from 2010 to 2014. In 2015, erosion of the channel caused the rating curve to become unreliable.

Table 1 provides and overview of the three flow monitoring stations and each flow gauge is shown on Figure 3.

TABLE 1   Flow Gauge Monitoring Stations in Highland Creek

Station ID	Flow Gauge Name	Source	Drainage Area (km²)	Years of Data Available (Recording Interval)
02HC013	Highland Creek near West Hill	Water Survey of Canada	89.1	1969-1998 (15-minute) 2005-2018 (5-minute)
02HC058	West Highland Creek near Scarborough	Water Survey of Canada	39.3	2006-2015 (15 and 30-minute) 2016-2019 (5-minute)
HY034	Highland Creek at Malvern	Toronto and Region Conservation Authority	12.3	2003-2007 (hourly) 2010-2012 (hourly) 2010-2014 (15-minute)

Legend
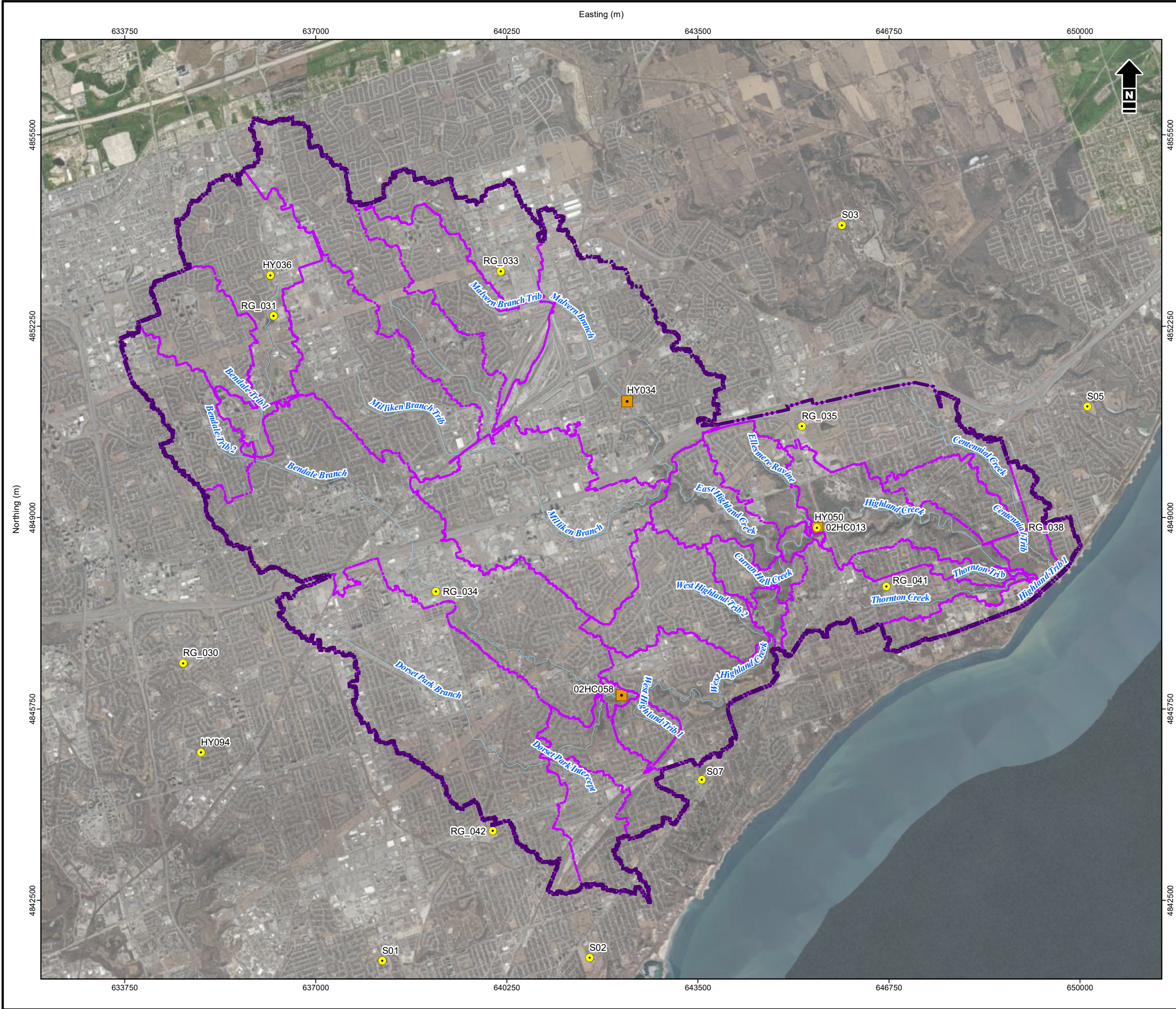
- Highland Watershed
- Subwatershed
- Watercourse
- Rainfall Monitoring Station
- Flow Monitoring Station

Station ID	Rain Gauge Name
HY036	Kennedy Pump Station
HY050	Morningside Works Yard
HY094	Broadlands Community Centre
HY057	Rouge at 14th
HY051	Petticoat CA
HY044	Milne Dam
HY070	York Region Works Yard
S01	Providence Villa
S02	St. Aug. Seminary
S03	Toronto Zoo
S04 / RG-030	Pharmacy/401
S05	Friendship
S06 / RG-031	L'Amoreaux
S07	Scarborough Village
S08 / RG-033	Nashdene Yard
S09 / RG-034	Ellesmere Yard
S10 / RG-035	Morningside Yard
RG_038	Fire Station 215
RG_041	Poplar
RG_042	Seminole

Station ID	Flow Gauge Name
02HC013	Highland Creek near West Hill
02HC058	West Highland Creek near Scarborough
HY034	Highland Creek at Malvern

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NAD 1983 UTM Zone 17N

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Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Monitoring Station Locations

Date:	May 2020	Project:	27623	Submitter:	A. McKay	Reviewer:	S. Bellamy

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Figure

3

2.1.1.2   Rainfall Data

Rain gauge data was collected from monitoring stations operated by TRCA, ECCC, and the City of Toronto. Gauge selection was based on data availability, gauge location, monitoring interval, and quality of data. Table 2 summarizes the rain gauges that were used to assess storm events for calibration and verification of the hydrologic model. Figure 3 shows the spatial extent of the rain gauges relative to the Highland Creek watershed boundary. Most rainfall data were recorded in 5-minute intervals. Since the rainfall/runoff response time in Highland Creek is so rapid, having a minimum rainfall and flow recorded interval of 15 minutes is required to truly assess the response.

TABLE 2   Rain Gauge Monitoring Stations in and Surrounding Highland Creek

Station ID	Rain Gauge Name	Source	Available Period	Years of Data Available[1]
HY036	Kennedy Pump Station	TRCA	2006-2017	12
HY050	Morningside Works Yard	TRCA	2005-2017	13
HY094	Broadlands Community Centre	TRCA	2015-2017	3
HY057	Rouge at 14th	TRCA	2003-2007	5
HY051	Petticoat Conservation Area	TRCA	2003-2015	13
HY044	Milne Dam	TRCA	2007-2017	10
HY070	York Region Works Yard	TRCA	2004-2017	14
S01	Providence Villa	City of Toronto	1993, 1995, 1998-2002	7
S02	St. Augustine Seminary	City of Toronto	1994-2010	16
S03	Toronto Zoo	City of Toronto	1995-2007	13
S04/RG-030	Pharmacy/Highway 401	City of Toronto	1997-2018	22
S05	Friendship	City of Toronto	2003-2004	2
S06/RG-031	L'Amoreaux	City of Toronto	2003-2018	16
S07	Scarborough Village	City of Toronto	2003-2011	9
S08/RG-033	Nashdene Yard	City of Toronto	2004-2018	15
S09/RG-034	Ellesmere Yard	City of Toronto	2004-2018	15
S10/RG-035	Morningside Yard	City of Toronto	2004-2018	15
RG_038	Fire Station 215	City of Toronto	2015-2018	4
RG_041	Poplar Road	City of Toronto	2015-2018	4
RG_042	Seminole Avenue	City of Toronto	2015-2018	4

(1)   Data may not be continuous through each year.
TRCA - Toronto and Region Conservation Authority

2.1.2 Watercourse Network and Topography

TRCA provided Light detecting and ranging data (LiDAR) data in a 1-m Esri grid format. The data was collected in 2015 for the Highland Creek watershed (Figure 5). The LiDAR data was used to verify the existing watercourse network, define cross-section dimensions, delineate catchments, and derive hydrologic model parameters.

The watercourse network was provided by TRCA and reviewed against 2018 ortho-imagery and the 2015 LiDAR. While many of the watercourse in Highland Creek are engineered channels, some reaches in the network are highly active (i.e., frequently move within the valley) and/or have had recent channel work which modified the channel planform. To ensure that the best representation of the channel planform was applied to the hydrologic model, the watercourse network was manually modified in areas to ensure that it followed the thalweg of the channel. An example of an area where manual channel modifications were made is provided in Figure 4.

FIGURE 4   Manual Watercourse Edit Example

Topography
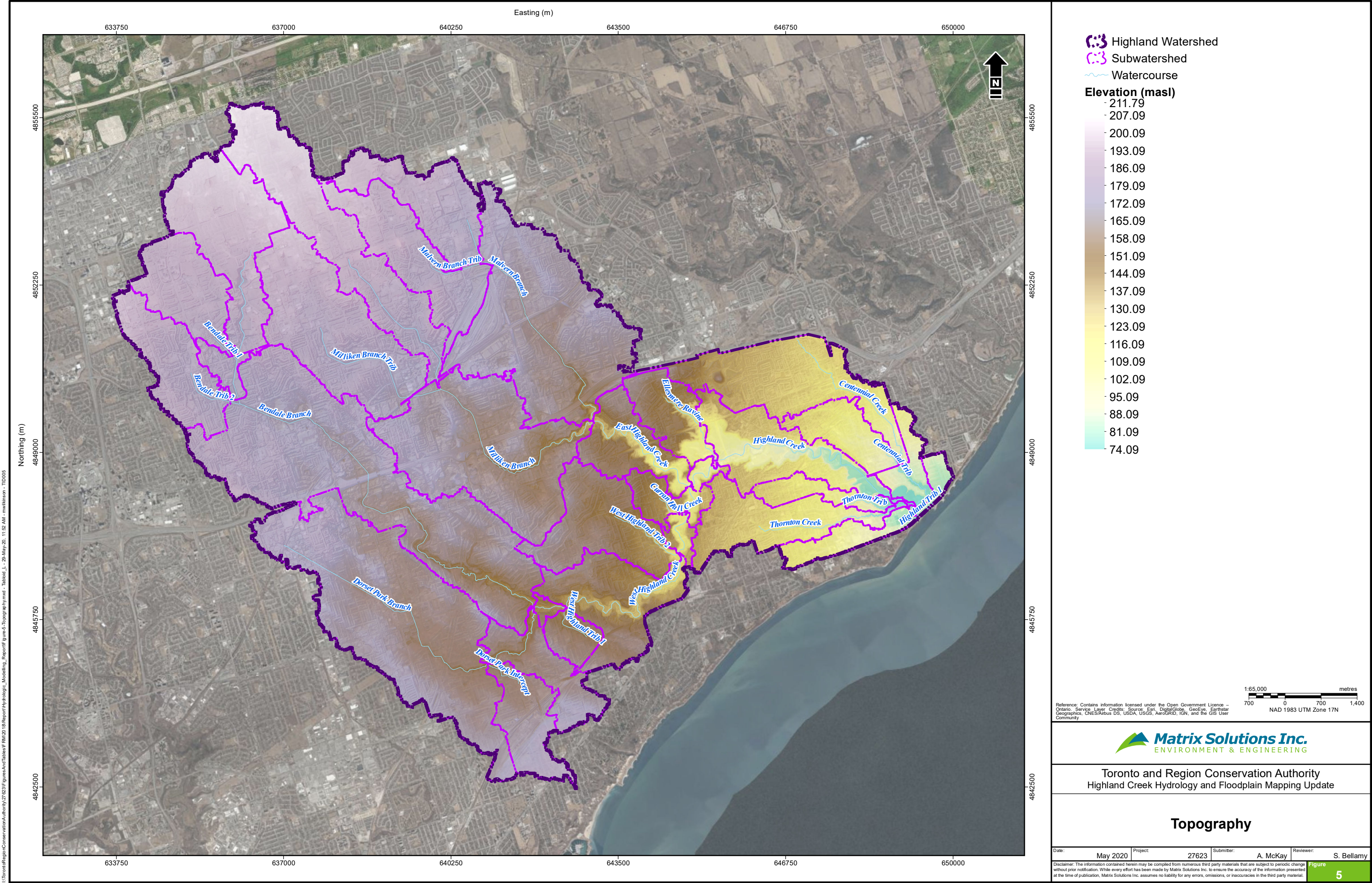
2.1.3 Soils Mapping

TRCA provided soils, surficial geology, and physiography mapping. The soils data was originally sourced from Ontario Ministry of Agriculture, Food and Rural Affairs. Surficial geology was sourced from the York, Peel, Durham, Toronto Conservation Authorities Moraine Coalition (YPDT-CAMC; ORMGP 2019). Physiography was provided by the Ontario Geologic Survey.

The physiography through the majority of Highland Creek watershed was classified as Till Plains, with some Drumlins, and the downstream portion of the watershed is classified as Sand Plains. Soils mapping through the watershed is limited, due to the majority being classified as "built-up" area for the historical urbanizing. In the built-up areas, the underlying surficial geology mapping was used to determine local infiltration as discussed in Section 2.4. A figure showing the soils and surficial geology classification within the Highland Creek watershed is shown on Figures 6 and 7.

Easting (m)

Northing (m)

Highland Watershed
Subwatershed
Watercourse

Soil Name
Bookton Sandy Loam
Bottom Land
Brighton Sandy Loam
Brighton Sandy Loam - Over Gravel
Built Up Area
Fox Sandy Loam
Lyons Loam
Malton Clay
Milliken Loam
Muck
Tecumseth Sandy Loam - Over Gravel
Woburn Loam
Woburn Sandy Loam

Milliken Branch Trib
Milliken Branch
Milliken Branch Trib
Bendale Trib 1
Bendale Trib 2
Bendale Branch
Ellesmere Ravine
East Highland Creek
Centennial Creek
Highland Creek
Centennial Trib
Curran Hall Creek
West Highland Trib 2
Thornton Trib
Highland Trib 1
West Highland Creek
Thornton Creek
Dorset Park Branch
West Highland Trib 1
Dorset Park Intercept

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1:65,000

NAD 1983 UTM Zone 17N

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Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Soils Mapping

Date:	Project:	Submitter:	Reviewer:
May 2020	27623	A. McKay	S. Bellamy

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Figure
6

Legend

- Highland Watershed
- Subwatershed
- Watercourse

Surficial Geology
- Clay, silt
- Clay, silt, sand, diamicton
- Clay, silt, sand, gravel
- Diamicton
- Organic deposits
- Sand
- Sand, gravel

Malvern Branch Trib
Malvern Branch
Bendale Trib 1
Bendale Trib 2
Milliken Branch Trib
Bendale Branch
Milliken Branch
Ellesmere Ravine
East Highland Creek
Highland Creek
Centennial Creek
Centennial Trib
Highland Trib 1
Thornton Trib
Thornton Creek
Cardin Hall Creek
West Highland Trib 2
West Highland Creek
West Highland Trib 1
Dorset Park Branch
Dorset Park Intercep.

1:65,000

700   0   700   1,400 metres

NAD 1983 UTM Zone 17N

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Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Surficial Geology Mapping

Date:	Project:	Submitter:	Reviewer:
May 2020	27623	A. McKay	S. Bellamy

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Figure **7**

2.1.4 Land Use Mapping

TRCA provided detailed land use mapping for the Highland Creek watershed. Within the watershed, 19 different land use types were identified with the largest portion being medium-density residential (47.4%) followed by industrial (12.1%) and recreational (11.6%). The remaining land use types each compose less than 10% of the watershed area.

Land use was overlaid with aerial imagery to check specific land use classifications and made minor changes to some land use areas that required reclassification. A breakdown of land use is provided in Table 3 and shown on Figure 8. A detailed description of each land use type is provided in Appendix A.

TABLE 3   Land Use in Highland Creek Watershed

Land Use Code	Land Use Type	Area (ha)	Percentage of Watershed (%)
MCE	Mixed Commercial Entertainment	<1	<0.1
MDR	Medium-low Density Residential	4,969	47.4
IND	Industrial	1,266	12.1
REC	Recreation of Open Space	1,211	11.6
COM	Commercial	740	7.1
NCF	Forest	624	6.0
RDS	Roads	383	3.7
INS	Institutional	332	3.2
NCM	Meadow	280	2.7
HDR	High Density Residential	234	2.2
RWY	Railway	178	1.7
GC	Golf Course	96	0.9
OWR	Open Water - River	59	0.6
NCS	Successional	56	0.5
NCW	Wetland	30	0.3
CEM	Cemetery	7	0.1
OWL	Open Water - Lake	7	0.1
AGR	Agriculture	6	0.1
GRAND TOTAL		**10,478**	**100.0%**

Legend

Highland Watershed
Subwatershed
Watercourse

Land Use Type

Impervious
- Commercial
- High Density Residential
- Industrial
- Institutional
- Medium-low Density Residential
- Roads
- Railway

Pervious
- Agriculture
- Cemetery
- Golf Course
- Mixed Commercial Entertainment
- Forest
- Meadow
- Successional
- Wetland
- Open Water – Lake
- Open Water – River
- Recreation or Open Space

1:65,000

NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2017). Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Matrix Solutions Inc.
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Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Land Use Mapping

Date:	Project:	Submitter:	Reviewer:
May 2020	27623	A. McKay	S. Bellamy

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Figure 8

2.2   Model Selection

TRCA identified PCSWMM in the Terms of Reference as the preferred model platform for the hydrologic model development. PCSWMM 2018 Professional computer modelling software (CHI 2019) can be used for both single event and continuous simulations. The model platform integrates the full United States Environmental Protection Agency (US EPA) Storm Water Management Model Version 5.1 (EPA SWMM; EPA 2017) hydrology and hydraulics engine with a powerful GIS platform. The EPA SWMM engine is a comprehensive dynamic rainfall-runoff model that is used widely throughout the world in the analysis of complex hydrologic, hydraulic, and water quality problems for urban (and rural) areas. EPA SWMM, and its SWMM variants, has been used extensively for the simulation of surface runoff, conveyance through complex open-channel and closed-conduit drainage networks (storm, sanitary, and combined sewer systems), floodplain analysis, and soil erosion and sediment transport.

PCSWMM was selected to represent the hydrologic process within the Highland Creek watershed as it has built-in capability to represent the detailed hydrologic processes for each catchment, while also being able to represent a variety of SWM features and complex hydraulic routing.

2.3   Catchment Delineation

Catchment delineation within the Highland Creek watershed was completed in several stages, as outlined in Section 2.3.1 to ensure the catchments represent current conditions, align with the adjacent modelling studies (Rouge and Don hydrology) and allow sufficient detail (i.e., several flow input locations along each reach) to best inform the hydraulic model.

There are limitations to SWMM-based modelling in representing larger watersheds, particularly as it relates to the representation of sheet flow/overland flow length and the internal catchment routing. In addition to overland flow, routing occurs through the minor system (i.e., stormwater sewer network) and major flow routes (roadways and ditches) which are not explicitly represented in a watershed-scale model. Care was taken to delineate catchments where significant routing elements could be represented without adjusting parameters (e.g., Manning's n) outside of their "typical" ranges (Chin 2006).

2.3.1   Catchment Discretization

Catchments were initially delineated using the 2015 LiDAR data, with drainage enforced along the watercourse network described in Section 2.1.2. To develop initial catchments, pour points (i.e., specific outlet locations where runoff from an upstream area would concentrate to) were placed at the following locations:

- upstream end of watercourses to be mapped
- directly upstream of any confluence
- at each watercourse crossing
- at locations of the previously defined 2004 VO5 hydrology nodes

Aligning the 2019 catchments with the 2004 catchment locations allowed for a direct comparison of the 2004 VO5 model catchments and the newer LiDAR-derived catchments defined in this study.

A total of 37 SWM facilities were identified within the Highland Creek watershed. To initially assess the drainage to each of the SWM facilities, pour points were added at the location of each SWM pond. The area of each catchment was then refined based on the information from existing design reports and pond inventories (if available). The majority of SWM ponds within the Highland Creek watershed are established as overflow relief for the minor system; making the area which can be attenuated by the SWM facility hard to define. As the Highland Creek hydrologic model will ultimately be used to estimate Regional flows without the presence of SWM facilities, delineation considered only major overland catchment boundaries without consideration of the minor system. A summary of the SWM facility information is provided in Appendix B.

The Highland Creek watershed boundary was manually compared to the watershed boundaries defined in the existing approved Don River (AECOM 2018) and Rouge River (Wood 2018) reports (Figure 9) to ensure that areas were not being double counted or missing between the model domains. Any areas with discrepancies were double checked and then discussed with TRCA. Generally, the watershed delineation developed from LiDAR data was followed.
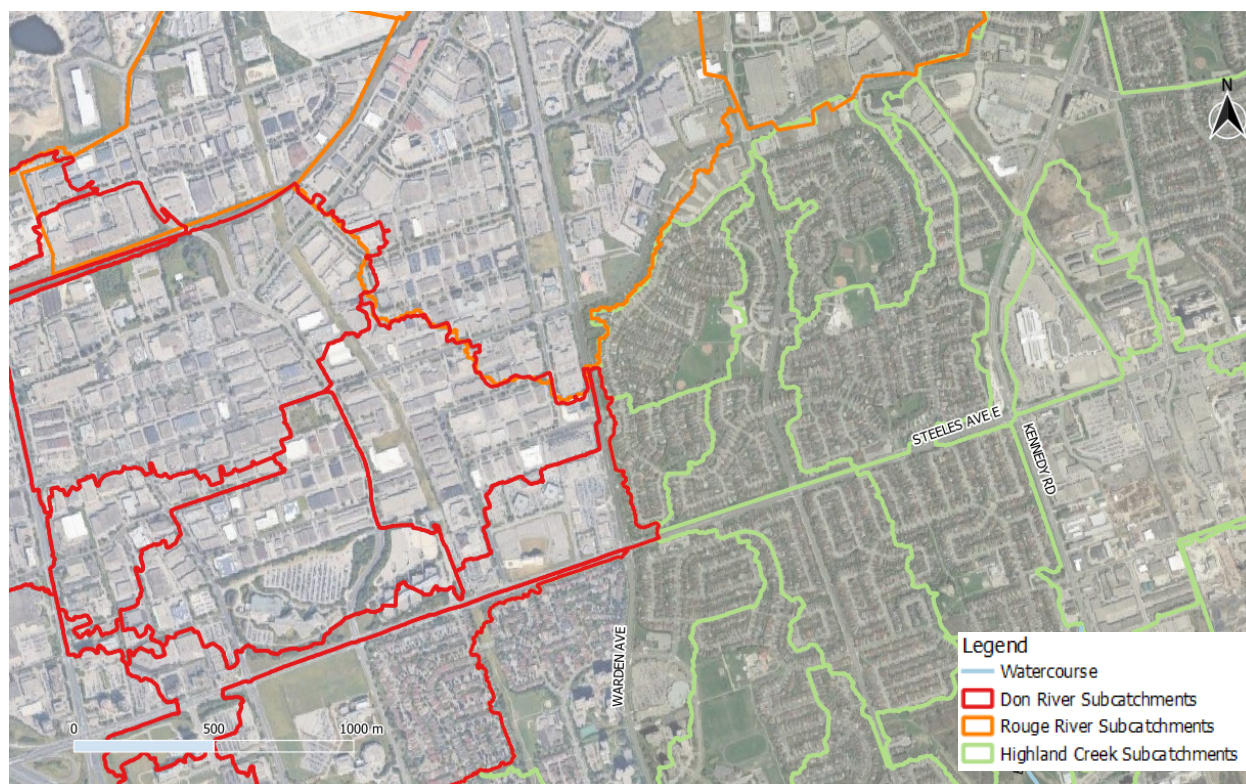
FIGURE 9   Neighbouring Subcatchment Boundaries

The initial delineation resulted in 269 catchments with an average catchment area of 39 ha. Although the average catchment area was reasonable for the scale of the model, there were several large (>200 ha) and small (1 ha) catchments that needed to be refined. Each catchment over 75 ha was reviewed to determine if further delineation could be completed based on a distinct separation in land use at an overland drainage boundary. If possible, pour points were added to overland flow path at the change in land use and additional catchments were delineated. An example of a catchment where this was completed is shown in Figure 10.

FIGURE 10 Refined Subcatchment Discretization

The final catchment areas were compared with a histogram analysis to the catchments delineated for the Don River and Rouge River hydrology models. The breakdown shown in Figure 11 shows that size distribution of the Highland Creek catchments align well with the other recent hydrologic models developed in PCSWMM. The majority of the Highland Creek catchments fall within the 25- to 50-ha range. Only six catchments are larger than 100 ha and one catchment is less than 1 ha.
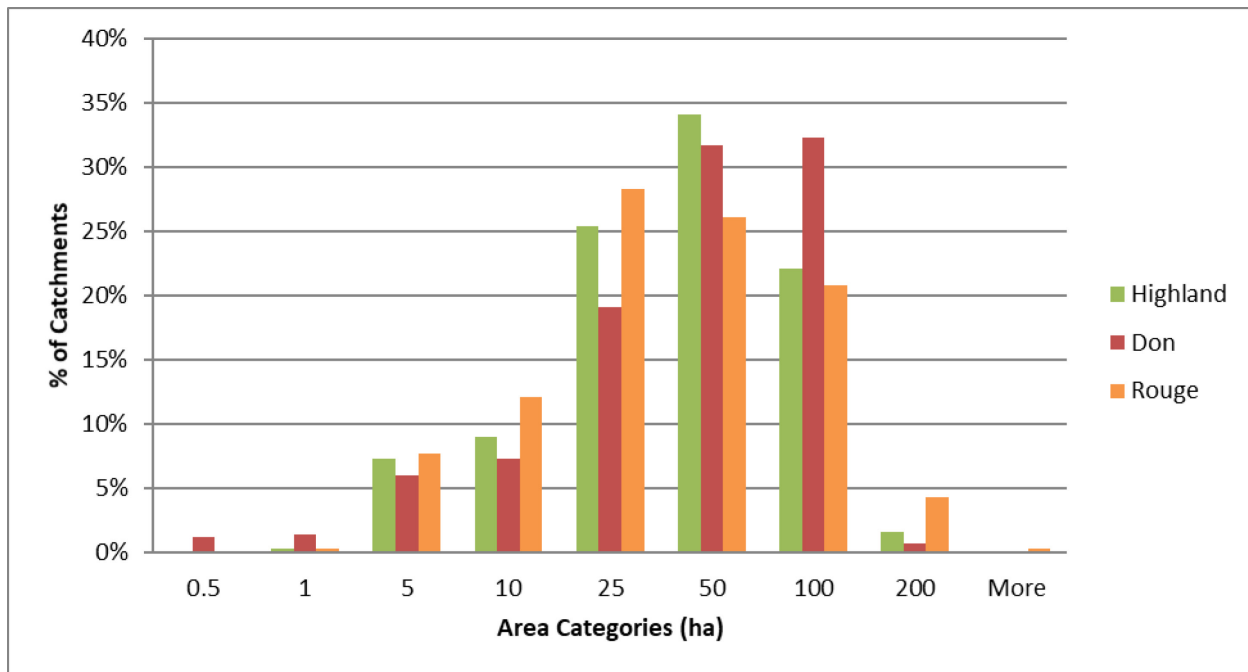
FIGURE 11 Catchment Delineation - Histogram Analysis Comparing Recent Watershed Hydrology Models

The Catchments are named with a unique identifier that specifies the catchment delineation method used. Catchments delineated solely from LiDAR were identified with the format H0XXX (where XXX is a unique numeric value), and catchments that were refined for the SWM facilities were identified with the format H1XXX.

TRCA reviewed the final catchment layer to confirm the general correctness of catchment boundaries and methods used. The final subcatchment discretization is shown on Figure 12. A total of 299 subcatchments were included in the hydrologic model. The catchment areas range from 0.8 to 164.6 ha, with an average area of 35.0 ha.

Figure 12 — Hydrologic Model Catchments

Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Matrix Solutions Inc.
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| Date: May 2020 | Project: 27623 | Submitter: A. McKay | Reviewer: S. Bellamy |

Figure 12
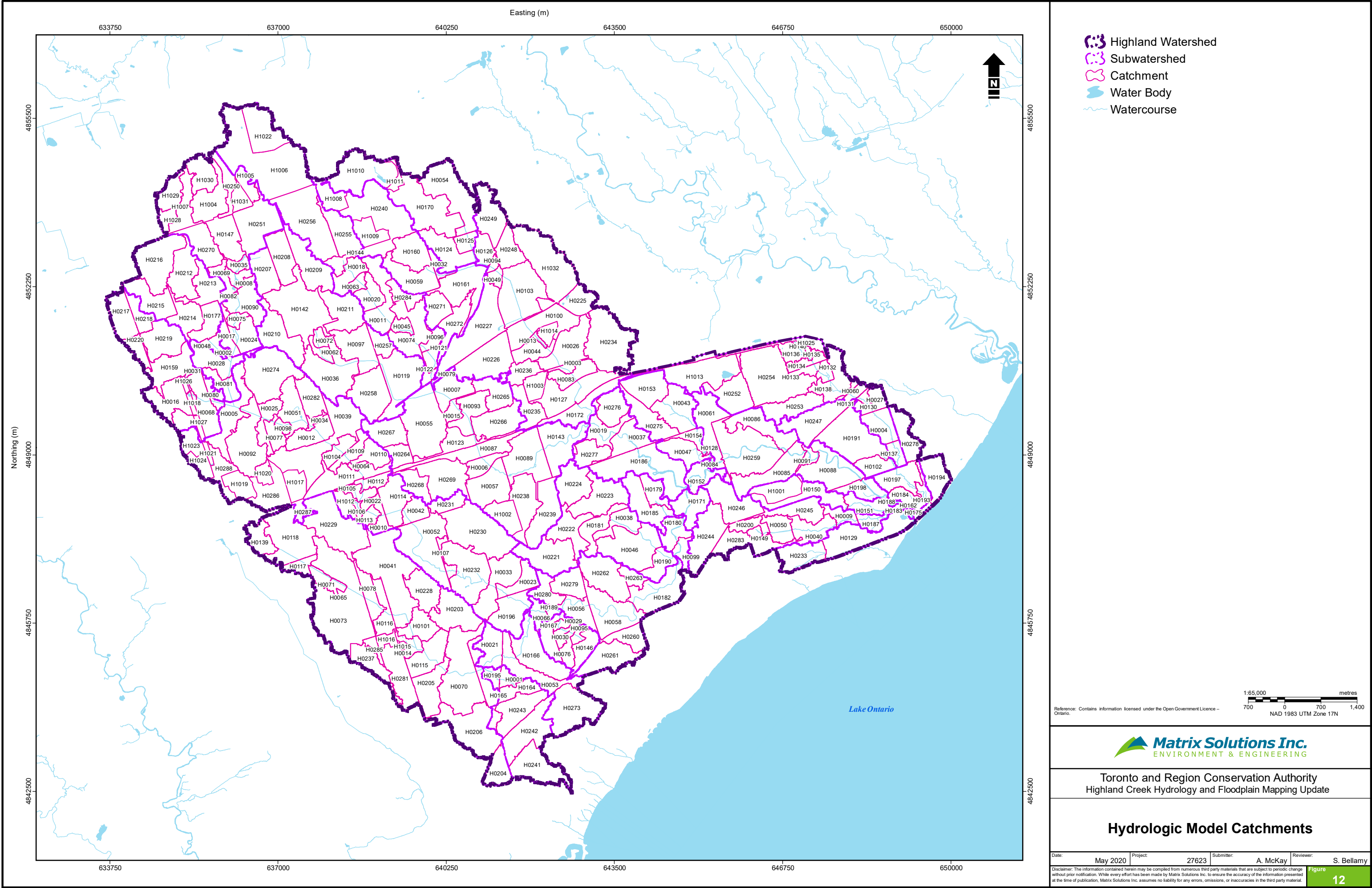
2.4 Catchment Parameterization

Parameterization of the hydrologic model was completed using the spatial datasets described in Section 2.1, literature values, and professional judgement based on knowledge of the watershed. The following parameters were required for each catchment in the PCSWMM model:

- catchment area
- catchment flow length
- average catchment slope
- percent impervious
- roughness coefficients for pervious and impervious areas
- depression storage for pervious and impervious areas
- catchment routing mechanism, and impervious portion that is routed to pervious
- soil infiltration parameters
- channel routing
- SWM facility parameterization

Catchment area was based on the GIS delineation described in Section 2.3.1. Details on how the remaining catchment parameters were derived is described in the following subsections.

2.4.1 Percent Impervious

Percent impervious for each catchment is required to determine the portion of area that will be subjected to the pervious and impervious model routines to determine the runoff from each catchment. In the previous 2004 hydrology studies, percent impervious was assigned based on the portion of land use type within the watershed. For the updated study, the portion of impervious area was calculated for each catchment through an aerial image raster analysis.

This process relied upon 2018 orthoimages that were provided by TRCA. The raster image classification was carried out using the following steps:

1. A pilot area within the model domain that represented a range of land use types was selected (e.g., residential, commercial, recreational land use types).

2. Training of the images was completed by selecting coloured pixels and assigning either pervious, impervious, or shadow as the classification. It is generally understood that the more training pixels the classification has, the better the image classification for the remaining areas will be.

3. Shadows were classified separately as they usually led to error in the classification if left to only pervious or impervious categories. The shadow classifications were then assigned to the largest adjacent classification (either pervious or impervious).

4. A buildings layer was downloaded from the City of Toronto open data portal (City of Toronto 2019). The buildings were "stamped" onto the classified raster layer to enforce impervious representation.

5. To account for imperviousness associated with the road network, a roads GIS layer was downloaded from the City of Toronto. Typical road widths were assigned to each road line, based on the attributed road type. By buffering the road by the corresponding road width (Table 4), the total area of road imperviousness was determined. Similar to the building layer, this buffered road layer was also stamped onto the classified raster.

TABLE 4   Assumed Road Width from Road Classification

Road Classification	Road Width (m)
Alleyway/Laneway	6
Arterial	15.7
Collector	11.5
Local/Strata	8.5
Local/Street	8.5
Ramp	8.5
Service	8.5
n/a	8.5

Source: *Review of Transportation Policies, Road Classification System, and Design Standards and Criteria* (AECOM Canada Ltd. 2012)

6. The raster classification had trouble classifying "water" areas in the high-resolution images due to the reflective surface. As such, the water bodies polygon layer and the digitized watercourse layer (developed from the bank lines in the hydraulic model) was used to define water in the raster. The water layer was then overlaid onto the classified raster layer.

7. Sand traps in golf courses were initially picked up as impervious areas by the raster classification process. To correct this, the sand traps were manually digitized onto the classified raster layer.

8. Once the above steps were completed, the raster went through a process to remove isolated polygons or "noise" (i.e., triangular 1 m^2 areas) in the data by merging it with the surrounding classification types.

9. The resulting imperviousness raster layer was then overlaid with the land use layer. If the percent impervious for a specific land use type seemed to high or low compared to the typical values, the area was manually inspected with the orthoimages, and if required, additional training of the raster classification was completed and the above steps were repeated.

A comparison between the classified raster and aerial imagery is shown in Figure 13.
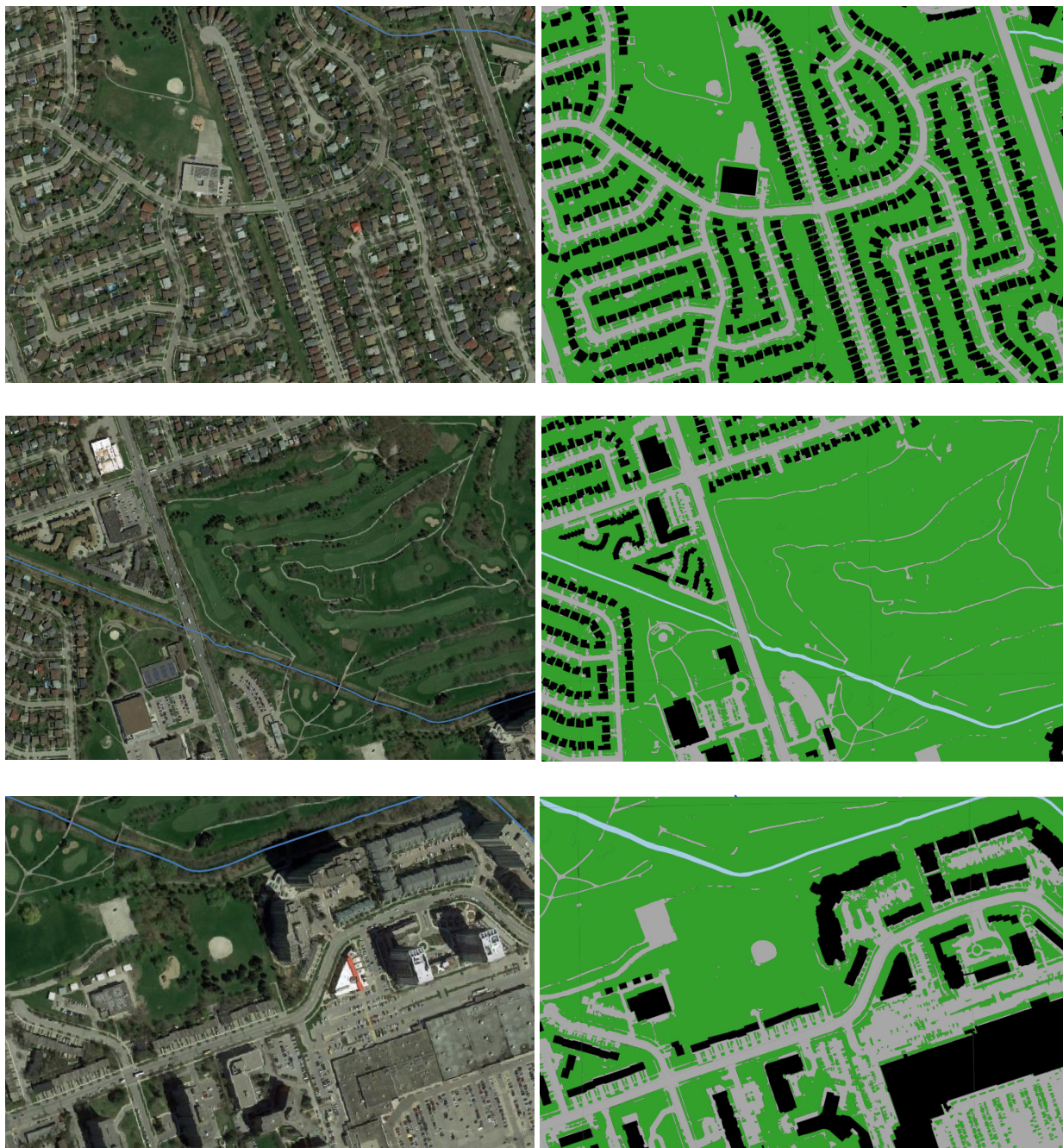
FIGURE 13 Impervious Raster Characterization Comparison to Imagery

In general, the raster classification picked up roads, buildings, and pathways well. Issues with misclassification occurred in areas with extensive shadows and dark rooftops as well as driveways and parking lots with parked cars or overhanging trees. Overall, the raster characterization trended towards classifying more pervious areas than identified in the reference imagery (Figure 13).

The final raster classification breakdown for each land use type is provided in Table 5. The raster classification shows similar results to the raster classification completed for the Don River hydrology model (AECOM 2018). In general, the raster analysis estimated lower imperviousness values for the various land use types (e.g., medium-density residential, commercial) when compared to typical values associated with those land use types. The final layer was provided to TRCA for review. Although it was discussed that the percent impervious values were lower than expected for the Highland Creek watershed, the values were used in the model development. Any modifications to the impervious cover values were address during calibration (Section 3.2).

TABLE 5   Percent Impervious Comparison Based on Land Use Type

Land Use Type	Percent of Highland Watershed	TRCA Land Use Based Percent Imperviousness	Don River Percent Imperviousness Raster Classification	Highland Creek Percent Imperviousness Raster Classification
Cemetery	0.2	35	12.0	11.4
Commercial	7.1	95	75.0	72.7
Golf Course	0.6	0	7.4	8.8
High-density Residential	2.0	80	54.0	62.8
Industrial	11.9	95	66.0	72.4
Institutional	3.0	80	44.0	72.1
Multi-commercial Entertainment	<0.05	-	-	13.1
Medium Low-density Residential	46.2	60	44.0	45.2
Forest	5.6	0	-	1.5
Meadow	3.1	0	-	3.1
Successional	0.7	0	-	1.0
Wetland	0.3	100	-	4.0
Water - Open Water Bodies	1.9	100	8.0	100
Water - Rivers	0.4	100	8.0	57.6
Roads	4.0	90	64.0	100
Recreational/Open Space	10.8	20	41.0	9.5
Railway	1.4	-	41.0	56.5

2.4.2   Catchment Slope

Catchment slope is used in PCSWMM as part of Manning's equation for overland routing. The greater the catchment slope, the higher the proportion and faster the runoff is from the catchment. Although slope does have some impact on the volume of runoff from the catchment, it is more influential on peaks and shape of the hydrograph. Catchment slope in the hydrology model was defined by overlying each catchment with the provided digital elevation model (DEM). PCSWMM has a built-in tool to determine average catchment slope. Computational Hydraulics International (CHI) recommends resampling a detailed DEM (1 to 2 m resolution) to a 5 or 10 m resolution before the catchment slope tool is run, to remove any abrupt changes in the topography. The 1 m DEM for the Highland Creek watershed was

resampled to both 5 and 10 m, but minimal differences were found in the resulting slopes. The 5 m resampled DEM was ultimately used to define the initial catchment slopes in the model.

2.4.3 Flow Length

The approach to defining catchment flow length in a PCSWMM model is a debated topic that largely depends on why and how a hydrologic model is developed. Many discussions on SWMM forums allude to flow length being a true calibration parameter, one that is initially estimated but has unlimited boundaries to how high or low the parameter can range. Similar to slope, flow length is built into the reservoir routing equation and affects the timing of runoff but, depending on the imperviousness, can also affect the volume. Generally, the lower the imperviousness, the greater the effect flow length has on the volume of runoff, as only one flow length is given to represent both pervious and impervious portions of the catchment. A sensitivity analysis demonstrating the variation in runoff based on catchment width and percent imperviousness is provided in Table 6.

TABLE 6   Catchment Length Sensitivity Analysis

Catchment Width (m)	Catchment Length (m)	Runoff (m³)		% Increase in Runoff	
		25% Imperviousness	75% Imperviousness	25% Imperviousness	75% Imperviousness
100	1,000	1,163	3,391	-	-
250	400	1,218	3,446	5%	2%
500	200	1,285	3,493	11%	3%
750	133	1,336	3,522	15%	4%
1,000	100	1,376	3,540	18%	4%

Note: Analysis was completed using a 10-ha catchment area, a sandy loam soil type and a 5-year, 4-hour Chicago storm distribution.

Typically, a SWMM model is developed to represent an urban area where various components of infrastructure are explicitly defined (e.g., catch basins, pipes, storage facilities). In a large-scale watershed model, this level of detail is not suitable and flow length becomes a representation of many processes that are occurring within the catchment including:

- overland sheet flow, such as runoff from driveways and backyards, before it enters the street or catch basin
- conveyance through pipe networks, once water enters into the minor stormwater system
- major overland flow routes, typically through roadways, ditches, and right of ways

Without explicit representation of these routing elements (e.g., roads and pipes), flow length becomes a lumped parameter representing all routing processes through the catchment.

Overland drainage pathways were developed during the ArcHydro catchment delineation process (Figure 14). During the initial calibration, flow lengths were estimate by clipping the overland flow where they intersected roads and averaging the lengths within each catchment. By completing this, the flow length would theoretically represent the overland sheet flow occurring within each catchment, before runoff reached a conveyance structure (road or pipe). The resulting flow lengths averaged 178 m (theoretically acceptable for overland sheet flow) within the catchments, but the short flow lengths routed runoff too quickly to the watercourses. Urban routing elements (i.e., catch basins and conduits) needed to be added to each catchment in the model to represent the minor system routing in order to create acceptable runoff peaks. Adding urban elements to each of the modelled catchments was highly subjective and required additional estimates of length, roughness, and conduit shape for each routing element. Therefore, alternatives to estimate flow lengths within each catchment (such as using the longest flow path length) were explored.

FIGURE 14   Overland Drainage Pathways

Longest flow path lengths were also estimated for each catchment using a United States Department of Agriculture relationship to total catchment area (USDA 2010):

$$l = 209A^{0.6}$$

Where:
   l = flow length (ft)
   A = drainage area (acres)

The United States Department of Agriculture (USDA) approach to flow length resulted it much longer pathways, which may account for some of the minor and major system routing that would happen within each catchment.

These flow lengths represented the longest flow path within each catchment that would translate to the time of concentration. To test this empirical approach to actual longest flow path length, flow paths were manually measured in five of the 299 catchments. Table 7 shows the results and concludes that the area-based empirical formula is valid.

TABLE 7   Comparison of Manually Measured and Empirical Formula Estimated Flow Lengths

Catchment ID	Empirical Formula Based Flow Length (m)	Manually Measured Flow Length (m)
H0012	1,097	784
H0098	272	393
H0104	539	639
H0215	1,545	1,799
H0274	1,694	1,558

Ultimately, the empirical formula-based flow lengths were used for the final model calibration, as described in Section 3.2.

2.4.4   Additional Parameters

Initial parameterization of other storage and routing parameters were initially defined with widely accepted default values. These values were assessed and modified during the sensitivity analysis and calibration process but initially defined as:

- N Impervious: 0.013
- N Pervious: 0.25
- Depression Storage Impervious (mm): 2 mm
- Depression Storage Pervious (mm): 5 mm
- impervious area with no depression storage : 25%

- subarea routing was set to pervious, which defines that a portion of the impervious area will be routed through the pervious area before reaching the outlet

2.4.4.1   Percent Routed

The percent routed parameter (i.e., the portion of impervious area whose runoff is routed to pervious areas) is a sensitive parameter in the PCSWMM model, specifically when there is a high proportion of impervious surfaces, such as in the Highland Creek watershed. Newer developments direct portions of impervious areas to pervious areas to help reduce runoff volumes and peaks on stormwater infrastructure. Downspout disconnections and low-impact development measures are now mandatory in new developments; however, during the 1960s and 1970s when much of the Highland Creek watershed was developed, SWM was not a common practice. Rooftops and parking lots were directly connected into the sewer system, leaving limited opportunities for runoff from impervious areas to flow over adjacent pervious surfaces.

Percent routed within each catchment was based on land use and refined during the calibration process.

2.4.5   Infiltration

Infiltration in the PCSWMM model was defined using the Modified Green and Ampt method. Green and Ampt is a physically based method of estimating infiltration assuming a homogenous soil profile with a wetting front (Kipkie 1998). Green and Ampt requires the input of three parameters to PCSWMM:

- hydraulic conductivity (mm/hour)
- suction head/wetting front
- initial moisture deficit (IMD)

The soils and surficial geology mapping were used to define the infiltration parameters for each catchment (Figures 6 and 7). The resulting soils layer was overlaid with the catchments and parameters were area weighted. Each soil type (ranging from sand to clay) was assigned a value for each of the three Green and Ampt parameters listed above. Soils mapping is limited throughout the Highland Creek watershed, and the large scale of the model and extensive urbanization means that surficial geology likely provides better insight to the infiltration potential within each catchment. The greater uncertainty associated with the soil conditions also means that larger ranges of soil parameters were reviewed during calibration.

Table 8 shows the mapped soils within Highland Creek, the portion of the watershed the soil represents, and the Green and Ampt parameters. Hydraulic conductivity and suction head remained constant through the model simulations; however, initial moisture deficit was modified based on the antecedent moisture conditions from each event (discussed further in Section 3.1.3).

Soils within the Malvern, Milliken, Bendale, and Dorset Park subwatersheds were largely defined as till (diamicton) or sandy clay loam. Areas along West Highland, East Highland, and Main Highland creeks had sandier soils and were assigned higher infiltration parameters.

TABLE 8   Mapped Soils within Highland Creek

Soils[1, 2]	Percent of Highland Watershed	Assigned Green and Ampt Soils Type	Hydraulic Conductivity (mm/hour)	Suction Head (mm)	Initial Moisture Deficit
Bottom Land	2.1%	Loamy Sand	30.0	61	0.39
Diamicton	74.4%	Sandy Clay Loam	1.5	220	0.26
Fox Sandy Loam	2.1%	Sandy Loam	10.9	110	0.37
Milliken Loam	3.5%	Sandy Clay Loam	1.5	220	0.26
Sand and Silty Sand	11.1%	Sandy Loam	10.9	110	0.37
Silt and Clay	1.2%	Silty Clay	0.5	290	0.23
Woburn Loam	2.7%	Sandy Clay Loam	1.5	220	0.26
Woburn Sandy Loam	1.3%	Sandy Loam	10.9	110	0.37

(1) Surficial Geology was used to define infiltration parameters in areas where soil mapping was designated as "built-up areas."
(2) Soils making up less than 0.5% of the watershed were not included in the summary table.

2.5   Channel Routing

Channel routing is the representation of watercourses in the hydrology model and affects how water from each catchment is conveyed downstream to the outlet of the model. Channel routing is important as it affects the timing of peak flows that will ultimately be used as input into the hydraulic model. In the previous 2004 hydrology model (Aquafor Beech 2004), channel routing was represented using route hydrographs where a single cross-section geometry, length, and slope defined the conveyance. In PCSWMM, there is the capability to directly import HEC-RAS geometry, including bridges and culverts, to more discretely represent channel routing elements in the model.

Cross-sections used for channel routing in the PCSWMM model were derived from the HEC-RAS channel dimensions based on the LiDAR data and used characteristic cross-sections to represent a larger reach area. This process results in a more accurate model representation of the valley corridors within Highland Creek while maintaining reasonable reach lengths to limit routing instabilities.

2.5.1   Road Crossings and Structures

The Highland Creek hydrology model took advantage of the HEC-RAS geometry import tool in PCSWMM by importing the concurrently developed HEC-RAS model geometry to represent channel conveyance. Before importing, each hydraulic structure in the watershed was reviewed to determine if the structure was "hydrologically significant," meaning that it would modify the peak flows enough that it should be represented within the hydrology model. Hydrologic significant structures were defined by reviewing the

previous floodlines upstream of the structure and comparing the change in water level upstream and downstream of the structure. If the difference was more than a 0.3 m during the 10-year design storm event, then the structure was considered hydrologically significant. The review resulted in 77 structures that were defined as hydrologically significant. These structures are provided in Appendix C.

2.5.2 Cross-sections

During the HEC-RAS import, cross-sections were autogenerated as irregular conduits with assigned bank stations connected by junctions. Initially, over 1,500 reaches were imported into the hydrology model representing each cross-section in the hydraulic model. During the validation runs, it was found that having too many short, steep conduits resulted in model instabilities, and the watercourse network required simplification. A watercourse simplification process built in to the PCSWMM model was used to remove small conduits and merge with the most similar conduit (i.e., similar slope and cross-sectional area) up or downstream. Initially, all conduits less than 25 m were selected in the model and, where appropriate, merged with the adjacent conduits. The model was then run during the 100-year and Regional storm events, and hydrographs from each conduit were reviewed to assess whether an instability occurred. Areas with instabilities were further refined until the instabilities were addressed. The resulting PCSWMM model consists of:

- 881 irregular conduits representing cross-sections
- 129 bridge of culvert conduit openings
- 114 high cord conduits over roadways
- 35 circular and irregular conduits to represent SWM facility outlets and overflows (discussed further in Section 2.6)

Cross-sections represented in each conduit from the HEC-RAS model were reviewed and trimmed (low portions outside the channel were removed) to prevent flow from splitting over a bank (see Figure 15). As ineffective flow areas and obstructions cannot be represented PCSWMM model, trimming of cross-sections was required to reduce artificial conveyance capacity. How flow splits in a cross-section will be different during each storm event, but the largest storm events (350-year and Regional) were used to assess where modification to the cross-sections would be required. There were also some cross-sections where the water level exceeded the left or right extents (Figure 16). As PCSWMM creates vertical walls at the edge of each cross-section, no water was lost from the system and these cross-sections were not modified. As the purpose of the hydrology model is to determine the expected peak flow at a specific instance (and not how that flow interacts with the floodplain and channel geometry) this representation was considered acceptable.
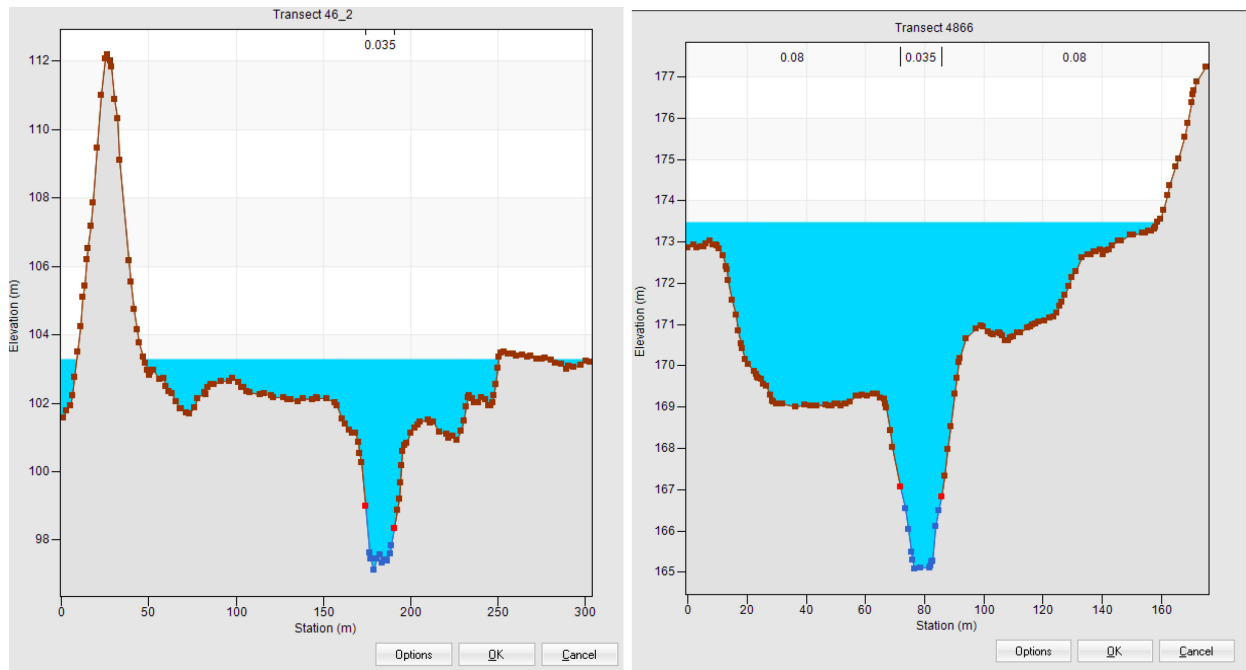
FIGURE 15 PCSWMM Cross-section (left shows flow splitting, right shows flow exceedance)

The horizontally varied Manning's n values used in HEC-RAS cross-sections could not be represented in the PCSWMM model because PCSWMM only allows three Manning's n values within a cross-section. Mannings n values for each cross-section were set to TRCA's standard values: 0.035 for the channel and 0.08 for the overbanks. Mannings n values were further evaluated during the calibration process.

2.6   Stormwater Management Facilities

TRCA provided a spatial file showing 37 SWM facilities within the Highland Creek watershed. SWM facilities will affect the timing and peak flows within the watercourse by attenuating runoff from the catchments. Therefore, it is important to represent SWM facilities to accurately reflect the attenuation that would occur during the calibration and validation events. Locations of the SWM facilities is shown on Figure 16.

Easting (m)

Northing (m)

Highland Watershed
Subwatershed
Watercourse
● **SWM Facility**

West Riseborough North Detention Pond - Phase 2
East Riseborough Phase 1 North Park Pond
Milliken District Park Pond
West Riseborough Phase 1 - North Facility
Riseborough Centre Area Pond
East Riseborough Phase 1 South Park Pond
Goldhawk Park Pond
Milliken District Park Pond
West Riseborough Phase 1 - South Facility
West Riseborough South Detention Pond - Phase 2
H.E.P.C. (Hydro) Lands Pond
City Owned Land Pond
Malvern Branch Trib
Lamoreaux Park Pond
Lamoreaux Park Pond
Malvern Branch
Malvern Core & Neighbourhood 7-C Pond
Lamoreaux Park Pond (3 Ponds) {58.1, 58.2 added later}
Bendale Trib 1
Milliken Branch Trib
Markham Gardens Pond
Willowlea Pond
Barchester Park Pond
Ellesmere Pond
Bendale Trib 2
Warden North Hydrolands (Pond G)
Bendale Branch
Meadowvale Pond
Centennial Creek
Bridlewood Park Pond
Warden North Hydrolands (Pond D)
Inglewood Park Pond
Milliken Branch
East Highland Creek
Ellesmere Ravine
Highland Creek
Centennial Trib
H.E.P.C. (Hydro) Lands Pond
Scarden Park Pond
Lynn Gate Park Pond
Bendale Pond
North Bendale Park Pond
West Highland Trib 2
Curran Hall Creek
Manse Road Subdivision
Thornton Trib
Carma/Coscan Pond
Highland Trib 1
Dorset Park Branch
H.E.P.C (Hydro) Lands Pond
Masaryk Town Pond
West Highland Creek
Livingston Road Pond
Thornton Creek
Kennedy/Lawrence Pond
West Highland Trib 1
Dorset Park Intercept

1:65,000
metres
700   0   700   1,400
NAD 1983 UTM Zone 17N

Reference: Contains information licensed under the Open Government Licence – Ontario. Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

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ENVIRONMENT & ENGINEERING

Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Stormwater Management Facility Locations

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Figure
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2.6.1   Stormwater Management Facility Review

TRCA provided location and design reports for the SWM facilities. The information was reviewed and used to determined how each SWM facility would be represented within the hydrologic model. Parameters related to the SWM facility drainage area, outlet structure, maximum release rate, pond control level, and pond type (wet/dry, online/offline) were summarized and are provided in Appendix B.

Highland Creek was largely developed in the 1960s and 1970s with limited SWM practices. The majority of existing SWM facilities in the watershed were designed as overflows for sewer relief and implemented after stormwater drainage systems had already been constructed. As a result, the majority of SWM facilities are not necessarily designed to attenuate flows for a specific catchment or for a wide range of design storms. Rather, most SWM facilities are used as stormwater sewer relief, such that when the capacity of a storm sewer is exceeded, water can back up into a specified storage area, such as a park, until capacity is available in the system for the water to drain back into the storm sewer system.

Based on the review of design reports, each SWM facility was put into one of three categories:

- Online facility: SWM facilities located along watercourses which provide attenuation through weirs or outlet structures. An example of an online facility is Ellesmere Pond in the Centennial Creek subwatershed.

- Offline facility: traditional SWM facilities that control runoff from a designated catchment area, where flows are controlled up to a certain design storm (e.g., 100-year). An example of an offline facility is West Riseborough North Detention Facility in the Bendale Branch subwatershed.

- Overflow facility: retrofitted SWM facilities that provide storage when the minor system is at capacity. An example of an overflow facility is Inglewood Park Pond in the Dorset Park Branch subwatershed.

Drainage areas for the SWM facilities were difficult to distinguish, specifically around the overflow facilities, as they align more with a sewershed area than an overland catchment. As the model's objective is to ultimately represent the hydrologic response during a Regional storm, emphasis was placed on major overland flow paths and ensuring that catchment boundaries derived from the LiDAR data were respected. Recommendations for how each SWM facility should be represented within the hydrologic model was provided to TRCA for approval. Of the 37 reviewed SWM facilities, 31 were included in the hydrologic model. The six SWM facilities not represented in the model were either not significant for flood control (erosion control only) or did not have enough data to be reasonably represented.

2.6.2 Model Representation

SWM facilities were represented in the hydrologic model using storage nodes with stage/storage curves and outlets with stage/discharge curves. Where available, storage and outflow curves were taken from the design reports. Only a small number of SWM facilities had detailed stage/storage and stage/outflow information available. When only maximum storage or maximum outflow was provided, the storage or outflow curve was assumed to be linear. Similarly, when only a maximum outflow rate was provided, the stage discharge curve was also assumed to be linear. A summary of the stage/storage and stage/discharge curves are provided in Appendix D.

The representation of overflow facilities provided a unique challenge within the hydrologic model, as the minor pipe system was not explicitly represented. Theoretically, the overflow facilities would only be used when the sewer system was at capacity. Representing this in the hydrologic model means that the runoff from the catchment should be unimpeded up to a certain flow/level but then trigger the use of the stormwater facilities to attenuate flows above a specific threshold. To represent this function in the hydrologic model, the following approach was taken:

1. Runoff from the SWM facility catchment was directed to a junction (labelled J_XX).

2. From the junction, two conduits were added: one conduit was offset from the junction and conveyed flow to a storage node (labelled CS_XX) and the other conduit was not offset and directed flow to the watercourse (labelled C_XX).

3. The 2-year, 12-hour AES storm was run and the peak runoff (m^3/s) for the catchment was set as the flow limit on the C_XX conduit to the watercourse. The 2-year, 12-hour AES storm was selected as it was used as the design storm distribution in several of the SWM facility background documents. The maximum depth/elevation in the junction (J_XX) during the event was also used as the offset elevation for conduit CS_XX.

Configuring the SWM facilities in this manner directed any flows above the 2-year, 12-hour AES peak to the storage facility, but flows below the 2-year, 12-hour AES peak flow would runoff unimpeded to the watercourse.

3   MODEL CALIBRATION AND VALIDATION

Model calibration is the process in which the modeller adjusts model parameters to minimize differences between simulated output (typically flows for hydrologic models) and observed conditions. By being able to reasonably replicate historical flow conditions, the confidence in the model to predict a watershed's response to differing climatic conditions (or modified land use) is increased. Following model calibration, the model is further tested (or validated) by evaluating the predicted response from an independent set of rainfall events. This validation exercise ensures that the calibrated model parameters are appropriate for events beyond those considered during the calibration exercise.

In the case of the Highland Creek hydrologic update, the model will be ultimately used to estimate peak flows in all watercourses for the 2- through 100-year, 350 year and Regional flood events. As a result, the focus of the calibration/validation exercise is placed on higher flows associated with specific flood events, rather than low flows or the average seasonal variation.

The following approach was taken to calibrate and validate the Highland Creek hydrologic model:

- Event selection: rainfall and flow data from the monitoring stations within and surrounding Highland Creek were reviewed for events to perform model calibration and validation.

- Sensitivity analysis: sensitivity analysis of the various model parameters was completed during the model calibration to understand the effect of parameter adjustments on the simulated results.

- Model calibration: parameters were adjusted during model calibration to achieve the TRCA requirements to match peak flows, volumes, and hydrograph timing.

- Model validation: once the model was calibrated, five validation events were simulated using the hydraulic model to ensure that the current model calibration was adequate.

TRCA was consulted throughout the model calibration and validation process to ensure the approach and objectives of the hydrologic model calibration were being met.

3.1   Event Selection

Events selected for calibration/validation correspond with times where multiple rain gauges and flow monitoring gauges were recording. Multiple rain gauges are important to properly represent the spatial distribution of a rainfall event over the watershed. As a first step to identify appropriate calibration events, rainfall and flow monitoring data were reviewed to determine when overlapping recording intervals occurred.

Events were selected for rainfall periods only (April to October). No snowmelt events were considered in the assessment, as the model was not set up to simulate temperature or snow-pack conditions. For the most part, data was available between 2005 and 2015 at most flow and rainfall monitoring gauges. A summary of data availability is shown in Table 9. Data was also available for flow monitoring station 02HC013 and rainfall monitoring stations S01, S02, S03, and S04 prior to 1998; however, most of this data was only available in hourly intervals, which was too coarse to represent the rapid respond time of the watercourses in Highland Creek. As such, priority was placed on those time periods where 5-minute rainfall and 15-min flow data was available.

TABLE 9   Rainfall and Flow Monitoring Station Availability

Station IDs	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Flow Monitoring Stations																
02HC013			X	X	X	X	X	X	X	X	X	X	X	X	X	X
02HC058				X	X	X	X	X	X	X	X	X	X	X	X	X
HY034	X	X	X	X	X			X	X	X	X	X				
Rainfall Monitoring Stations																
HY036				X	X	X	X	X	X	X	X	X	X	X	X	
HY050			X	X	X	X	X	X	X	X	X	X	X	X	X	
HY094	X	X	X	X	X	X	X	X	X	X	X	X	X			
HY057	X	X	X	X	X	X	X	X	X	X	X	X	X			
HY051	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
HY044					X	X	X	X	X	X	X	X	X	X	X	X
HY070		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
City of Toronto Rainfall Monitoring Stations																
S01																
S02	X	X	X	X	X	X	X	X								
S03	X	X	X	X												
S04/RG-030	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S05	X	X	X													
S06/RG-031	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S07	X	X	X	X	X	X	X	X	X	X	X	X				
S08/RG-033		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S09/RG-034		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S10/RG-035		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
RG_038													X	X	X	X
RG_041													X	X	X	X
RG_042													X	X	X	X

(1)   Data may not be continuous through each year.

Calibration and validation events were initially selected by reviewing the 15 events with the highest peak flows from both the 02HC013 and 02HC058 monitoring stations. Rainfall from the TRCA climate monitoring stations were also included for comparison. An example of this comparison is included in Figure 17 for a selected event, with the remaining graphs provided in Appendix E.
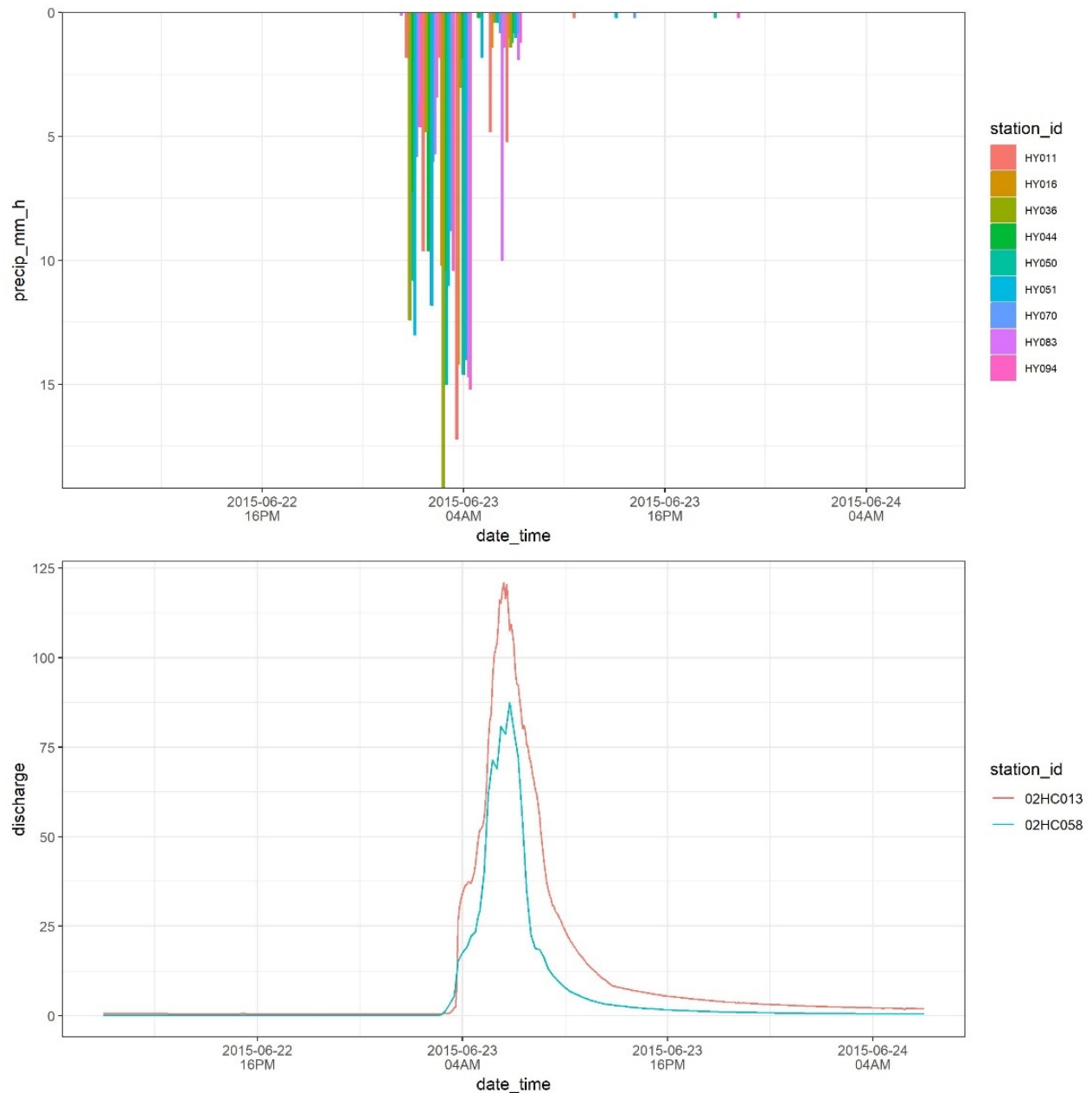
FIGURE 17   Peak Flow Event Hydrograph and Rainfall in Highland Creek

During event selection, emphasis was placed on events that resulted in the greatest peak flows, which occurred at both 02HC013 and 02HC058 flow gauges. If flow data was not recorded at both monitoring stations for an event, the event was not selected for the calibration or validation process. Event data was also reviewed for TRCA monitoring station HY034; however, for most events, flow data was not available or only available in an hourly recording interval, making it of limited use for calibration. The selected calibration and validation events were summarized and provided to TRCA for approval. A summary of the final calibration and validation event selection is shown in Table 10.

TABLE 10   Calibration and Validation Event Selection

Event ID[1]	Simulation Date	Average Rainfall (mm)	02HC013 Peak Flow (m³/s)	02HC058 Peak Flow (m³/s)	HY034 Peak Flow (m³/s)
C1	2015-06-22	45.1	120.9	87.4	-
C2	2013-05-28	44.1	120.9	61.4	17.4
C4	2012-07-25	46.5	86.7	72.5	23.0
C5	2015-10-27	66.2	79.6	50.0	-
C6	2014-08-03	32.6	87.4	42.0	-
V2	2014-10-16	24.0	94.5	43.5	-
V3	2012-08-09	52.6	89.4	57.9	30.5
V4	2010-07-08	40.4	86.1	40.5	-
V5	2014-04-28	30.8	68.5	36.7	18.8
V6	2015-06-04	24.3	74.0	44.8	-
August 19, 2005	2005-08-19	112.5	-	-	-

(1)   IDs with the prefix "C" denote calibration events; IDs with the prefix "V" denote validation events.

The August 19, 2005, event was also simulated in the hydrologic model for additional validation. No peak flows were recorded during the event, as monitoring station 02HC013 was being moved during this period and 02HC058 had not yet been established. Additionally, TRCA provided high-water marks throughout the watershed, which were compared against water levels simulated by the hydrologic model.

3.1.1   Rainfall Data Processing

Once flow events were selected, rainfall data was compiled from the available monitoring stations within, and adjacent to, Highland Creek. The recording interval of rainfall was typically available in 5-minute increments, with a few stations recording at a 15-minute interval prior to 2013.

To produce a rainfall dataset with a consistent 5-minute interval for all rainfall stations, those stations with 15-minute datasets were disaggregated to 5-minute intervals by assuming equal distribution of rainfall through the 15-minute period (15-minute total divided by three, for 5-minute intervals). When two monitoring stations were near each other (i.e., <2 km; e.g., RG031 and HY036) the total rainfall depths were compared to ensure that the most accurate capture of rainfall data was used in the model.

Rainfall data was also compared to confirm if daylight savings had been applied to the provided data series. WSC monitoring data is provided in Coordinated Universal Time, and thus can have a 4- or 5-hour offset from the rainfall data in the Toronto area if it is corrected to Eastern Standard Time. The City of Toronto confirmed that all rainfall data provided for their stations was not corrected for daylight savings, which aligned with the observed rainfall/runoff response time. The majority of TRCA data was also not corrected for daylight savings; however, there were some data periods where a 1-hour offset appeared to be added, indicating that daylight savings had been applied. These instances were adjusted in the time series for the calibration and validation exercise.

3.1.2 Rainfall Application

Following rainfall data processing and QA/QC checks, the rainfall time series must be applied to the land surface within the model representation. Ideally, sufficient rain gauges are available to properly characterize the spatial patterns of the rainfall event. Properly representing the spatial distribution of rainfall is a key component to accurately simulating the watershed's response to an event. Without a proper representation of the watershed receiving rainfall, it is likely that simulated flow conditions will not match observed conditions.

For urban systems, higher densities of rain gauges are recommended to capture convective systems and the rapid runoff that occurs from impervious areas (Vieux 2005). The World Meteorological Organization's *Guide to Hydrological Practices* (WMO 2008) recommends a rainfall network density range of 10 to 20 km²/gauge for urban areas to capture convective events. To achieve this density, care was taken to use as many rain gauges as possible to simulate each calibration and validation event. Once processed, events modelled after 2015 typically used nine rainfall gauges, where events before 2015 typically used six rainfall gauges. In both instances, the recommended gauge density was achieved.

Spatial interpolation using the rainfall radar tool in PCSWMM was used to develop catchment-specific hyetographs for each calibration and validation event.

3.1.3 Antecedent Moisture Conditions

Antecedent moisture conditions represent the level of saturation in the soil prior to the rainfall event. Antecedent moisture conditions can be determined by reviewing the climate conditions anywhere from 5 to 30 days prior to an event; however, the National Engineering Handbook (US SCS 1964) suggests 5 days of prior rainfall is suitable. The total daily rainfall 5 days and 3 days before each calibration and validation event were summed (Table 11). Three of the selected calibration/validation events showed "wet" conditions (>6 mm of rainfall) prior to the event and were represented as such by varying the IMD within each catchment.

TABLE 11   Antecedent Moisture Conditions Prior to Calibration and Validation Events

Event ID[1]	Event Date	Average Event Rainfall (mm)	Pre-event 5-day Average Rainfall (mm)	Pre-event 3-day Average Rainfall (mm)	Condition
C1	2015-06-22	45.1	0	0	Dry
C2	2013-05-28	44.1	3.2	0	Dry
C4	2012-07-25	46.5	29.8	4.4	Very Wet
C5	2015-10-27	66.2	14.8	0.2	Wet
C6	2014-08-03	32.6	24.4	24.1	Very Wet
V2	2014-10-16	24.0	6.2	6.2	Semi-Wet
V3	2012-08-09	52.6	5.5	0.2	Dry
V4	2010-07-08	40.4	3.5	3.5	Dry
V5	2014-04-28	30.8	1.1	0	Dry
V6	2015-06-04	24.3	0.1	0	Dry
August 19, 2005	2005-08-19	112.5	0.7	0	Dry

(1)   IDs with the prefix "C" denote calibration events; IDs with the prefix "V" denote validation events.

There is no set standard to varying IMD in the Green and Ampt equation to represent different soil moistures. Typically, IMD is confirmed during the calibration process by comparing observed rainfall to runoff volumes over a watershed. However, given the uncertainty with the observed flows (described further in Section 3.1.4) comparing rainfall to runoff volumes did not seem a suitable way to estimate IMD in the local soils.

An IMD sensitivity analysis was completed for different soils to develop IMD ratios that would represent different saturation points of the soil. Table 12 outlines the different IMD ratios for the main soil types within the model. These factors were used during the calibration and validation exercise.

TABLE 12   Initial Moisture Deficit Factors for Varying Soil Saturations

Soil Type	IMD Dry Factor (0 mm of prior rainfall)	IMD Semi-wet Factor (6 mm prior rainfall)	IMD Wet Factor (12 mm prior rainfall)	IMD Very Wet Factor (24 mm prior rainfall)
Loamy Sand	1	1	1	0.8
Sandy Clay	1	0.5	0.3	0.2
Sandy Clay Loam	1	0.7	0.5	0.2
Sandy Loam	1	0.9	0.7	0.2
Silty Clay	1	0.5	0.3	0.2

IMD - initial moisture deficit

3.1.4 Flow Data Processing

Observed flow data from WSC monitoring stations 02HC058 and 02HC013, as well as TRCA's monitoring station HY034, required manual review and processing to ensure that the observed dataset contained no major errors or questionable data that may negatively affect the calibration process. Highland Creek is a highly-responsive system, and often the rise and fall of the hydrographs can occur over a period less than 1 hour. The peakiness of the flows presents issues with the collection for manual flow data as well as recording intervals in the level loggers. In order to collect a manual high flow measurement, field teams need to respond within hours of a rainfall event and capture the flow in the creek before the hydrograph recedes. In the case of Highland Creek, in the time to capture a manual measurement (typically 1 hour), flows can vary between 30% and 40%, leading to a high variability in the manual measurement. High flow events are also difficult to capture due to safe access.

3.1.4.1 Flow Statistics

Flow statistics were assessed in the West and Main Highland branches of the watershed using the continuous monitoring data at the 02HC013 and 02HC058 gauges. The flow statistics were used to understand the baseflow/low flow conditions, seasonality, and return period flows based on monitoring data for each watercourse. No statistics were evaluated for monitoring station HY034 due to inconsistencies in the dataset.

Mean monthly flow data for both the 02HC013 and 02HC058 monitoring stations is provided in Table 13. As shown in both the West and Main Highland branches, there is little seasonality in the monthly flows. The highest monthly mean flows tend to occur in spring and isolated summer months, with the lowest monthly mean flows occurring in late fall and winter.

TABLE 13   Mean Monthly and Annual Flows

Month	Mean Monthly Flows (m³/s)	
	02HC058	02HC013
January	0.27	1.36
February	0.17	1.21
March	0.31	1.69
April	0.25	2.14
May	0.37	1.75
June	0.42	1.82
July	0.22	1.21
August	0.40	1.42
September	0.25	1.31
October	0.27	1.42
November	0.26	1.05
December	0.25	0.98
Annual	**0.47**	**1.45**

The flow duration curves presented on Figure 18 provides insight into the flow regime. In both the West and Main Highland branches, flows are below 1 m^3/s over 75% of the time and below 0.5 m^3/s over 30% of the time. Both watercourses show very low and stable baseflows, which is not anticipated to affect the peak flows within the watershed. As such baseflow was not accounted for in the modelled calibration and validation events.
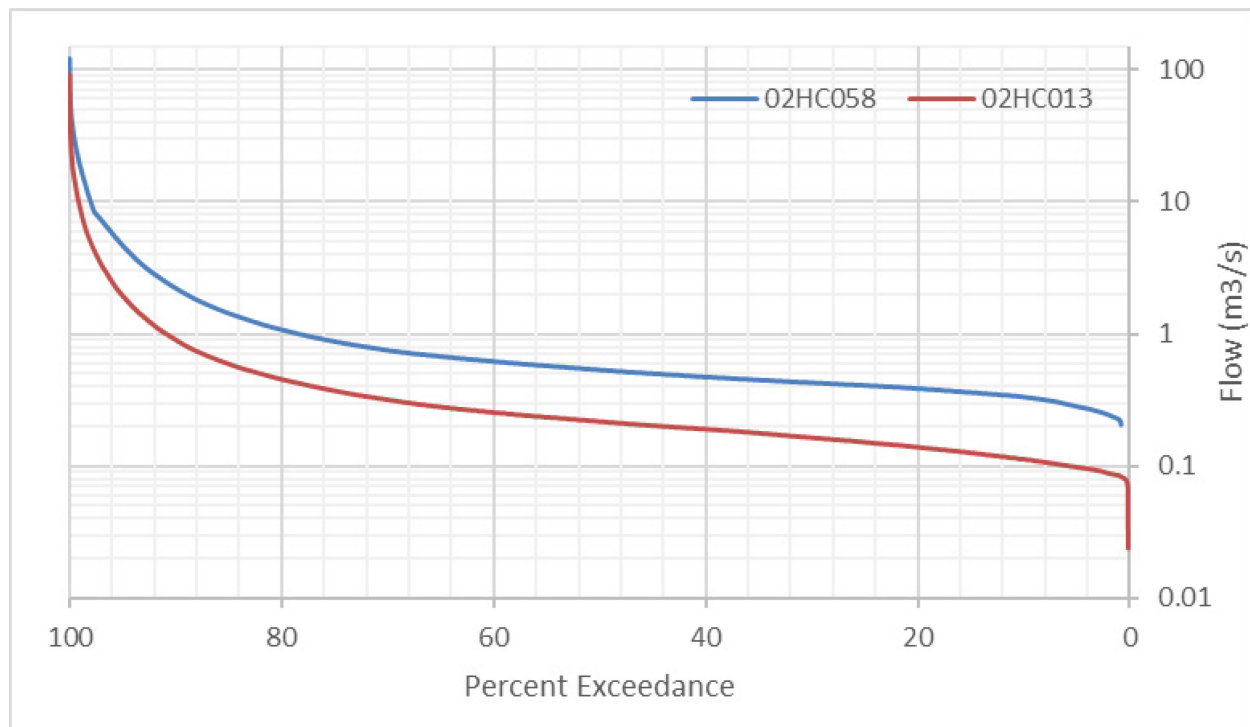
FIGURE 18 Flow Duration Curve for the West and Main Highland Creek Branches

At monitoring station 02HC013, instantaneous flows were available for 27 years. The Log Pearson Type III distribution was used to estimate return period peak flows for the 2- through 100-year events. Instantaneous peak flows were only available at 02HC058 for 5 years from WSC which is not sufficient to estimate return period flows. To supplement the flow record, instantaneous flows for each year were estimated from the continuous monitoring data (either 5- or 15-minute intervals), which provided data for 10 years, allowing return period peak flows to be calculated. Annual peak flow data for 02HC058 and the recorded source is provided in Table 14.

TABLE 14   Instantaneous and Annual Peak Flow Data for 02HC058

Year	Flow (m³/s)	Source
2009	62.3	Maximum instantaneous
2010	74.1	Maximum instantaneous
2011	60.7	Maximum instantaneous
2012	91.4	Maximum recorded peak flow in 15-minute continuous data record
2013	61.4	Maximum recorded peak flow in 15-minute continuous data record
2014	62.3	Maximum instantaneous
2015	87.4	Maximum recorded peak flow in 5-minute continuous data record
2016	65.9	Maximum recorded peak flow in 5-minute continuous data record
2017	52.3	Maximum instantaneous
2018	25.8	Maximum recorded peak flow in 5-minute continuous data record

Estimates of the return period flows are provided in Table 15 and were used to support the design storm selection. No flow records are available for the August 19, 2005, storm event, which is considered one of the largest recent rainfall events to have occurred in Highland Creek. The absence of this event may result in the return period flows presented in Table 15 to be underestimated. Plots of the computed return period peak flow fits are provided on Figures 19 and 20.

TABLE 15   Estimate Return Period Flow Events

Return Period	Estimated Return Period Flows (m³/s)	
	02HC058	02HC013
100	93.7	209
50	92.3	189
25	90.4	170
10	86.2	144
5	80.9	123
2	66.6	91.1
Years of Used in the Analysis	**10**	**27**
Actual Years of Record	**5**	**25**
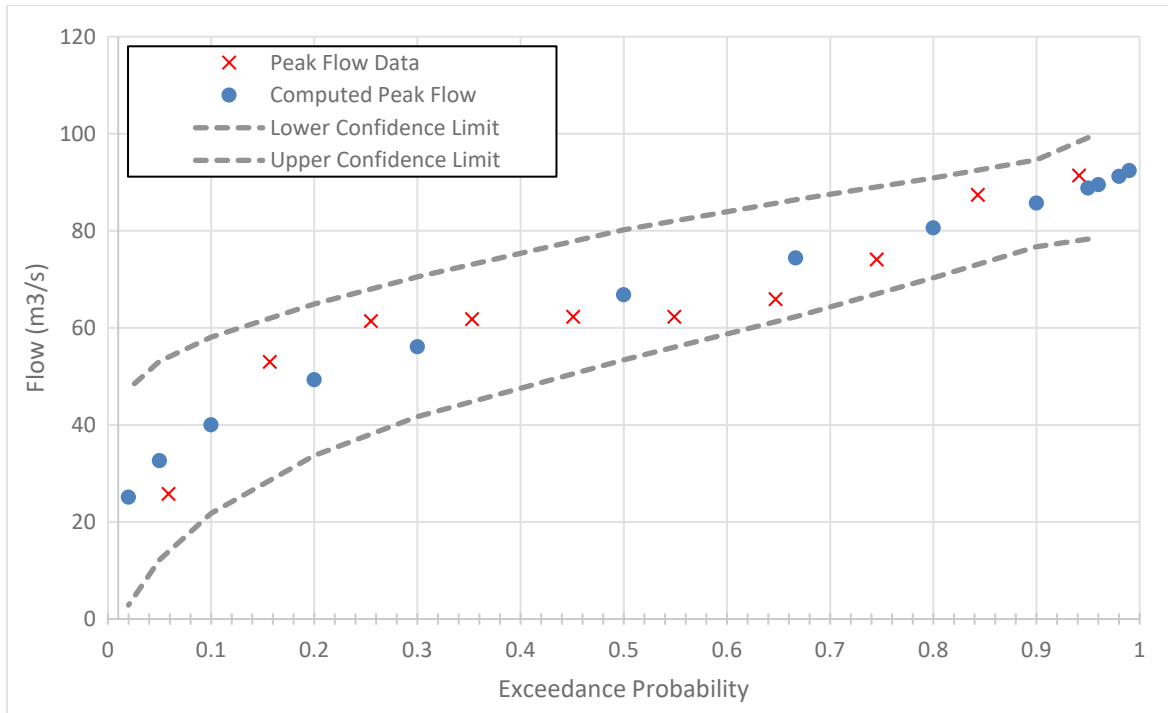
FIGURE 19   02HC058 Computed Peak Flow Plot
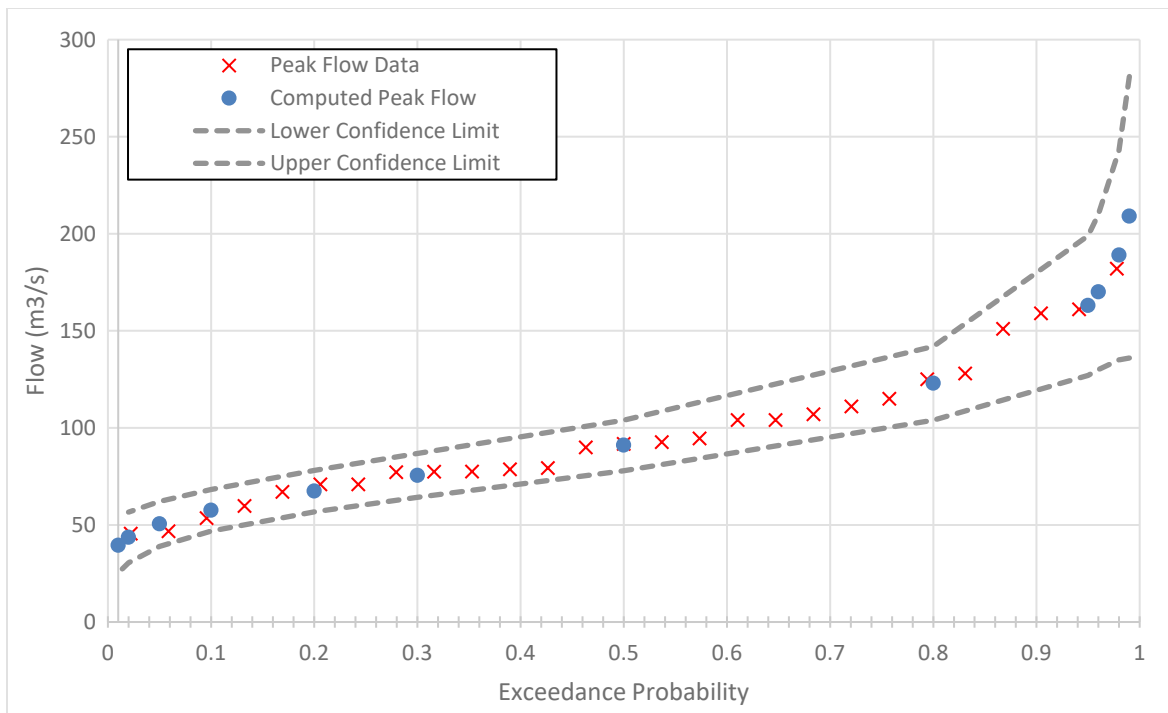
FIGURE 20   02HC013 Computed Peak Flow Plot

3.1.4.2   Event Analysis

The total observed rainfall and runoff from each event selected for calibration/validation was summarized and compared at each monitoring station to help inform the model calibration process. Table 16 outlines the rainfall depth and runoff proportion for each event at monitoring stations 02HC013, 02HC058, and HY034. At monitoring station 02HC013, runoff as a proportion of rainfall ranges from 33% to 52% and averages 42%. At monitoring station 02HC058, runoff ranges from 41% to 69%, averaging 54% of total rainfall volumes. HY034 has limited data for the event analysis but does show runoff volumes generally between 71% and 76% of rainfall. A graph showing the corresponding rainfall/runoff portion for each event is shown in Figure 21.

TABLE 16   Event Rainfall/Runoff Proportions

Event ID	Event Date	02HC013 Event Rainfall (mm)	02HC058 Event Rainfall (mm)	HY034 Event Rainfall (mm)	02HC013 Runoff (as % of Rainfall)	02HC058 Runoff (as % of Rainfall)	HY034 Runoff (as % of Rainfall)
C1	6/22/2015	45.1	43.3	46.6	45%	59%	-
C2	5/28/2013	44.1	41.1	38.5	50%	69%	48%[1]
C4	7/25/2012	46.5	47.4	42.5	38%	55%	71%
C5	10/27/2015	66.2	65.1	62.9	38%	51%	-
C6	8/3/2014	32.6	27.4	26.2	37%	50%	-
V2	10/16/2014	24.0	22.9	40.7	52%	57%	-
V3	8/9/2012	52.6	41.2	46.2	40%	54%	76%
V4	7/8/2010	40.4	38.9	51.1	33%	41%	-
V5	4/28/2014	30.8	32.0	29.1	44%	53%	73%
V6	6/4/2015	24.3	22.8	24.3	45%	52%	-
				AVERAGE	**42%**	**54%**	**73%[2]**

(1)   A portion of the hydrograph is missing from observed dataset.
(2)   Does not include May 28, 2013, event.
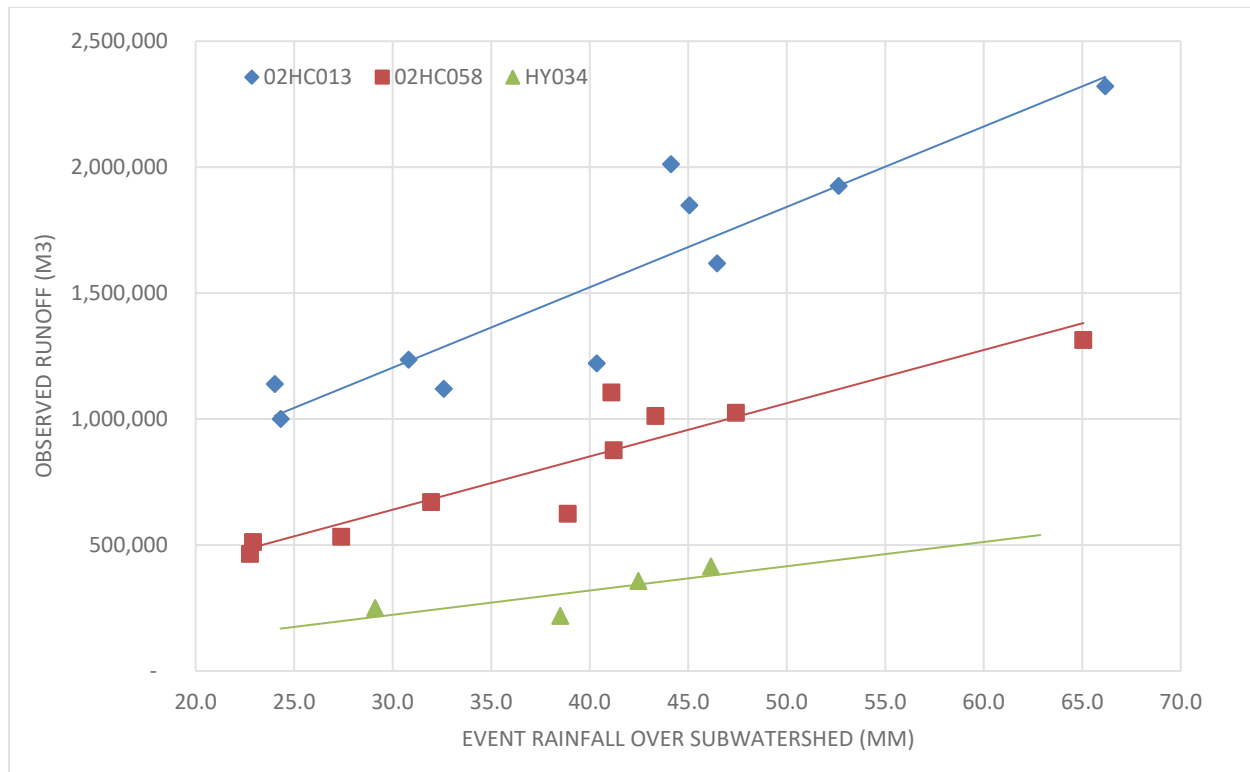
FIGURE 21 Rainfall/Runoff Analysis

Although the rainfall is fairly consistent between the 02HC013 and 02HC058 monitoring station watersheds during the selected events, runoff is on average 12% higher at monitoring station 02HC058 when compared to 02HC013. Given that 02HC058 is located within the upstream watershed of 02HC013 (Figure 12; 02HC058 makes ups the majority of the West Highland Creek) and the high proportion of impervious areas within the East Highland Creek watershed (Section 3.2.1), means that either there is some retention of flows/water within the Milliken/Malvern branches of East Highland Creek Branch or there may be some uncertainty associated with the rating curve at 02HC013. Investigation into the Malvern and Milliken branches did not find any information that would lead to less runoff from the East Highland watershed; therefore, a review of the rating curve and potential uncertainty with the high flow events was considered.

3.1.4.3   Rating Curve Uncertainty

During model calibration, it was found that many rainfall events did not result in simulated flows that corresponded well with the observed peak flows recorded at the 02HC013 monitoring stations. Peak flows and volumes were simulated on average 30 to 50% higher based on the event rainfall. To understand the potential uncertainty of the rating curve, and the resultant impact on observed flows (particularly associated with high flows), manual flow measurement records were requested from WSC and compared to selected flow events.

The manual flow measurements collected at each monitoring station provided insight into the potential uncertainty associated with the rating curves at monitoring stations 02HC013 and 02HC058. As shown in Table 17, the majority of the manual measurements used to derive the rating curve fall within the lower ranges of the hydrograph (1 to 2 m^3/s). At monitoring station 02HC013, the highest recorded manual measurement was 23.5 m^3/s, compared to the recorded peak flows of 74.0 to 120.9 m^3/s. Not having manual measurements for the upper portion of the flow regime (high flows), means that the observed flows are being calculated based on extrapolating the stage-discharge relationship from lower flow conditions, and therefore there is increased uncertainty with those higher flow records. At monitoring station 02HC058, the highest manually recorded flow was 30.1 m^3/s, which is closer to the selected calibration/validation event peaks of 36.7 to 87.4 m^3/s. Based on this assessment, a higher priority was placed onto matching the events at monitoring station 02HC058 during the calibration process.

TABLE 17   Water Survey of Canada, Rating Curve Information Summary

Parameter	sub02HC013	02HC058
Average Discharge of Manual Measurements (m^3/s)	2.04	1.80
Number of Manual Measurements (up to 2016)	50	68
Highest Manual Measurement (m^3/s)	23.5 (March 10, 2011)	30.1 (April 4, 2009)
Calibration/Validation Event Peak Flows (m^3/s)	74.0 to 120.9	36.7 to 87.4

Note: Rating curve information was not provided for the HY034 gauge

3.2   Calibration Methods and Results

Local calibration of the hydrologic model considered five different rainfall events where model parameters were adjusted to match runoff volume, runoff peaks, and peak timing to observed events at the 02HC013, 02HC058, and HY034 monitoring stations.

3.2.1   Calibrated Parameters and Approach

Before calibration began, each hydrologic modelling parameter was reviewed to determine its sensitivity to adjustment, what effects adjustment would have on the simulated hydrograph, and whether the parameter was suitable for adjustment during calibration. A summary of the hydrologic model parameters and approach to calibration is outlined in Table 18. The approach was discussed with TRCA prior to model calibration and TRCA was consulted on any deviations from the original calibration approach during the process. The final calibrated hydrologic model values are provided in Appendix F.

TABLE 18   Calibration Parameters and Approach

Parameter	Sensitivity	Hydrograph Effects	Initial Parameterization	Calibration Approach
Area (ha)	High	Volume	GIS delineated	not modified
Width (m) or Flow Length (m)	High	Volume, Peak, Shape	longest flow path length	various approaches (see Section 3.2.1.2)
Slope (%)	Low[*]	Peak, Shape	averaged over the catchment	modified by applying factors ranging from 0.3 to 3
Percent Impervious (%)	High	Volume, Peak	raster characterization exercise	see Section 3.2.1.2
Mannings N Impervious	Low	Peak, Shape	single textbook values for impervious surfaces - 0.013	tested a range of values from 0.012 to 0.014
Mannings N Pervious	Low	Peak, Shape	single textbook values for pervious surfaces, 0.25	Varied textbook values for pervious surfaces, weighted by land use type (e.g., forest 0.6, residential 0.25)
Depression Storage Impervious (mm)	Low	Volume	single textbook value for impervious surfaces, 2 mm	tested a range of values from 1 to 3 mm
Depression Storage Pervious (mm)	Moderate	Volume	single textbook values for pervious surfaces, 5 mm	varied textbook values for pervious surfaces, weighted by land use type (e.g., forest 8 mm, residential 3.5 mm)
Zero Impervious (%)	Low	Volume	set a default 25%	not modified
Subarea Routing	High	Volume, Peak	pervious Routing	tested alternatives, but eventually left at pervious routing
Percent Routed (%)	High	Volume, Peak	estimated values based on land use type	modified values based on land use type
Suction Head (mm)	Moderate	Volume	based on assigned soil type	modified for different soils types, most soils were till/loam based
Conductivity (mm/hour)	High	Volume	based on assigned soil type	modified for different soils types, most soils were till/loam based, decrease infiltration rates to account for compaction in disturbed/urban areas
Initial Deficit (frac.)	Moderate	Volume	based on assigned soil type	modified for dry/wet events; most events were dry

Discussion on the calibration approach for each of the hydrologic parameters is provided in the following sections.

3.2.1.1   Flow Length

Overland flow length is a sensitive parameter that affects how rapidly runoff is conveyed to the catchment outlet. Several alternatives were used to estimate flow length within each catchment to achieve the desired model calibration. As discussed in Section 2.4.3, flow lengths were initially estimated using a traditional approach whereby the flow length represents overland sheet flow before it is channelized (e.g., typically 100 to 150 m). Although this approach makes sense in a typical urban model set up, without the representation of the minor system network or major overland flow routes, there is no other mechanism to represent catchment routing. Simulating such short flow lengths within each catchment created a response to runoff that was too rapid in comparison to observed events.

Various alternatives to estimate flow length were tested within a subset of catchments to determine what other hydrologic parameters could be adjusted to replicate the routing impact of minor and major conveyance systems, while maintaining the event volumes. Manning's roughness n, catchment slope, and flow length all affect the runoff peak, with less effect on runoff volumes. While Manning's n and catchment slope can be adjusted within certain ranges, the resultant impact on peak flows was not significant enough. Larger adjustments to the catchment flow length were needed to meet the runoff response for the watershed.

The second approach was to estimate flow length based on a drainage area relationship that has been developed by the USDA (USDA 2010). This method matched well to the measured longest flow path lengths in GIS and showed a response more reflective of the observed events. The catchment length was then adjusted to convert the natural watershed shape into an equivalent rectangular cascading plane (kinematic wave (KW) approach) (Guo and Urbonas 2009). Equivalent KW planes are estimated for natural watershed shapes using area, slope, Z factor (area skewness coefficient) and K factors (typically 4 to 6). Several options to modify the flow length were tested during the calibration process for the Highland model and the final calibrated version used a KW modified flow length with a Z factor of 0.5 and a KW factor of 4.

More details on the flow length calibration method are provided in Appendix G.

3.2.1.2   Percent Impervious

Percent imperviousness for each catchment was estimated using the raster-based characterization process described in Section 2.4.1. Although the final percent impervious values appeared to be low relative to previous estimates of imperviousness in the watershed (43% vs 50% [Aquafor Beech 2004]), calibration of the hydrologic model was carried out with the intention that the calculated percent impervious would not be adjusted during calibration.

Once the calibration process began, it was clear that the percent imperviousness within each catchment was too low to generate the runoff required to match the observed flow conditions. Alternatives were explored, including making all impervious areas directly connected to the watercourse, which led to other issues with the calibration, as well as not being not reflective of physical conditions or defensible as an approach.

Adjusting the percent imperviousness within each catchment was discussed with TRCA during a technical meeting. The impervious raster was reviewed in more detail to evaluate whether some impervious areas were missed in the raster training. It was found that for some areas (particularly shadows, dark rooftops, and parking lots) noise captured by the ortho-imagery proved to be problematic to the raster algorithm, causing more pervious/natural surfaces being classified. In general, it was noted that the training tended to favour pervious surfaces, resulting in a under-estimation of impervious surfaces. The problematic areas were reviewed, comparing a land-use based percent impervious to the raster-based approach. Differences in the catchments ranged from +14% to -70% but on average show a 13% lower imperviousness than the land-use based estimates (Figure 22). After discussion and testing with TRCA it was concluded that the imperviousness within each watershed should be increased by 10% to reflect the watershed conditions and improve the model calibration. A value of 10% was chosen based on model calibration and provided a consistent approach for all subwatersheds. A 10% increase balances the impervious values found through the raster-based characterization (underestimate of imperviousness) and the land-use-based approach (typically an overestimate of imperviousness).
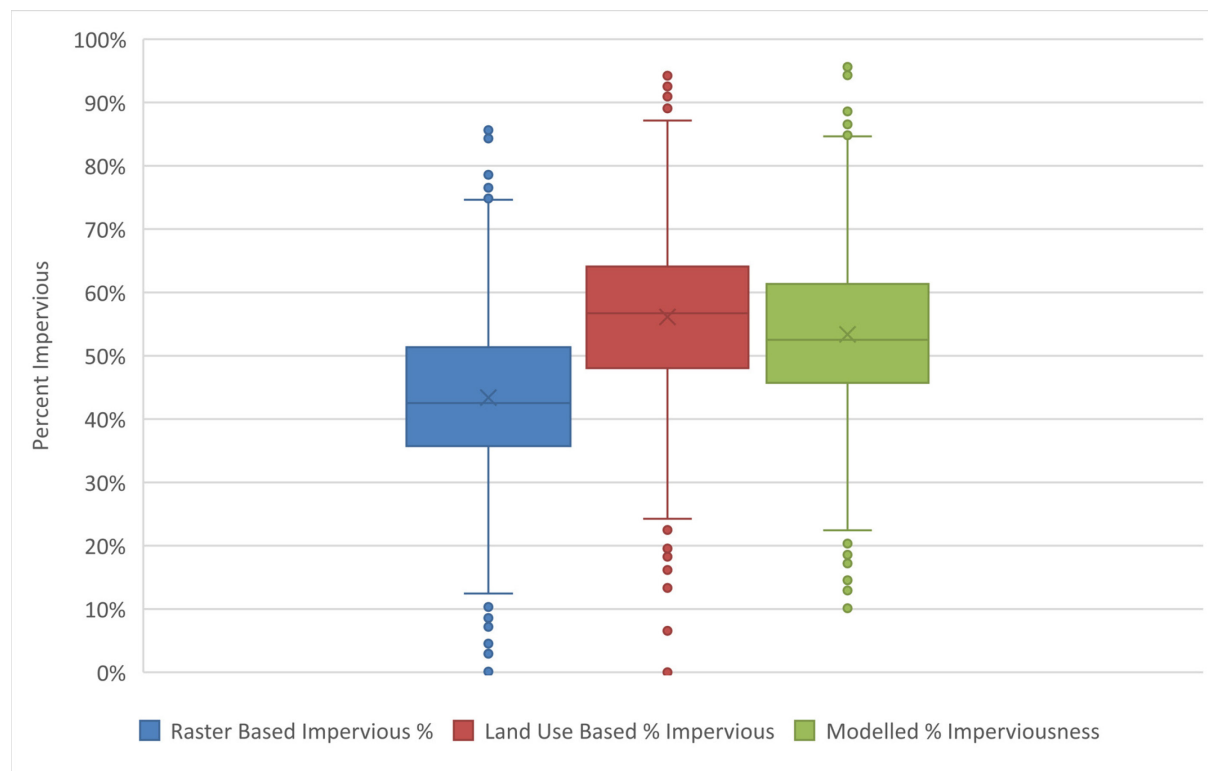
FIGURE 22 Catchment Imperviousness Approach Comparison

3.2.1.3   *Land-use- and Soil-type-based Calibration Parameters*

To maintain a defensible and repeatable approach to model calibration, adjustments to model parameters were not made to individual catchments or subwatersheds, but through the area weighted breakdown of land use and soils types. As there was little evidence to suggest that a particular soil type responds differently in one subwatershed of Highland Creek than another subwatershed, modifications to model parameters tied to specific soil or land use types were made a watershed scale.

Parameters in the hydrologic model that were adjusted based on land use/soils type included:

- Manning's n
- depression storage
- soils parameters (suction head, hydraulic conductivity and initial deficient)
- percent routed

An overview of the soil and land use types within each major subwatershed is outlined in Tables 19 and 20.

TABLE 19   Land Use Types by Subwatershed

Subwatershed	Subwatershed Area (km²)	Highly Impervious Areas[1]	Moderately Impervious Areas/Residential[2]	Pervious Areas[3]	Other Areas[4]
Bendale Branch	23.9	24%	55%	21%	1%
Dorset Park Branch	15.2	34%	47%	17%	1%
West Highland Creek	9.6	14%	57%	28%	<0.5%
East Highland Creek	37.8	38%	39%	20%	4%
Centennial Creek	7.2	11%	66%	23%	<0.5%
Thornton Tributary	4.0	20%	59%	21%	<0.5%
Highland Creek (Main)	7.2	19%	30%	50%	1%

(1) Highly impervious areas include commercial, roads, industrial, institutional, and high-density residential areas.
(2) Moderately impervious areas include medium-low density residential
(3) Pervious areas include golf course, recreational, cemetery, natural areas, and mixed-commercial entertainment.
(4) Other areas include railways and urban gardens.

TABLE 20   Soils/Surficial Geology Types by Watershed

Subwatershed	Subwatershed Area (km²)	Loamy Sand	Sandy Clay /Silty Clay	Sandy Clay Loam	Sandy Loam
Bendale Branch	23.9	0.9%	0.1%	96.5%	2.5%
Dorset Park	15.2	0.5%	-	95.7%	3.8%
West Highland Creek	9.6	3.0%	-	82.2%	14.8%
East Highland	37.8	1.6%	0.2%	95.5%	2.7%
Centennial Creek	7.2	1.3%	10.1%	11.6%	77.0%
Thornton Tributary	4.0	4.1%	-	3.2%	92.7%
Highland Creek (Main)	7.2	10.5%	6.1%	31.2%	52.1%

3.2.1.4   Channel Routing

In PCSWMM, only one Manning's n value can be assigned to the channel between banks stations and one value assigned to the left and right overbank. The majority of channel conduits were left at TRCA standards values of 0.035 for channel and 0.08 for overbank. The only modification to the Manning's n values were the main channel watercourse on East Highland, West Highland, and Main Highland Creek branches, which were increased to 0.04 to reflect the additional routing causes by increase sinuosity and vegetation within the valley.

3.2.2   Calibration and Validation Results

Calibrating the hydrologic model focused on matching the runoff event volumes and peak flows at 02HC058 first, as there was a higher confidence in the rating curve, as discussed in Section 3.1.4. Calibration to 02HC013 and HY034 were completed as a secondary priority as there is more uncertainty with the observed flows.

TRCA provided criteria for matching calibration and validation events and require that at least three of the five selected events fall within the acceptable criteria ranges for:

- runoff volume, -10% to +20% of observed
- peak flow, -15% to +25% of observed
- time to peak, comparison of peaks
- goodness of fit parameters:

  + **Nash-Sutcliffe Efficiency (NSE):** measures the predictive power of hydrologic models by comparing whether the observed mean is a better predictor than the modelled data. A value of 1 is consider a perfect model match. A satisfactory result is typically considered to be 0.65 or above (Moriasi et al. 2007).
  + **Coefficient of Determination (R^2):** output of a regression analysis measuring the proportion of variance between dependent and independent variables, with 1 being a perfect regression. A satisfactory result is typically considered to be 0.75 or above (Moriasi et al. 2007).

◆ **Integral Square Error (ISE) and Integral Square Error Rating:** integrates the square of the difference between the observed and simulated data over the event period (Sarma et al. 1973). Ratings are shown in Table 21.

TABLE 21   Integral Square Error Values and Integral Square Error Ratings

Rating	Integral Square Error Value
Excellent	<3.0
Very good	3.0-6.0
Good	6.0-10.0
Fair	10.0-25.0
Poor	>25.0

Calibration of the hydrologic model initially focused on matching event volumes. Parameters were then refined to meet peak flows and peak timing in the observed data. The final calibrated parameters for each catchment in the watershed are provided in Appendix F.

The results for each calibration and validation event are summarized in Tables 22, 23, and 24 for monitoring stations 02HC058, 02HC013, and HY034, respectively. Figures showing the observed and simulated hydrographs are provided in Appendix H.

At the 02HC058 monitoring station, three of the five simulated calibration events met the goodness of for requirements for peak flow and event volumes (C3, C4, and C5). The June 2015 (C1) and May 2013 (C2) events both simulated less runoff than what was found in the observed data, although the trends in the hydrograph match well. Reviewing the observed data at 02HC058 during the C1 and C2 events found data quality flags on the data from WSC indicating that the values were "estimated" during the peak flow period. For the validation events, four of five events are within the range of acceptable peak flows; however, most events were only slightly outside (within 5%) of the acceptable volume event range.

Calibrating flows at 02HC013 was more difficult, as the model tended to overestimate the observed peak flows and volumes. As discussed in Section 3.1.4, there was more uncertainty associated with the high flow portion of the rating curve at 02HC013 due to extrapolation from lower manual measurements. While matching the acceptable ranges for the calibration and validation events was strived for at 02HC013, reducing peak flows and event volumes to match the observed data conflicted with the objective of matching events at the upstream gauges (02HC058 and HY034). Calibration to 02HC013 observed flows was discussed with TRCA during a technical meeting and it was decided to prioritize the calibration of the upstream gauge (02HC058) as there was more confidence in the observed data. Additionally, should it later be found that the 02HC013 gauge is accurate, and the model is over-estimating flows at this location, the impact of this discrepancy would be result in more conservative (higher) design storm and Regional flow estimates.

TABLE 22   02HC058 Event Calibration and Validation Results

Event ID	Date of Simulation	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R²	ISE	ISE Rating
C1	2015-06-22	87.4	1,012	73.1	879	-16.4%	-13.2%	0.96	0.98	3.51	Very good
C2	2013-05-28	61.4	1,106	55.1	772	-10.2%	-30.2%	0.78	0.84	9.61	Good
C4	2012-07-25	72.5	1,025	72.3	1,106	-0.3%	8.0%	0.97	0.97	3.29	Very good
C5	2015-10-27	50.0	1,314	50.7	1,433	2.6%	9.1%	0.97	0.98	1.95	Excellent
C6	2014-08-03	42.0	533	53.1	585	15.8%	9.9%	0.96	0.99	5.35	Very good
V2	2014-10-16	43.5	512	36.6	416	-15.8%	-18.7%	0.82	0.85	8.32	Good
V3	2012-08-09	57.9	876	33.2	766	-42.7%	-12.6%	0.82	0.92	7.23	Good
V4	2010-07-08	40.5	624	48.1	751	18.9%	20.4%	0.56	0.75	10.3	Fair
V5	2014-04-28	36.7	670	34.6	567	-6.0%	-15.3%	0.98	0.99	2.81	Excellent
V6	2015-06-04	44.8	465	40.9	414	-8.7%	-11.0%	0.96	0.97	4.37	Very good
					EVENT AVERAGE	**-6.3%**	**-5.4%**				

within acceptable range

lower than acceptable range

above acceptable range

NES - Nash Sutcliffe Efficiency

R² - Coefficient of Determination

ISE - Integral Square Error

TABLE 23   02HC013 Event Calibration and Validation Results

Event ID	Date of Simulation	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R²	ISE	ISE Rating
C1	2015-06-22	120.9	1,848	165.8	2,016	37.2%	9.1%	0.83	0.96	3.53	Very good
C2	2013-05-28	120.9	2,012	133.3	1,778	10.3%	-11.6%	0.81	0.82	6.12	Good
C4	2012-07-25	86.7	1,618	153.4	2,356	76.8%	45.7%	0.21	0.93	11.50	Fair
C5	2015-10-27	79.6	2,321	116.4	3,213	46.1%	38.4%	0.48	0.98	3.78	Very good
C6	2014-08-03	87.4	1,120	139.8	1,522	59.9%	35.9%	0.55	0.95	10.90	Fair
V2	2014-10-16	94.5	1,139	105.2	1,085	11.4%	-4.8%	0.93	0.94	4.68	Very good
V3	2012-08-09	89.4	1,925	125.2	2,059	40.2%	6.9%	0.86	0.93	3.99	Very good
V4	2010-07-08	86.1	1,221	150.2	1,808	74.4%	48.1%	-0.64	0.54	19.80	Fair
V5	2014-04-28	68.5	1,236	75.4	1,178	10.2%	-4.7%	0.79	0.84	5.92	Very good
V6	2015-06-04	74.0	1,000	83.8	974	13.2%	-2.7%	0.95	0.95	2.31	Excellent
					EVENT AVERAGE	**38.8%**	**16.0%**				

within acceptable range

lower than acceptable range

above acceptable range

NES - Nash Sutcliffe Efficiency

R² - Coefficient of Determination

ISE - Integral Square Error

TABLE 24   HY034 Event Calibration and Validation Results

Event ID	Date of Simulation	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)	NSE	R²	ISE	ISE Rating
C1	2015-06-22	-	-	-	-	-	-	-	-	-	-
C2[1]	2013-05-28	17.4	219	29.3	240	68.7%	9.6%	0.80	0.81	4.8	Very good
C4	2012-07-25	23.0	357	26.8	331	16.4%	-7.3%	0.72	0.72	17.2	Fair
C5	2015-10-27	-	-	-	-	-	-	-	-	-	-
C6	2014-08-03	-	-	-	-	-	-	-	-	-	-
V2	2014-10-16	-	-	-	-	-	-	-	-	-	-
V3	2012-08-09	30.5	415	14.4	291	-52.9%	-29.8%	0.03	0.79	6.9	Good
V4	2010-07-08	-	-	-	-	-	-	-	-	-	-
V5	2014-04-28	18.8	250	12.7	175	-32.3%	-30.1%	-0.11	0.67	10.1	Fair
V6	2015-06-04	-	-	-	-	-	-	-	-	-	-
	EVENT AVERAGE					0.0%	-14.4%				

within acceptable range

lower than acceptable range

above acceptable range

(1) Missing a portion of the hydrographs.

NES - Nash Sutcliffe Efficiency

R² - Coefficient of Determination

ISE - Integral Square Error

As shown in Table 23, the simulated flows at 02HC013 generally over-estimate the peak flows and event volumes when compared to the observed data. Only one of the calibration events met the acceptable peak flow and volume range. The validation events did meet the TRCA criteria for matching peak flows and volumes for three of five events. To further confirm the calibration of 02HC013, a small event validation exercise was completed and summarized in Section 3.2.2.

Observed data from HY034 was limited for calibration and validation event exercises. Much of the observed data was missing during intense storms or only had recordings at 30-minute or 1-hour intervals. Due to the limitations in the data, only two calibration and validation events were used to compare simulated and observed flows. Simulated data matched well for the C4 calibration event. The peak flow portion of the hydrograph was missing during event C2 in the observed data, which is why the simulated flow appears to be overestimating the peak. The validation events generally showed lower peak and events volumes than the observed data. The timing of the hydrographs also appears to be shifted during some events and is likely due to daylight savings being applied to the observed flows.

3.2.2.1   August 19, 2005 Event Analysis

No flow data was available for model comparison during the August 19, 2005, storm event; however, high-water marks were collected at several locations throughout the watershed. Rainfall during the August 2005 event showed volumes two to three times greater than any other event volumes seen in the watershed since 2006, which is why simulating this event in the hydrologic model was important. (Table 25) shows the simulated peak flow from the calibrated hydrologic model.

TABLE 25   August 19, 2005 Rainfall Event Depths and Simulated Peak Flows

Monitoring Location	Simulated Peak Flow (m³/s)
02HC013	523.3
O2HC058	213.3
HY034	192.1

TRCA provided high-water mark elevations for six locations in the Highland Creek watershed. Most locations are near existing flow monitoring gauges (HY034 - Malvern Branch, 02HC058 - West Highland Creek, 02HC013 - Main Highland Creek), but there are also records for Dorset Park and Bendale Branches. A comparison of high-water mark elevations to simulated water levels in junctions near the collected data is provided in Table 26. As shown, there is good correlation between the simulated flows and the high-water marks in areas where return period water level elevation was exceeded (as recorded by TRCA - in Highland Creek [SG 14], Bendale Branch [55], and downstream section of Malvern Branch [SG 46]). There is less correlation with the simulated water levels and high-water marks in areas where the recorded elevation appears to be low (i.e., corresponded with the lower return period water level) or areas around bridges and culverts where PCSWMM may not be accurately representing water levels.

TABLE 26   August 19, 2005 – High-water Mark Simulation Comparison

ID No.	High Water Mark Location	High Water Mark Elevation (m asl)	Return Period Water Level Exceeded[1]	Simulated Water Level (m asl)	Difference (m)
52	West Highland Creek, South of Lawrence, West of Markham Road	136.66	5	137.31	0.65
		137.31	10	138.06	0.75
		137.38	10	138.33	0.95
53	Dorset Park Branch, Birchmount Road and Ellesmere Road	170.1	2	171.05	0.95
		169.62	2	171.05	1.43
55	Bendale Branch Lawrence Avenue East and McCowan Road	144.32	100	144.13	-0.19
		144.86	100	145.01	0.15
SG 14	Highland Creek, Morningside Works Yard	99.34	50	99.23	-0.11
		99.34	100	99.74	0.40
		99.85	100	100.26	0.41
SG 46	Malvern Branch, Sheppard Avenue/ East Highway 48	157.73	Regional	157.96	0.23
		157.73	Regional	159.88	2.15
		158.43	Regional	159.94	1.51
SG 98	West Highland Creek Bellamy Road North and Lawrence Avenue East	139.92	<2 years	142.02	2.10

(1)   Based on previous hydrologic/hydraulic modelling.
asl - above sea level

3.2.2.2   Small Event Validation

A small event validation exercise was completed to assess the ability of the hydrologic model to match observed storm events where there is high confidence in the observed flow derived from the rating curve. Five small events (15 to 20 mm rainfall) were selected for additional model validation and simulated in the hydrologic model using the same methods outlines in Section 3.1. Using small events for model validation is difficult as there is typically more variability in the rainfall distribution through the watershed and, depending on the total rainfall at any one monitoring gauge, rainfall can be overrepresented or underrepresented within the watersheds.

The results of the small event validation exercise are shown in Tables 27 and 28 for monitoring stations 02HC058 and 02HC013, respectively. Although peak flows and volumes are still over-estimated for two of the five validation events at 02HC013, the simulated and observed flows and volumes match more closely. At 02HC058, three of five small validation events meet the TRCAs acceptable criteria, further confirming the final calibration of the model.

TABLE 27   Small Event Validation Results - 02HC013

Event ID	Date of Simulation	Pre-event Conditions	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)
SVA	8-Oct-15	Dry	42.2	605	55.0	756	30.3%	25.0%
SVB	2-Sep-14	Dry	34.2	484	24.5	403	-28.3%	-16.9%
SVC	11-Jun-14	Dry	30.8	494	40.9	546	32.9%	10.5%
SVD	7-Jul-14	Dry	17.3	408	18.0	445	4.1%	9.0%
SVE	25-Jul-16	Wet	42.6	437	40.0	435	6.1%	-0.4%
						EVENT AVERAGE	6.6%	5.5%

within acceptable range
lower than acceptable range
above acceptable range

TABLE 28   Small Event Validation Results - 02HC058

Event ID	Date of Simulation	Pre-event Conditions	Observed Peak Flow (m³/s)	Observed Volume (ML³)	Modelled Peak Flow (m³/s)	Modelled Volume (ML³)	Peak Flow Difference (%)	Volume Difference (%)
SVA	8-Oct-15	Dry	22.5	292	23.0	332	2.4%	13.5%
SVB	2-Sep-14	Dry	18.2	200	13.7	188	-24.7%	-6.0%
SVC	11-Jun-14	Dry	16.5	257	18.0	248	8.7%	-3.4%
SVD	7-Jul-14	Dry	8.7	203	8.7	223	0.0%	9.9%
SVE	25-Jul-16	Wet	35.1	248	22.4	235	-36.1%	-5.2%
						EVENT AVERAGE	-9.9%	1.8%

within acceptable range
lower than acceptable range
above acceptable range

4   DESIGN STORM AND REGIONAL SIMULATIONS

Once the Highland Creek model was considered calibrated and confirmed by TRCA, the Regional, 2 through 100-year, and 350-year design storm events were simulated to estimate return period and Regional storm event peak flows for input to the hydraulic model. As the Regional flow estimates require that all SWM facilities and structures be removed, two PCSWMM models were developed with the calibrated hydrologic parameters. A PCSWMM model with SWM facilities and structures represented was used to simulate the 2- through 100-year design storm distributions, and a PCSWMM model without the SWM infrastructure pieces was used to simulate the Regional and 350-year events.

4.1 Design Storm Simulations

Design storm event depths were obtained from Environment Canada's City of Toronto IDF curves (Station ID: 6158355 – formerly known as the Bloor Street Station). The IDF curve was developed based on 67 years of data between 1940 and 2017. To select the most appropriate precipitation distribution, nine different design storm distributions were simulated in the hydrologic model to compare to the return period flows calculated from the gauge record. The simulated storm distributions included:

- SCS: 6-hour, 12-hour, and 24-hour
- AES: 1-hour, 30% 12-hour, 70% 12-hour
- Chicago: 3-hour, 4-hour, and 12-hour

It should be noted that the previous Highland hydrology model used a 6-hour and 12-hour AES rainfall distributions.

The rainfall depths for each return period, for each of the design storm distributions is shown in Table 29. The SCS storms and AES 12-hour, 30% and 70% are more applicable to rural watershed (less then 20% imperviousness), where the shorter duration, higher intensity 1-hour AES and Chicago storms distributions are typically applied to urbanized watersheds, such as Highland Creek. All design storms were simulated in the hydrologic model using IMD for equivalent Antecedent Moisture Condition (AMC) II soil conditions.

TABLE 29   Design Storm Distribution Depths for 2- through 100-year Return Periods

Return Period	Design Storm Depths (mm)								
	SCS			AES			Chicago		
	6-hour	12-hour	24-hour	AES 1-hour	AES 30% 12-hour	AES 70% 12-hour	Chi_3hr	Chi_4hr	Chi_12hr
2	34.9	41.3	46.4	24.1	41.3	41.3	29.0	31.4	41.3
5	47.3	54.5	60.1	33.1	54.5	54.5	39.0	42.1	54.5
10	55.6	63.1	69.1	39.0	63.1	63.1	45.6	49.2	63.1
25	66.0	74.1	80.6	46.5	74.1	74.1	54.0	58.3	74.1
50	73.7	82.2	89.0	52.1	82.2	82.2	60.1	64.8	82.2
100	81.4	90.3	97.5	57.6	90.3	90.3	66.3	71.4	90.3

Output from the hydrologic model was extracted at the 02HC013, 02HC058, and HY034 monitoring stations for comparison (Figures 23, 24, and 25 respectively). The 30% and 70% 12-hour AES storm produced the lowest return period flows at each location. All remaining distributions produced similar peak flow estimates with the highest being the 6-hour SCS and 12-hour Chicago storms at 02HC058 and 02HC013 and 1-hour AES storm at HY034.

The design storm return period flows were also compared to estimates from the flood frequency analysis at monitoring stations 02HC013 and 02HC058. Overall, the observed flood frequency distributions trend lower than most of the estimates from the design storms. Comparing the frequency flows to the design storms results may not be an appropiate comparision as some instantaneous flow data was missing from the records (e.g., August 19, 2005, event) and the records only contained less than 30 years of peak flow data, which would effect the flood frequency results.
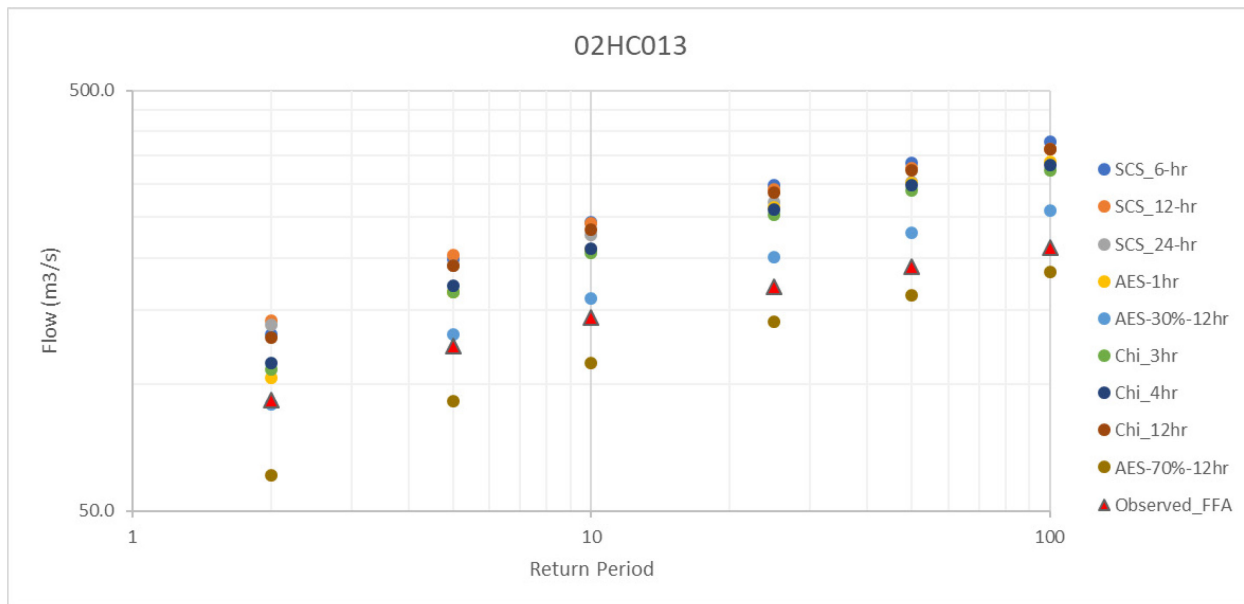
FIGURE 23   Hydrological Model Output for 02HC013
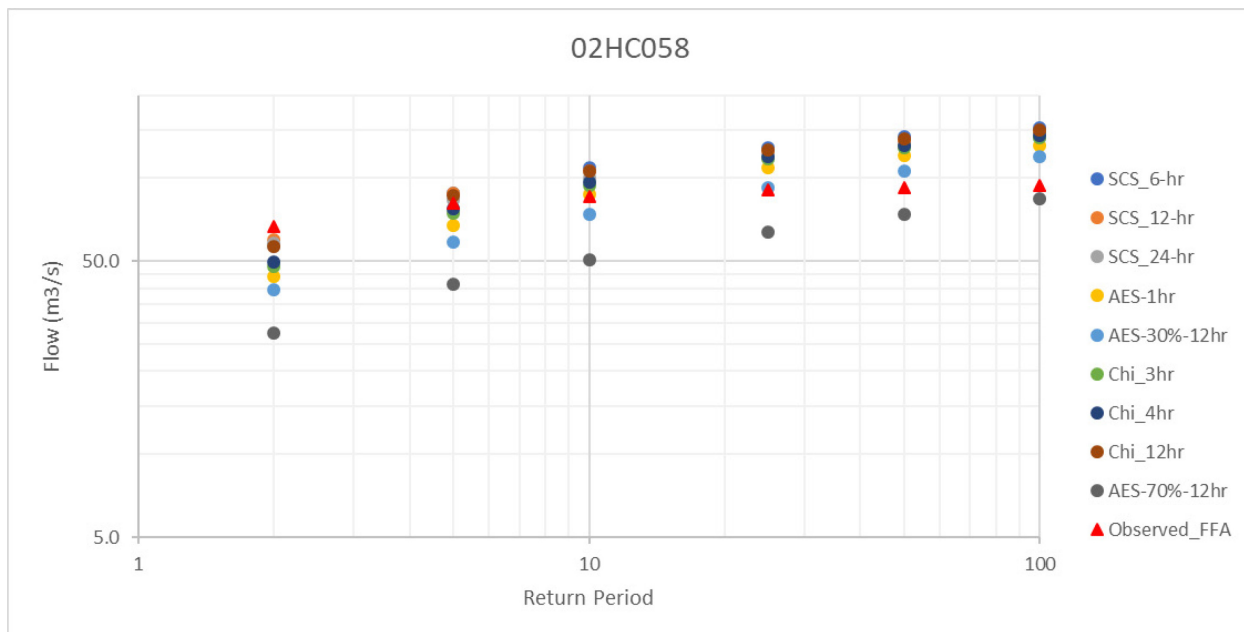
FIGURE 24   Hydrological Model Output for 02HC058
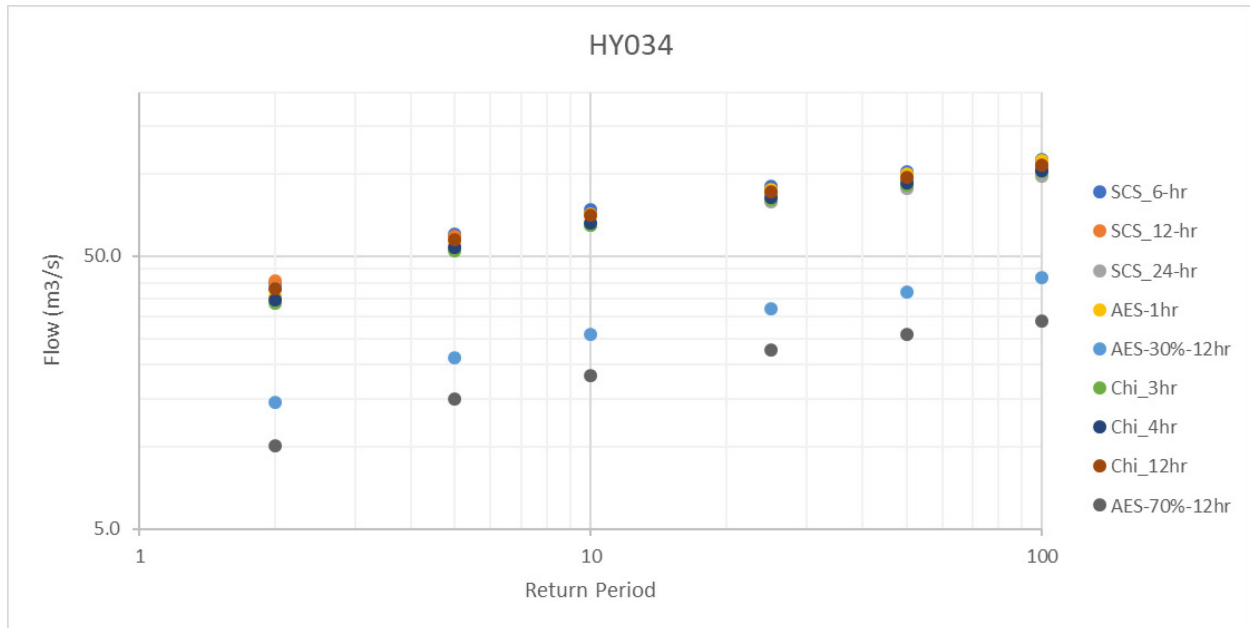
FIGURE 25 Hydrological Model Output for HY034

Matrix reviewed and discussed the result of the analysis with TRCA to determine which design storm would be most suitable for representation in the hydraulic model. Ultimately the 1-hour AES was selected to represent the design storm flows in the Highland Creek based on the following:

- The 1-hour AES distribution is applicable to urbanized watersheds, such as Highland Creek.

- The high-intensity, short-duration, 1-hour AES storm distibution is similar to the historical events that have occurred over the watershed in the past few decades.

- Given the relatively small size of the watershed (105 km^2), a 1-hour AES storm distibution could occur simutanesouly throughout the watershed.

- The 1-hour AES design storm results trend higher than the flood frequency analysis results using observed flows; however, significant storm events, such as the August 19, 2005, were not captured by the flow records. If available, the data from these large storm events would trend the observed flow frequency estimates higher, potentially reflecting the results of the 1-hour AES simulation.

Due to the relatively small size of the Highland Creek watershed, areal reduction factors were not applied to the design storm simulations. Areal reduction factors are used to convert point rainfalls to averages over a larger area, to represent the spatial variability of rainfall that occurs over a watershed. No reduction in point rainfall is typically applied to drainage areas less than 25 km^2 and adjustment curves are applied to drainage areas greater than 25 km^2. In the context of Highland Creek, a review of the calibration/validation events showed that most historical extreme rainfall events showed little deviation between the gauged rainfall, indicating that the application of areal reduction factors may not be valid.

Given the historical events and the short duration of the 1-hour AES design storm, it was decided to proceed with the more conservative approach of not applying areal reduction factors to design storm events. Results of the 1-hour AES designs storm distributions are provided in Appendix I.

A comparison to the 2004 hydrology (Aquafor Beech 2004) results is also provided in Appendix I. Diffferences in peak flows from the previous hydrology study are largely due to refinements with the catchment delineation (from updated LiDAR), increased resolution of channel routing elements, incorporation of additional hydraulic structures, the refined model parameterization, as well as the revised storm distribution.

4.2   Regional Storm Simulations

The Regional storm event (Hurricane Hazel) was simulated in the calibrated hydrologic model. To account for saturated conditions, the full 48 hyetograph was used to simulate the Regional event. As per the Ministry of Natural Resources and Forestry's (MNRF; formerly Ministry of Natural Resources) Technical Guidelines (MNR 2002), all culvert and bridge crossings as well as SWM facilities were removed as they may not used to provide a reduction in peak flows for flood hazard assessments.

4.2.1   Areal Reduction Factors

As per the MNRF (MNR 2002) and EWRG (2017) guidelines, where a watercourse has a drainage area greater than 25 km^2, an areal reduction factor should be applied to the Regional storm. Areal reduction factors were derived using the equivalent circular area method and were applied to the Regional storm based on the upstream catchment area (Table 30). The nine reduced Regional storm scenarios are simulated in the model. In the post-processing of the model output, the final Regional scenario is selected from each run based on equivalent circular area upstream. A summary of the Regional flows for the Highland Creek watershed is provided in Appendix J.

TABLE 30   Areal Reduction Factors for the Regional Storm

Equivalent Circular Area (km^2)	Areal Reduction Factor
<25	1.0 (No Reduction)
26-45	0.992
46-65	0.982
66-90	0.971
90-115	0.963
116-140	0.954
141-165	0.948
166-195	0.942
196-220	0.935

A comparison to the 2004 hydrology results is provided in Table 31. Similar to the design storms comparison, diffferences in peak flow from the previous hydrology study are largely due to refinements with the catchment delineation (from updated LiDAR), increased resolution of channel routing elements, incorporation of additional hydraulic structures, the refined model parameterization, as well as the revised storm distribution. In general, the updated Regional flows are slightly lower (average 6% lower) than the previous models estimates.

TABLE 31   Comparison of 2004 and Updated 2020 Regional Flow Estimates

| Location | 2004 Hydrology Report | | | | 2020 Hydrology Update | | | | Comparison | |
	2004 Flow Node	Drainage Area (km²)	ARF	Regional Flow (m³/s)	2020 Flow Node/ Catchment	Drainage Area (km²)	ARF	Regional Flows (m³/s)	Regional Flow Difference	Drainage Area Difference
Dorset Park Branch	104.1	*3.24*	100.0%	**42.7**	H0073	3.30	100.0%	**38.7**	-9%	2%
Dorset Park Branch	100.1	*10.77*	100.0%	**138.1**	H0021	13.38	100.0%	**143.5**	4%	24%
Dorset Park Branch	100.2	*13.82*	99.2%	**165.1**	H0166	15.15	99.2%	**154.6**	-6%	10%
Bendale Branch	206.1	*7.28*	100.0%	**94.7**	H0028	7.81	100.0%	**88.0**	-7%	7%
Bendale Branch	205.1	*14.64*	99.2%	**178.9**	H0104	17.47	99.2%	**187.7**	5%	19%
Bendale Branch	204.1	*16.19*	99.2%	**191.9**	H0111	18.40	99.2%	**196.7**	3%	14%
Bendale Branch	201.1	*21.16*	98.2%	**242.3**	H0042	19.81	98.2%	**207.8**	-14%	-6%
Bendale Branch	200.1	*25.34*	97.1%	**256.8**	H0023	23.43	97.1%	**232.6**	-9%	-8%
West Highland Creek	608.1	*39.16*	96.3%	**399.3**	H0066	39.21	96.3%	**377.3**	-6%	0%
West Highland Creek	608.2	*49.48*	95.4%	**455.8**	H0099	47.31	95.4%	**418.7**	-8%	-4%
West Highland Creek	606.1	*50.23*	96.3%	**462.5**	H0171	48.63	95.4%	**425.6**	-8%	-3%
Miliken Trib	302.1	*5.89*	100.0%	**75.8**	H0055	7.49	100.0%	**84.3**	11%	27%
Miliken Branch	304.1	*7.37*	99.2%	**95.4**	H0122	5.73	99.2%	**65.3**	-32%	-22%
Miliken Branch	301.1	*13.26*	99.2%	**170.5**	H0007	13.60	99.2%	**153.6**	-10%	3%
Miliken Branch	301.2	*16.95*	98.2%	**215.2**	H0123	15.35	98.2%	**170.3**	-21%	-9%
Miliken Branch	300.1	*21.25*	97.1%	**248.0**	H0143	19.87	97.1%	**213.7**	-14%	-6%
Malvern Branch	402.1	*5.29*	100.0%	**69.4**	H0126	6.81	100.0%	**81.7**	18%	29%
Malvern Branch	401.1	*11.21*	99.2%	**145.0**	H0044	12.27	99.2%	**142.7**	-2%	9%
Malvern Branch	400.1	*14.11*	99.2%	**180.5**	H0172	15.71	99.2%	**180.7**	0%	11%
East Highland Creek	605.1	*38.02*	97.1%	**447.9**	H0186	37.83	96.3%	**396.6**	-11%	0%
Highland Creek	604.1	*88.26*	96.3%	**860.8**	H0152	86.73	96.3%	**773.2**	-10%	-2%
Highland Creek	603.1	*96.60*	94.8%	**902.6**	H0086	90.52	94.8%	**780.0**	-14%	-6%
Highland Creek	600.1	*97.58*	94.2%	**880.3**	H0198	92.06	94.2%	**769.1**	-13%	-6%
Thornton Creek	601.1	*2.98*	100.0%	**39.3**	H0183	3.97	100.0%	**29.6**	-25%	33%
Centennial Creek	501.1	*1.73*	100.0%	**22.9**	H0131	3.93	100.0%	**32.5**	42%	127%
Centennial Creek	501.2	*4.79*	100.0%	**64.0**	H0197	6.91	99.2%	**57.3**	-10%	44%
Highland Creek	600.2	*105.35*	93.5%	**936.8**	H0175	103.29	93.5%	**773.8**	-17%	-2%

5   UNCERTAINTIES AND LIMITATIONS

It is important to note that models are simply tools to help analyze, estimate, and predict values based on a set of inputs. A high level of care and professional judgement was used to calibrate and validate the hydrologic model to ensure the physical processes of infiltration, runoff, and routing within the Highland Creek watershed are properly represented. Within any model, there are sources of inherit uncertainty whether that be in inputs, calibration parameters, or process representation within the model itself. The following section is intended to highlight the largest sources of uncertainty encountered in this study as well as provide guidance on the limitations of use associated with the PCSWMM model for Highland Creek.

Recognizing the uncertainty associated with the analysis reported herein, appropriate measures were taken to reduce the uncertainty associated with the peak flow estimates and increase confidence in the model's ability to predict peak flows. Measures to improve model uncertainty included calibration and validation of flow estimates to two WSC station gauges 02HC013 and 02HC058 for a range of flow events. In areas where observed flow data was not available for comparison, unit peak flows (peak flow divided by drainage area) was reviewed against soils conditions and percent impervious to confirm reasonable peak flows were being simulated from these areas. Although these measures help to increase confidence in the model predictions, areas of residual uncertainty associated with the hydrologic modelling include:

- Lack of reliable flow data for the HY034 gauging station, and lack of additional flow observations in the upper reaches of Highland Creek. There is uncertainty surrounding the peak flow estimates for watercourses that do not have gauge records that the simulated flows can be compared against. From a watershed-wide perspective, it is felt this uncertainty is minor; however, this uncertainty increases when focussing on smaller watercourses within Highland Creek that do not have gauging records.

- Lack of detailed soils mapping for the watershed. Soils mapping available for the Highland Creek watershed was largely categorized as "built-up area" and infiltration parameters were estimated from the underlying surficial geology. Due to the highly impervious nature of Highland Creek, it is felt this is an uncertainty of minor significance.

- No representation of the minor system. In urbanized watersheds, the majority of runoff is conveyed to the watercourse through the sewer network, which was not explicitly represented in the Highland Creek hydrology model. Catchments were parameterized to balance routing that would occur through minor system as well as overland to achieve model calibration, while adequately representing the Regional storm hydrology. While it is felt that this uncertainty is minor when considering high return period flows (e.g. 50 to 100 year) or Regulatory flows, this uncertainty is increased when considering low return period flows (e.g. 2 year) during which the minor drainage system would be responsible for a greater proportion of the flow response.

5.1 Limitations

The PCSWMM model was calibrated to match runoff volumes and peak flows for single events. The PCSWMM model was not developed for, and should not be relied on for, continuous modelling analysis (i.e. multi-event simulation), water balance modelling, or generating low flow estimates. Furthermore, the model does not include a representation of the minor system network which would convey the majority of runoff during more frequent storm events. Given the model's purpose to determine regulatory flows, SWM facilities and watercourse crossings were ignored for the Regional event and no credit was given to attenuation around structures in the channel. Care should be taken when using the model to predict flow estimates for purposes other than floodline generation.

6 RECOMMENDATIONS

Recommendations to improve the hydrologic model parameterization and calibration to reduce uncertainty associated with the peak flow estimates include the following:

- Additional data to confirm stage-discharge relationships. Increasing flow measurements, particularly during high flow periods and installing more flow gauging stations. Installing long-term continuous flow monitoring gauges in Bendale Branch, Centennial Creek, Milliken Creek and/or East Highland Creek will improve calibration in the headwater areas. Recommended monitoring locations are shown on Figure 26.

- Enhanced representation of the SWM facilities. SWM facility representation within Highland Creek was simplified and could be refined with additional field data or as-built survey information (i.e., outlet structure details, volume/area confirmation). As most SWM facilities was used for minor system overflows, knowing the service level of the storm sewer system would also strengthen the underlying runoff assumptions around the SWM facility representation.

- Refinement of the soils mapping throughout the watershed. Soils mapping through different areas could be refined based on existing information from borehole records. This information could be used to confirm the topsoil and underlying surficial geology throughout each subwatershed. This would be a greater priority in those areas that have a low proportion of impervious land cover.

Recommended Monitoring Locations

Toronto and Region Conservation Authority
Highland Creek Hydrology and Floodplain Mapping Update

Legend

- Highland Watershed
- Subwatershed
- Watercourse
- Rainfall Monitoring Station
- Flow Monitoring Station
- Recommended Monitoring Location

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| Date: | Project: | Submitter: | Reviewer: |
| May 2020 | 27623 | A. McKay | S. Bellamy |

Figure 26

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2017). Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

1:65,000
NAD 1983 UTM Zone 17N

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7   SUMMARY

An updated hydrologic model was developed in PCSWMM for the Highland Creek watershed. Key aspects of the hydrologic model development and calibration include:

- Catchments in the hydrologic model were delineated from 1 m LiDAR, resulting in 299 individual catchments to represent the watershed. Catchments were parameterized based on land use, ortho-imagery, soils and surficial geology mapping.

- Thirty-one SWM facilities were incorporated in the hydrologic model to provide representative detention storage. Hydrologically significant culvert and bridge crossings were also included in the channel routing to reflect potential attenuation.

- The hydrologic model was calibrated to five recorded rainfall events and validated to five recorded rainfall events between 2010 and 2017.

  - At the 02HC058 monitoring station on West Highland Creek, the model was able predict peak runoff rates and runoff volumes within the acceptable criteria for three of the five calibration and validation events.

  - At the 02HC013 monitoring station on Highland Creek, the model only able to predict one of the calibration events within acceptable criteria but was able to predict three of five of the validation events. Despite being unable to meet criteria for calibration, a secondary small event validation exercise provided further confidence in the model's ability to replicate runoff hydrographs in Highland Creek. Further confidence is created when the August 19, 2005, simulation was able to match high water mark elevations reasonably well (within 0.11 to 0.41 m) at this location.

  - Limited data was available for calibration at the HY034 monitoring station on the Malvern Branch. The model was able predict peak runoff rates and runoff volumes within the acceptable criteria for one of the two calibration events.

- The 1-hour AES design storm distributions was selected to represent return period in the hydrologic model. The 1-hour AES storm was seen as most suitable based on the scale and condition of the Highland Creek Watershed.

- The Regional event was simulated in the hydrologic model with the SWM facilities and watercourse structures removed. Areal reduction factors were also applied to the Regional Storm event analysis was per the technical guidelines (EWRG 2017, MNR 2002).

- The model provides flow estimates for all 21 watercourses in the Highland Creek watershed for the Regional and 2- through 350-year return period events.

8   REFERENCES

AECOM Canada Ltd. (AECOM). 2018. *Don River Hydrology Update*. Prepared for Toronto and Region Conservation Authority. Richmond Hill, Ontario. December 2018.

AECOM (AECOM Canada Ltd.). 2012. *Review of Transportation Policies, Road Classification System, and Design Standards and Criteria*. Prepared for City of Vaughan. Markham, Ontario. Spetember 2012.

Aquafor Beech Limited (Aquafor Beech). 2004. *Highland Creek Hydrology Update*. Prepared for Toronto and Region Conservation Authority. Brampton, Ontario. December 2004.

City of Toronto. 2019. *City of Toronto Open Data Portal*. Data last refreshed November 30, 2019. https://open.toronto.ca/dataset/3d-massing/

Computational Hydraulics International (CHI). 2019. *PSCWMM*. Modelling software for stormwater, wastewater, watershed and water distribution systems.

Environmental Water Resources Group Ltd. (EWRG). 2017. *Technical Guidelines for Flood Hazard Mapping*. Prepared for Central Lake Ontario Conservation, Credit Valley Conservation, Ganaraska Conservation, Grand River Conservation Authority, Nottawasaga Valley Conservation Authority, and Toronto and Region Conservation Authority. March 2017.

Greenland International Consulting Inc. 2001. *Visual OTTHYMO*. Stormwater management software. Version 2.0.

Guo J.C.Y. and B. Urbonas. 2009. 'Conversion of Natural Watershed to Kinematic Wave Cascading Plane'. *Journal of Hydrologic Engineering 14* (*8*): 839–846. August 2009.

Kipkie C.W. 1998. 'Feasibility of a Permeable Pavement Option in the Storm Water Management Model (SWMM) for Long-term Continuous Modelling'. Master of Science thesis. A Project Presented to The School of Engineering of The University of Guelph. University of Guelph. Guelph, Ontario. April 1998. https://www.chiwater.com/Company/Staff/WJamesWebpage/original/homepage/Research/T52Kipkie/T52.html

McDonald J. 2011. 'Response of river channel morphology to urbanization: the case of Highland Creek, Toronto, Ontario, 1954-2005'. Master of Science thesis. University of Western Ontario. London, Ontario. 221 pp. 2011.

Moriasi D.N. et al. 2007. 'Model evaluation guidelines for systematic quantification of accuracy in watershed simulations'. *Transactions of the American Society of Agricultural and Biological Engineers 50* (*3*): 885–900. 2007.

OakRidges Moraine Groundwater Programm (ORMGP). 2019. *Bedrock Geology - OakRidges Moraine Groundwater Program*. https://www.oakridgeswater.ca/bedrock-geology/

Ontario Ministry of Natural Resources (MNR). 2002. *Technical Guide, River & Stream Systems: Erosion Hazard Limit*. Water Resources Section. Peterborough, Ontario.

Sarma P.B.S. et al. 1973. 'Comparison of rainfall-runoff models for urban areas'. *Journal of Hydrology 18*: 329–347. 1973.

Satgunarajah A. 2009. 'Determination of imperviousness in the highland creek catchment'. *Studies by Undergraduate Researchers at Guelph 3* (*1*): 26–30. 2009.

Toronto and Region Conservation Authority and City of Toronto (TRCA and City of Toronto). 1999. *State of the Catchment Report: Highland Creek Catchment*. Toronto, Ontario. 1999.

United States Department of Agriculture (USDA). 2010. *Part 630 Hydrology National Engineering Handbook*. Chapter 15 Time of Concentration. May 2010.

United States Environmental Protection Agency (EPA). 2017. *Storm Water Management Model (SWMM) V5.1*. Software to help predict runoff quantity and quality from drainage systems.

United States Soil Conservation Service (US SCS). 1964. *SCS National Engineering Handbook*. U.S. Department of Agriculture. 1964.

Vieux B.E. 2005. 'Distributed Hydrologic Modeling Using GIS' 2005.

Wood Environment & Infrastructure Solutions (Wood). 2018. *Rouge River Watershed, Hydrology Study Update*. Prepared for Toronto and Region Conservation Authority. Burlington, Ontario. September 2018.

World Meteorological Organization (WMO). 2008. *Guide to Hydrological Practices Volume I: Hydrology - From Measurement to Hydrological Information*. WMO-No. 168: 302 pp, Sixth Edition. 2008.

APPENDIX A
Land Use Descriptions

TABLE A1   Land Use Descriptions in Highland Creek Watershed

Land Use Code	Land Use Type	Description	Area (ha)	Percentage of Watershed
AGR	Agriculture	Urban gardens and green houses	6	0.1%
CEM	Cemetery	Well-manicured areas with visible grave markers, monuments, some trees, some buildings (could include a small church), and small winding roads.	7	0.1%
COM	Commercial	Wide variety of building types including box-store complexes, variety stores, restaurants, grocery stores, malls, plazas, and office towers. Includes parking lots, buildings, flat-paved roofs, roads, shipping/receiving entryway, alleyways, rear parking, and a lack of manicured areas.	740	7.1%
GC	Golf Course	Includes driving ranges, practice greens, mini-putts, all manicured areas of golf courses (greens, fairways), cart paths, and all associated buildings (club house, maintenance, etc.). Does not include the "natural areas" or "open water".	96	0.9%
HDR	High-density Residential	High-rise apartment buildings and high-density town house complexes in isolated subdivisions/contained development units with minimal to no existence of manicured lots visible, apartment and large condominium complexes and their associated property (includes small manicured areas and parking areas, if part of the complex).	234	2.2%
IND	Industrial	Large warehouse and factory buildings with flat-paved roofs, plus associated manicured areas and parking, the existence of storage yards, scrap materials or automobile wreckers, transport truck storage, small amounts of dedicated railway track, hydro transfer or transformer stations are key indicators of these areas. Power generating stations are included in this class.	1,266	12.1%
INS	Institutional	Schools (including universities and colleges), conference centers, hospitals, and dedicated church properties.	332	3.2%
MCE	Mixed Commercial Entertainment	Land uses such as stadiums, large-scale arenas, racetracks (animal or automobile), casinos, amusement parks, science centers, zoos, aquariums, historic villages/museums, permanent fairgrounds, equestrian parks.	<1	<0.1%
MDR	Medium-low Density Residential	Includes lots for single detached homes with small to moderate manicured areas, semi-detached homes through to small town house complexes and small condominium complexes within mixed subdivisions and low-rise apartment buildings (less than five stories).	4,969	47.4%
NCF	Forest	Treed areas with greater than 60% tree cover. No distinction between coniferous, deciduous, or mixed species was made. Open areas smaller than 0.5 ha are not isolated.	624	6.0%

Land Use Code	Land Use Type	Description	Area (ha)	Percentage of Watershed
NCM	Meadow	Comprised of a minimum of 50% herbaceous (non-woody) cover, less than 25% tree cover, less than 25% shrub cover and the total coverage of trees and shrubs is less than 50%. Roadside ditches are also included in this category.	280	2.7%
NCS	Successional	Identified by having a composition of 25% to 60% tree cover, 25% to 50% shrub cover. Trees are sufficiently sparse and/or immature that no distinct canopy has been established as is representative of "natural succession". No evidence of being manicured.	56	0.5%
NCW	Wetland	Presence of specific vegetation types (terrestrial and/or emergent and/or submergent), and/or visible moisture (open water and/or soil/ground colour changes). Farm ponds, stormwater ponds, reservoirs, etc. are not considered wetlands unless there is appropriate vegetation accompanying the feature to be considered habitat.	30	0.3%
OWL	Open Water - Lake	All ponds, lakes, and reservoirs including those that are natural, manmade, controlled, online, offline, stormwater management ponds, irrigation ponds, farm ponds, etc. Boundary is places where the shoreline is seen to be or can be reasonably assumed to be	7	0.1%
OWR	Open Water - River	All open water along rivers, creeks, and streams. Also included the riparian vegetation in some areas.	59	0.6%
RDS	Roads	Roads include 400 series highways, other major highways, on and off ramps, and concession or regional roads. Edge of the roadway is the edge of the gravel or paved shoulder if present. Sidewalks should only be included if there is less than 1 to 2 m separating the road or shoulder edge from the sidewalk. Bus stations are included as part of this category. Local roads were not classified as separate entities but were instead incorporated without preference into adjacent land classification units.	383	3.7%
REC	Recreation of Open Space	Includes manicured, semi-manicured, or maintained urban areas such as parkland, parkettes, and recreation-specific facilities (e.g., recreation center, "sportsplex", ski hill, or a single play area (playground, baseball diamond, soccer field, track, etc.). Includes treed areas with evidence of groundskeeping, open park areas, school yards, large boulevards, hydro towers, trailer parks, and campgrounds.	1,211	11.6%
RWY	Railway	Includes railway transfer stations or yards and train stations, parking lot, sidewalks, boulevard, platforms, "kiss-and-ride" drop-off/pick-up areas and other paved or developed areas associated with the facility.	178	1.7%
Grand Total			10,478	100.0%

APPENDIX B
Stormwater Management Facility Summary

TABLE B1 Stormwater Management Facilities Inventory

Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/ Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
Ellesmere Pond	Wet Land	21	Centennial Creek	Y	Online	1190 (likely incorrect)	N	Concrete wall with 150mm pipe opening	0.459 m³/s (100-yr), 2.678 m³/s (regional)	100 yr	2510	Y	Fluctuation 0.75m. Runoff from most of the upstream drainage area enters the storm sewer, intercepting the flow. See tab for curves (includes DA from 21.1)	Model with detailed cross sections to account for the rip/rap overflow, use structure info provided on data sheets and GIS delineated drainage area.	
Willowlea Pond	Wet Land	21.1	Centennial Creek	Y (see 21)	Online	31.8	N	2 celled facility, seepage through berm into controlled manhole, orifice plate inside the manhole.	1.844 m³/s (100-yr), 3.028 m³/s (regional)	2 - 100 yr	6410	Y	Max fluc. = 0.5. Culvert on the south side of Hwy 401 control the flow contribution up to a maximum of 2.3 m³/s. Flows above are diverted to the Rouge River through a swale on the south side of Hwy 401. Headwaters of Centennial Creek on the north side of Hwy 401 was cut-off from headwaters when Hwy 401 was widened.	Model as a storage node with info provided on data sheets, use GIS delineated and hand drawn drainage area on HWY 401.	
Meadowvale Pond	Wet Pond	21.3	Centennial Creek	Y (see 21)	Online	125	N	Concrete wall with low flow opening	8.867 m³/s (100 yr), 19.5 m³/s (Regional)	2 - 100 yr	20000	Y	0.745 cms quality outflow for 25mm storm, includes drainage area from 21, 21.1, and 15010	Model with info provided on data sheets and GIS delineated drainage area.	
Riseborough Centre Area Pond	Pond or Tank	30	Bendale Branch	Y	Offline	107.15	Y	Control outlet to storm drainage (conceptual in report)	0.41	5-100 yr	5850	Y	Pond provides storage for a portion of the DA, additional controls are laid out for the other portions of the Master Plan such as onsite storage and flow controls (portions mentioned to be going to SWM facilities 86.1 and 85.1). See tab for Master Drainage Plan. Overland and minor system DAs are different for the 5 yr and 100 yr controlled outflows. The nursery SWM info is from 1982 where the Master Plan info mentioning the underground storage, is dated 1986.	Model with storage and outflows provided. Use GIS delineated watershed extending by hand to Kennedy Road and Steeles.	
Lamoreaux Park Pond (3 Ponds) {58.1,58.2 added later}	Wet Pond	58	Bendale Branch	Y	Online	420	N	Weir with piers (see structure ID# 95 for details)	-	2 - 100 yr	84000 (for all 3 ponds)	N	Three storage areas in series with control weirs. 58.2 north, flows into 58.1 middle and finally 58 south. Max elev in lower storage area is governed by culvert (176.5) which allows for 5.5 m fluctuation at control	Use GIS delineated watershed areas, model weir structures for each pond explicitly in the hydrologic model, use detailed cross sections to represent storage upstream of each crossing. We will check the lowest weir level at each crossing and ensure that the LiDAR extends to meet it.	
Lamoreaux Park Pond	Wet Pond	58.1	Bendale Branch	Y (see 58)	Online	420	N	Multi-stage weir (see structure ID: #113 for details)	-	2 - 100 yr		N	Max elevation is governed by storm outfall, fluctuates 4m at the control structure to an elevation of 178.05		
Lamoreaux Park Pond	Wet Pond	58.2	Bendale Branch	Y (see 58)	Online	420	N	Multi-stage weir (see structure ID: #10 for details)	-	2 - 100 yr		N	Max fluctuation in upper pond is 0.75m for 100 yr (max elev = 179.7) and is governed by watercourse profile/weir.		
Bridlewood Park Pond	Dry Pond	59	Bendale Branch	N	Offline	-	N	-	-	-	-	N	No info provided, part of facility shown on Pond 60 data, but illegible. Likely a sewer overflow facility with the same set up as 60-64.	Use Lidar to develop stage storage, assume an outflow rate based on 100 yr volume. Likely larger than 4.6 ha delineated drainage area, upstream residential community is ~13 ha. Proposed to use the GIS delineated drainage area from the community to the north. *Sewer Overflow	
H.E.P.C. (Hydro) Lands Pond	Dry Pond	60	Bendale Branch	Y	Offline	15	N	Prop chamber?	1.4	25 yr	7250	N	Sewer overflow/surcharge storage. depth varies 1.1m - 1.8 m. Max depth = 2.9m	Use Lidar to develop stage/storage, hand drawn drainage area (approximate). Potentially link with SWMF 304.1 and 59 upstream *Sewer Overflow	

TABLE B1 Stormwater Management Facilities Inventory

Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
Scarden Park Pond	Dry Pond	61	Bendale Branch	Y	Offline	-	N	Pipe (1500 mm to 450 mm)	1.13	25 yr	17000	N	Fluctuates from 2.1 m to 3.4 m. Water is diverted to the pond by large tipping gate when water in sewer breaches predetermined elevation	Assume hand delineated upstream DA of 24 ha. Use Lidar to develop stage/storage. Use reported max outflow rate. *Sewer Overflow	
Lynn Gate Park Pond	Dry Pond	62	Bendall Branch	Y	Offline	-	Y (partial)	Overflow weir structure with diversion manhole upstream (pipe?)	0.28	25 yr	2900	N	Fluctuates between 2.15 m to 3.35 m	Use LiDAR to develop stage/storage, use hand drawn drainage area (approximate). Assume max outflow rate based on 100 yr storm and maximum storage. *Sewer Overflow	
Inglewood Park Pond	Dry Pond	63	Bendale Branch	Y	Offline	-	N (partial)	CCB?, looks to be a similar system as 62	1.13	25 yr	5140	N	Fluctuates from 1.2 m to 2.7 m	Assume partial hand/GIS delineated upstream DA of 21 ha. Use Lidar to develop stage/storage. Use reported maximum release rate. *Sewer Overflow	
H.E.P.C (Hydro) Lands Pond	Dry Pond	64	Dorset Park Branch	Y	Online	-	N	Hydraulic structure details (structure ID# 93)	-	all	14000	N	"created to reduce the HGL in the Dorset St. ditch". Basically just a basin that when the flow exceeds a certain mark, the channel just spills into it and fills. Then it outlets through the same opening when event is finished. This was originally a dry pond, but the data sheets hint at a proposition to make it a wet pond. Very little information on elevations/ inverts exist.	Use GIS delineated DA for the crossing structure, outflow will be based on the structure ID# 93 details. Proposed that storage be modelled using detailed cross sections that cover the extended detention.	
North Bendale Park	Dry Pond	65	Milliken Branch	Y	Offline	na	N	Pipe (both inlet and outlet) photo under tab. No other info	-	2-25 yr	-	-	Park pond - inlet/outlet (surcharge storage). 25 yr design storm depth varies from 0.5 m - 1.4 m (36.5 hours to empty), looks like overflow from ErinLea Crescent? SWFM is also right on drainage divide between two subwatersheds.	Assume hand delineated upstream DA of 28 ha. Use Lidar to develop stage/storage. Assume a max outflow rate. *Sewer Overflow	
Livingston Road Pond	Dry Pond	67	West Highland Creek	Y	Offline	6.08	N	450 mm diam pipe	0.575	2 yr	610	N	High overflow channel elev = 118.2 m, pond was only sized to store the difference in runoff volume between the 1 in 2 year pre- and post-development flows.	Suggest **Not Modelling.** The SWMF has minimal capacity in the main valley of Highland Creek, only contains a portion of the 2 yr flow volume and minimal drainage area.	

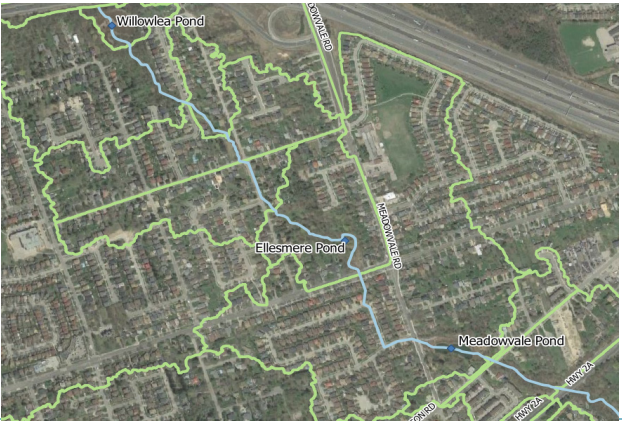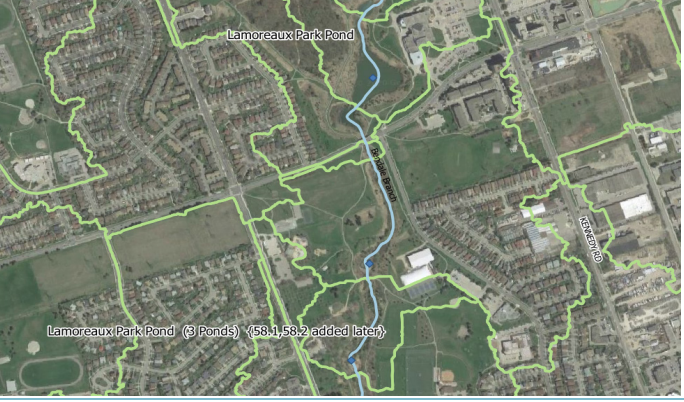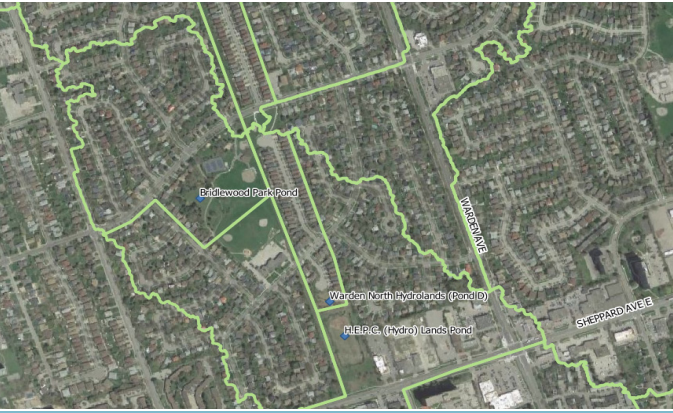TABLE B1 Stormwater Management Facilities Inventory

Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/ Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/ Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
Milliken District Park Pond	Wet Pond	68	Malvern Branch	Y	Offline	52.8 (100 yr DA)	N	Overflow weir pipe	1.47 m³/s (25 yr), max 5.0 m³/s	25 yr	1416	Y	Area of the pond at normal elevation (185 m) is 1.2 ha.	Model wet and dry pond separately, use GIS delineated watershed removing the northwest corner of Steeles (30 ha). Use information provide for stage/storage and outflow.	
Milliken District Park Pond	Dry Pond	68.1	Malvern Branch	Y	Offline	7.2 + overflow from wet pond	N	Culvert, 450 mm @ 1.95%	0.3 (100 yr)	2-100 yr	14854	Y	Max WL fluctuation 2.2 m		
H.E.P.C. (Hydro) Lands Pond	Dry Pond	70	Milliken Branch	Y	Offline	-	N	Inlet is controlled CB	na	na	610	N	Looked like storage to provide some sewer overflow capacity of sewer travelling from the north, no info for the outlet	Suggest **Not Modelling.** The SWMF has minimal capacity from a small drainage area.	
Dean Park Pond	Dry Pond	71	Centennial Creek	Y	Offline	1190	N	Inlet controlled CB's	0.056	2 - 100 yr	6167	N	Looks to be outside of the Highland Creek Watershed (in Rouge Watershed), flows above 2.3 m³/s in Pond 21 goes to Rouge (maybe connect with this pond). Reported DA doesn't make sense.	**Do not model,** outside of Highland watershed (it was previously included in the Rouge Model)	
Goldhawk Park Pond	Dry Pond	74	Malvern Branch Trib	Y	Offline	-	N	Catchbasin	5.6	na	4610	N	Likely a sewer surcharge relief pond	Use Lidar to develop stage/storage. Assumed GIS delineated drainage area cutting off at Steeles (20 ha approximate). Use provided outflow rate. *Sewer Overflow	
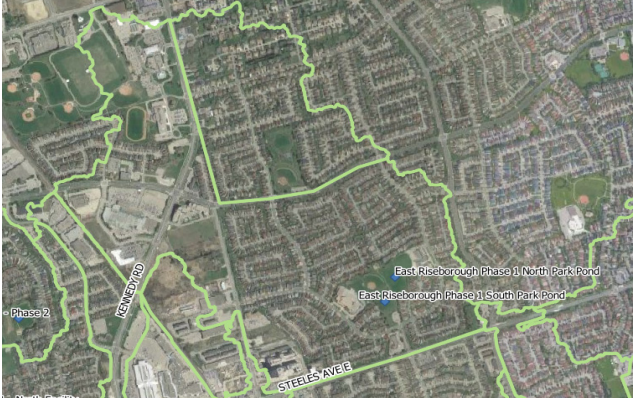
Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/ Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
City Owned Land Pond	Dry Pond	75	Malvern Branch Trib	Y	Offline	-	N	Catchbasin	5.3	2 - 100 yr	3700	N	Max 100 yr WL - 184.5 m , has separate inlet and outlet for the facility, appears to inlet in the north and outlet the south. Seems to function opposite way to ARChydro line delineation?	Use Lidar to develop stage/storage. Assumed GIS delineated drainage area from residential community to the north. Use provided outflow rate. *Sewer Overflow	
Malvern Core & Neighbourhood 7-C Pond	Dry Pond	76	Malvern Branch	Y	Offline	-	N	1 CCB 225 mm	-	-	5267	N	Likely a sewer surcharge relief pond based on drawing	Use Lidar to develop stage storage, assume an outflow rate. Use hand-drawn assumed drainage area (12 ha) from surrounding residential community. *Sewer Overflow	
East Riseborough Phase 1 North Park Pond	Dry Pond	85	Milliken Branch	Y	Offline	207	N	Orifice on outgoing pipe	0.141	2-100 yr	14200	N	Includes both Phase 1 and Phase 2 reports. Phase 2 reports has updated release rates for the north and south ponds. Map of the ponds looks like the shapefiles has the north pond in the wrong area.	Model the ponds together with storage and combined outflow rates provided. Use the a GIS delineated watershed with some slight modifications to account for Steeles road (209 ha). *Sewer Overflow	
East Riseborough Phase 1 South Park Pond	Dry Pond	85.1	Milliken Branch	Y	Offline	207	N	Orifice on outgoing pipe	0.283	5-100 yr	15430	N			

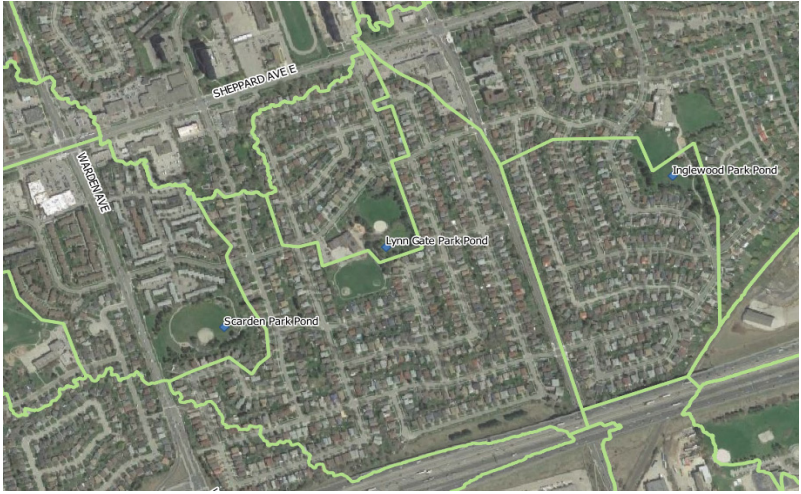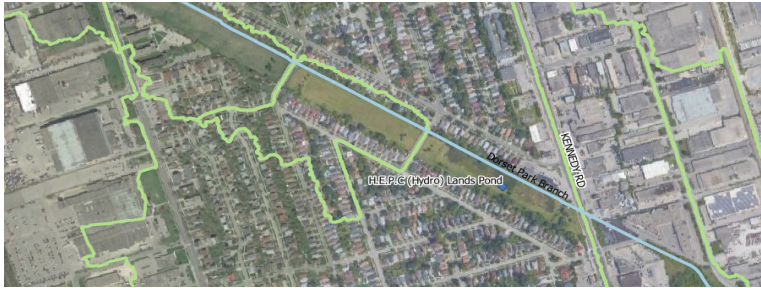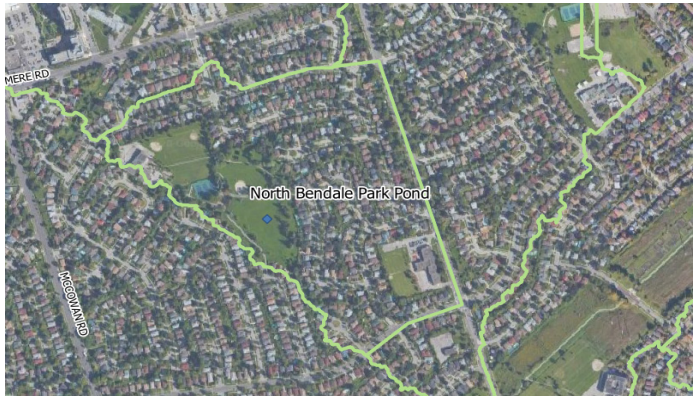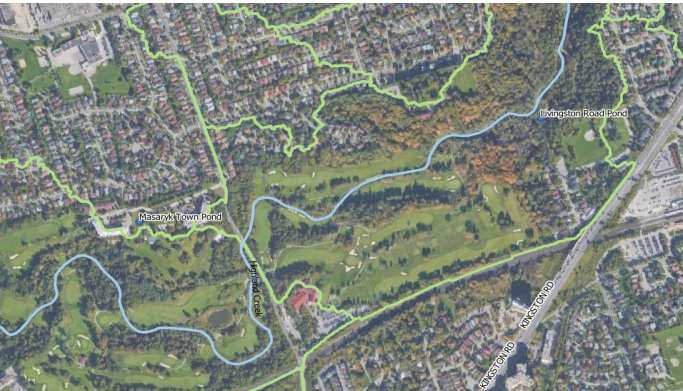TABLE B1 Stormwater Management Facilities Inventory
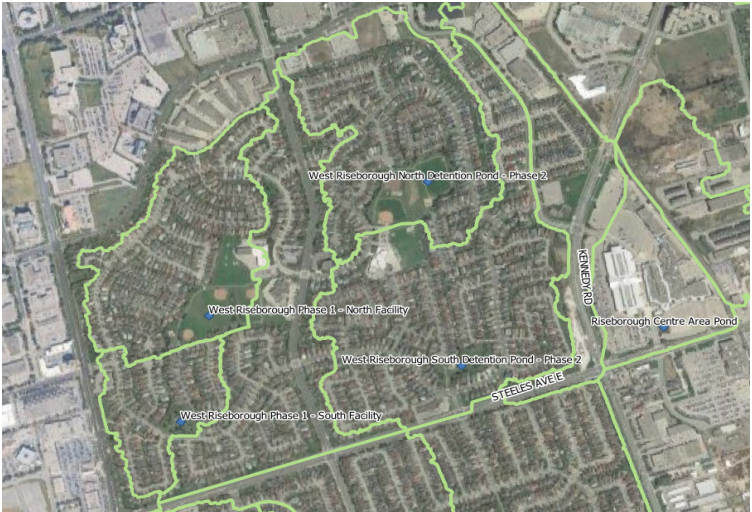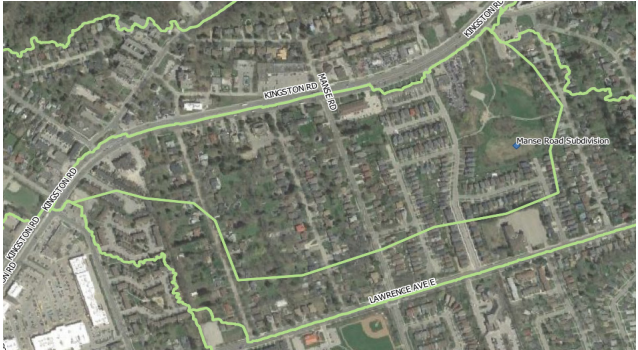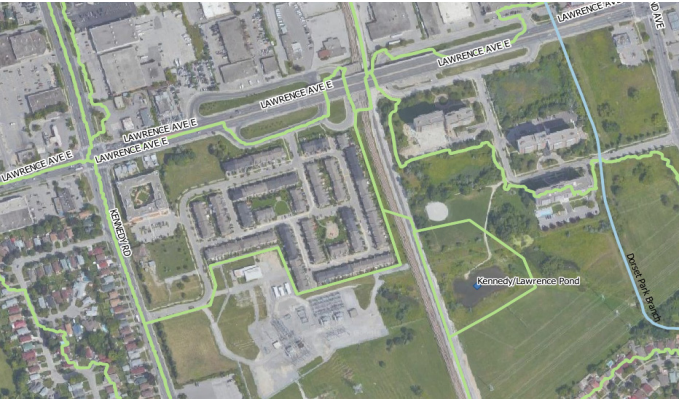
Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/ Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/ Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
West Riseborough North Detention Pond - Phase 2	Dry Pond	86.1	Bendale Branch	Y	Offline	32	N	Pipe	2.0 m³/s (5 yr), 2.3 m³/s (25 yr)	25 yr	4690, 3090 (superpipe)	-	Underground storage + park detention for major storms (25 yr +)	Model these facilities together (single outflow) with the hand-drawn drainage area, ignore the industrial facility to the north (outside of Highland watershed), use information provided and set the outflow rate from the catchment. *Sewer overflow	
West Riseborough South Detention Pond - Phase 2	Dry Pond	86.2	Bendale Branch	Y	Offline	30	N			25 yr	2350	-	86.1 and 86.2 are one system that uses superpipes to store less than 25 yr events. 25 yr + overflow into the north and south dry pond		
West Riseborough Phase 1 - North Facility	Dry Pond	86.3	Bendale Branch	Y	Offline	64.75	Y	North and South facilities are combined see hydrographs under tab 86.3 - 86.4 for more outflows broken down into sub watersheds	2.12 m³/s (from pipe), 0.57 m³/s from overland in 25 yr	2-100 yr	-	N	86.3 is a dry pond that works in conjunction with 86.4 and a superpipe under Birchmount Road. The two dry ponds only see water in a 25 yr storm event and are designed to accommodate runoff from the 25 through 100 yr events. Note, only runoff from the northern subwatershed (94 ha) contributes to the superpipe. No storage volumes or water levels are provided, they only have time/outflow hydrographs.	Model the facilities together using the hand-drawn drainage area, (64.75 ha), and the provided outflow rates. *Sewer overflow	
West Riseborough Phase 1 - South Facility	Dry Pond	86.4	Bendale Branch	Y (see 86.3)	Offline		Y			2-100 yr	-	N			
Carma/Coscan Pond	Wet Pond	135	Centennial Creek	Y	Offline	40	N	250 mm hickenbottom with 98 mm orifice, 1.7 m weir	0.022	No flood control, just erosion (13 mm)	1308	Y	MNR, TRCA, and City agreed to reduce the pond volume criteria from 25 mm to 13 mm to maintain it in the valley	Suggest **Not Modelling.** The SWMF is for a modified 13 mm erosion control volume only.	
Markham Gardens Pond	Dry Pond	181	Malvern Branch	Y	Offline	18 ha (5 yr)	Y (5 yr DA)	DICB w/ 675 mm pipe with 450 mm orifice.	0.77 cms (100 yr) pond outflow, 4.12 cms (100 yr) minor system outflow	5-100 yr	3446	Y	Over control to 4 CMS, hand-drawn 5 yr drainage area from data, unclear of major DA (potential the delineated GIS area north of Sheppard?)	Model with the hand-drawn 5-year drainage area, using outflow and storage volumes provided. Additional areas may contribute in major storms but this approach is conservative. *Sewer Overflow (Updated)	

TABLE B1 Stormwater Management Facilities Inventory

Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
Bendale Pond	Wet Pond	190	Bendale Branch	Y	Offline	16.8	N	Reverse sloped pipe (158.75 m (-1.5 from perm pool elev) to an elevation of 160.25 (=perm pool elev) located in a control manhole within the pond berm). Controlled by 168 mm orifice set at an invert of 160.25 m. Safety overflow =20 x 3 m x 0.3 m high broad crested weir.	0.068	2-100 yr	3721	Y	See tab for storage curve. 316 ha external drainage conveyed beside the site, outlet directly to the Creek	Model with the hand-drawn drainage area, using outflow and storage volumes/curve provided. Potentially include the south portion of delineated GIS drainage area.	
Masaryk Town Pond	Dry Pond	284	West Highland Creek	Y	Offline	1.5	N	300 mm pipe with 200 mm orifice	0.126 cms (100 yr)	2-100 yr	810	Y	Max fluctuation = 3m	Suggest **Not Modelling.** The SWM facility has minimal capacity in the main valley of Highland Creek, minimal drainage area (< 2ha)	
Warden North Hydrolands (Pond D)	Wet Land	304.1	Bendale Branch	Y	Offline	4.05	N	DICB, (discharging into existing pond 60)	0.063	2-100 yr	162	-	Max fluctuation 0.5m, no DA map provided, but since references the hydroland, assumed it was the linear residential community north of the pond.	Model with hand-drawn drainage area (assumed based on 304.2 pond/community). Develop stage/storage curve from LiDAR (max 0.5 elevation), Assume max outflow rate from 100 yr storm simulation, outflow discharges to Pond 60	

TABLE B1 Stormwater Management Facilities Inventory
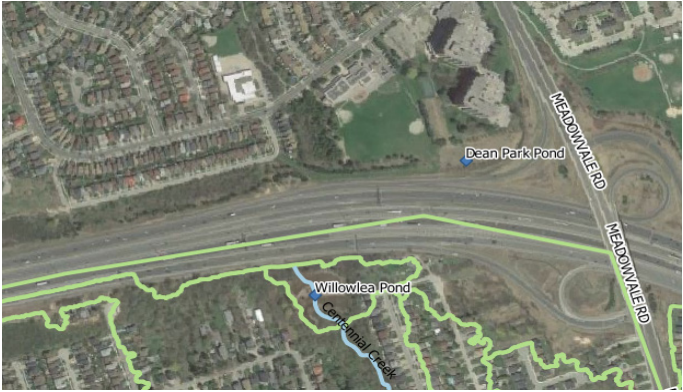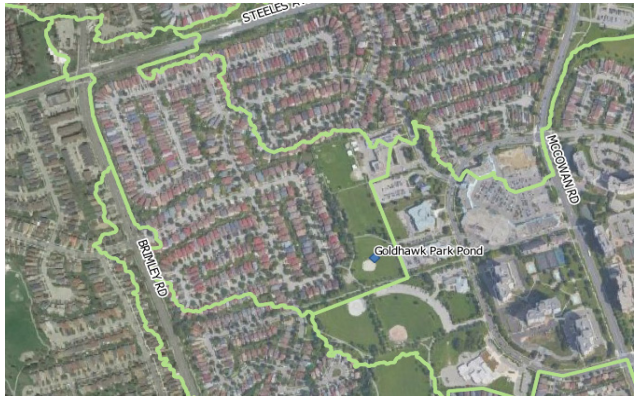
Facility Name	Pond Type	Pond ID	Sub-watershed	Data Sheet (Y/N)	Off/ Online	Reported Total Contributing DA (ha)	DA Mapped (Y/N)	Outlet Structure Details	Maximum Release Rate (m³/s)	Flood Control Level	Maximum Active Storage Volume (m³)	Stage/ Storage Info Provided (Y/N)	Additional SWMF Notes	Matrix Recommendation	Image
Warden North Hydrolands (Pond G)	Wet Land	304.2	Bendale Trib 2	Y	Offline	11.02	N	Reverse slope pipe with max invert = 172.70m, orifice plate 110mm. 2nd outlet: (5yr): DICB#1, grate invert=173.6, outlet invert=172.72, 335mm orifice @ outlet. 3rd Outlet: (100yr): DICB#2, grate invert=173.70m, outlet invert=172.71 m, 445 mm orifice @ outlet.	0.8	2 - 100 yr	3392	Y	Max fluctuation = 1.55. A lot of data available in data sheets (modelling outputs, etc)	Use hand delineated DA (assumed based on reference to hydro-corridor community. Use stage/storage/outflow from modelling data.	
Manse Road Subdivision	Dry Pond	310	Thornton Creek	Y	Offline	28.92	N	614 mm diam orifice plate	1.17	100 yr	5000	Y	Max fluctuation= 0.95 m, only receives overland flow for the major system	Model with the delineated drainage area (30.2 ha), use stage/storage outflow provided.\n\n*Sewer Overflow	
Kennedy/Lawrence Pond	Wet Pond	343	Dorset Park Branch	Y	Offline	9.4	Y	Outlet #1: 250mm (w/ 150mm diam orifice) reverse slope pipe, connects to manhole east of the pond at an elevation of 155.3 m.Weir (0.5 m wide x 0.8 m high), with a bottom elevation of 155.9 m (for more severe events)	0.44	2 - 100 yr	4626	Y	Fluctuates from 155.3 to 156.6m	Model with hand-drawn drainage area, and provide model with info provided on data sheets and the hand-drawn drainage area and provided stage/storage, outflow data.	
Barchester Park Pond	Wet Pond	15010	Centennial Creek	N	Offline	-	N	-	-	-	-	N	Surface area of wet pond measured from imagery = 2.06 ha	Do not think this is a SWM pond, however, it is a large pond that would attenuation runoff from the Morningside Facility. The soils in this area are also sandy so much of the storage water may infiltrate. Suggest using GIS delineated DA cutting off at Morningside. Will modify the representation of the catchment during calibration.	

APPENDIX C
Hydrologically Significant Structures

Table C1 Hydrologically Significant Structure Assessment

| Culvert # | River Name | Reach Name | Road Name / Watercourse Crossing Name | Structure (Field Inventory) | | | | | | | | Hydrologic Significance Check | | |
				Type	Material	Opening Height (m)	Opening Width (m)	Length (m)	Skew	Obvert to Road		Backwater >0.5m on 10yr storm	Affects Previous Floodlines	Hydrologically Significant? (Y/N)
1	Dorset Park Intercept	Reach 1	Danforth Road	Culvert	Conc	2.41	3.7	21	95	1.9		-	-	Y
2	Bendale Trib 1	Reach 1	Finch Avenue	Culvert	CSP	2.65	8.6	60	120	2.92		-	-	Y
23	Bendale Trib 2	Reach 1	Collingsbrook Boulevard	Culvert	CSP	2.6	4.6	31	70	2.66		-	-	Y
34	Bendale Branch	Reach 3	Tam O'Shatner Golf Course Bridge	Bridge	CSP	4.5	22.6	4.1	90	0.15		-	-	N
39	West Highland Trib 1	Reach 1	Cedargrove Park Pedestrian Bridge	Bridge	CSP	2.88	13.05	4.1	90	0.2		-	-	N
40	Bendale Trib 2	Reach 1	Pinemeadow Boulevard	Culvert	CSP	2.8	4.6	37	60	1.21		-	-	Y
41	Malvern Branch Trib	Reach 1	Tiffield Road	Culvert	Conc	2.79	6.12	46	90	4		-	-	Y
45	Bendale Branch	Reach 1	L'Amoreaux North Park Pedestrian Bridge	Bridge/ Weir	Conc	1.22	9.96	6.9	90	-		-	-	Y
51	West Highland Trib 2	Reach 1	Curran Hall Ravine Park Pedestrian Bridge	Bridge	CSP	1.48	10.66	4.3	100	0.36		-	N	N
60	Ellesmere Ravine	Reach 1	Morningside Park Pedestrian Bridge	Bridge	Steel	4.5	22.63	3.1	100	0.2		-	N	N
61	Bendale Trib 1	Reach 1	L' Amoreaux Dr	Culvert	CSP	3.15	5.5	41	120	2.42		-	-	Y
75	Malvern Branch Trib	Reach 1	Middlefield Rd	Culvert	Conc	2.95	5.98	63	45	3.1		-	-	Y
86	Bendale Trib 2	Reach 1	Warden Ave	Culvert	CSP	3.5	5.85	70	65	2.25		-	-	Y
95	Bendale Branch	Reach 1	L'Amoreaux Sports Complex Pedestrian Bridge	Bridge/ Weir	Conc	2.3	16.2	4.1	110	-		-	Y	Y (SWMF)
97	Bendale Branch	Reach 3	Tam O'Shatner Golf Course Bridge	Bridge	Steel	24.1	4	4.1	90	0.2		-	-	N
105	Ellesmere Ravine	Reach 1	Morningside Park Pedestrian Bridge	Bridge	Steel	3.8	21.8	5.5	25	0.1		-	N	N
113	Bendale Branch	Reach 1	L'Amoreaux Sports Complex Pedestrian Bridge	Bridge/ Weir	Conc	-	-	4.3	100	-		-	Y	Y (SWMF)
137	West - Bendale	Reach 3	Private Access South of CPR	Bridge	Conc	3.51	17.15	13.5	115	1.89		N	N	N
143	West - Bendale	Reach 3	Railway	Bridge	Conc	10.68	30.5	19	140	2		N	N	N
170	Ellesmere Ravine	Reach 1	Morningside Park Driveway	Culvert	CSP	0.63		15	90	1		-	Y	Y
68	Dorset Park Branch	Reach 2	McCowan Rd	Bridge	Conc	3.7	17.73	4.75	135	0.92		N	N	N
28	Dorset Park Branch	Reach 2	Danforth Rd	Culvert	Conc	2.46	3.04	34	90	1.85		Y	N	Y
88	Dorset Park Branch	Reach 1	Brimley Rd	Culvert	Conc	2.41	3.04	36	90	2.9		Y	Y	Y
158	Dorset Park Branch	Reach 1	Pedestrian Bridge	Bridge	Steel	3.45	17.65	4.8	100	0.88		N	N	N
18	Dorset Park Branch	Reach 1	Midland Ave	Culvert	Conc	2.3	4.9	230	10	2		Y	Y	Y
128	Dorset Park Branch	Reach 1	Prudential Dr	Culvert	CSP	2.48	4.91	21	80	2.75		Y	Y	Y
54	Dorset Park Branch	Reach 1	Lawrence Ave	Culvert	Conc	2.48	4.91	76	95	1.75		Y	Y	Y
159	Dorset Park Branch	Reach 1	TTC Railway Crossing	Culvert	CSP	1.75	2.25	47	80	2.3		Y	Y	Y
98	Dorset Park Branch	Reach 1	Nantucket Boulevard	Culvert	CSP	3.25	4.9	55	40	1		Y	Y	Y
93	Dorset Park Branch	Reach 1	Kennedy Rd	Culvert	CSP	2.7	4.85	195	45	1.8		Y	Y	Y
81	Dorset Park Branch	Reach 1	Wye Valley Rd	Culvert	Steel	2.71	3.8	25	90	1.37		N	Y	Y
90	Dorset Park Branch	Reach 1	Canlish Rd	Culvert	CSP	2.34	3.62	15.5	90	0.65		Y	Y	Y
160	Dorset Park Branch	Reach 1	Birchmount Rd	Culvert	Conc/CSP	1.78	1.78	365	40	0.8		Y	Y	Y
161	Dorset Park Branch	Reach 1	Ellesmere Rd	Culvert	Conc	1.85	2.13	55	130	0.8		N	N	Y
30	Bendale Branch	Reach 3	Lawrence Ave	Bridge	Conc	6.77	35.45	30.5	90	2.43		N	N	N
43	Bendale Branch	Reach 3	McCowan Rd	Bridge	Conc	4	21.8	25.5	55	2.6		N	N	N
135	West - Bendale	Reach 3	Thomson Memorial Park Pedestrian Bridge	Culvert	Conc	2.07	3.67	38	90	6.66		Y	Y	Y
67	Bendale Branch	Reach 3	Brimley Rd	Culvert	Conc	3.04	4.58	30	85	2.5		Y	N	Y
55	Bendale Branch	Reach 3	Ellesmere Rd	Culvert	Conc	3.38	3.38	34.5	105	2		Y	Y	Y
13	Bendale Branch	Reach 3	Midland Ave	Bridge	Conc	4.44	12.18	23	90	1.5		N	N	N
142	West - Bendale	Reach 3	Railway Spurline	Bridge	Conc	3.22	36.25	13.5	140	1.55		N	N	N
29	Bendale Branch	Reach 3	Progress Ave	Culvert	Conc	3.15	4.12	24	115	0.75		N	Y	Y
134	West - Bendale	Reach 3	CNR crossing north of Progress Avenue	Culvert	Conc	3.23	4.56	7	50	1		N	N	N
133	West - Bendale	Reach 3	CNR crossing south of 401	Culvert	Conc	3.61	3.91	5	125	1.2		N	N	N
140	West - Bendale	Reach 3	Private Access South of 401	Culvert	CSP	3.53	6.22	20	90	1.5		N	N	Y
139	West - Bendale	Reach 3	Highway 401	Culvert	Conc	3.72	4.46	150	70	8.75		N	Y	Y
80	Bendale Branch	Reach 3	Emblem Crt	Culvert	CSP	3	4.7	22.5	115	0.8		N	N	Y
80	Bendale Branch	Reach 3	Emblem Crt											
80	Bendale Branch	Reach 3	Emblem Crt											
138	West - Bendale	Reach 3	Private Access North of Emblem Court	Bridge	Conc	3.3	19.16	11	115	2.2		N	N	N
132	West - Bendale	Reach 3	WEST HIGHLAND CREEK CULVERT	Culvert	Conc	3.44	6.12	25.5	25	0.7		N	Y	N
136	West - Bendale	Reach 3	Metrolinx GO Stouffville Railway	Bridge	Steel	11.2	45.58	11	100	2		N	N	N

Table C1 Hydrologically Significant Structure Assessment

Culvert #	River Name	Reach Name	Road Name / Watercourse Crossing Name	Structure (Field Inventory)							Hydrologic Significance Check		
				Type	Material	Opening Height (m)	Opening Width (m)	Length (m)	Skew	Obvert to Road	Backwater >0.5m on 10yr storm	Affects Previous Floodlines	Hydrologically Significant? (Y/N)
52	Bendale Branch	Reach 3	Collingwood Park Pedestrian Bridge	Bridge	CSP	3.33	25.7	4.15	90	0.75	N	N	N
16	Bendale Branch	Reach 3	Sheppard Ave	Bridge	Conc	3.1	11.5	31	105	1.6	N	Y	N
44	Bendale Branch	Reach 3	Cardwell Ave	Culvert	Conc	3.66	3.87	34	130	1.8	N	N	N
65	Bendale Branch	Reach 3	Kennedy Rd	Bridge	Conc	4.4	13.95	36	60	1.7	N	Y	N
124	Bendale Branch	Reach 3	Ron Watson Park Pedestrian Bridge	Bridge	Conc	3.3	12.17	11	90	0.8	N	N	N
117	Bendale Branch	Reach 3	Birchmount Rd	Culvert	Conc	3.35	3.05	42	50	1.8	N	N	N
6	Bendale Branch	Reach 3	Huntingwood Dr	Culvert	CSP	4.25	6.37	43	135	2.3	N	N	Y
102	Bendale Branch	Reach 2	Timberbank Blvd	Culvert	CSP	2.88	4.82	32	90	1.7	N	Y	Y
37	Bendale Branch	Reach 2	Timberbank Park Pedestrian Bridge	Bridge	Conc	2.6	18.4	4	90	0.85	N	N	N
24	Bendale Branch	Reach 1	Finch Avenue	Culvert	CSP	2.65	4.4	62	60	2.6	N	Y	Y
32	Bendale Branch	Reach 1	Birchmount Rd	Culvert/ Weir	CSP	2.65	4.28	82	30	2.65	N	N	N
101	Bendale Trib 2	Reach 1	Garrybrook Dr	Culvert	CSP	3.6	6.03	24	90	1.62	N	-	Y
103	Bendale Branch	Reach 1	L'Amoreaux Sports Complex Pedestrian Bridge	Culvert	Conc	2.15	3.65	4.1	90	3.4	N	N	N
87	Bendale Branch	Reach 1	McNicoll Ave	Bridge	Conc	6.6	32.1	18	85	2.25	N	N	N
10	Bendale Branch	Reach 1	L'Amoreaux North Park Pedestrian Bridge / Weir	Bridge/ Weir	Conc	0.9	38.7	3.8	90	-	N	Y	Y (SWMF)
111	East - Markham	Reach 2	Markham Rd	Bridge	Conc	5.7	12.2	32	85	1.7	N	N	N
73	East - Markham	Reach 2	Bellamy Rd	Culvert	Conc	3.68	3.64	41	55	1.5	Y	Y	Y
7	East - Markham	Reach 2	Progress Ave	Culvert	Conc	3.91	3.6	27.5	90	2.7	Y	Y	Y
109	East - Markham	Reach 2	Corporate Dr	Culvert	Conc	3.67	3.67	52.5	120	1.5	Y	Y	Y
165	East - Markham	Reach 2	Highway 401	Culvert	Conc	4.21	6.09	125	90	1.8	Y	Y	Y
119	East - Markham	Reach 2	Milner Ave	Culvert	Conc	3.07	3.09	30.5	90	2.25	Y	Y	Y
20	East - Markham	Reach 2	Invergordon Ave	Culvert	Conc	4.17	4.87	22	130	1.5	N	N	N
9	East - Markham	Reach 2	Sheppard Ave	Bridge	Conc	6.17	12.25	30.5	115	1.6	N	N	N
71	Milliken Branch Trib	Reach 1	McCowan Rd	Culvert	CSP	3.41	6.88	39.5	90	0.75	Y	Y	Y
162	Milliken Branch Trib	Reach 1	Railway	Culvert	Conc	3	3.65	245	150	7.2	Y	N	Y
162	Milliken Branch Trib	Reach 1	Railway										
123	Milliken Branch Trib	Reach 1	Brimley Rd	Culvert	Conc	2.76	3.05	71	45	4.2	N	N	Y
46	Milliken Branch Trib	Reach 1	Stubbswood Square	Bridge	Conc	3.8	21.34	3.1	90	1	N	N	N
78	Milliken Branch Trib	Reach 1	Midland Ave	Culvert	CSP	3.56	5.68	71	45	1.5	Y	N	N
91	Milliken Branch Trib	Reach 1	Baylawn Dr	Culvert	CSP	3.53	5.66	22.5	100	1	Y	N	N
100	East - Markham	Reach 1	Nugget Ave	Culvert	Conc	2.74	6.12	28	100	1.5	Y	Y	Y
164	East - Markham	Reach 1	Railway	Culvert	Conc	4.53		92.5	70	5.4	Y	Y	Y
163	East - Markham	Reach 1	CPR Private Access Road	Culvert	Steel	3.17	2.59	35	40	1.2	Y	Y	Y
122	East - Markham	Reach 1	Middlefield Rd	Culvert	CSP	2.6	4.28	37.5	110	2.15	Y	N	Y
94	East - Markham	Reach 1	McCowan Rd	Culvert	Conc	2.69	3.63	55	45	2.1	N	Y	Y
58	East - Markham	Reach 1	Silverstead Dr Pedestrian Bridge	Bridge	Conc	3.45	23.9	3	90	1.05	N	N	N
15	East - Markham	Reach 1	Chartland Blvd S	Culvert	CSP	2.88	4.69	33.5	60	2.5	Y	Y	Y
27	East - Markham	Reach 1	Finch Ave	Culvert	Conc	2.44	3.35	43.5	110	2.2	Y	N	N
79	East - Markham	Reach 1	Brimley Woods Park Pedestrian Bridge	Bridge	Conc	4.26	19.65	4.1	90	0.9	N	N	N
25	East - Markham	Reach 1	Brimwood Blvd	Culvert	Conc	2.45	5.19	35	90	2.55	Y	N	N
169	Malvern Branch	Reach 2	Highway 401	Culvert	Conc	3.68	6.1	152	90	7	N	Y	Y
104	Malvern Branch	Reach 2	Milner Ave	Culvert	Conc	3.71	5.79	35	95	2.5	Y	Y	Y
3	Malvern Branch	Reach 2	Burrows Hall Blvd	Culvert	Conc	3.72	5.8	36.5	110	3	N	N	N
35	Malvern Branch	Reach 2	Sheppard Ave	Bridge	Conc	5.2	15.2	28.5	100	2.05	N	N	N
57	Malvern Branch	Reach 2	Mammoth Hall Trl	Culvert	Conc	3	3	24	85	3	Y	Y	Y
17	Malvern Branch	Reach 2	Littleleaf Dr Pedestrian Bridge								N	N	N
84	Malvern Branch	Reach 2	Pinetree Park Pedestrian Bridge	Bridge	Conc	4.7	24.8	4.1	90	1	N	N	N
127	Malvern Branch	Reach 2	McLevin Ave	Culvert	Conc	3.07	3.07	30	90	2.5	Y	Y	Y
131	Malvern Branch	Reach 2	CPR Culvert	Culvert	Conc	3.36	3.33	78	90	5.5	N	N	N
62	Malvern Branch	Reach 2	Markham Rd	Culvert	Conc	3.38	3.33	72	55	3.5	Y	N	N
120	Malvern Branch	Reach 2	Finch Ave	Culvert	Conc	3.75	3.34	83	125	8.1	N	N	N
168	Malvern Branch	Reach 2	Railway	Culvert	Conc	2.53	2.53	45	90	5	Y	N	Y
166	Malvern Branch	Reach 1	Railway Spurline	Culvert	CSP/Conc	2.91	8.56	55	90	2	N	N	N
167	Malvern Branch	Reach 1	Private Access	Culvert	CSP	2.67	4.31	25	95	1.5	Y	Y	Y
70	Malvern Branch	Reach 1	Nashdene Rd	Culvert	Conc	3.09	4.27	85	125	2.5	Y	N	N
183	Centennial Creek	Reach 1	Lawrence Ave over Highland Creek Tributary	Culvert	Conc	2.5	2.7	63.3	60	2.5	N	N	N

**Table C1 Hydrologically Significant Structure Assessment**

Culvert #	River Name	Reach Name	Road Name / Watercourse Crossing Name	Structure (Field Inventory)							Hydrologic Significance Check		
				Type	Material	Opening Height (m)	Opening Width (m)	Length (m)	Skew	Obvert to Road	Backwater >0.5m on 10yr storm	Affects Previous Floodlines	Hydrologically Significant? (Y/N)
5	Centennial Creek	Reach 1	Clemes Dr	Culvert	Conc	2.16	6.1	27	90	1.5	N	N	N
173	Centennial Creek	Reach 1	Culvert	-	-	-	-	-	-	-	Y	-	N
36	Centennial Creek	Reach 1	Lawson Rd	Culvert	Conc	1.76	6.3	55	100	2.3	N	N	Y
174	Centennial Creek	Reach 1	Pedestrian Bridge	Bridge	Steel	1.46	7.5	7.1	110	0.7	Y	Y	Y
175	Centennial Creek	Reach 1	Highway 2A	Culvert	Conc	2.68	5	56.5	125	3.95	N	N	N
76	Centennial Creek	Reach 1	Kingston Rd	Culvert	Conc	2.62	5				N	N	Y (184)
184	Centennial Creek	Reach 1	Pond Outlet Structure	Pond Outlet	Conc	2.68	5	?	?	2	N	Y	Y
176	Centennial Creek	Reach 1	Ellesmere Road to Meadowvale Road	Sewer Inlet	Conc	2.58		445	-	1.4	Y	Y	Y
129	Centennial Trib	Reach 1	Lawrence Ave	Culvert	Conc	-	-	41	110	4	N	Y	Y
178	Centennial Creek	Reach 1	Zaph Avenue	Culvert	CSP	0.65	0.65	6.2	120	0.35	Y	Y	Y
179	Centennial Creek	Reach 1	Euclid Ave	Culvert	Conc	0.75		26	150	0.57	N	Y	Y
180	Centennial Creek	Reach 1	Private Driveway culvert	Culvert	Conc		0.6	0.9	4	90	1	N	N
181	Centennial Creek	Reach 1	Goldene Way	Culvert	Conc	0.6	1.78	32	50	1.9	Y	Y	Y
171	Highland Creek	Reach 5	Railway	Bridge	Stone/steel	11.5	54	10.9	90	2	N	N	N
110	Highland Creek	Reach 2	Lawrence Ave	Bridge	Conc	19.5	110.6	34	110	3.8	N	N	N
114	Highland Creek	Reach 2	Colonel Danforth Park Bridge	Bridge	Conc	2.05	24.4	9.5	75	1.15	N	N	Y
107	Highland Creek	Reach 2	Kingston Rd	Bridge	Conc	27	89.5	32.2	100	3.7	N	N	N
11	Thornton Creek	Reach 1	Beechgrove Dr	Culvert	Steel	2.87	4.3	31.5	90	2	Y	Y	Y
53	Thornton Creek	Reach 1	Bennett Rd	Culvert	CSP	1.8	4.3	10.5	90	2	N	N	N
64	Thornton Creek	Reach 1	Forest Grove Dr	Culvert	Conc	2		75	70	2	Y	-	Y
108	Highland Creek	Reach 2	Old Kingston Rd	Bridge	Conc	7.7	56.3	12.6	85	2.2	N	N	N
77	Highland Creek	Reach 2	Morningside Ave	Bridge	Conc	17.6	60.2	11.9	110	2.2	N	N	N
56	Ellesmere Ravine	Reach 1	Ellesmere Rd	Culvert	CSP	2.55	3.29	80	100	5	Y	Y	Y
48	East - Markham	Reach 4	Ellesmere Rd	Bridge	Conc	17.3	79.25	30	100	1.75	N	N	N
26	East - Markham	Reach 4	Military Trl	Bridge	Conc	3.88	12.5	13.5	100	1.8	N	N	N
125	West Highland Creek	Reach 3	Lawrence Ave	Bridge	Conc	25	215.6	27	95	3.8	N	N	Y
59	West Highland Trib 2	Reach 1	Lawrence Ave	Culvert	Conc	2.43	4.9	97	115	8.85	N	Y	Y
74	West Highland Creek	Reach 2	Scarborough Golf Club Rd	Bridge	Conc	4.06	23.68	16.3	125	2.57	N	N	Y
72	West Highland Creek	Reach 2	Markham Rd	Bridge	Conc	3.8	11.56	21	90	1.61	Y	N	N
82	West Highland Creek	Reach 1	Bellamy Rd	Bridge	Steel/conc	5	36.44	20	90	3.1	N	N	N
38	West Highland Trib 1	Reach 1	Banmoor Blvd	Culvert	Conc	1.87	3	27	105	1.32	N	N	N
96	West Highland Trib 1	Reach 1	Chestermere Blvd	Culvert	CSP	2.56	3.96	43.1	115	4.41	N	N	Y
121	West Highland Trib 1	Reach 1	Blakemanor Blvd	Culvert	CSP	2.4	3.85	28	90	5.36	N	Y	Y

APPENDIX D
Stormwater Management Facility Stage/Storage/Discharge Curves

Facility Name:	Willowlea Wetland		
Pond ID:	21.1		
Type:	Online		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	0	0	0
0.10	1,580	0.001	158
0.20	1,650	0.003	330
0.30	1,727	0.005	518
0.40	1,805	0.007	722
0.50	1,884	0.011	942
0.60	1,962	0.015	1,177
0.70	2,039	0.021	1,427
0.80	2,119	0.126	1,695
0.90	2,199	0.538	1,979
1.00	2,277	1.111	2,277
1.10	2,347	1.813	2,582
1.15	2,377	2.206	2,734
1.20	2,407	2.626	2,888
1.25	2,433	3.068	3,041
1.30	2,458	3.534	3,196
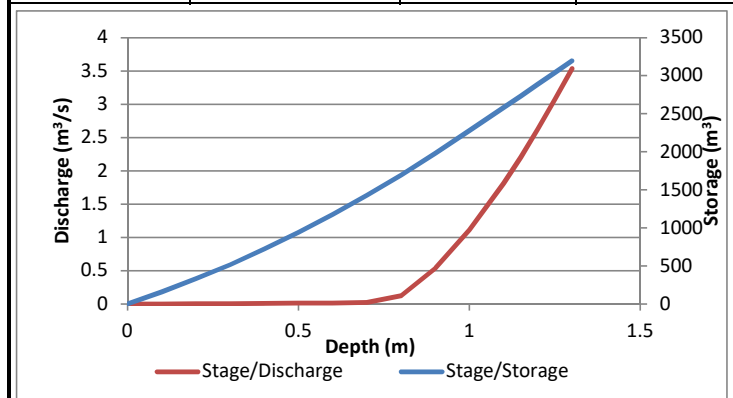
Taken from QualHYMO Model Simulation (SWM Report)

Facility Name:	Meadowvale Pond		
Pond ID:	21.3		
Type:	Online		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	0	0	0
0.25	832	0.082	208
0.50	2,082	0.170	1,041
1.00	3,791	0.271	3,791
1.50	4,695	0.344	7,042
2.00	5,421	0.403	10,842
2.20	5,691	1.792	12,520
2.50	6,072	5.824	15,179
2.70	6,315	9.327	17,051
2.80	6,505	11.679	18,215
3.00	6,681	16.818	20,042
3.15	6,984	22.202	22,000

Taken from QualHYMO Model Simulation (SWM Report)

Facility Name:		Ellesmere Pond	
Pond ID:		21	
Type:		Online	
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	0	0	0
0.01	100	0.001	1
0.25	1,884	0.009	471
0.75	3,348	0.016	2,511
1.00	3,722	0.405	3,722
1.50	4,357	2.000	6,535
2.00	4,841	2.200	9,681

Taken from Stage/Storage/Outflow Curves (SWM Report)

Facility Name:		Lynn Gate Park Pond	
Pond ID:		62	
Type:		Offline/Overflow	
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	866	0	0
3.35	866	0.280	2,900

Taken from SWM Inventory Sheet

Facility Name:	Inglewood Park Pond
Pond ID:	63
Type:	Offline/Overflow

Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	1,904	0	0
2.70	1,904	1.130	5,140
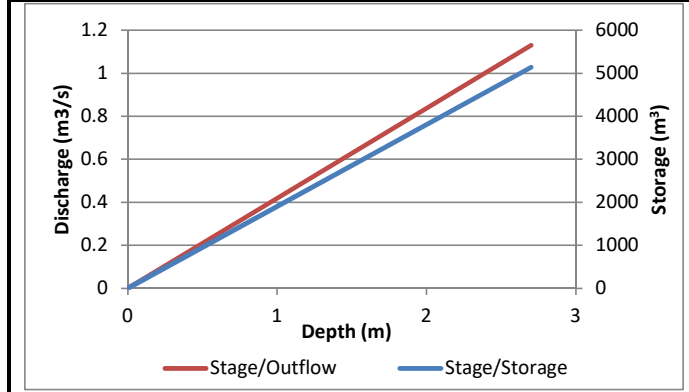
Taken from SWM Inventory Sheet

Facility Name:	Scarden Park Pond
Pond ID:	61
Type:	Offline/Overflow

Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	5,000	0	0
3.40	5,000	1.130	17,000
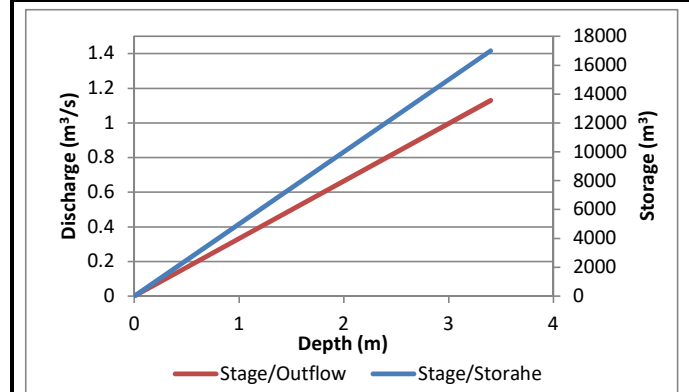
Taken from SWM Inventory Sheet

Facility Name:	H.E.P.C. (Hydro) Lands Pond		
Pond ID:	60		
Type:	Offline/Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	2,500	0	0
2.90	2,500	1.400	7,250
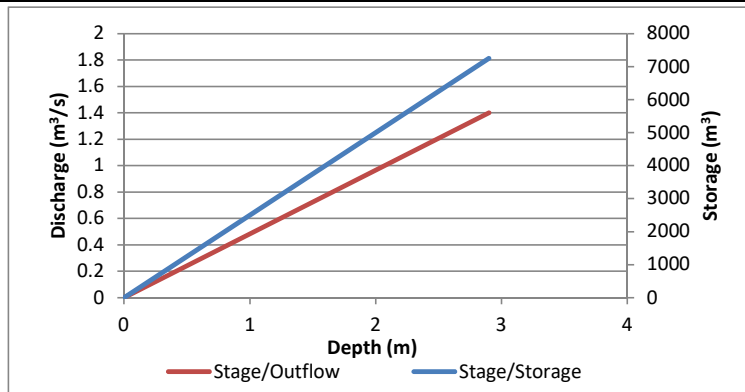
Taken from SWM Inventory Sheet

Facility Name:	Warden North Hydrolands (Pond D)		
Pond ID:	304.1		
Type:	Offline, 2-100 year		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	324	0	0
0.50	324	0.063	162
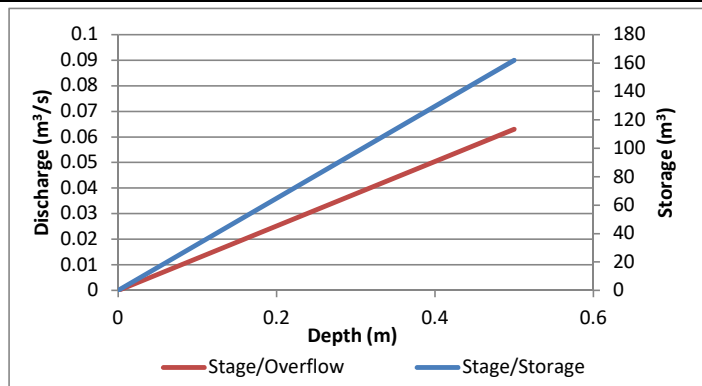
Discharges into SWMF 60

Taken from SWM Inventory Sheet

Typical Road added as overflow to SWMF 60

Facility Name:		North Bendale Park	
Pond ID:		65	
Type:		Offline/Overflow	
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	3,700		0
2.00	3,700		7,400

Stage/Storage

Storage estimated from LiDAR

Outflow use an orifice, assumed size 600 mm based on field photo from inventory report

Facility Name:		Kennedy/Lawrence Pond	
Pond ID:		343	
Type:		Offline, 2-100 year	
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	3,040	0	0
0.15	3,040	0.013	456
0.30	3,100	0.023	930
0.45	3,160	0.030	1,422
0.60	3,222	0.035	1,933
0.70	3,261	0.066	2,283
0.90	3,351	0.176	3,016
1.10	3,452	0.308	3,797
1.20	3,855	0.440	4,626

Stage/Outflow   Stage/Storage

Taken from SWM Report, Stage, Storage Discharge Table 5.1

Facility Name:		Bendale Pond	
Pond ID:		190	
Type:		Offline, 2-100 year	
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	2,602	0	0
1.43	2,602	0.068	3,721

Stage/Outflow — Stage/Storage
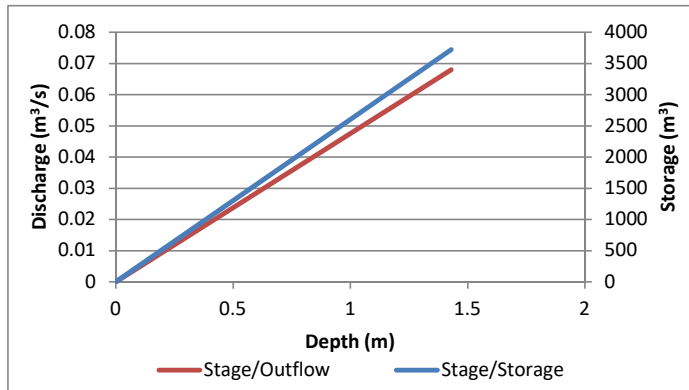
Taken from SWM Inventory Sheet

Ignored permanent pool storage

Facility Name:		Manse Road Subdivision	
Pond ID:		310	
Type:		Overflow, 100 year	
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	50	0	0
0.10	50	0.937	5
0.20	510	0.970	102
0.30	1,140	1.003	342
0.40	1,770	1.032	708
0.50	2,278	1.061	1,139
0.60	2,758	1.086	1,655
0.70	3,153	1.111	2,207
0.80	3,465	1.133	2,772
0.90	3,718	1.159	3,346
1.00	3,932	1.185	3,932
1.10	4,117	1.211	4,529
1.20	4,282	1.237	5,138

Stage/Outflow — Stage/Storage
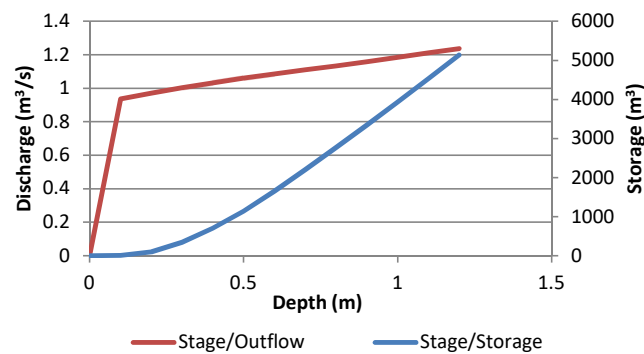
Taken from SWM Inventory Sheet

Facility Name:	Warden North Hydrolands (Pond G)		
Pond ID:	304.2		
Type:	Offline, 2-100 year		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	8,100	0	0
0.10	8,100	0.006	810
0.20	4,970	0.010	994
0.30	3,930	0.013	1,179
0.40	3,408	0.015	1,363
0.50	3,094	0.017	1,547
0.60	2,885	0.019	1,731
0.70	2,737	0.021	1,916
0.80	2,625	0.023	2,100
0.90	2,580	0.228	2,322
1.00	2,583	0.618	2,583
1.10	2,585	0.656	2,844
1.20	2,588	0.692	3,105
1.30	2,589	0.726	3,366
1.40	2,591	0.758	3,627
1.50	2,592	0.790	3,888
1.55	2,592	0.805	4,018
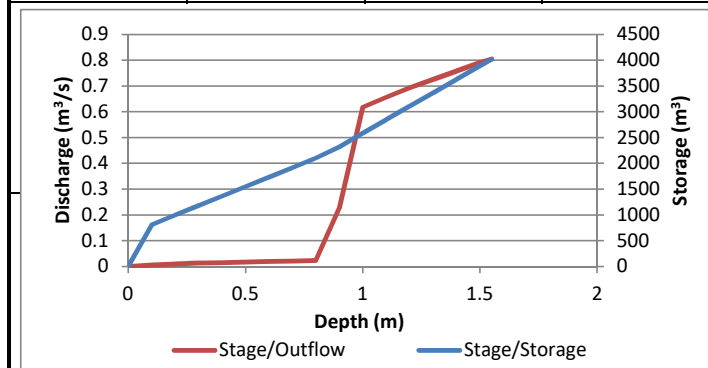
Taken from SWM Inventory Sheet

Facility Name:	Markham Gardens Pond		
Pond ID:	181		
Type:	Overflow, 5-100 year		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	1,595	0	0
2.16	1,595	0.770	3,446

Taken from SWM Inventory Sheet
Ignored permanent pool storage

Facility Name:	Malvern Core & Neighbourhood 7-C Pond		
Pond ID:	76		
Type:	Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	4,389		0
1.20	4,389		5,267

Stage/Storage

Taken from SWM Inventory Sheet

Used Orifice for outflow - 225 mm based on SWM report

Ignored permanent pool storage

Facility Name:	Milliken District Park Pond		
Pond ID:	68.1		
Type:	Offline, 2-100 year		
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	237	0	0
0.30	237	0.156	71
0.50	2,060	0.207	1,030
1.00	3,640	0.246	3,640
1.50	5,492	0.283	8,238
1.90	7,818	0.308	14,854

Stage/Outflow   Stage/Storage

Taken from SWM Report, Stage, Storage Discharge Table

Used simple curve for storage in PCSWMM model to force maximum volume

Facility Name:	Milliken District Park Pond				
Pond ID:	68				
Type:	Offline, 2-100 year				
Storage/Discharge Curve					
Depth (m)	Area (m²)	Discharge Sewer (m³/s)	Discharge Dry Pond (m³/s)	Discharge Total (m³/s)	Volume (m³)
0	12,000	0	0	0	0
0.10	12,080	0.076	0.000	0.076	1,208
0.20	12,290	0.201	0.000	0.201	2,458
0.30	12,497	0.369	0.331	0.701	3,749
0.40	12,703	0.510	1.102	1.612	5,081
0.50	12,910	0.520	2.328	2.848	6,455
0.60	13,115	0.530	3.970	4.499	7,869
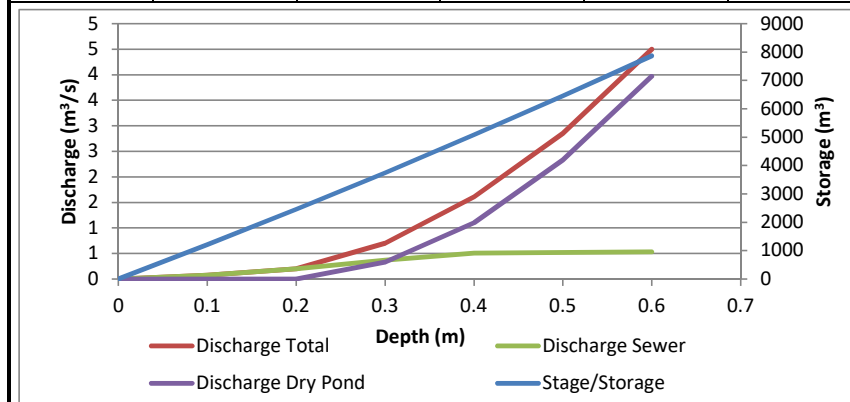
Used simple curve for storage in PCSWMM model to force maximum volume

Taken from SWM Report, Stage, Storage Discharge Table pg. 40

Facility Name:	Goldhawk Park Pond		
Pond ID:	74		
Type:	Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	4,610	0	0
1.00	4,610	5.600	4,610
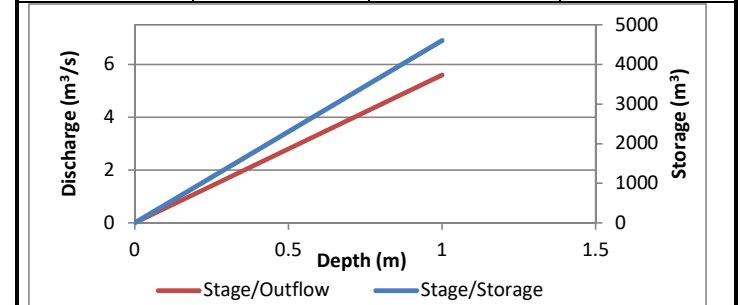
Taken from SWM Inventory Sheet and elevations from drawing

Facility Name:	City Owned Land Pond		
Pond ID:	75		
Type:	Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	4,353	0	0
0.85	4,353	5.300	3,700
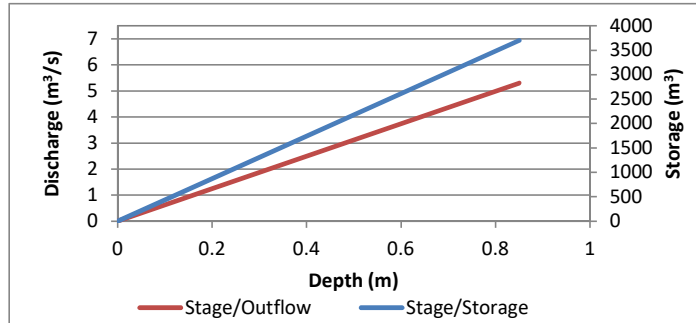
Taken from SWM Inventory Sheet and elevations from drawing

Facility Name:	East Riseborough Phase 1 North Park Pond		
Pond ID:	85		
Type:	Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m²)	Discharge (m³/s)	Volume (m³)
0	41,765	0	0
0.34	41,765	0.141	14,200

Taken from SWM Inventory Sheet and elevations from drawing

Facility Name:	City Owned Land Pond		
Pond ID:	85.1		
Type:	Overflow		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	41,703	0	0
0.37	41,703	0.283	15,430

Taken from SWM Inventory Sheet and elevations from drawing

Facility Name:	Riseborough Centre Area Pond		
Pond ID:	30		
Type:	2-100 year		
Storage/Discharge Curve			
Depth (m)	Area (m^2)	Discharge (m^3/s)	Volume (m^3)
0	250	0	0
0.5	250	0.07	125
1	801	0.12	801
1.5	1739	0.31	2609
2	2891	0.41	5782

Taken from SWM Inventory Sheet

Facility Name:	West Riseborough Phase 1 - North/South Facility
Pond ID:	86.3/86.4
Type:	2-25 year
Model Set Up	

PCSWMM was set up to represent the max flow rates provided in the SWM inventory report. One conduit was labelled 5-yr and had a flow limit of 2.12 m^3/s. A second conduit was offset by 2.0 m and had an 25-yr flow limit of 0.57 m^3/s. The final conduit was represented as a road transect. The conduit did not have a flow limit but was offset by 5.0 m to ensure that the other conduits were first used to convey smaller storm flows.

Facility Name:	West Riseborough North Detention Pond - Phase 2
Pond ID:	86.1/86.2
Type:	2-25 year
Model Set Up	

PCSWMM was set up to represent the max flow rates provided in the SWM inventory report. One conduit was labelled 5-yr and had a flow limit of 2.0 m^3/s. A second conduit was offset by 2.0 m and had an 25-yr flow limit of 0.30 m^3/s. The final conduit was represented as a road transect. The conduit did not have a flow limit but was offset by 5.0 m to ensure that the other conduits were first used to convey smaller storm flows.

Facility Name:	West Riseborough North Detention Pond - Phase 2
Pond ID:	58, 58.1, 58.2
Type:	Online
Model Set Up	

Storage areas were represent within the cross-section of the channel (exported from HEC-RAS). The weir structures were complex and the lateral structures in HEC-RAS had to be simplified to compatible formats for the PCSWMM model. Structures at 58 and 58.2 were represented as weirs. Structure at 58.1 was represented as a stage/outflow curve based on the weir structure rating curve.

APPENDIX E
Event Hydrographs/Hyetographs

APPENDIX E

SELECTED EVENT HYDROGRAPHS/HYETOGRAPHS
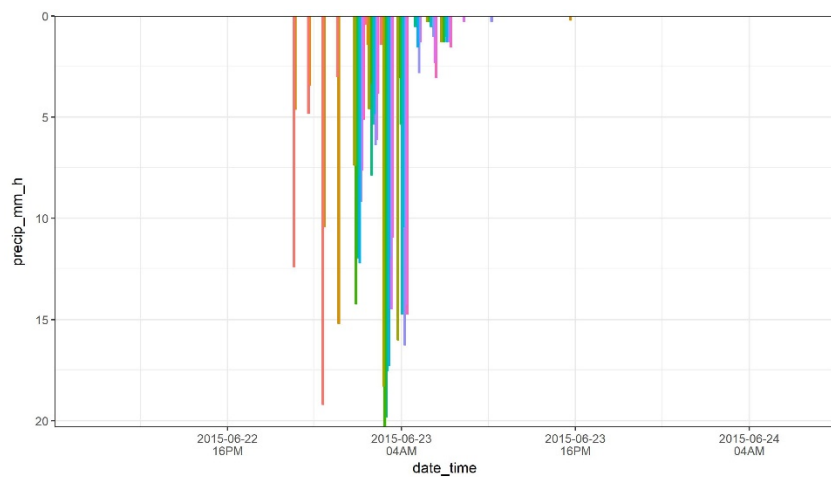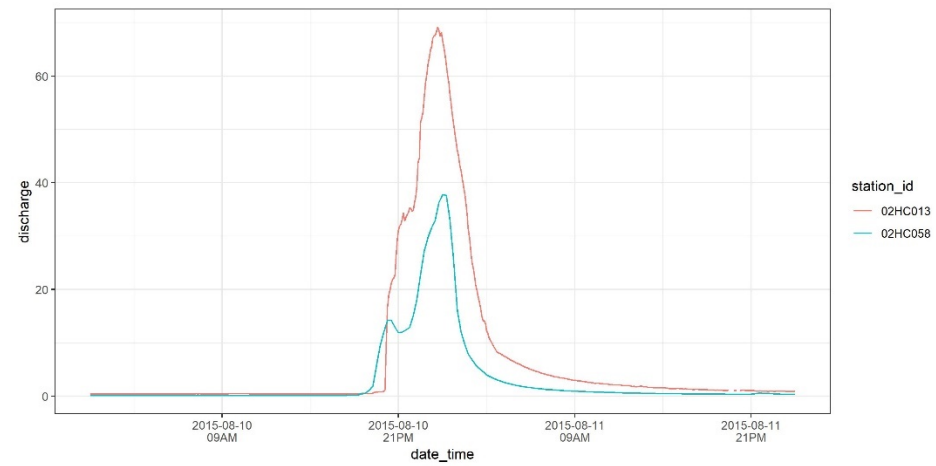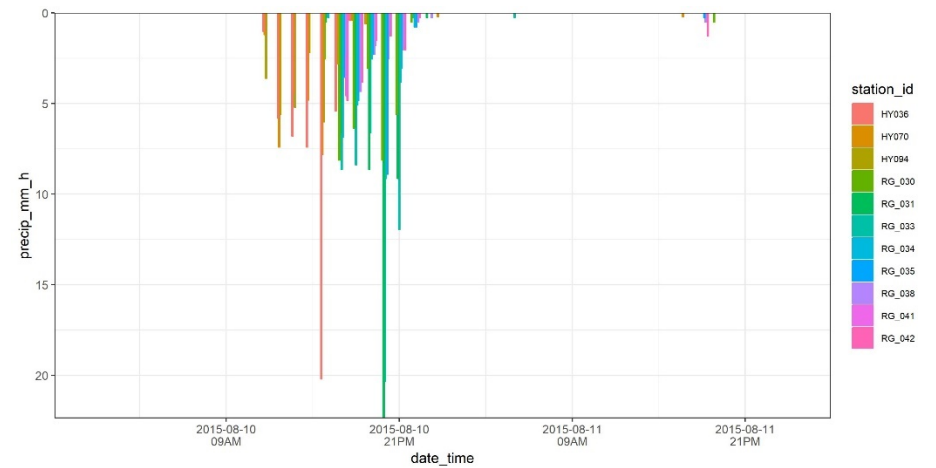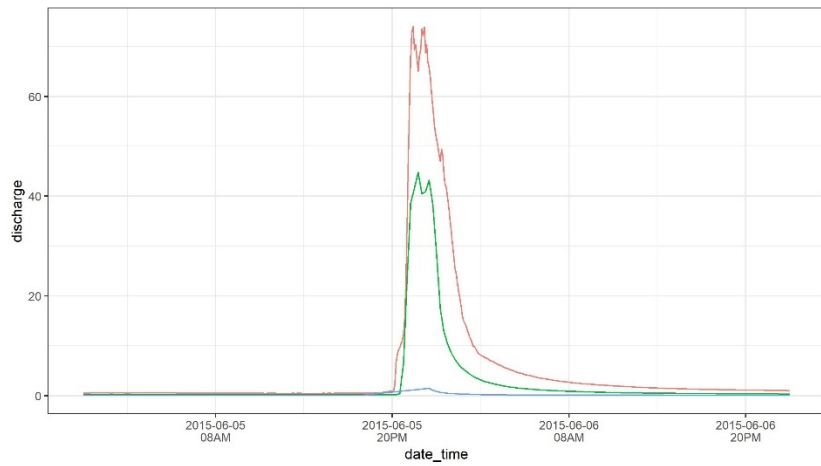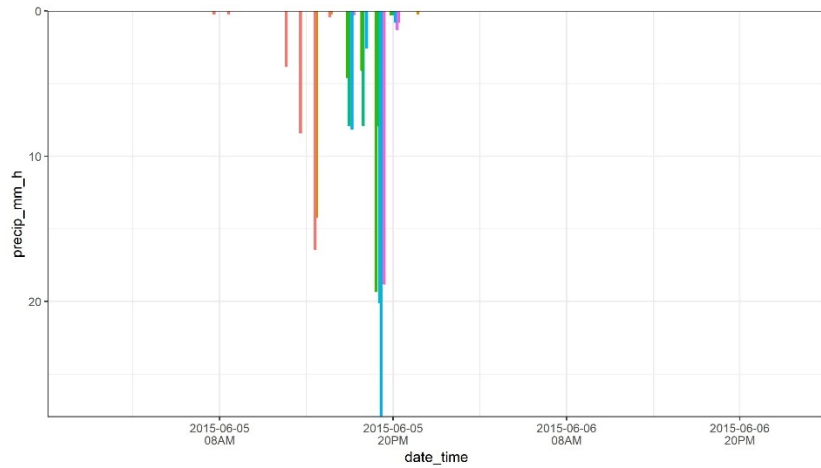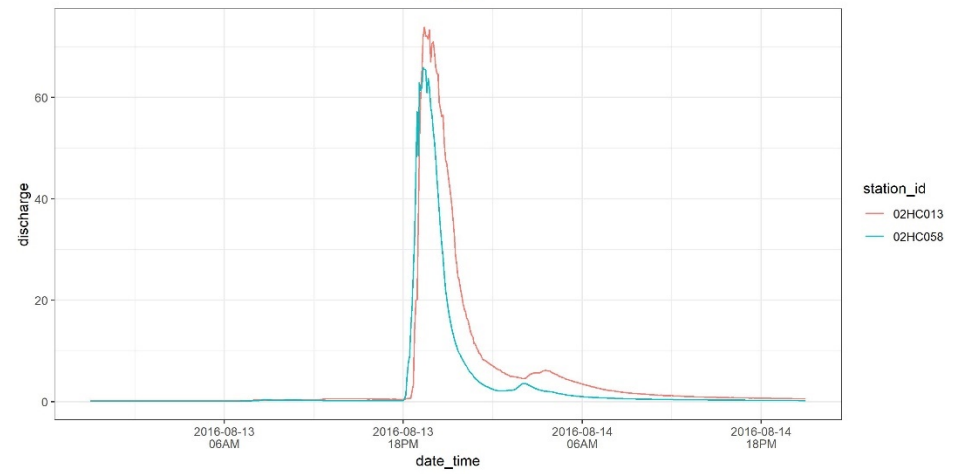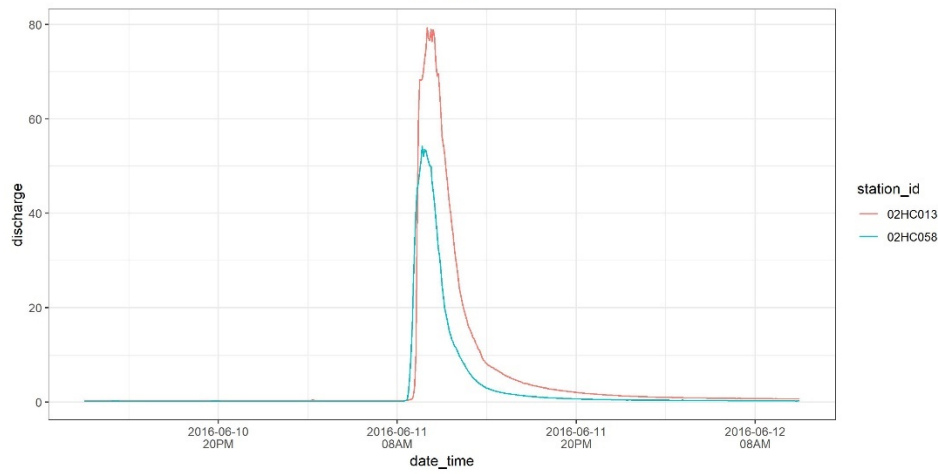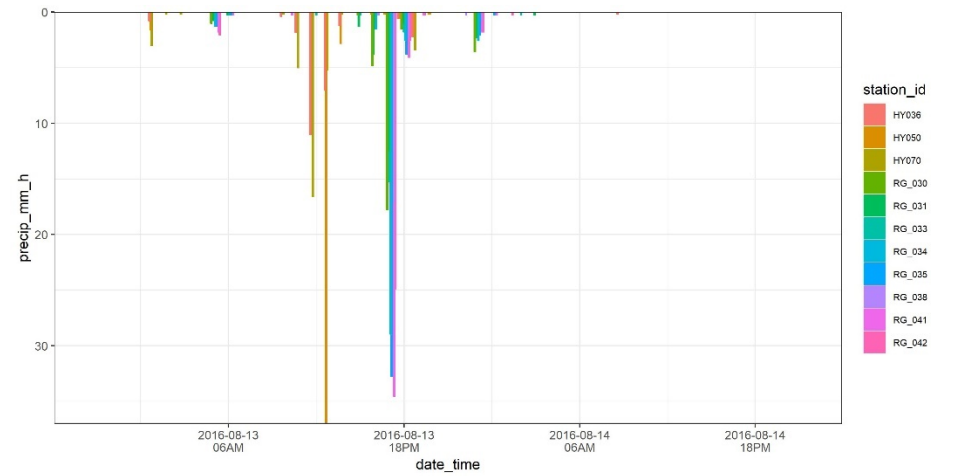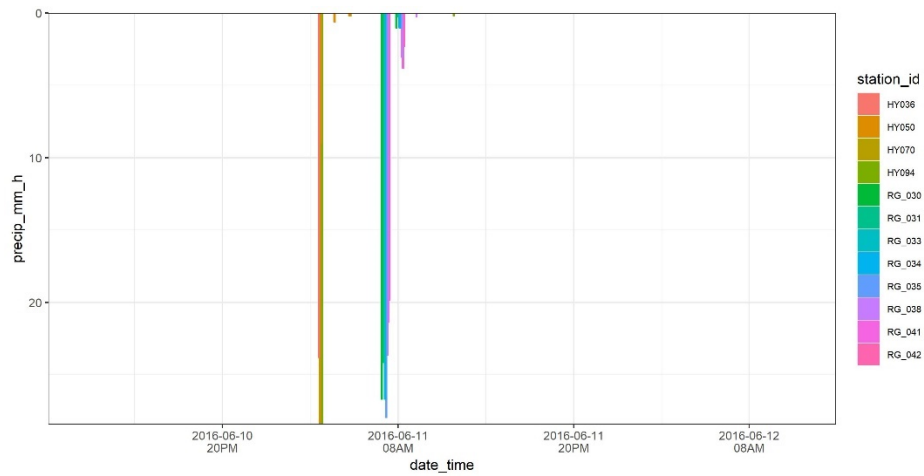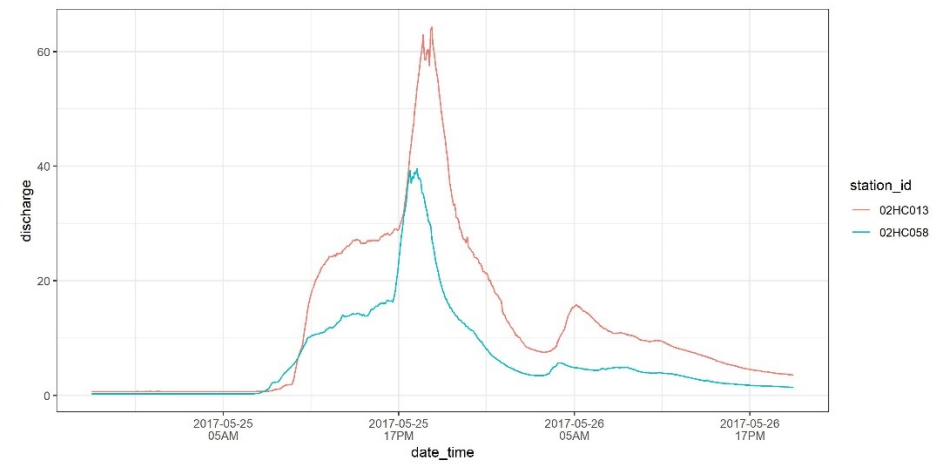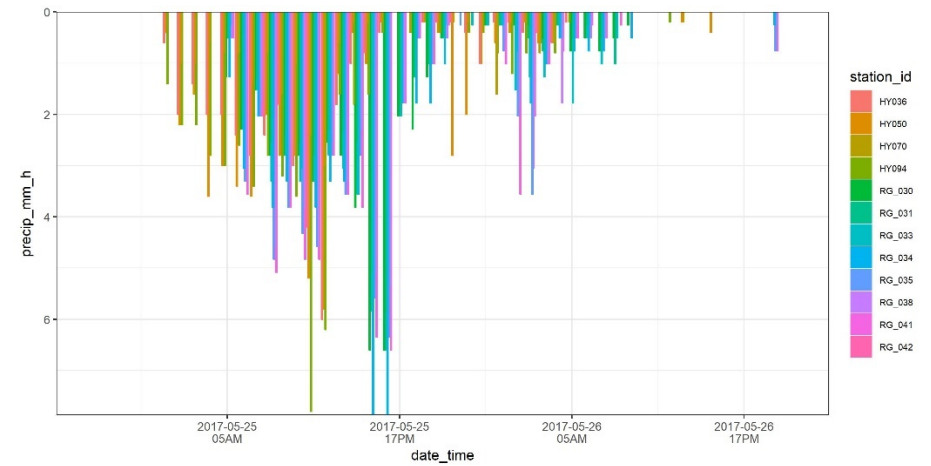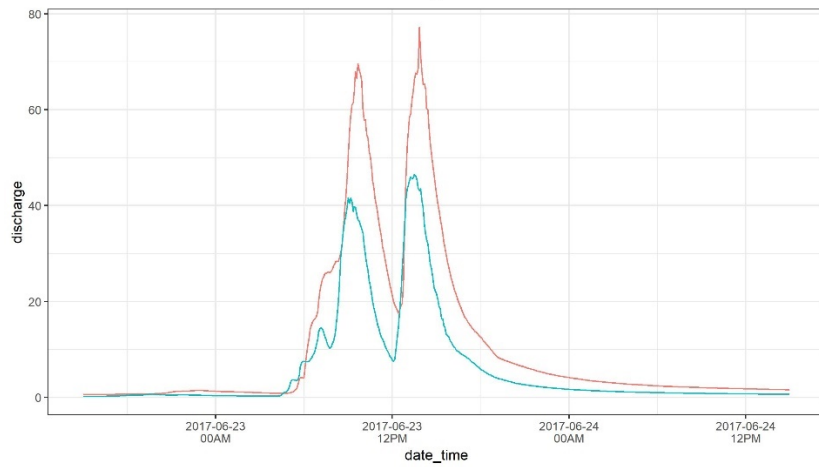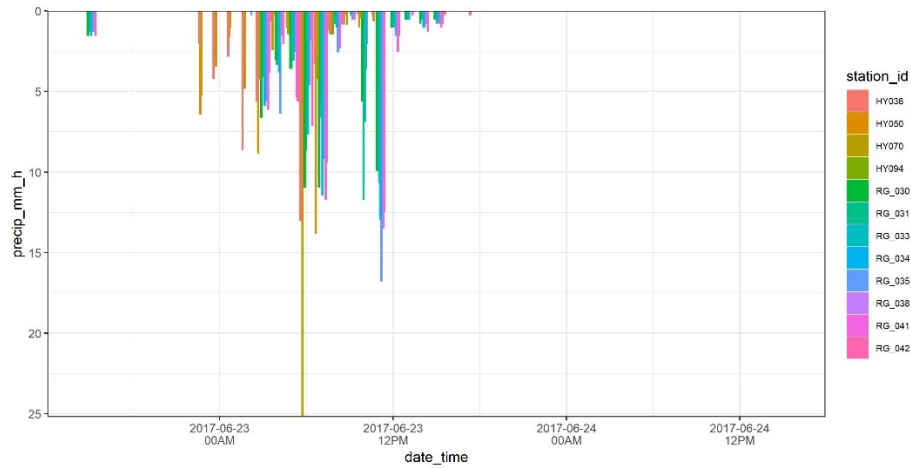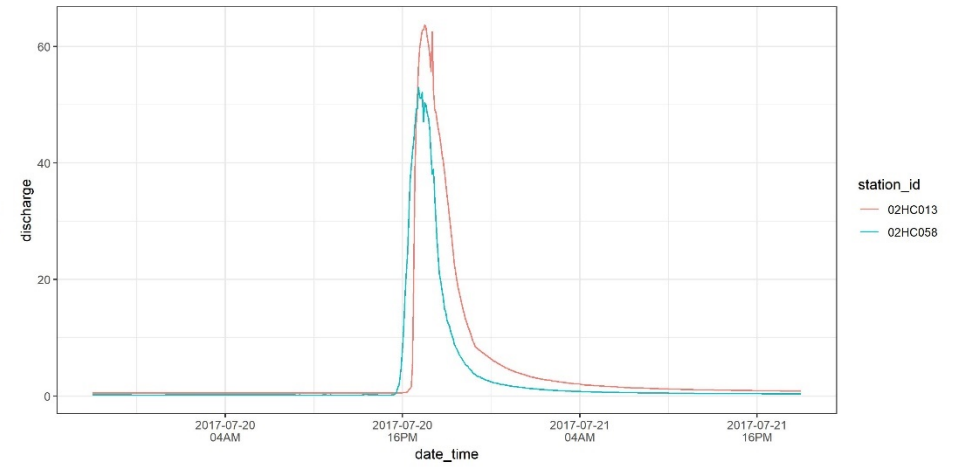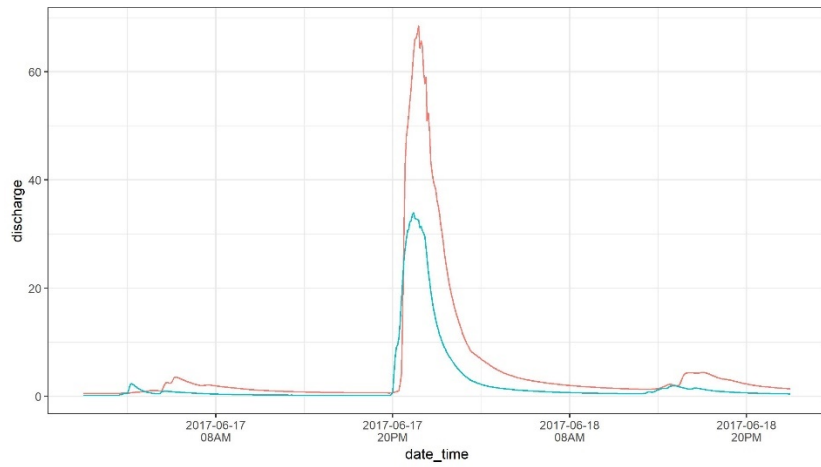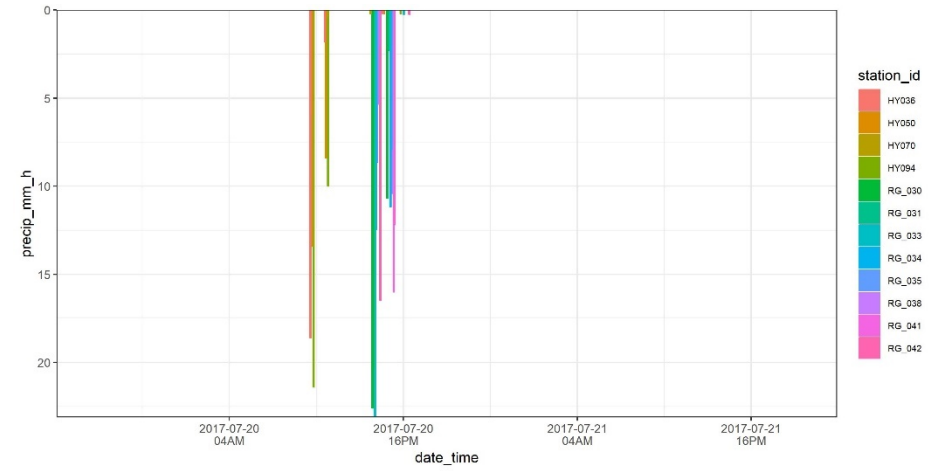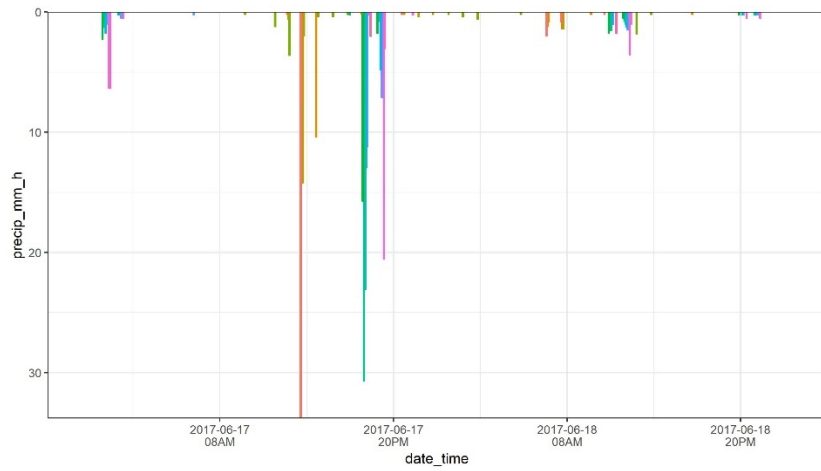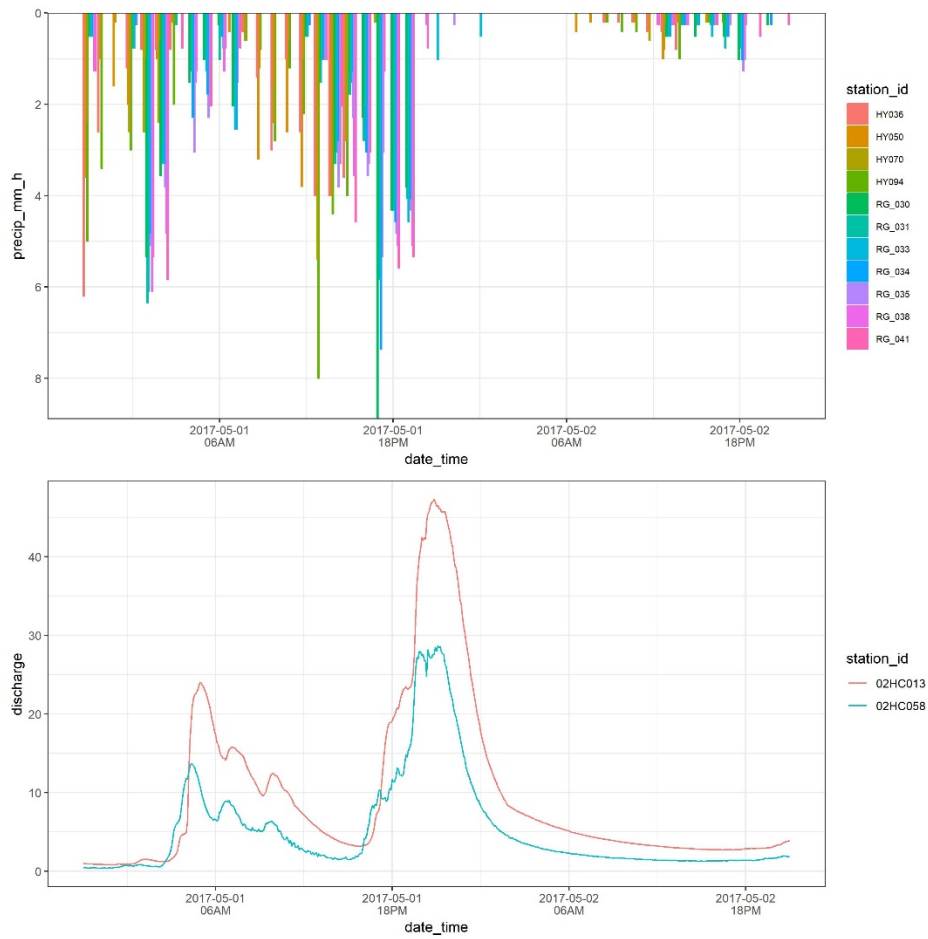
APPENDIX F
Calibrated Hydrologic Model Parameters

Table F1 Calibrated Hydrologic Parameters

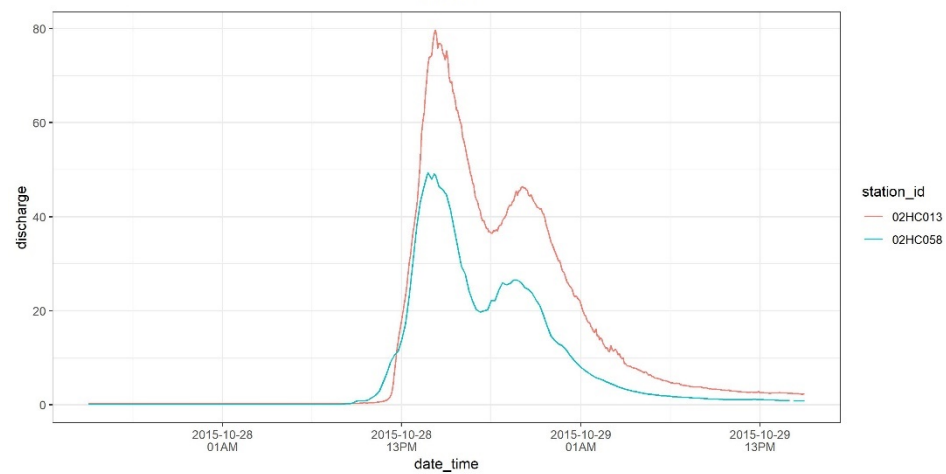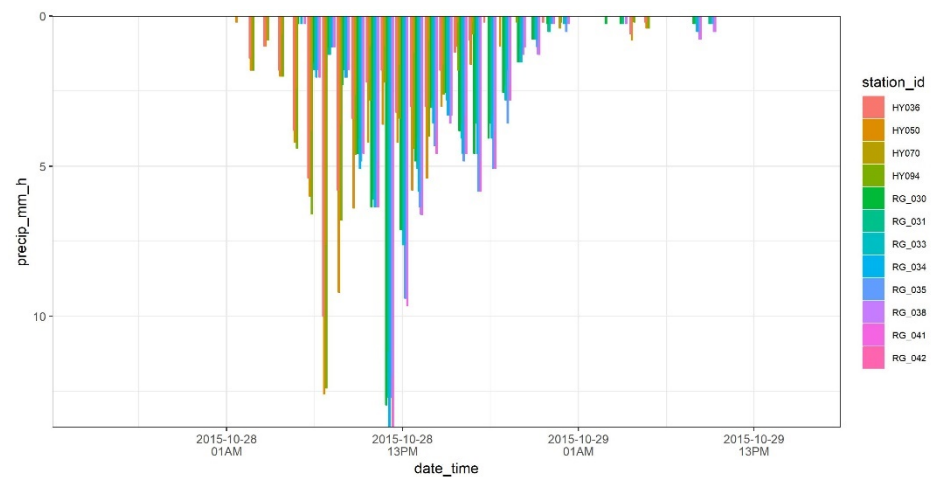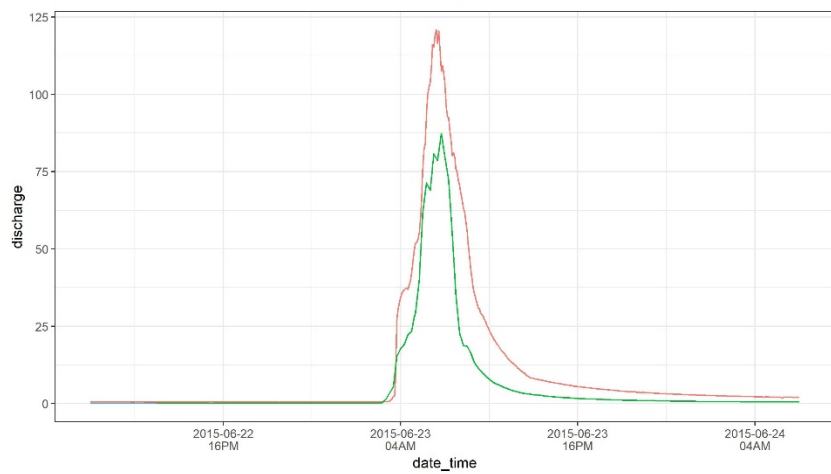| Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0001	641447	4844682	H0001	J474	10.89	215	507	2.48	53.4	0.013	0.29	2	4.1	25	PERVIOUS	18.9	220	1.5	0.26
H0002	635953	4850953	H0002	J197	1.83	76	241	5.25	41.0	0.013	0.31	2	4.8	25	PERVIOUS	32.6	220	1.5	0.26
H0003	642568	4850684	H0003	J1390	6.61	160	412	3.26	47.0	0.013	0.36	2	4.8	25	PERVIOUS	32.7	220	1.5	0.26
H0004	648654	4849573	H0004	J2598	31.43	400	785	2.11	50.0	0.013	0.31	2	4.3	25	PERVIOUS	16.9	134	8.8	0.34
H0005	636081	4849835	H0005	J8769	57.59	572	1006	1.71	56.7	0.013	0.25	2	3.5	25	PERVIOUS	5.1	220	1.5	0.26
H0006	640951	4848809	H0006	J2622	18.96	298	637	1.87	77.0	0.013	0.27	2	3.9	25	PERVIOUS	10.5	198	5.5	0.28
H0007	640355	4850270	H0007	J4184	35.49	430	825	1.77	83.2	0.013	0.26	2	3.7	25	PERVIOUS	4.4	220	1.5	0.26
H0008	636231	4852436	H0008	J11509	11.81	225	524	2.30	46.4	0.013	0.42	2	6.0	25	PERVIOUS	49.4	220	1.5	0.26
H0009	647877	4847838	H0009	J1407	16.02	269	595	3.04	31.1	0.013	0.40	2	5.5	25	PERVIOUS	40.6	129	11.7	0.35
H0010	638960	4847778	H0010	J4555	15.52	264	587	1.52	83.0	0.013	0.26	2	3.7	25	PERVIOUS	6.6	220	1.5	0.26
H0011	638969	4852053	H0011	J6352	49.62	524	947	1.72	59.1	0.013	0.26	2	3.7	25	PERVIOUS	9.7	220	1.5	0.26
H0012	637632	4849382	H0012	J6860	31.37	400	784	1.88	74.9	0.013	0.27	2	3.7	25	PERVIOUS	7.6	220	1.5	0.26
H0013	642010	4851240	H0013	J2172	3.66	114	322	4.63	39.2	0.013	0.32	2	4.8	25	PERVIOUS	31.2	119	10.1	0.36
H0014	639559	4845322	H0014	J3621	13.27	241	550	2.29	20.3	0.013	0.33	2	5.5	25	PERVIOUS	56.7	173	7.2	0.30
H0015	640401	4849852	H0015	J3868	11.14	218	512	3.01	61.1	0.013	0.27	2	4.0	25	PERVIOUS	14.6	220	1.5	0.26
H0016	634910	4850079	H0016	J874	46.34	504	920	1.75	52.2	0.013	0.26	2	3.8	25	PERVIOUS	14.3	220	1.5	0.26
H0017	636023	4851238	H0017	J9810	14.27	252	567	2.22	61.3	0.013	0.26	2	3.8	25	PERVIOUS	9.8	220	1.5	0.26
H0018	638359	4852464	H0018	J7471	26.34	361	730	1.93	50.0	0.013	0.27	2	3.9	25	PERVIOUS	14.8	220	1.5	0.26
H0019	643268	4849497	H0019	J2339	31.53	401	786	5.28	32.1	0.013	0.50	2	6.6	25	PERVIOUS	51.5	177	9.0	0.30
H0020	638781	4852099	H0020	J6771	24.21	343	705	1.78	35.0	0.013	0.42	2	5.9	25	PERVIOUS	49.5	220	1.5	0.26
H0021	641106	4845278	H0021	J1462	34.30	421	814	2.05	46.0	0.013	0.30	2	4.1	25	PERVIOUS	19.2	209	2.5	0.27
H0022	638668	4847978	H0022	J4955	6.30	156	404	1.66	83.5	0.013	0.26	2	3.8	25	PERVIOUS	8.3	220	1.5	0.26
H0023	641686	4846558	H0023	J677	25.71	356	723	2.28	53.1	0.013	0.29	2	4.1	25	PERVIOUS	13.9	188	5.1	0.29
H0024	636333	4851347	H0024	J10074	31.30	399	784	1.95	38.1	0.013	0.30	2	4.5	25	PERVIOUS	41.2	204	4.3	0.27
H0025	636791	4849647	H0025	J8044	24.98	350	714	1.59	34.9	0.013	0.32	2	4.6	25	PERVIOUS	48.8	220	1.5	0.26
H0026	642606	4851098	H0026	J1788	52.54	542	969	1.83	52.9	0.013	0.26	2	3.7	25	PERVIOUS	11.0	220	1.5	0.26
H0027	648488	4850033	H0027	J3032	18.96	298	637	1.74	50.9	0.013	0.26	2	3.7	25	PERVIOUS	7.6	188	4.2	0.29
H0028	635808	4850840	H0028	J9523	39.62	459	863	1.91	53.8	0.013	0.27	2	4.0	25	PERVIOUS	17.5	220	1.5	0.26
H0029	642485	4845724	H0029	J225_1	5.49	144	382	3.44	48.5	0.013	0.30	2	4.1	25	PERVIOUS	14.4	220	1.5	0.26
H0030	642470	4845492	H0030	J392	7.53	173	435	2.63	37.7	0.013	0.30	2	4.4	25	PERVIOUS	26.1	220	1.5	0.26
H0031	635276	4850475	H0031	J1168	1.96	79	248	4.41	51.7	0.013	0.32	2	5.1	25	PERVIOUS	41.7	220	1.5	0.26
H0032	640089	4852663	H0032	J692	9.32	196	475	3.40	70.1	0.013	0.27	2	4.0	25	PERVIOUS	11.3	220	1.5	0.26
H0033	641246	4846518	H0033	J937	55.81	562	993	1.97	49.9	0.013	0.29	2	4.3	25	PERVIOUS	22.9	181	5.2	0.30
H0034	637712	4849658	H0034	J7121	6.05	152	397	2.13	54.4	0.013	0.26	2	3.6	25	PERVIOUS	5.9	220	1.5	0.26
H0035	636227	4852680	H0035	J11792	10.31	208	496	2.36	39.3	0.013	0.32	2	5.0	25	PERVIOUS	39.0	220	1.5	0.26
H0036	638017	4850606	H0036	J2285	74.18	665	1116	1.78	51.7	0.013	0.26	2	3.8	25	PERVIOUS	12.4	206	2.7	0.28
H0037	643783	4849301	H0037	J1656	35.64	431	826	5.04	31.8	0.013	0.44	2	6.3	25	PERVIOUS	56.5	200	5.0	0.28
H0038	643620	4847673	H0038	J1280	26.39	362	730	2.15	44.4	0.013	0.30	2	4.3	25	PERVIOUS	20.1	220	1.5	0.26
H0039	637829	4849261	H0039	J6649	100.16	794	1262	1.68	54.2	0.013	0.26	2	3.7	25	PERVIOUS	10.4	220	1.5	0.26
H0040	647312	4847564	H0040	J1892	33.49	416	806	2.99	44.3	0.013	0.39	2	5.3	25	PERVIOUS	33.4	104	13.8	0.37
H0041	639159	4846724	H0041	J4101	116.72	869	1343	1.62	80.2	0.013	0.25	2	3.5	25	PERVIOUS	3.1	220	1.5	0.26
H0042	639641	4847915	H0042	J3977	20.25	309	655	2.37	78.7	0.013	0.30	2	4.1	25	PERVIOUS	11.8	205	2.8	0.28
H0043	644708	4849887	H0043	J965	51.75	537	963	5.54	30.3	0.013	0.49	2	6.6	25	PERVIOUS	58.2	166	8.4	0.31
H0044	641912	4851000	H0044	J1977	23.51	338	696	1.78	55.6	0.013	0.30	2	4.3	25	PERVIOUS	18.9	203	3.0	0.28
H0045	639394	4851490	H0045	J5954	10.66	212	502	2.49	34.1	0.013	0.30	2	4.7	25	PERVIOUS	32.7	220	1.5	0.26
H0046	643830	4847228	H0046	J531	75.89	673	1127	2.01	52.4	0.013	0.28	2	4.0	25	PERVIOUS	13.7	220	1.5	0.26
H0047	644816	4849068	H0047	J211	32.90	411	800	4.73	29.1	0.013	0.61	2	8.0	25	PERVIOUS	73.2	217	1.8	0.26
H0048	635757	4851145	H0048	J320	10.20	207	493	2.78	52.3	0.013	0.28	2	4.3	25	PERVIOUS	24.2	220	1.5	0.26
H0049	641215	4852446	H0049	J3823	8.81	190	464	2.33	68.7	0.013	0.29	2	4.5	25	PERVIOUS	26.5	177	9.2	0.30
H0050	646688	4847583	H0050	J2659	24.32	344	706	1.84	48.1	0.013	0.26	2	3.7	25	PERVIOUS	11.3	110	10.9	0.37
H0051	637271	4849925	H0051	J7482	38.73	453	855	2.01	29.6	0.013	0.33	2	4.7	25	PERVIOUS	50.8	220	1.5	0.26

Table F1 Calibrated Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0052	639847	4847236	H0052	J2640	86.41	727	1188	2.40	49.0	0.013	0.32	2	4.5	25	PERVIOUS	22.5	187	5.2	0.29
H0053	641921	4844839	H0053	J1154	44.82	494	908	2.39	57.0	0.013	0.28	2	3.9	25	PERVIOUS	15.6	215	1.9	0.27
H0054	640345	4854049	H0054	J5071	75.84	674	1126	1.56	75.7	0.013	0.25	2	3.6	25	PERVIOUS	3.5	220	1.5	0.26
H0055	639821	4849617	H0055	J276	89.72	744	1206	1.77	62.5	0.013	0.27	2	3.9	25	PERVIOUS	12.6	209	2.5	0.27
H0056	642798	4845981	H0056	J5083	28.65	379	756	3.63	36.8	0.013	0.41	2	5.5	25	PERVIOUS	38.5	153	9.4	0.32
H0057	641094	4848396	H0057	J2246	51.88	538	964	1.81	72.4	0.013	0.28	2	4.0	25	PERVIOUS	16.3	203	4.5	0.28
H0058	643432	4845967	H0058	J3471	63.60	607	1048	4.66	30.0	0.013	0.42	2	5.7	25	PERVIOUS	59.1	178	5.1	0.30
H0059	639576	4852444	H0059	J902	45.61	499	914	1.81	57.8	0.013	0.26	2	3.7	25	PERVIOUS	9.2	220	1.5	0.26
H0060	648051	4850285	H0060	J3692	3.57	112	319	1.29	59.9	0.013	0.25	2	3.5	25	PERVIOUS	5.1	132	9.1	0.35
H0061	645345	4849566	H0061	J5794	54.29	553	982	2.89	49.4	0.013	0.40	2	5.6	25	PERVIOUS	40.4	150	8.8	0.33
H0062	637839	4851000	H0062	J2624	10.13	206	492	2.83	52.5	0.013	0.28	2	4.1	25	PERVIOUS	19.9	183	4.7	0.30
H0063	638553	4852320	H0063	J7258	8.32	183	454	3.15	47.8	0.013	0.28	2	4.2	25	PERVIOUS	21.4	220	1.5	0.26
H0064	638533	4848795	H0064	J5949	3.54	111	318	2.05	95.6	0.013	0.26	2	3.6	25	PERVIOUS	0.0	220	1.5	0.26
H0065	638109	4846448	H0065	J5617	8.04	180	447	2.17	42.2	0.013	0.26	2	3.9	25	PERVIOUS	18.0	181	4.8	0.30
H0066	642017	4845946	H0066	J6444	15.03	260	579	3.35	37.1	0.013	0.38	2	5.1	25	PERVIOUS	29.5	169	6.5	0.31
H0068	635471	4849878	H0068	J494	55.45	560	991	1.66	55.0	0.013	0.26	2	3.7	25	PERVIOUS	9.0	220	1.5	0.26
H0069	635935	4852415	H0069	J11172	14.91	258	577	1.84	30.6	0.013	0.46	2	6.3	25	PERVIOUS	55.9	220	1.5	0.26
H0070	640541	4844785	H0070	J2136	99.34	790	1258	1.54	50.1	0.013	0.27	2	3.8	25	PERVIOUS	10.7	220	1.5	0.26
H0071	637802	4846655	H0071	J5953	9.76	202	484	1.67	45.3	0.013	0.27	2	4.0	25	PERVIOUS	20.2	219	1.5	0.26
H0072	637806	4851248	H0072	J2984	8.43	185	456	2.46	47.8	0.013	0.29	2	4.5	25	PERVIOUS	27.9	220	1.5	0.26
H0073	638193	4846159	H0073	J5261	164.59	1065	1546	1.32	61.7	0.013	0.25	2	3.6	25	PERVIOUS	7.4	216	2.2	0.27
H0074	639567	4851438	H0074	J5616	54.25	552	982	1.98	56.1	0.013	0.26	2	3.8	25	PERVIOUS	11.4	220	1.5	0.26
H0075	636191	4851619	H0075	J10405	7.98	179	446	3.19	18.6	0.013	0.33	2	5.1	25	PERVIOUS	66.0	149	14.3	0.32
H0076	642625	4845290	H0076	J594	16.21	271	598	1.87	49.3	0.013	0.25	2	3.5	25	PERVIOUS	6.0	220	1.5	0.26
H0077	636942	4849396	H0077	J7949	16.42	273	601	1.67	47.4	0.013	0.31	2	4.4	25	PERVIOUS	44.7	220	1.5	0.26
H0078	638770	4846299	H0078	J4796	24.72	348	711	1.70	83.5	0.013	0.25	2	3.6	25	PERVIOUS	2.9	220	1.5	0.26
H0079	640101	4850469	H0079	J4556	2.68	95	283	6.59	36.4	0.013	0.38	2	5.5	25	PERVIOUS	67.8	220	1.5	0.26
H0080	635729	4850209	H0080	J199	9.48	198	479	2.32	55.6	0.013	0.27	2	3.9	25	PERVIOUS	12.3	220	1.5	0.26
H0081	635944	4850351	H0081	J8906	21.63	321	673	1.84	45.7	0.013	0.28	2	4.2	25	PERVIOUS	23.6	220	1.5	0.26
H0082	636131	4852101	H0082	J11121	0.78	46	168	4.04	37.4	0.013	0.29	2	4.7	25	PERVIOUS	39.9	220	1.5	0.26
H0083	642703	4850569	H0083	J1290	25.31	353	718	1.93	49.0	0.013	0.30	2	4.2	25	PERVIOUS	18.0	220	1.5	0.26
H0084	645381	4848886	H0084	J59_1	1.08	56	193	4.52	30.7	0.013	0.64	2	8.4	25	PERVIOUS	83.6	68	27.2	0.39
H0085	646519	4848671	H0085	J3787	53.59	549	977	3.37	47.8	0.013	0.38	2	5.1	25	PERVIOUS	28.2	106	12.5	0.37
H0086	646352	4849532	H0086	J4133	46.38	504	921	1.94	42.0	0.013	0.32	2	4.4	25	PERVIOUS	18.4	108	11.9	0.37
H0087	640733	4849060	H0087	J2963	42.89	481	892	1.80	86.5	0.013	0.27	2	3.9	25	PERVIOUS	11.9	182	5.5	0.30
H0088	647659	4848729	H0088	J1692	64.56	613	1054	5.18	31.5	0.013	0.51	2	6.5	25	PERVIOUS	48.4	101	15.1	0.37
H0089	641816	4848940	H0089	J1208	66.45	623	1067	2.35	74.1	0.013	0.28	2	4.1	25	PERVIOUS	13.8	195	6.0	0.28
H0090	636400	4851959	H0090	J10950	40.03	462	867	1.90	47.3	0.013	0.28	2	4.3	25	PERVIOUS	31.0	204	4.3	0.27
H0091	647258	4848964	H0091	J3128	8.92	191	467	8.09	35.6	0.013	0.63	2	8.0	25	PERVIOUS	67.2	93	17.6	0.38
H0092	636403	4849252	H0092	J8250	69.97	642	1090	1.73	57.1	0.013	0.26	2	3.8	25	PERVIOUS	11.5	221	1.5	0.26
H0093	640715	4849842	H0093	J3674	34.20	421	813	2.14	59.4	0.013	0.27	2	3.9	25	PERVIOUS	13.4	220	1.5	0.26
H0094	641154	4852671	H0094	J4006	4.44	127	349	4.25	55.5	0.013	0.32	2	4.8	25	PERVIOUS	33.5	149	14.1	0.32
H0095	642811	4845528	H0095	J699	6.94	165	421	2.72	44.8	0.013	0.29	2	4.0	25	PERVIOUS	12.1	220	1.5	0.26
H0096	639997	4851232	H0096	J5398	12.15	229	530	2.35	68.6	0.013	0.26	2	3.7	25	PERVIOUS	4.4	220	1.5	0.26
H0097	638527	4851070	H0097	J1634	50.52	530	954	1.72	49.4	0.013	0.27	2	3.9	25	PERVIOUS	16.5	220	1.5	0.26
H0098	637101	4849551	H0098	J7722	5.91	150	393	2.97	22.7	0.013	0.35	2	4.8	25	PERVIOUS	68.1	220	1.5	0.26
H0099	644827	4847128	H0099	J1344	14.60	255	572	5.14	32.7	0.013	0.50	2	6.6	25	PERVIOUS	53.3	108	12.7	0.37
H0100	642084	4851507	H0100	J2572	53.83	550	979	1.94	51.6	0.013	0.38	2	5.4	25	PERVIOUS	39.8	173	5.6	0.31
H0101	639734	4845685	H0101	J3846	29.59	386	766	1.44	57.7	0.013	0.28	2	4.3	25	PERVIOUS	24.3	162	6.7	0.32
H0102	648534	4848794	H0102	J274	22.27	327	681	2.58	37.5	0.013	0.29	2	4.2	25	PERVIOUS	25.1	278	1.2	0.24
H0103	641681	4852118	H0103	J2938	83.42	712	1171	2.03	75.2	0.013	0.27	2	3.9	25	PERVIOUS	11.2	220	1.5	0.26

Table F1 Calibrated Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0104	638172	4849098	H0104	J6358	19.08	299	639	2.67	46.0	0.013	0.34	2	4.9	25	PERVIOUS	32.6	220	1.5	0.26
H0105	638575	4848282	H0105	J5235	13.28	241	550	2.84	82.4	0.013	0.28	2	4.0	25	PERVIOUS	13.5	219	1.6	0.26
H0106	638544	4848014	H0106	J5057	3.03	102	298	4.40	41.3	0.013	0.48	2	6.2	25	PERVIOUS	55.1	220	1.5	0.26
H0107	640261	4846982	H0107	J2113	8.60	187	460	2.81	47.1	0.013	0.38	2	5.2	25	PERVIOUS	34.2	164	6.9	0.32
H0109	638426	4849064	H0109	J6135	18.91	297	637	3.58	74.1	0.013	0.28	2	3.8	25	PERVIOUS	10.1	220	1.5	0.26
H0110	638838	4848998	H0110	J6002	22.92	333	689	1.93	60.3	0.013	0.25	2	3.5	25	PERVIOUS	4.2	220	1.5	0.26
H0111	638259	4848558	H0111	J5759	47.85	513	933	2.69	65.9	0.013	0.29	2	4.3	25	PERVIOUS	22.6	214	2.5	0.27
H0112	638815	4848480	H0112	J5555	14.42	253	569	2.31	88.6	0.013	0.27	2	3.9	25	PERVIOUS	9.7	215	2.3	0.27
H0113	638773	4847804	H0113	J4694	10.49	210	499	2.27	77.8	0.013	0.27	2	3.8	25	PERVIOUS	10.1	220	1.5	0.26
H0114	639246	4848136	H0114	J4226	40.53	465	871	1.94	78.9	0.013	0.27	2	3.9	25	PERVIOUS	9.9	220	1.5	0.26
H0115	639909	4845134	H0115	J3015	41.77	474	882	1.50	49.2	0.013	0.26	2	3.7	25	PERVIOUS	11.2	219	1.6	0.26
H0116	639031	4845980	H0116	J4584	25.84	357	724	1.63	79.5	0.013	0.27	2	3.7	25	PERVIOUS	6.9	218	1.7	0.26
H0117	637438	4846857	H0117	J6502	13.97	249	562	1.65	72.7	0.013	0.27	2	3.9	25	PERVIOUS	11.7	220	1.5	0.26
H0118	637214	4847397	H0118	J6702	76.18	675	1128	1.71	78.8	0.013	0.27	2	3.8	25	PERVIOUS	9.3	220	1.5	0.26
H0119	639362	4850437	H0119	J849	72.83	657	1108	2.01	74.4	0.013	0.27	2	4.0	25	PERVIOUS	12.4	220	1.5	0.26
H0121	639972	4850872	H0121	J4921	11.48	222	518	3.43	72.2	0.013	0.28	2	4.1	25	PERVIOUS	12.5	220	1.5	0.26
H0122	639890	4850527	H0122	J4780	7.27	169	429	3.46	51.9	0.013	0.33	2	4.9	25	PERVIOUS	35.6	220	1.5	0.26
H0123	640477	4849248	H0123	J3152	29.42	385	764	2.25	69.5	0.013	0.29	2	4.5	25	PERVIOUS	23.1	211	2.3	0.27
H0124	640258	4852940	H0124	J4530	44.77	493	908	1.46	72.9	0.013	0.27	2	3.8	25	PERVIOUS	8.5	220	1.5	0.26
H0125	640630	4853112	H0125	J4738	13.29	241	551	2.48	75.8	0.013	0.27	2	4.0	25	PERVIOUS	10.9	220	1.5	0.26
H0126	640974	4852964	H0126	J4136	19.97	307	651	1.92	81.5	0.013	0.27	2	3.9	25	PERVIOUS	9.5	200	5.1	0.28
H0127	642688	4850223	H0127	J935_3	63.03	604	1044	2.20	71.6	0.013	0.32	2	4.5	25	PERVIOUS	18.4	193	6.3	0.28
H0128	645293	4849088	H0128	J244	1.50	68	222	1.12	12.9	0.013	0.51	2	8.2	25	PERVIOUS	96.6	220	1.5	0.26
H0129	648310	4847459	H0129	J37	71.51	650	1100	2.83	50.8	0.013	0.33	2	4.6	25	PERVIOUS	23.6	190	5.6	0.30
H0130	648347	4850095	H0130	J3292	5.58	145	384	3.85	40.3	0.013	0.47	2	6.2	25	PERVIOUS	46.3	181	4.8	0.30
H0131	648162	4850202	H0131	J3486	8.54	186	458	2.36	47.3	0.013	0.35	2	4.7	25	PERVIOUS	25.0	136	8.7	0.34
H0132	647570	4850600	H0132	S21	9.95	204	488	1.99	40.6	0.013	0.39	2	5.3	25	PERVIOUS	31.4	127	9.4	0.35
H0133	647216	4850627	H0133	J4658	8.75	189	463	1.58	49.8	0.013	0.25	2	3.5	25	PERVIOUS	5.4	110	10.9	0.37
H0134	647213	4850807	H0134	J4770	13.64	245	556	1.40	48.6	0.013	0.25	2	3.5	25	PERVIOUS	5.0	110	10.9	0.37
H0135	647251	4850980	H0135	J4926	3.17	105	303	2.08	47.9	0.013	0.25	2	3.5	25	PERVIOUS	5.1	110	10.9	0.37
H0136	646750	4850992	H0136	J5152	20.17	308	654	2.07	44.8	0.013	0.40	2	5.5	25	PERVIOUS	36.4	119	10.2	0.36
H0137	648953	4849029	H0137	J1844	12.62	234	539	3.01	41.7	0.013	0.37	2	4.9	25	PERVIOUS	25.5	127	10.0	0.36
H0138	647732	4850473	H0138	J3852	41.53	472	880	1.58	53.5	0.013	0.27	2	3.9	25	PERVIOUS	13.0	149	7.6	0.33
H0139	636654	4847389	H0139	J7039	25.91	357	725	1.47	71.5	0.013	0.26	2	3.7	25	PERVIOUS	7.2	220	1.5	0.26
H0140	647049	4851158	H0140	S21.1	1.98	80	249	1.47	14.5	0.013	0.55	2	7.6	25	PERVIOUS	74.9	110	10.9	0.37
H0142	637417	4851826	H0142	J3313	97.07	779	1246	1.39	73.1	0.013	0.26	2	3.7	25	PERVIOUS	6.3	217	1.8	0.27
H0143	642458	4849230	H0143	J160	60.08	587	1024	3.81	50.5	0.013	0.38	2	5.4	25	PERVIOUS	36.0	196	6.0	0.28
H0144	638189	4852711	H0144	J7852	12.55	233	538	1.42	35.2	0.013	0.29	2	4.5	25	PERVIOUS	33.7	200	5.1	0.28
H0146	642922	4845259	H0146	J884	23.71	339	699	1.78	43.8	0.013	0.27	2	3.7	25	PERVIOUS	14.9	220	1.5	0.26
H0147	636005	4853207	H0147	J12060	40.95	468	875	1.34	61.6	0.013	0.26	2	3.7	25	PERVIOUS	9.4	220	1.5	0.26
H0149	646227	4847496	H0149	J3449	5.33	141	377	2.38	37.5	0.013	0.45	2	6.1	25	PERVIOUS	45.9	110	10.9	0.37
H0150	647218	4848191	H0150	J1011	40.78	467	873	1.66	47.1	0.013	0.26	2	3.6	25	PERVIOUS	6.1	112	10.8	0.37
H0151	648366	4848031	H0151	J225	24.43	345	708	4.14	34.9	0.013	0.49	2	6.3	25	PERVIOUS	47.2	100	15.3	0.37
H0152	645187	4848603	H0152	J6222	26.90	365	736	7.52	22.4	0.013	0.61	2	8.0	25	PERVIOUS	72.8	110	14.3	0.36
H0153	644135	4850303	H0153	J1890	42.44	478	888	2.29	47.9	0.013	0.28	2	4.0	25	PERVIOUS	14.3	214	2.3	0.27
H0154	645016	4849322	H0154	J290	13.58	245	555	6.45	17.2	0.013	0.69	2	9.1	25	PERVIOUS	91.6	220	1.5	0.26
H0159	634914	4850694	H0159	J1261	45.39	497	913	1.56	59.6	0.013	0.26	2	3.8	25	PERVIOUS	12.8	220	1.5	0.26
H0160	639580	4852916	H0160	J1113	40.47	465	871	1.56	48.8	0.013	0.27	2	3.9	25	PERVIOUS	16.6	220	1.5	0.26
H0161	640582	4852241	H0161	J197_1	57.96	574	1009	1.72	69.8	0.013	0.31	2	4.3	25	PERVIOUS	29.2	217	1.7	0.26
H0162	649165	4847995	H0162	J379_1	1.38	64	214	5.01	60.6	0.013	0.56	2	7.1	25	PERVIOUS	52.6	74	27.7	0.38
H0164	641526	4844310	H0164	J815	26.72	364	734	1.14	66.4	0.013	0.26	2	3.7	25	PERVIOUS	11.1	220	1.5	0.26

Table F1 Calibrated Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0165	640971	4844745	H0165	J1996	24.89	349	713	1.29	55.0	0.013	0.27	2	3.8	25	PERVIOUS	10.5	220	1.5	0.26
H0166	641992	4845187	H0166	J50	62.20	599	1038	2.86	37.1	0.013	0.36	2	5.0	25	PERVIOUS	33.3	196	4.3	0.28
H0167	642285	4845480	H0167	J154	24.73	348	711	2.18	46.0	0.013	0.27	2	3.8	25	PERVIOUS	9.5	215	2.2	0.27
H0170	639847	4853782	H0170	J5221	86.76	729	1190	1.50	71.0	0.013	0.26	2	3.7	25	PERVIOUS	6.3	220	1.5	0.26
H0171	644980	4848013	H0171	J77	36.14	435	831	5.31	29.1	0.013	0.54	2	6.9	25	PERVIOUS	56.1	109	14.6	0.36
H0172	642899	4849935	H0172	J59	42.07	475	885	3.63	55.7	0.013	0.38	2	5.6	25	PERVIOUS	41.7	185	8.2	0.29
H0175	649229	4847878	H0175	J171	2.42	89	271	5.21	31.0	0.013	0.52	2	6.6	25	PERVIOUS	78.0	97	23.6	0.36
H0177	635655	4851561	H0177	J624	28.56	378	755	1.34	51.7	0.013	0.26	2	3.8	25	PERVIOUS	13.6	220	1.5	0.26
H0179	644273	4848298	H0179	J808	21.53	320	672	1.86	51.2	0.013	0.27	2	3.7	25	PERVIOUS	8.7	217	1.7	0.26
H0180	644644	4847508	H0180	J749	26.31	360	730	5.73	34.0	0.013	0.56	2	7.2	25	PERVIOUS	63.3	144	11.6	0.33
H0181	643168	4847584	H0181	J1594	29.10	383	760	1.63	55.1	0.013	0.25	2	3.6	25	PERVIOUS	8.9	220	1.5	0.26
H0182	644362	4846369	H0182	J2361	61.43	595	1033	5.14	21.0	0.013	0.50	2	6.6	25	PERVIOUS	70.1	137	9.9	0.34
H0183	648986	4847981	H0183	J167	2.54	92	277	5.58	17.7	0.013	0.74	2	9.3	25	PERVIOUS	100.0	161	11.3	0.31
H0184	649257	4848241	H0184	J255	27.71	372	745	3.85	17.9	0.013	0.56	2	7.8	25	PERVIOUS	78.8	157	12.6	0.32
H0185	644097	4848059	H0185	J518	47.44	511	929	2.59	49.0	0.013	0.32	2	4.3	25	PERVIOUS	18.0	214	2.4	0.27
H0186	644109	4848730	H0186	J110	98.37	785	1253	5.72	31.3	0.013	0.51	2	6.9	25	PERVIOUS	58.5	193	6.3	0.28
H0187	648492	4847726	H0187	J504	16.74	277	605	5.28	31.0	0.013	0.56	2	7.4	25	PERVIOUS	64.9	129	13.8	0.34
H0188	648897	4848076	H0188	J718	2.37	88	269	4.76	51.8	0.013	0.57	2	7.1	25	PERVIOUS	41.9	176	7.3	0.30
H0189	642293	4845980	H0189	J6017	5.32	141	377	4.87	40.1	0.013	0.40	2	5.5	25	PERVIOUS	40.5	140	10.6	0.34
H0190	644370	4846875	H0190	J147	24.52	346	709	3.85	38.0	0.013	0.41	2	5.5	25	PERVIOUS	35.1	171	8.7	0.30
H0191	648088	4849333	H0191	J387_1	82.71	709	1167	2.28	45.9	0.013	0.28	2	3.9	25	PERVIOUS	13.8	138	9.3	0.35
H0193	649464	4847932	H0193	J121	4.92	135	365	6.58	10.1	0.013	0.44	2	7.1	25	PERVIOUS	98.1	180	8.7	0.29
H0194	649700	4848589	H0194	J439	34.04	420	811	1.65	53.2	0.013	0.27	2	4.0	25	PERVIOUS	18.7	272	2.1	0.24
H0195	641147	4844726	H0195	J105	10.24	207	494	2.30	46.6	0.013	0.32	2	4.6	25	PERVIOUS	24.5	220	1.5	0.26
H0196	641508	4845943	H0196	J60_1	47.32	510	928	2.61	50.1	0.013	0.31	2	4.2	25	PERVIOUS	16.1	197	3.8	0.28
H0197	649027	4848545	H0197	J1119	36.68	439	836	2.61	46.8	0.013	0.33	2	4.4	25	PERVIOUS	18.5	259	2.3	0.25
H0198	648323	4848323	H0198	J1435	26.78	364	735	5.19	28.5	0.013	0.61	2	7.9	25	PERVIOUS	69.6	103	15.3	0.37
H0200	646113	4847630	H0200	J3156	15.64	266	589	1.70	53.6	0.013	0.33	2	4.6	25	PERVIOUS	25.7	110	10.9	0.37
H0203	640411	4845949	H0203	J2136	52.10	293	1780	1.48	53.1	0.013	0.26	2	3.8	25	PERVIOUS	14.2	189	4.1	0.29
H0204	641251	4842924	H0204	J2136	27.02	119	2275	1.87	50.5	0.013	0.32	2	5.2	25	PERVIOUS	39.0	220	1.5	0.26
H0205	639950	4844486	H0205	J2804	42.04	476	884	1.74	48.1	0.013	0.29	2	4.0	25	PERVIOUS	13.5	220	1.5	0.26
H0206	640736	4843711	H0206	J2136	78.55	402	1956	1.27	59.3	0.013	0.26	2	3.6	25	PERVIOUS	7.3	220	1.5	0.26
H0207	636736	4852554	H0207	J3313	36.99	225	1644	1.26	49.2	0.013	0.32	2	5.0	25	PERVIOUS	41.0	220	1.5	0.26
H0208	637072	4852827	H0208	J3313	39.26	236	1664	1.46	69.1	0.013	0.26	2	3.9	25	PERVIOUS	12.7	219	1.6	0.26
H0209	637600	4852709	H0209	J3313	54.79	306	1790	1.50	57.0	0.013	0.26	2	3.7	25	PERVIOUS	12.3	220	1.5	0.26
H0210	637031	4851299	H0210	J3313	53.70	301	1782	1.32	64.1	0.013	0.25	2	3.6	25	PERVIOUS	5.5	220	1.5	0.26
H0211	638253	4851779	H0211	J3313	48.96	520	942	1.69	54.3	0.013	0.27	2	3.8	25	PERVIOUS	9.6	220	1.5	0.26
H0212	635180	4852516	H0212	J624	46.18	250	1849	1.20	51.6	0.013	0.27	2	4.0	25	PERVIOUS	19.4	220	1.5	0.26
H0213	635605	4852235	H0213	J624	36.49	287	1271	1.44	64.1	0.013	0.25	2	3.5	25	PERVIOUS	6.5	220	1.5	0.26
H0214	635230	4851662	H0214	J624	33.81	272	1245	1.20	39.2	0.013	0.27	2	4.2	25	PERVIOUS	26.8	220	1.5	0.26
H0215	634555	4852004	H0215	J624	42.39	236	1799	1.33	48.7	0.013	0.26	2	3.9	25	PERVIOUS	16.5	220	1.5	0.26
H0216	634681	4852743	H0216	J624	68.84	268	2567	1.52	57.9	0.013	0.26	2	3.7	25	PERVIOUS	11.1	220	1.5	0.26
H0217	633981	4851680	H0217	J1261	36.60	213	1715	1.33	76.0	0.013	0.26	2	3.8	25	PERVIOUS	9.0	220	1.5	0.26
H0218	634331	4851722	H0218	J1261	20.97	118	1771	1.42	52.8	0.013	0.26	2	3.8	25	PERVIOUS	12.5	220	1.5	0.26
H0219	634778	4851218	H0219	J1261	46.38	315	1471	1.47	55.6	0.013	0.26	2	3.7	25	PERVIOUS	9.7	220	1.5	0.26
H0220	634293	4851024	H0220	J1261	16.31	142	1149	1.63	54.5	0.013	0.26	2	3.8	25	PERVIOUS	13.8	220	1.5	0.26
H0221	642239	4847045	H0221	J1594	58.75	298	1974	1.60	53.7	0.013	0.27	2	3.9	25	PERVIOUS	13.2	206	2.7	0.28
H0222	642645	4847535	H0222	J1594	40.45	309	1311	1.45	60.1	0.013	0.25	2	3.6	25	PERVIOUS	5.9	213	2.1	0.27
H0223	643229	4848178	H0223	J1594	54.13	381	1421	1.39	55.3	0.013	0.25	2	3.6	25	PERVIOUS	6.7	220	1.5	0.26
H0224	642701	4848441	H0224	J1594	43.88	237	1852	1.19	51.9	0.013	0.26	2	3.9	25	PERVIOUS	16.6	192	3.9	0.29
H0225	642821	4851969	H0225	J2486	28.41	210	1352	1.74	65.9	0.013	0.30	2	4.3	25	PERVIOUS	18.1	220	1.5	0.26

Table F1 Calibrated Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0226	641040	4850825	H0226	J2765	65.22	393	1658	1.71	78.9	0.013	0.28	2	3.9	25	PERVIOUS	9.2	220	1.5	0.26
H0227	640817	4851424	H0227	J2765	89.07	494	1802	1.30	76.8	0.013	0.44	2	5.0	25	PERVIOUS	71.5	220	1.5	0.26
H0228	639819	4846384	H0228	J4297	38.09	220	1731	1.34	54.7	0.013	0.26	2	3.8	25	PERVIOUS	13.7	220	1.5	0.26
H0229	638105	4847638	H0229	J4297	87.37	421	2076	1.97	69.5	0.013	0.27	2	4.1	25	PERVIOUS	17.7	215	2.4	0.27
H0230	640862	4847521	H0230	J1232	95.27	493	1932	1.55	57.3	0.013	0.26	2	3.6	25	PERVIOUS	7.8	220	1.5	0.26
H0231	640276	4848065	H0231	J1232	18.29	86	2121	2.28	64.7	0.013	0.37	2	5.0	25	PERVIOUS	28.5	220	1.5	0.26
H0232	640652	4846754	H0232	J1394	72.59	656	1106	2.53	37.9	0.013	0.37	2	5.1	25	PERVIOUS	36.8	170	6.7	0.31
H0233	647097	4847058	H0233	Junction_11	39.25	277	1416	1.74	32.2	0.013	0.40	2	5.5	25	PERVIOUS	42.1	113	10.6	0.36
H0234	643386	4851187	H0234	J1064	86.13	539	1597	1.65	54.2	0.013	0.25	2	3.6	25	PERVIOUS	6.9	220	1.5	0.26
H0235	641827	4849898	H0235	J739	28.61	204	1403	1.77	69.2	0.013	0.26	2	3.9	25	PERVIOUS	12.2	220	1.5	0.26
H0236	641726	4850604	H0236	J739	21.37	128	1670	1.54	70.9	0.013	0.27	2	3.8	25	PERVIOUS	7.9	220	1.5	0.26
H0237	638813	4844946	H0237	J5261	32.01	174	1838	1.06	43.6	0.013	0.27	2	4.1	25	PERVIOUS	22.0	202	3.0	0.28
H0238	641762	4848076	H0238	J1704	46.42	293	1587	1.58	62.6	0.013	0.26	2	3.8	25	PERVIOUS	11.6	217	1.7	0.26
H0239	642145	4847880	H0239	J1704	52.69	543	970	1.34	46.4	0.013	0.29	2	4.5	25	PERVIOUS	30.1	182	4.7	0.30
H0240	638949	4853599	H0240	J1113	98.57	556	1773	1.50	52.3	0.013	0.28	2	4.1	25	PERVIOUS	21.7	220	1.5	0.26
H0241	642011	4842962	H0241	J815	54.22	211	2569	1.47	49.8	0.013	0.26	2	3.7	25	PERVIOUS	9.8	220	1.5	0.26
H0242	641845	4843661	H0242	J815	58.63	297	1976	2.20	47.9	0.013	0.33	2	4.7	25	PERVIOUS	30.5	220	1.5	0.26
H0243	641628	4844069	H0243	J815	43.81	331	1322	2.02	65.9	0.013	0.26	2	3.8	25	PERVIOUS	9.3	220	1.5	0.26
H0244	645264	4847422	H0244	J1557	59.16	245	2413	1.41	51.8	0.013	0.26	2	3.8	25	PERVIOUS	13.6	110	10.9	0.37
H0245	647072	4847926	H0245	J1557	34.02	299	1138	1.53	52.5	0.013	0.26	2	3.7	25	PERVIOUS	10.3	109	11.2	0.37
H0246	645766	4848102	H0246	J1557	52.67	297	1773	1.14	61.1	0.013	0.25	2	3.6	25	PERVIOUS	6.2	110	10.9	0.37
H0247	647346	4849657	H0247	J387_1	55.34	320	1732	1.86	54.1	0.013	0.28	2	3.9	25	PERVIOUS	10.7	110	10.9	0.37
H0248	641457	4852969	H0248	J3178	29.53	195	1511	1.49	81.4	0.013	0.26	2	3.6	25	PERVIOUS	2.9	220	1.5	0.26
H0249	641087	4853640	H0249	J3178	46.53	220	2112	1.40	77.6	0.013	0.26	2	3.8	25	PERVIOUS	9.3	220	1.5	0.26
H0250	635989	4854272	H0250	J12060	19.89	170	1173	1.36	67.2	0.013	0.26	2	3.7	25	PERVIOUS	8.3	220	1.5	0.26
H0251	636593	4853459	H0251	J12060	66.96	626	1070	1.07	82.7	0.013	0.25	2	3.5	25	PERVIOUS	1.4	220	1.5	0.26
H0252	645785	4850182	H0252	J3852	45.01	199	2266	1.56	46.7	0.013	0.29	2	4.5	25	PERVIOUS	28.4	110	10.9	0.37
H0253	646921	4849925	H0253	J3852	39.95	287	1392	1.35	43.3	0.013	0.31	2	4.2	25	PERVIOUS	15.1	110	10.9	0.37
H0254	646540	4850509	H0254	J3852	103.35	573	1804	1.39	58.2	0.013	0.27	2	3.9	25	PERVIOUS	13.1	113	10.6	0.36
H0255	638225	4853318	H0255	J7895	40.68	350	1162	1.36	56.9	0.013	0.26	2	3.7	25	PERVIOUS	9.2	220	1.5	0.26
H0256	637568	4853518	H0256	J7895	93.57	617	1517	1.39	61.3	0.013	0.25	2	3.6	25	PERVIOUS	8.7	220	1.5	0.26
H0257	638993	4851159	H0257	J1454	17.67	134	1316	1.71	58.0	0.013	0.25	2	3.5	25	PERVIOUS	4.5	220	1.5	0.26
H0258	638786	4850177	H0258	J1192	57.88	574	1008	1.24	47.9	0.013	0.26	2	3.7	25	PERVIOUS	12.0	220	1.5	0.26
H0259	646041	4849103	H0259	J4340	94.56	767	1233	5.09	27.2	0.013	0.56	2	7.4	25	PERVIOUS	66.3	107	14.8	0.36
H0260	643789	4845464	H0260	J3687	25.65	187	1373	2.57	31.2	0.013	0.35	2	5.1	25	PERVIOUS	39.4	220	1.5	0.26
H0261	643381	4845073	H0261	J3687	49.27	245	2009	1.83	52.6	0.013	0.28	2	4.1	25	PERVIOUS	17.6	220	1.5	0.26
H0262	643311	4846660	H0262	J3299	57.22	570	1004	1.62	60.3	0.013	0.26	2	3.7	25	PERVIOUS	10.3	220	1.5	0.26
H0263	643844	4846643	H0263	J2599	13.76	115	1198	2.37	52.1	0.013	0.25	2	3.5	25	PERVIOUS	5.5	220	1.5	0.26
H0264	639348	4848997	H0264	J3152	17.64	166	1062	1.72	46.2	0.013	0.32	2	4.5	25	PERVIOUS	24.0	220	1.5	0.26
H0265	641204	4850220	H0265	J3176	34.80	191	1825	1.46	71.4	0.013	0.25	2	3.5	25	PERVIOUS	4.0	220	1.5	0.26
H0266	641254	4849642	H0266	J3176	47.59	347	1373	1.49	72.1	0.013	0.26	2	3.7	25	PERVIOUS	7.4	198	3.4	0.28
H0267	639092	4849445	H0267	J276	36.87	229	1611	1.70	59.7	0.013	0.25	2	3.6	25	PERVIOUS	5.1	220	1.5	0.26
H0268	639659	4848428	H0268	J2893	24.84	133	1873	1.78	59.4	0.013	0.29	2	4.5	25	PERVIOUS	28.1	220	1.5	0.26
H0269	640211	4848558	H0269	J2893	58.78	379	1549	1.83	84.7	0.013	0.26	2	3.8	25	PERVIOUS	7.5	220	1.5	0.26
H0270	635543	4853057	H0270	J11256	40.17	340	1183	1.24	67.8	0.013	0.25	2	3.5	25	PERVIOUS	5.1	220	1.5	0.26
H0271	640064	4851818	H0271	J197_1	26.92	147	1827	1.73	58.6	0.013	0.25	2	3.6	25	PERVIOUS	7.3	220	1.5	0.26
H0272	640411	4851541	H0272	J197_1	33.01	232	1422	1.50	63.4	0.013	0.39	2	4.9	25	PERVIOUS	56.6	220	1.5	0.26
H0273	642678	4844074	H0273	J1318	70.63	430	1641	1.79	41.7	0.013	0.28	2	3.9	25	PERVIOUS	14.6	220	1.5	0.26
H0274	636820	4850580	H0274	J8106	79.73	512	1558	1.51	54.7	0.013	0.25	2	3.6	25	PERVIOUS	7.2	220	1.5	0.26
H0275	644157	4849692	H0275	J965	40.90	280	1462	1.68	49.9	0.013	0.27	2	4.1	25	PERVIOUS	20.7	220	1.5	0.26
H0276	643458	4849914	H0276	J2837	32.74	260	1257	1.87	54.3	0.013	0.25	2	3.5	25	PERVIOUS	5.5	220	1.5	0.26

Table F1 Calibrated Hydrologic Parameters

Name	X-Coordinate	Y-Coordinate	Rain Gage	Outlet	Area (ha)	Width (m)	Flow Length (m)	Slope (%)	Imperv. (%)	N Imperv	N Perv	Dstore Imperv (mm)	Dstore Perv (mm)	Zero Imperv (%)	Subarea Routing	Percent Routed (%)	Suction Head (mm)	Conductivity (mm/hour)	Initial Deficit (frac.)
H0277	643037	4849033	H0277	J2567	26.73	224	1193	1.51	51.6	0.013	0.26	2	3.7	25	PERVIOUS	9.4	220	1.5	0.26
H0278	649136	4849388	H0278	J1119	33.29	256	1298	1.71	49.3	0.013	0.26	2	3.8	25	PERVIOUS	13.9	170	6.0	0.31
H0279	642636	4846509	H0279	J5308	29.50	386	765	1.97	79.4	0.013	0.26	2	3.7	25	PERVIOUS	6.4	218	1.7	0.26
H0280	642178	4846374	H0280	J5745	23.70	339	699	2.37	56.5	0.013	0.25	2	3.6	25	PERVIOUS	8.7	219	1.7	0.26
H0281	639352	4844735	H0281	J3621	47.94	389	1231	1.60	34.5	0.013	0.30	2	4.6	25	PERVIOUS	34.1	201	3.2	0.28
H0282	637628	4850113	H0282	J7328	30.72	239	1286	1.57	49.6	0.013	0.26	2	3.6	25	PERVIOUS	8.4	220	1.5	0.26
H0283	646043	4847287	H0283	J2153	41.11	305	1349	1.44	56.0	0.013	0.25	2	3.6	25	PERVIOUS	6.8	110	10.9	0.37
H0284	639431	4852089	H0284	J5616	17.37	143	1216	1.47	66.4	0.013	0.26	2	3.8	25	PERVIOUS	11.3	220	1.5	0.26
H0285	638861	4845271	H0285	J3621	7.79	79	988	1.14	60.2	0.013	0.25	2	3.5	25	PERVIOUS	3.3	220	1.5	0.26
H0286	636863	4848292	H0286	J6769	41.90	202	2078	1.78	58.6	0.013	0.25	2	3.6	25	PERVIOUS	8.0	220	1.5	0.26
H0287	637451	4847913	H0287	J6769	10.35	61	1691	3.15	66.2	0.013	0.29	2	4.2	25	PERVIOUS	20.2	220	1.5	0.26
H0288	635918	4848666	H0288	J6769	25.82	91	2846	1.62	51.4	0.013	0.26	2	3.9	25	PERVIOUS	14.4	220	1.5	0.26
H1001	646685	4848326	H1001	J_310	30.86	396	779	1.71	45.6	0.013	0.26	2	3.7	25	PERVIOUS	10.2	110	10.9	0.37
H1002	641383	4847823	H1002	J_65	29.56	386	765	1.72	49.3	0.013	0.26	2	3.9	25	PERVIOUS	15.3	220	1.5	0.26
H1003	641970	4850333	H1003	J_181	18.60	294	632	1.54	69.2	0.013	0.26	2	3.8	25	PERVIOUS	13.7	220	1.5	0.26
H1004	635689	4853920	H1004	J_86.1	44.18	489	903	1.31	61.3	0.013	0.25	2	3.6	25	PERVIOUS	8.5	220	1.5	0.26
H1005	636402	4854229	H1005	J12060	15.19	261	582	1.29	54.1	0.013	0.32	2	4.9	25	PERVIOUS	35.6	220	1.5	0.26
H1006	636710	4854705	H1006	J_85.1	152.74	1019	1499	1.34	58.1	0.013	0.26	2	3.8	25	PERVIOUS	12.6	220	1.5	0.26
H1007	635193	4853829	H1007	J11256	31.31	399	784	1.44	57.2	0.013	0.25	2	3.6	25	PERVIOUS	6.5	220	1.5	0.26
H1008	638010	4853996	H1008	J_74	24.52	346	709	1.34	58.5	0.013	0.26	2	3.8	25	PERVIOUS	13.0	220	1.5	0.26
H1009	638758	4853298	H1009	J_75	25.05	350	715	1.34	68.1	0.013	0.25	2	3.5	25	PERVIOUS	4.9	220	1.5	0.26
H1010	638612	4854439	H1010	S68	72.12	654	1103	1.38	52.3	0.013	0.30	2	4.3	25	PERVIOUS	22.7	220	1.5	0.26
H1011	639273	4854331	H1011	S68.1	7.11	167	425	2.73	19.7	0.013	0.50	2	6.9	25	PERVIOUS	66.1	220	1.5	0.26
H1012	638305	4848049	H1012	S190	16.57	275	603	1.49	89.4	0.013	0.25	2	3.6	25	PERVIOUS	2.3	213	2.7	0.27
H1013	645180	4850580	H1013	J3852	71.27	237	3002	2.93	42.5	0.013	0.33	2	5.3	25	PERVIOUS	43.5	121	10.0	0.36
H1014	642212	4851354	H1014	J_76	10.75	213	504	1.78	55.3	0.013	0.26	2	3.7	25	PERVIOUS	10.6	119	10.2	0.36
H1015	639425	4845319	H1015	S343	1.87	77	243	2.71	36.6	0.013	0.40	2	6.5	25	PERVIOUS	66.1	216	1.9	0.27
H1016	639103	4845421	H1016	S343	9.35	196	476	1.42	64.9	0.013	0.27	2	3.9	25	PERVIOUS	15.8	141	8.2	0.34
H1017	637339	4848425	H1017	J_63	21.37	319	670	1.68	55.5	0.013	0.25	2	3.6	25	PERVIOUS	8.4	220	1.5	0.26
H1018	635333	4849985	H1018	S_304.2	4.12	122	338	2.29	48.7	0.013	0.29	2	4.4	25	PERVIOUS	26.4	220	1.5	0.26
H1019	636257	4848417	H1019	J_61	23.84	340	701	2.03	55.8	0.013	0.26	2	3.7	25	PERVIOUS	10.9	220	1.5	0.26
H1020	636738	4848636	H1020	J_62	11.37	220	516	1.62	55.5	0.013	0.26	2	3.8	25	PERVIOUS	12.4	220	1.5	0.26
H1021	635653	4849034	H1021	S_304.1	4.10	121	338	1.46	61.3	0.013	0.27	2	4.0	25	PERVIOUS	16.6	220	1.5	0.26
H1022	636699	4855282	H1022	J_85	51.59	536	962	1.30	49.5	0.013	0.25	2	3.6	25	PERVIOUS	8.8	220	1.5	0.26
H1023	635322	4849247	H1023	J6769	18.62	294	633	1.64	45.5	0.013	0.26	2	3.8	25	PERVIOUS	14.1	220	1.5	0.26
H1024	635515	4848813	H1024	J_60	15.84	268	592	1.56	49.0	0.013	0.26	2	3.7	25	PERVIOUS	10.9	220	1.5	0.26
H1025	646263	4851014	H1025	S21.1	21.68	322	674	1.54	84.8	0.013	0.29	2	4.1	25	PERVIOUS	17.3	120	10.1	0.36
H1026	635201	4850362	H1026	S_304.2	2.89	99	292	2.02	59.7	0.013	0.25	2	3.6	25	PERVIOUS	6.9	220	1.5	0.26
H1027	635486	4849526	H1027	S_304.2	4.69	131	357	1.47	61.6	0.013	0.26	2	3.7	25	PERVIOUS	11.4	220	1.5	0.26
H1028	634856	4853566	H1028	J_86.3	11.37	220	516	1.26	60.9	0.013	0.25	2	3.5	25	PERVIOUS	5.0	220	1.5	0.26
H1029	634926	4854047	H1029	J_86.3	25.68	356	722	1.30	53.6	0.013	0.26	2	3.8	25	PERVIOUS	13.0	220	1.5	0.26
H1030	635529	4854424	H1030	J_86.1	31.30	400	783	1.41	53.6	0.013	0.26	2	3.8	25	PERVIOUS	13.4	220	1.5	0.26
H1031	636265	4853952	H1031	S30	14.48	254	570	1.27	94.3	0.013	0.25	2	3.5	25	PERVIOUS	1.1	220	1.5	0.26
H1032	642188	4852669	H1032	J2938	98.33	785	1252	1.61	66.4	0.013	0.26	2	3.7	25	PERVIOUS	9.8	220	1.5	0.26

# APPENDIX G
Flow Length Calibration Method

APPENDIX G

OVERLAND FLOW LENGTH ANALYSIS

Overland catchment length is a sensitive model parameter that affects routing as well as runoff volumes from each catchment. As many parameters within a catchment can be measured or approximated with physical data (i.e., imperviousness, depression storage, etc.), flow length becomes a parameter to reflect how many elements alter runoff travelling to the outlet of a watershed. In the Highland Creek model, no urban infrastructure (i.e., sewers, roads, ditches, etc.) were included within the catchments. Flow length became the primary tool to calibrate runoff timing. This document examines the methods used to represent overland flow length within the Highland Creek model, how each method affects runoff and routing through the catchment, and ultimately how routing was represented within the hydrologic model.

1   METHODS AND ANALYSIS

Several alternatives to defining flow length within each catchment were tested to calibrate the Highland Creek model. Flow lengths were initially estimated using a traditional approach whereby the flow length represents overland sheet flow before it is channelized (e.g., typically 100 to 150 m). Although this approach aligned with a typical urban model set up, without the representation of the minor system network or major overland flow routes, there is no other mechanism to represent additional catchment routing. Simulating such short flow lengths within each catchment created a response to runoff that was too rapid in comparison to observed events (Figure G1).

Two other alternatives were tested in the hydrologic model. The first was manually adding nodes and conduits to each catchment to represent the roads/minor system. Catchments were set at a 150 m flow length, and runoff from the catchment was directed to the node which conveys the runoff through a conduit to the watercourse. The simulated conduit length and slope was measured from aerial imagery. The results of the pseudo road/minor system routing is shown on Figure G1. The third method measured the longest overland flow path within the catchment to represent the catchment length. The results of this method are also shown on Figure G1.
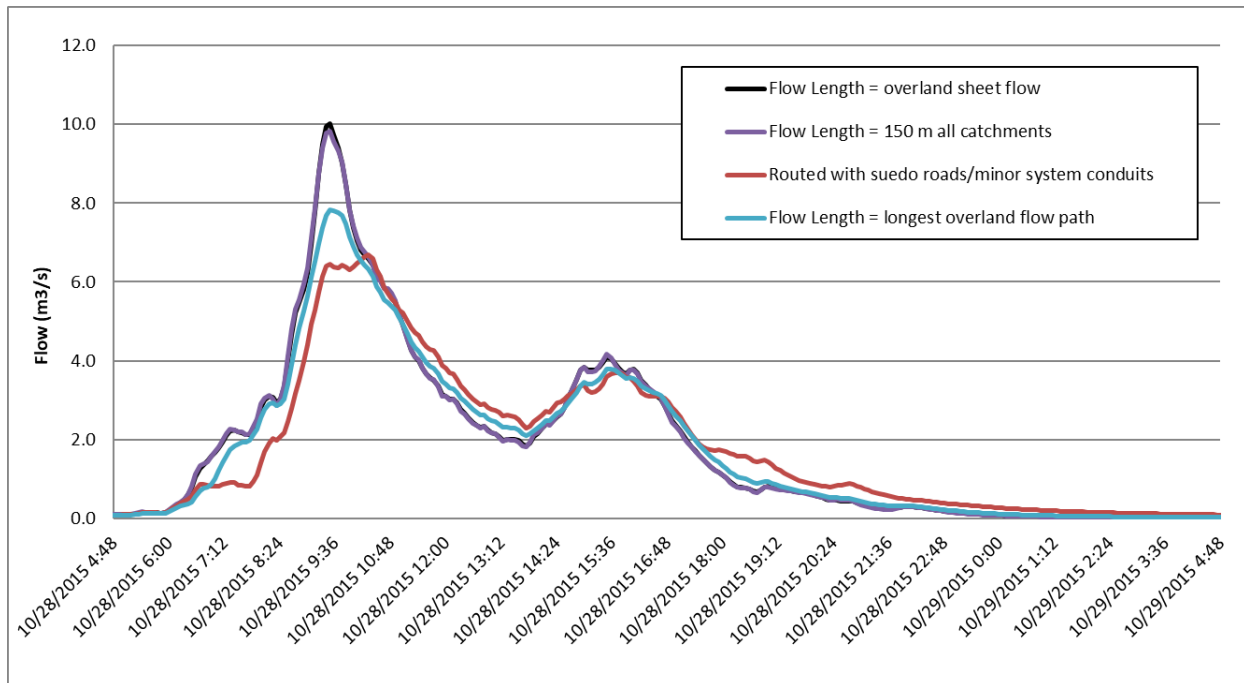
FIGURE G1   **Hydrograph Output from various Flow Length Scenarios**

The flow length analysis determined that having short flow lengths (averaging 150 m) provided a runoff response too rapid to represent routing within the catchment. The pseudo road/minor system routing and longest overland flow path show a similar runoff response. However, adding pseudo roads within each catchment is much more time intensive and requires several assumptions related to the slope, length, shape, and elevation of the routing conduit, all which contain more potential for errors. The analysis found that using the longest overland flow length within each catchment produced results that were similar to the road routing method but could be easily estimated and applied to each catchment.

The longest overland flow path for each catchment was estimated from a drainage area relationship developed by the United States Department of Agriculture (USDA 2010). This empirical method matched well to measured flow path lengths in GIS.

1.1   Equivalent Kinematic Wave Planes

The SWMM model code routes runoff within a catchment using a technique known as the kinematic wave (KW) approach which approximates routing in a natural irregular watershed to an equivalent KW plane with a cascading plane width (Guo and Urbonas 2009). Determine the cascading plane width is dependent on a number of variables that represent how water travels from the high point in a watershed to the low point/outlet. An example of how a natural watershed is approximated to an equivalent KW cascading plane is shown in Figure G2.
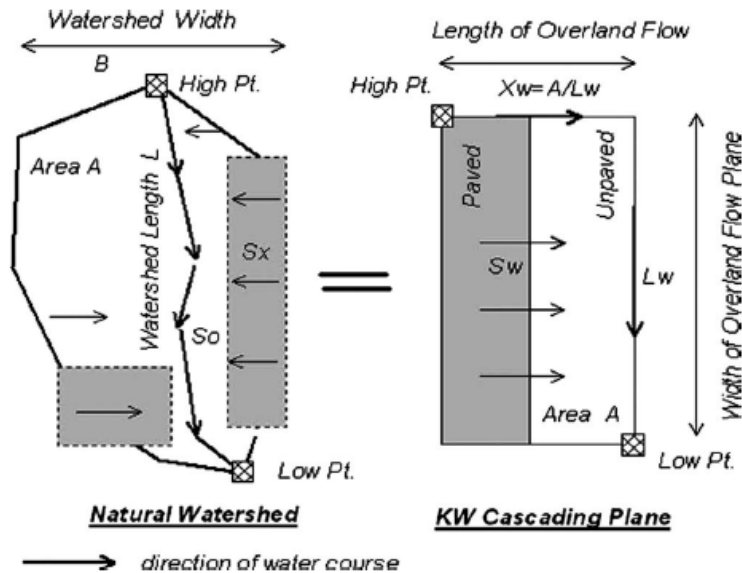
FIGURE G2   Natural Watershed and Kinematic Wave Plane (Guo and Urbonas, 2009)

The study completed by Guo and Urbonas (2009) found that one of the best predictors of converting a natural watershed to KW cascading plane is through the use of KW shape factor and can be used for a range of subwatershed sizes such as Highland Creek. The KW shape factor (Y) is made up of a number of factors and is related to the natural shape factor of a watershed (X), where:

$$\text{Y} = (1.5 - Z)(\frac{2}{1 - 2K}X^2 - \frac{4K}{1 - 2K}X)$$

Where:

X = watershed shape factor = $(\frac{A}{L^2})$ where A is the watershed area and L is the length of the overland channel.

K = upper limit of the shape factor (upper limit typically ranges from 4 to 6)

Z = area of skewness coefficient (ranges from 0.5 to 1.0)

Y = the KW shape factor = $\frac{Lw}{L}$ where Lw is the width of the KW plane

The relationship shown above was used to convert the empirically calculated length of the overland channel within each catchment to the equivalent width of the KW plane (Lw). A range of Z and K parameters were used to test how the empirically calculated lengths could translated Lw. Based on a review of the shape of the Highland Creek catchments, a Z factor of 0.5 was found to be most appropriate at many overland flow paths were aligned to the centre of the channel. The final calibrated model used a KW modified flow length with a Z factor of 0.5 and K factor of 4.

TABLE G1   KW Plane Analysis Summary

Metrics	Empirical Length (m)	*Lw* (m)							
		$K = 1$ $Z = 0.5$	$K = 1$ $Z = 1.0$	$K = 2$ $Z = 0.5$	$K = 2$ $Z = 1.0$	$K = 4$ $Z = 0.5$	$K = 4$ $Z = 1.0$	$K = 6$ $Z = 0.5$	$K = 6$ $Z = 1.0$
Maximum	2,343	2,389	2,599	1,733	1,803	1,546	1,576	1,494	1,514
Minimum	94	185	258	172	196	168	178	167	173
Median	834	1,113	1,262	841	891	764	785	743	756
Average	861	1,109	1,255	837	886	759	780	738	751

REFERENCES

Guo J.C.Y. and B. Urbonas. 2009. 'Conversion of Natural Watershed to Kinematic Wave Cascading Plane'. *Journal of Hydrologic Engineering 14* (*8*): 839–846. August 2009.

United States Department of Agriculture (USDA). 2010. *Part 630 Hydrology National Engineering Handbook*. Chapter 15 Time of Concentration. May 2010.

APPENDIX H
Calibration and Validation Plots

APPENDIX H

CALIBRATION AND VALIDATION PLOTS

C1 - Calibration - June 23, 2015

HY034 Simulated
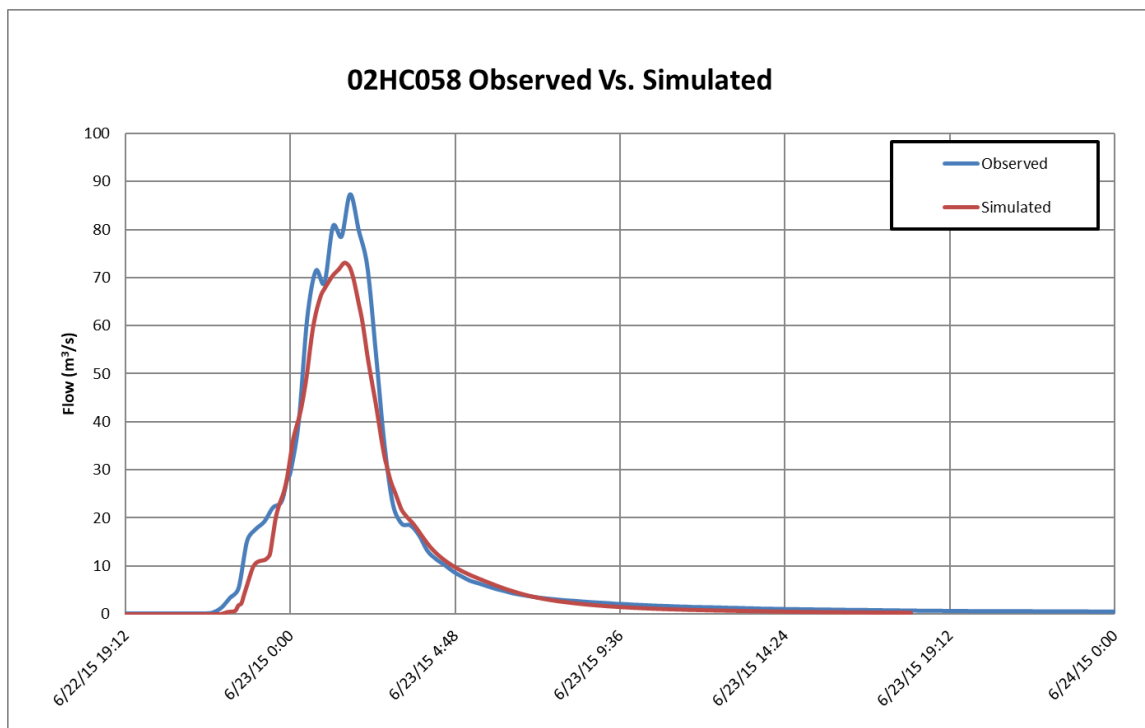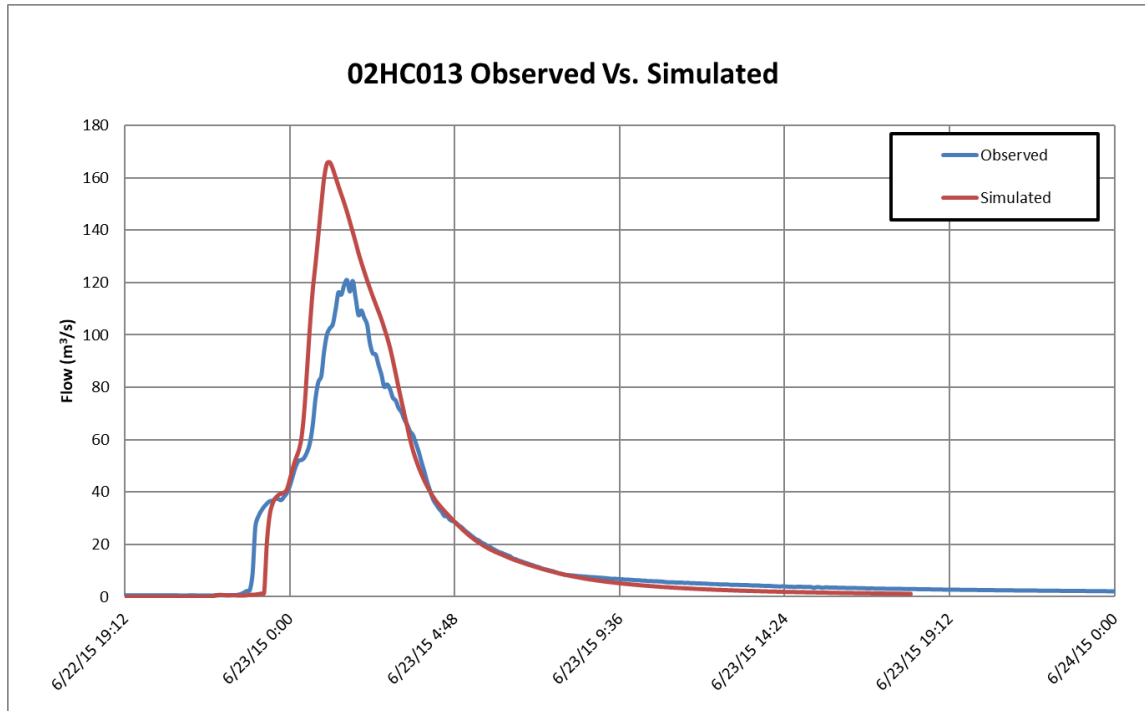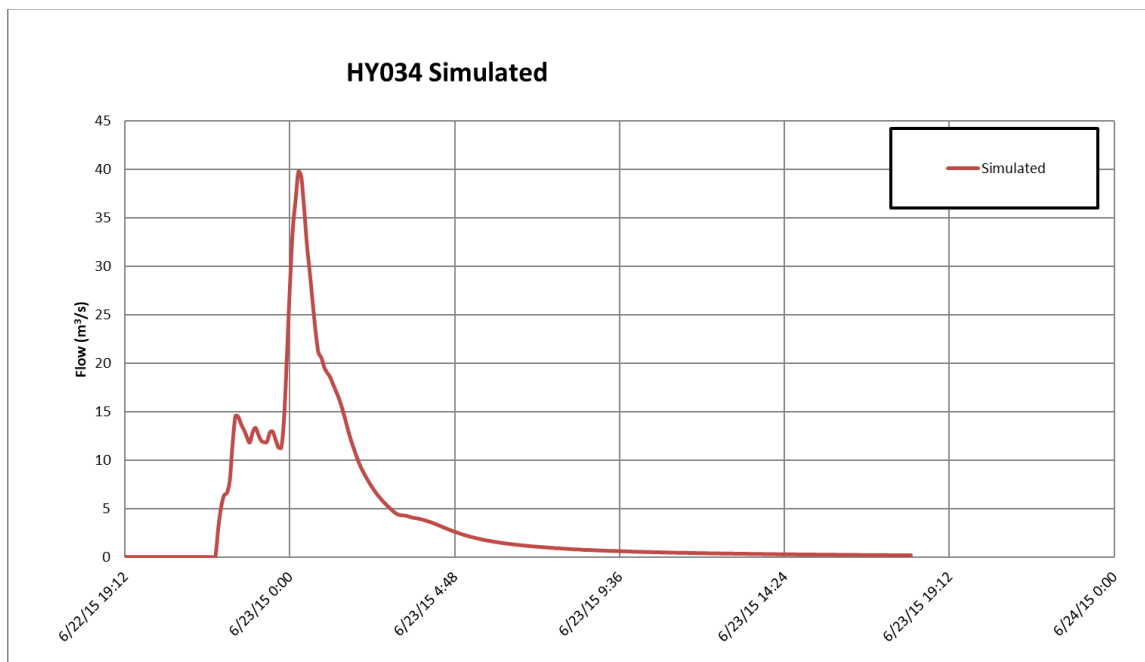
C2 - Calibration - May 29, 2013

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02HC058 Observed Vs. Simulated

HY034 Observed Vs. Simulated
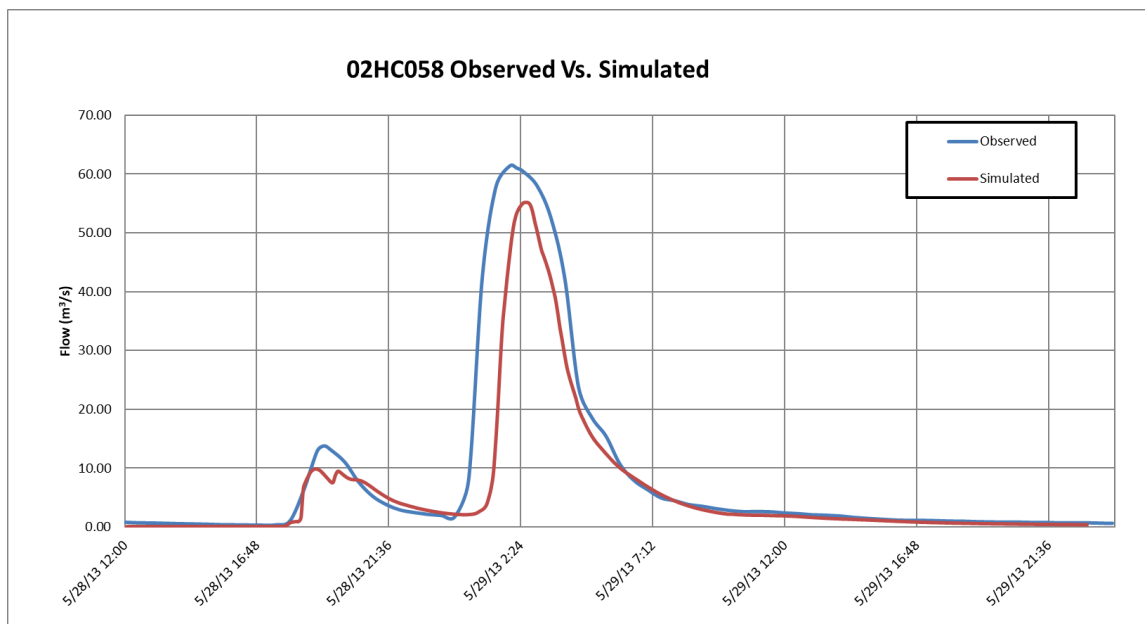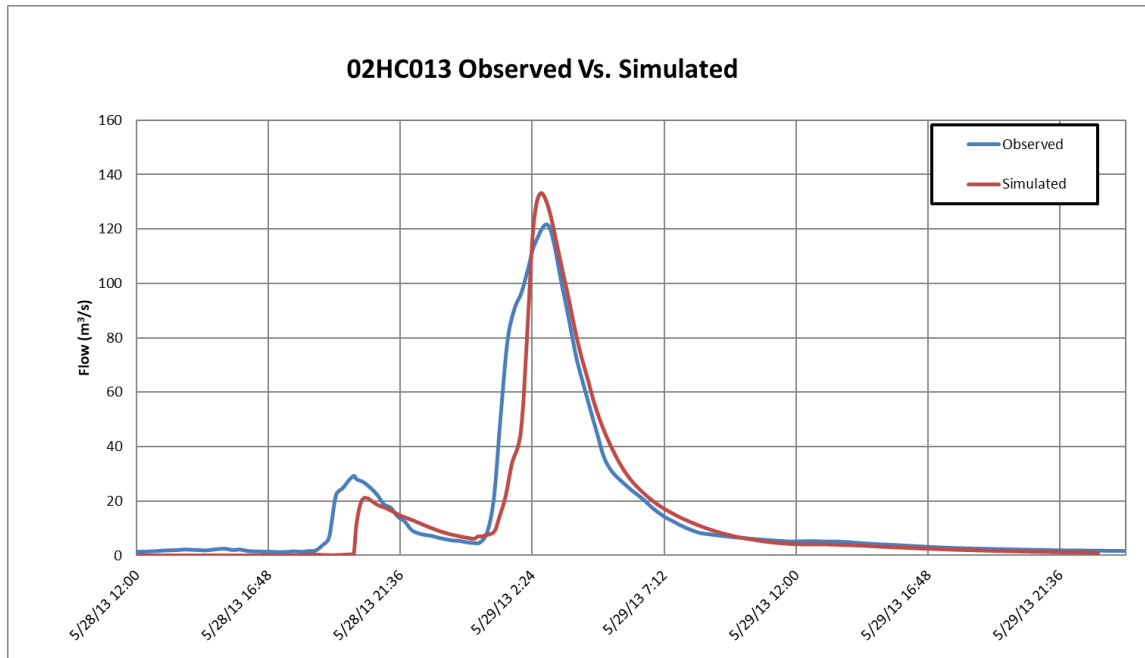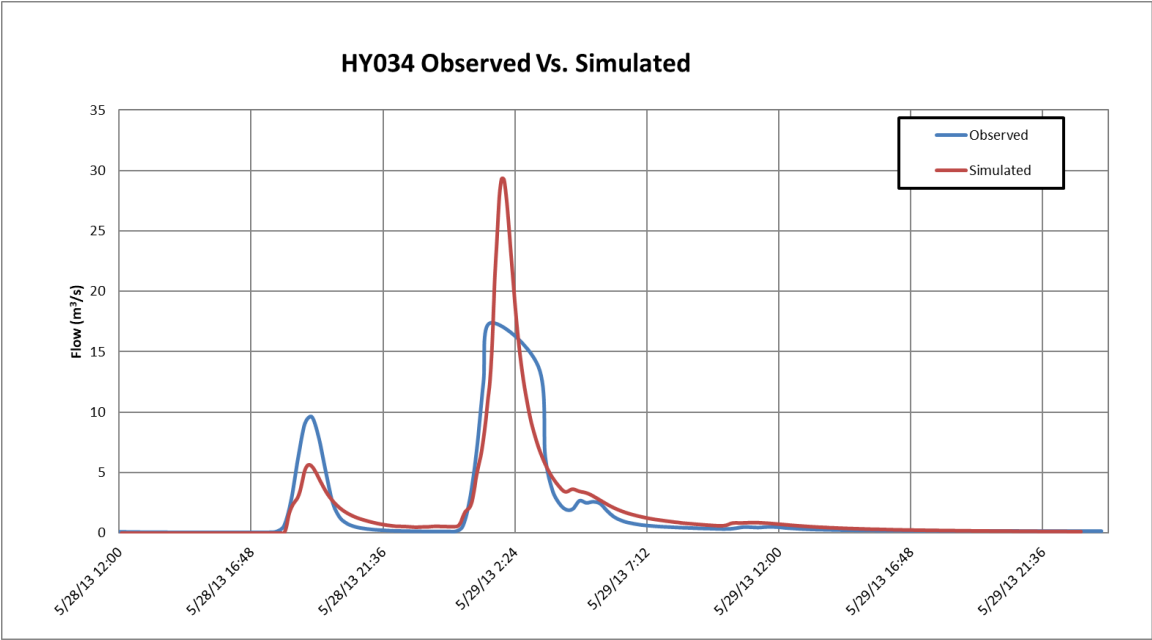
C4 - Calibration - July 26, 2012

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02HC058 Observed Vs. Simulated

HY034 Observed Vs. Simulated
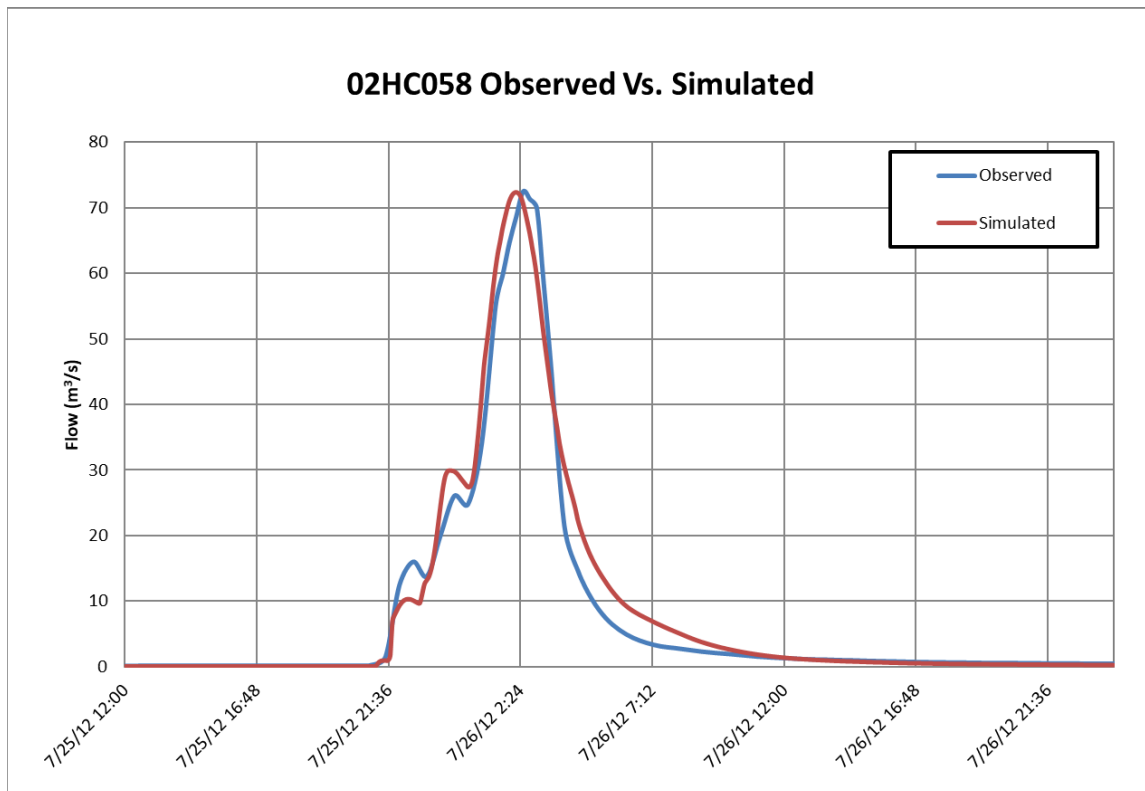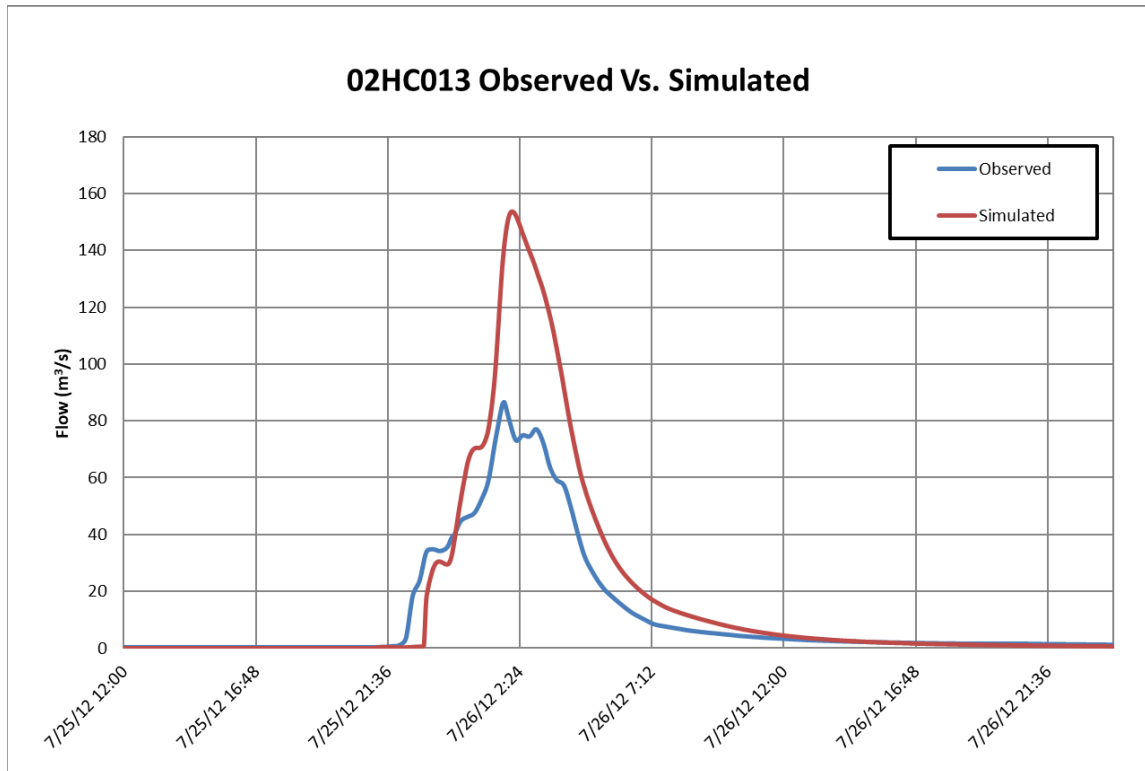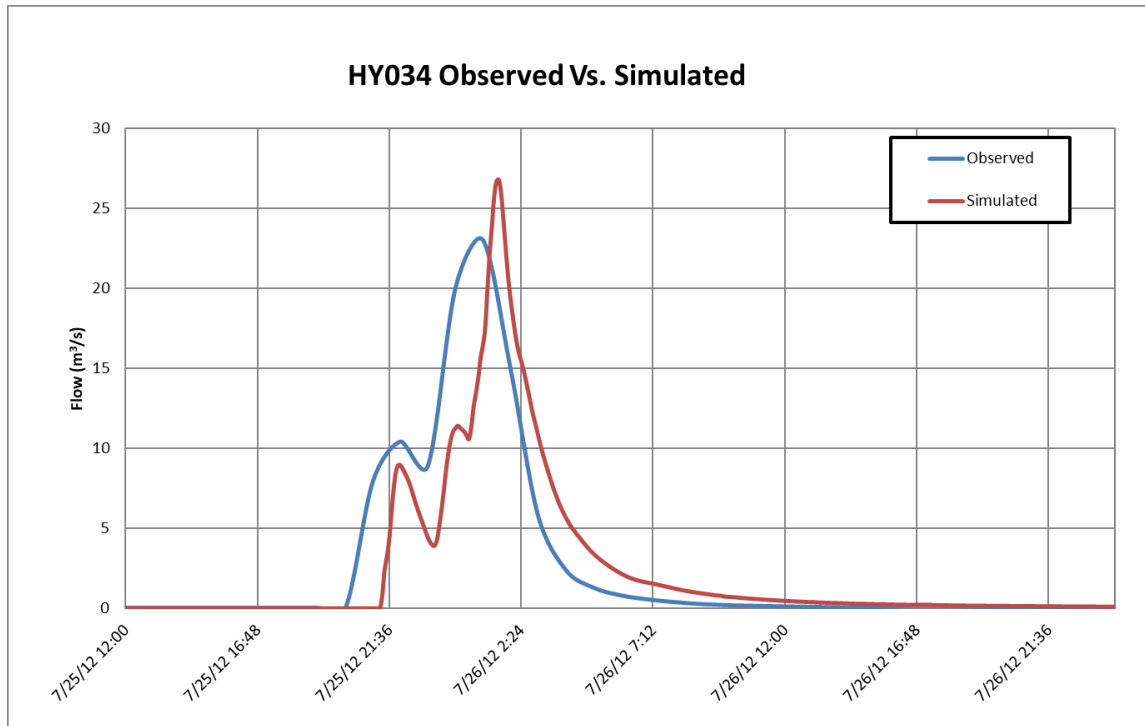
C5 - Calibration - October 28, 2015

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02HC058 Observed Vs. Simulated

HY034 Simulated
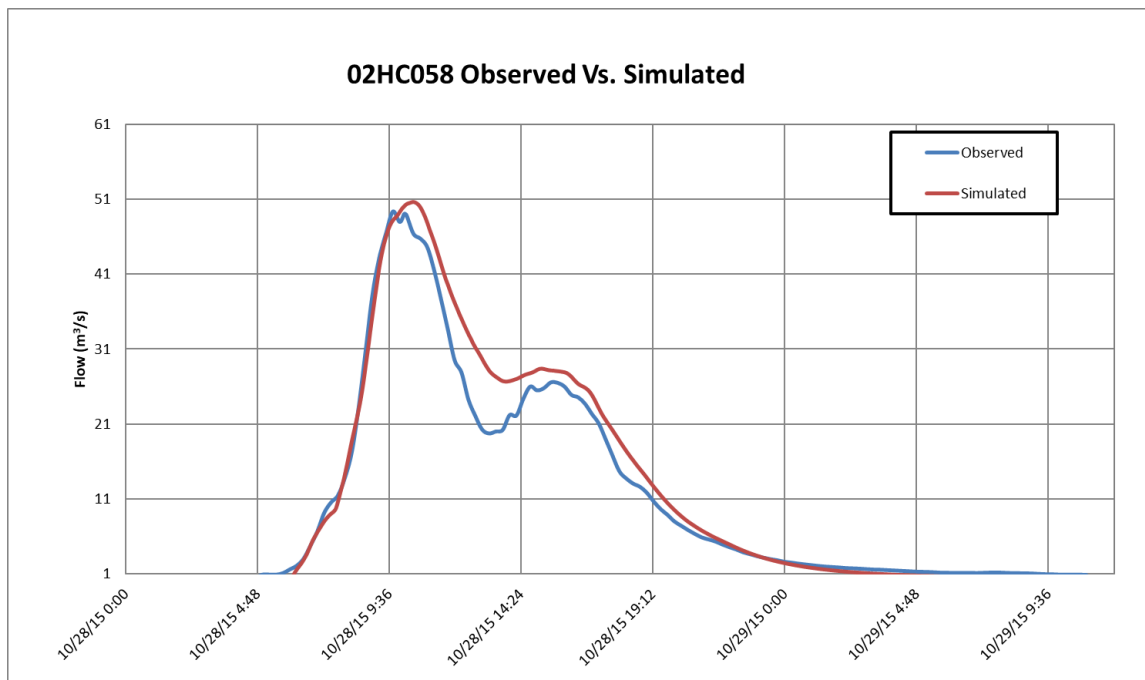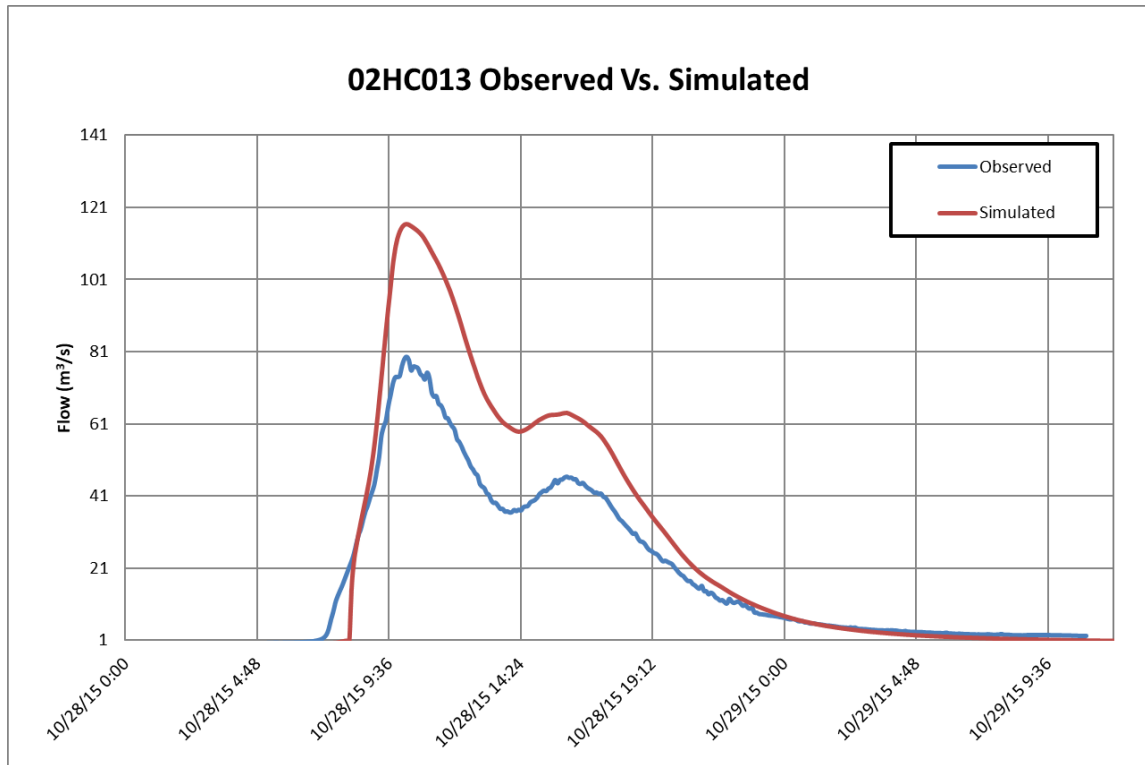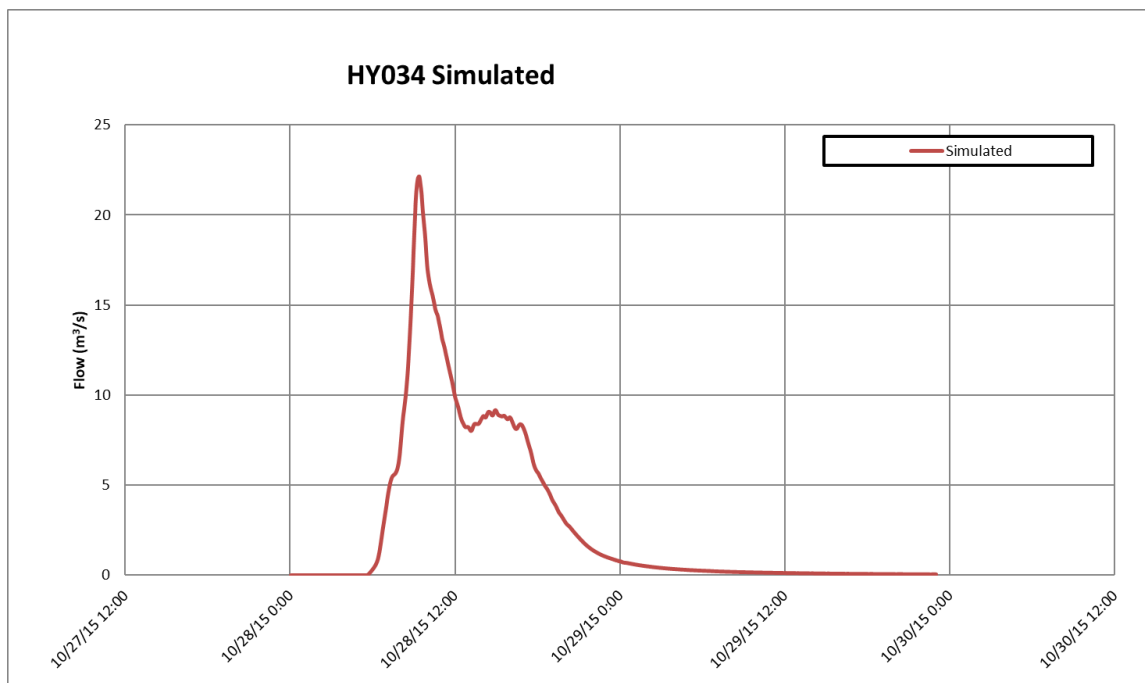
C6 - Calibration - August 4, 2014

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02HC058 Observed Vs. Simulated

HY034 Simulated

02HC013 Observed Vs. Simulated

02HC058 Observed Vs. Simulated

HY034 Simulated
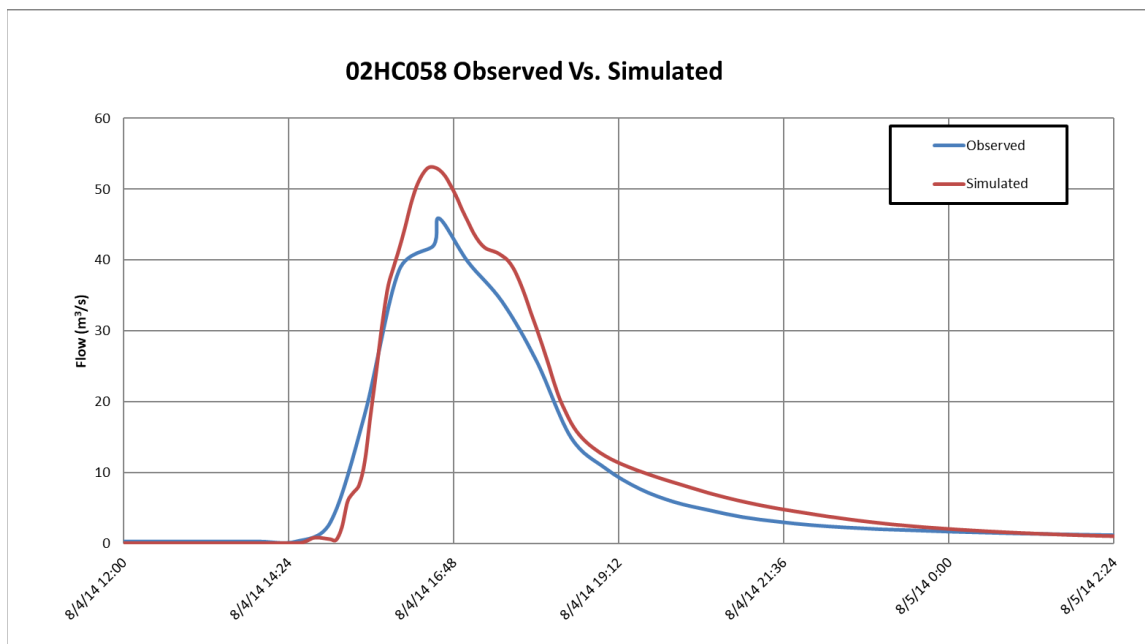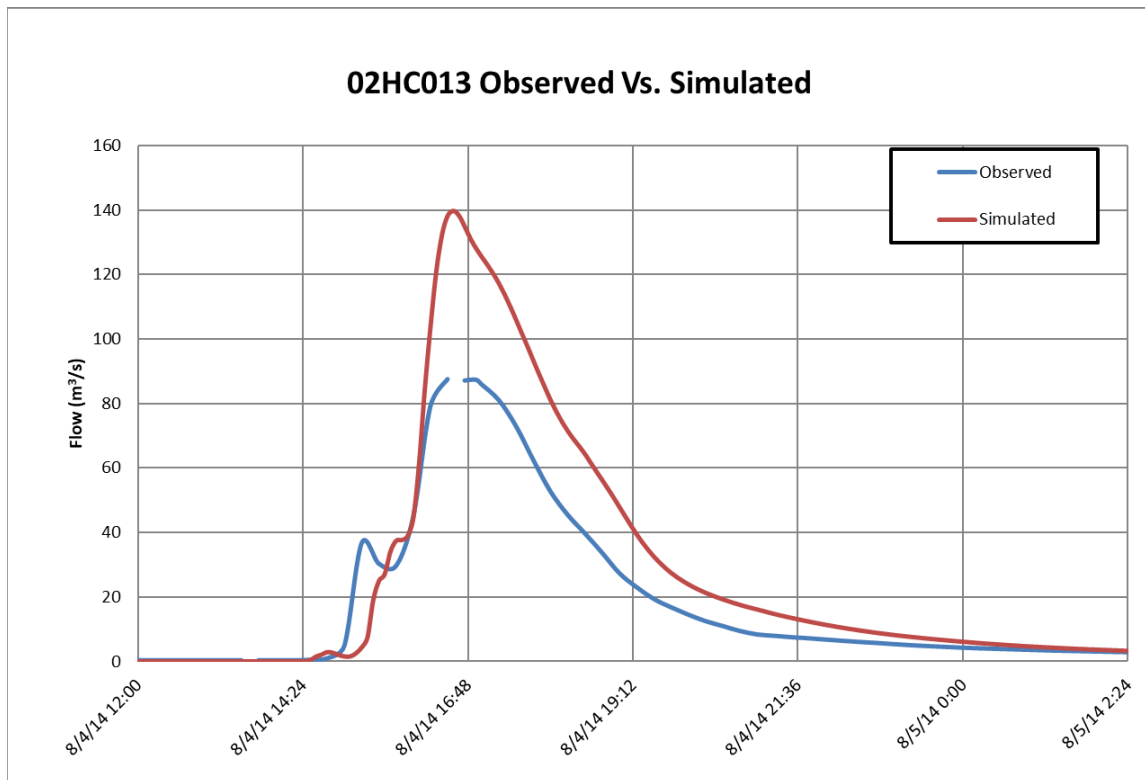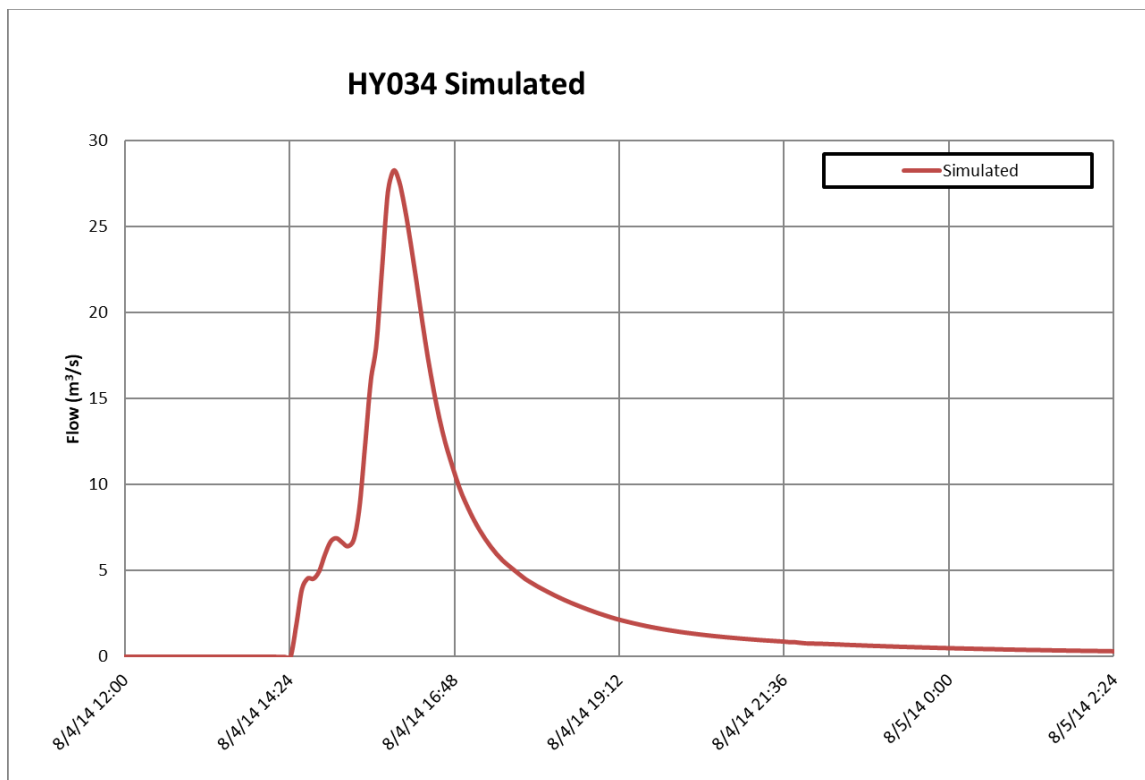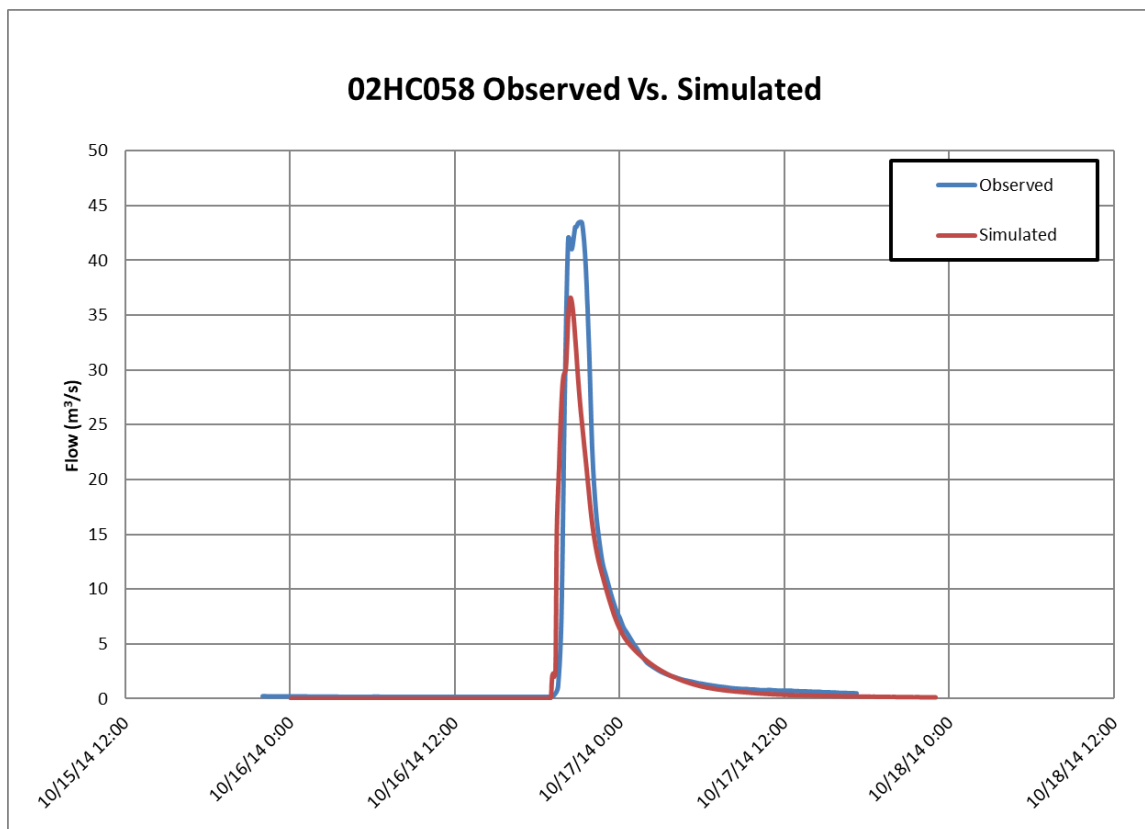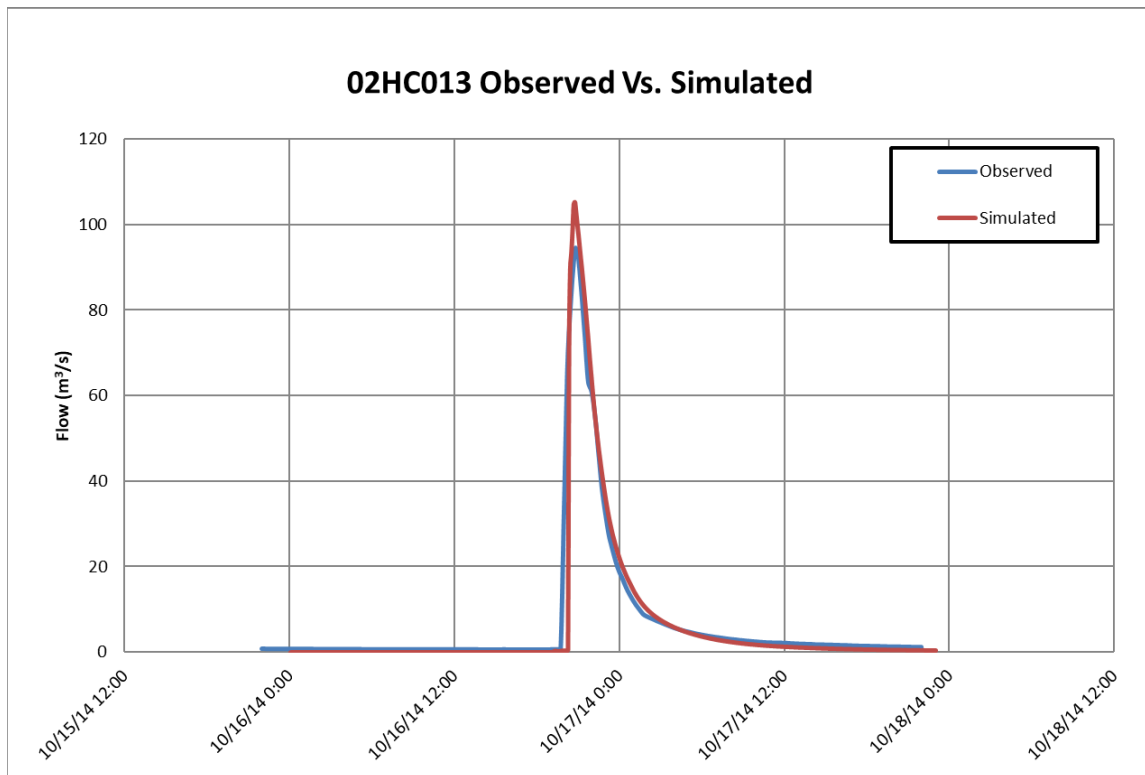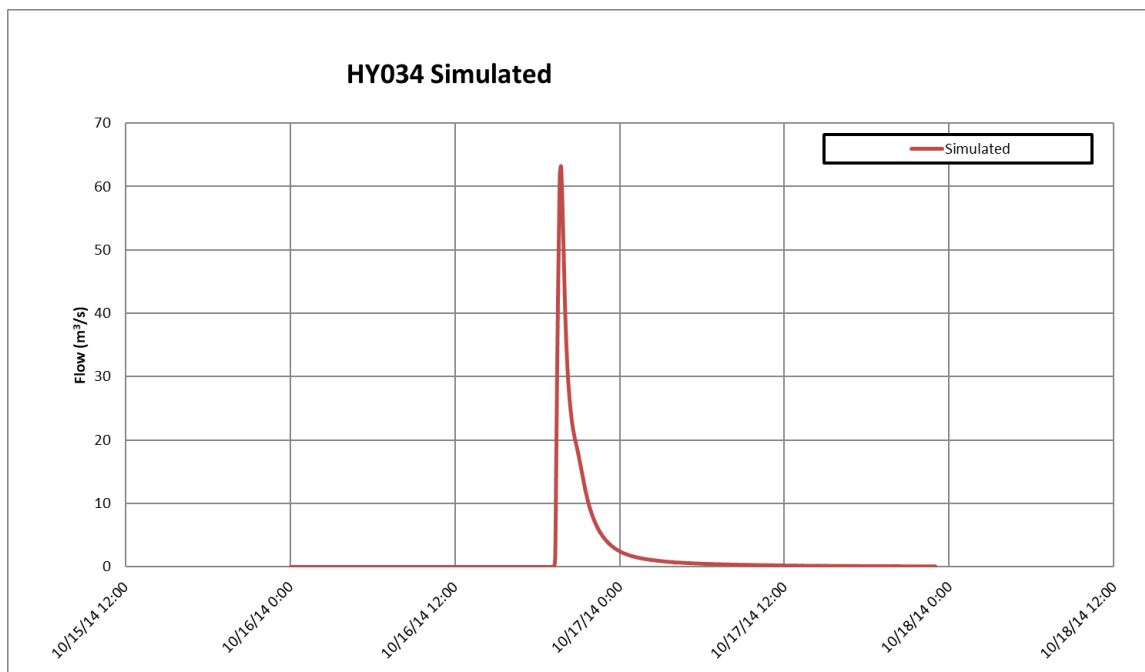
V3 - Validation - August 10, 2012

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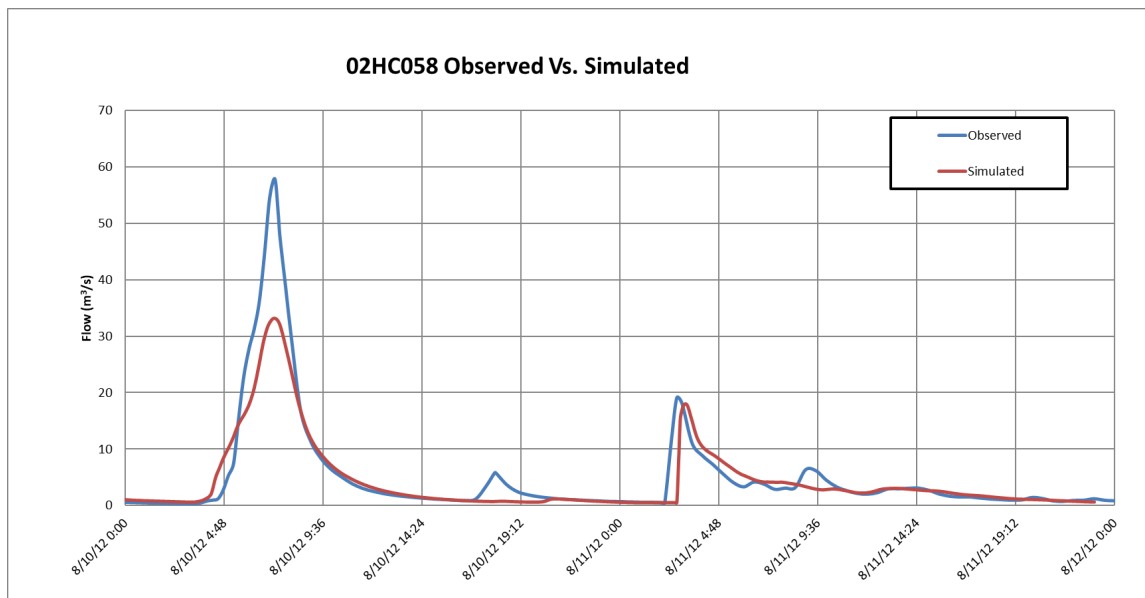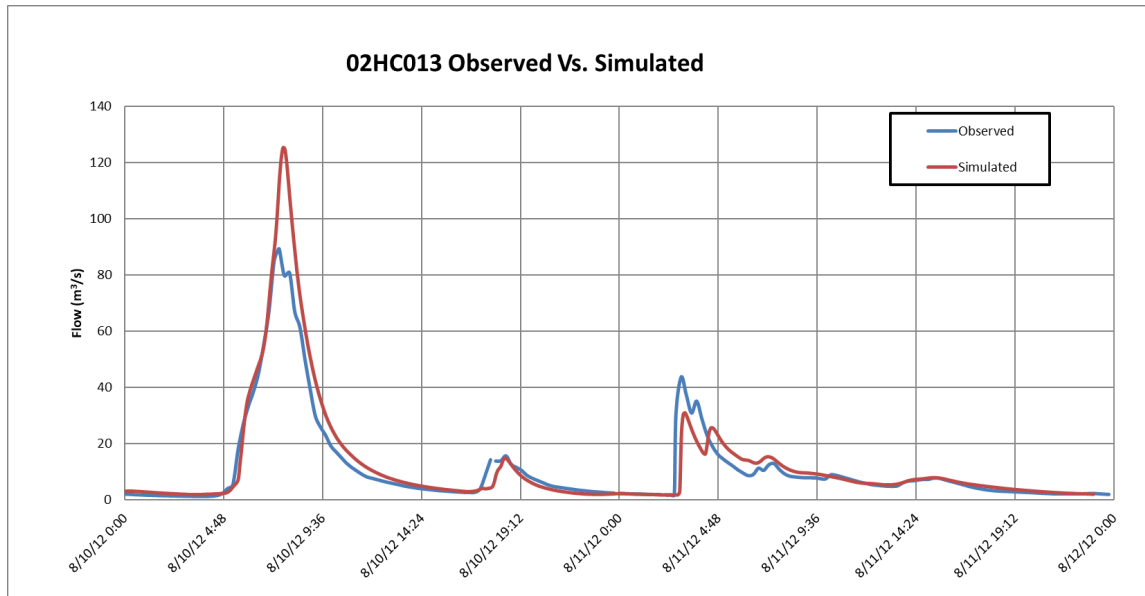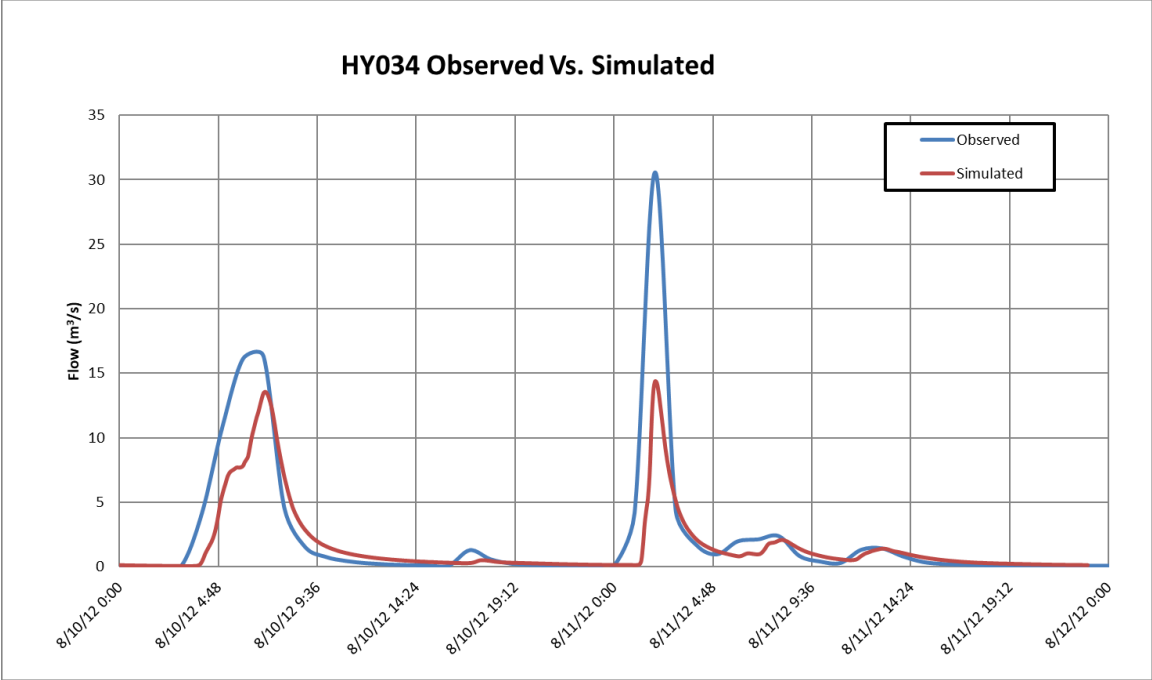
V4 - Validation - July 9, 2010

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02HC058 Observed Vs. Simulated

HY034 Simulated

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02HC058 Observed Vs. Simulated

HY034 Observed Vs. Simulated
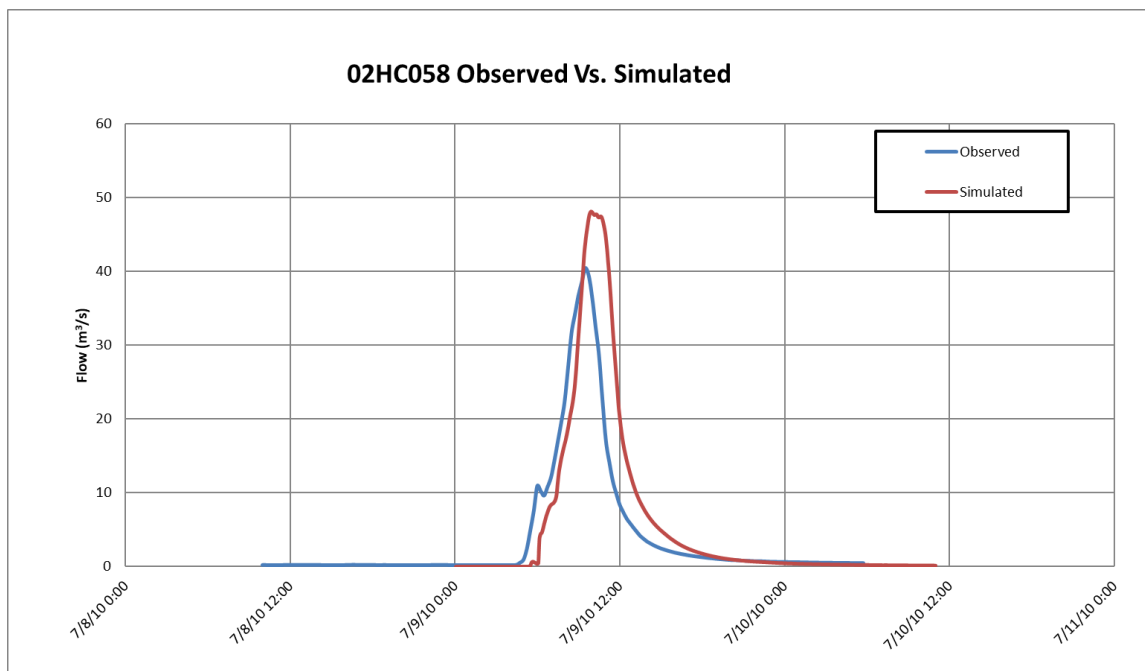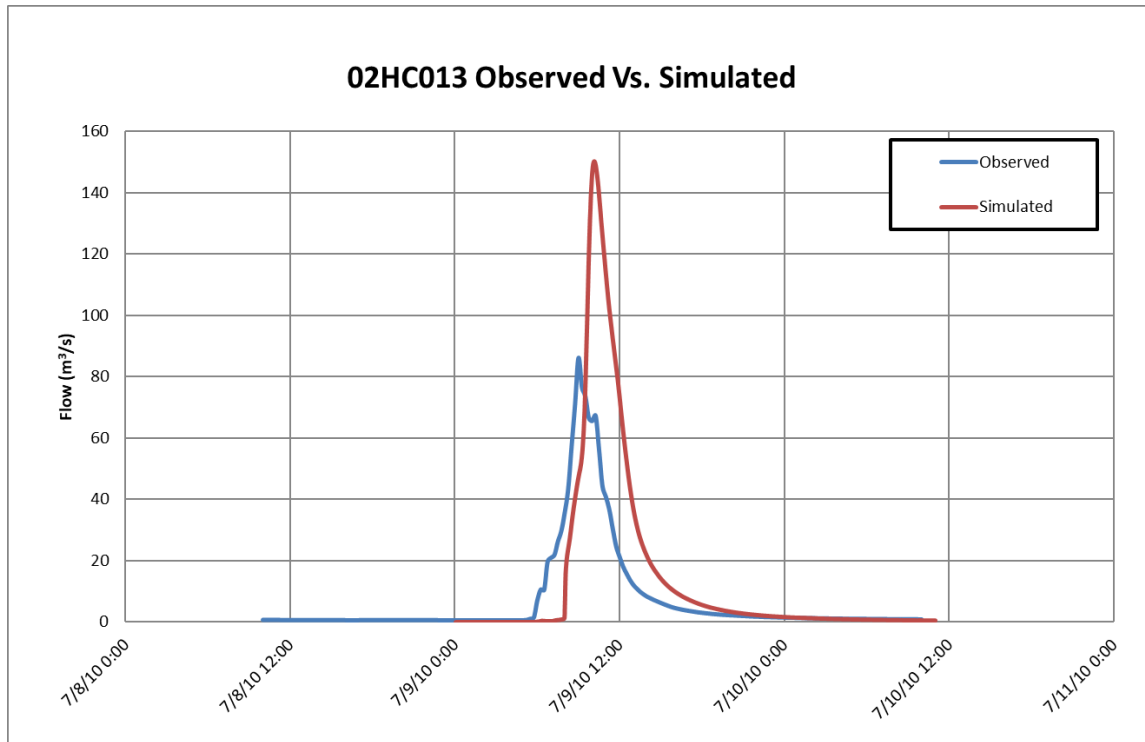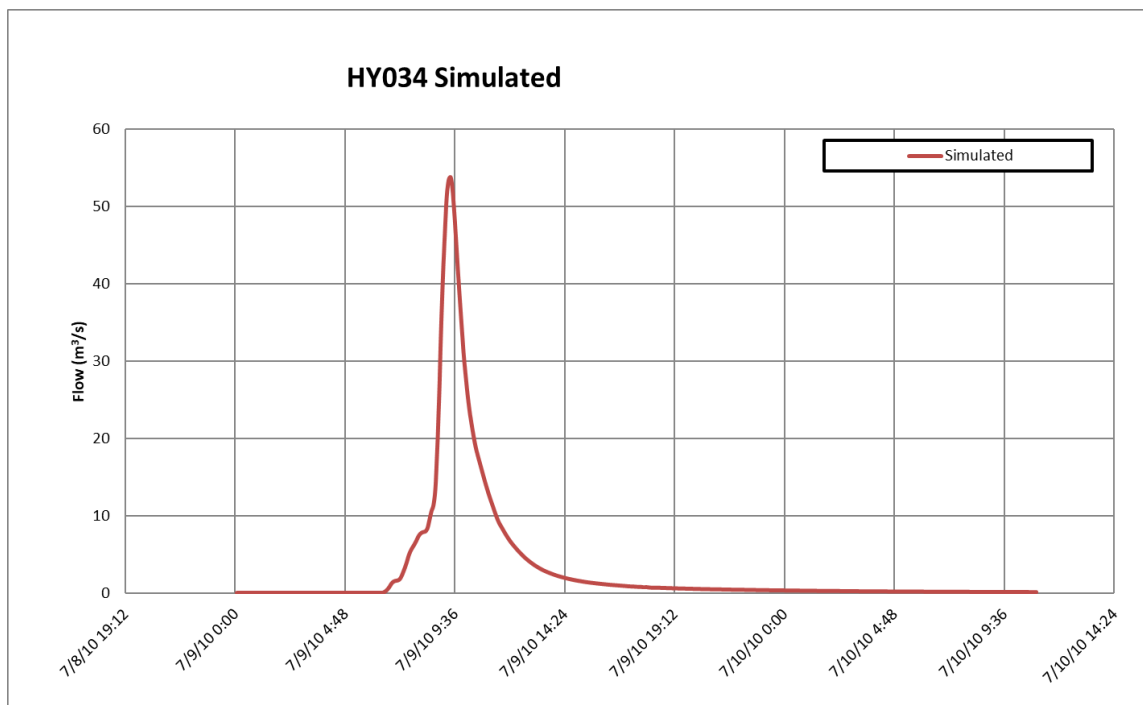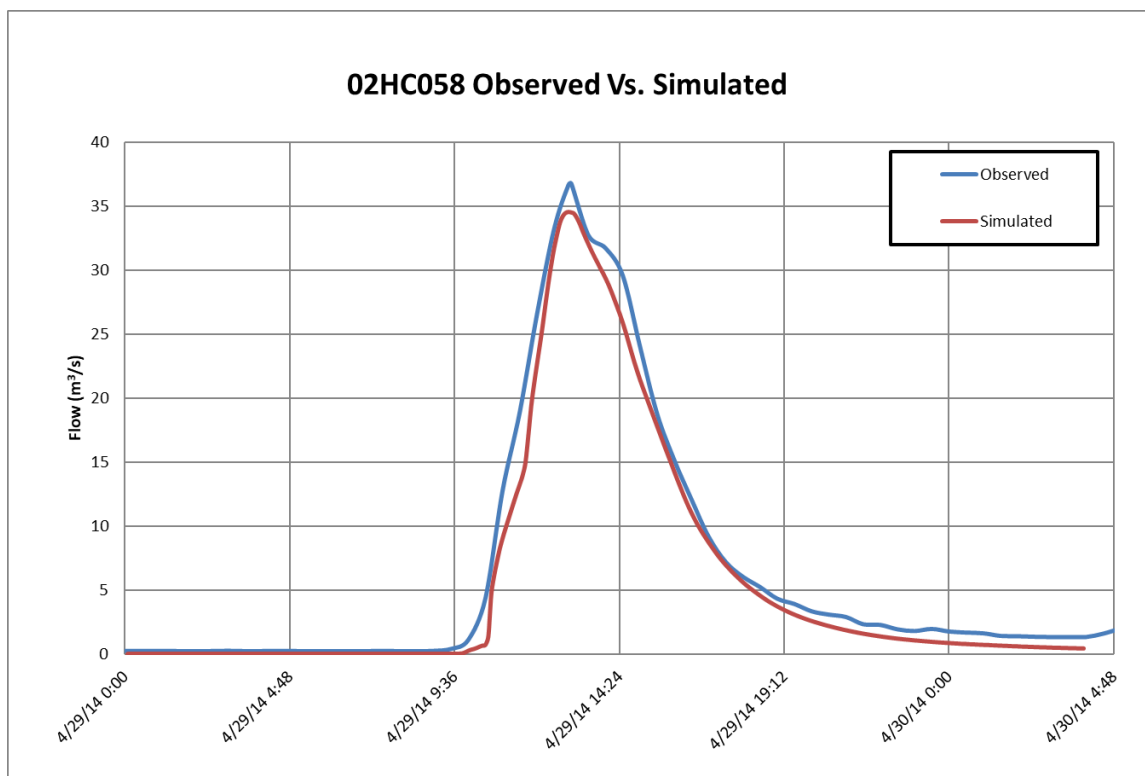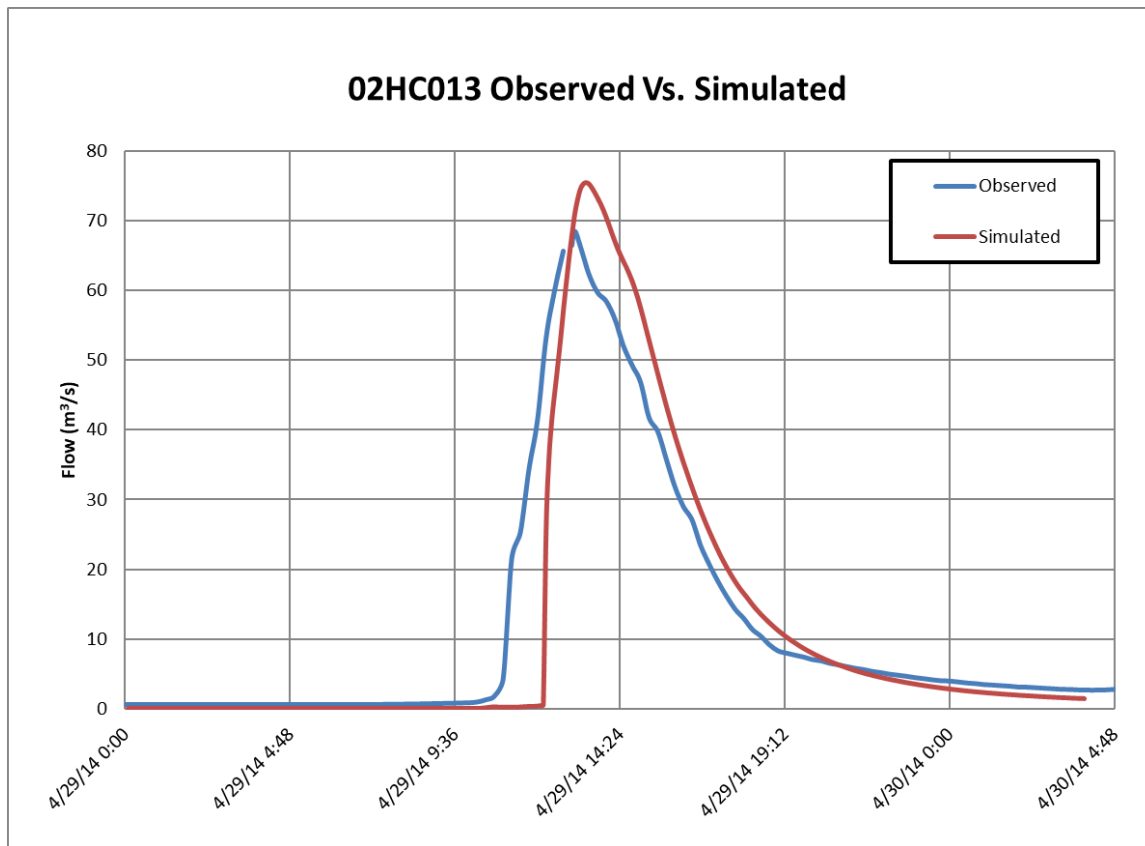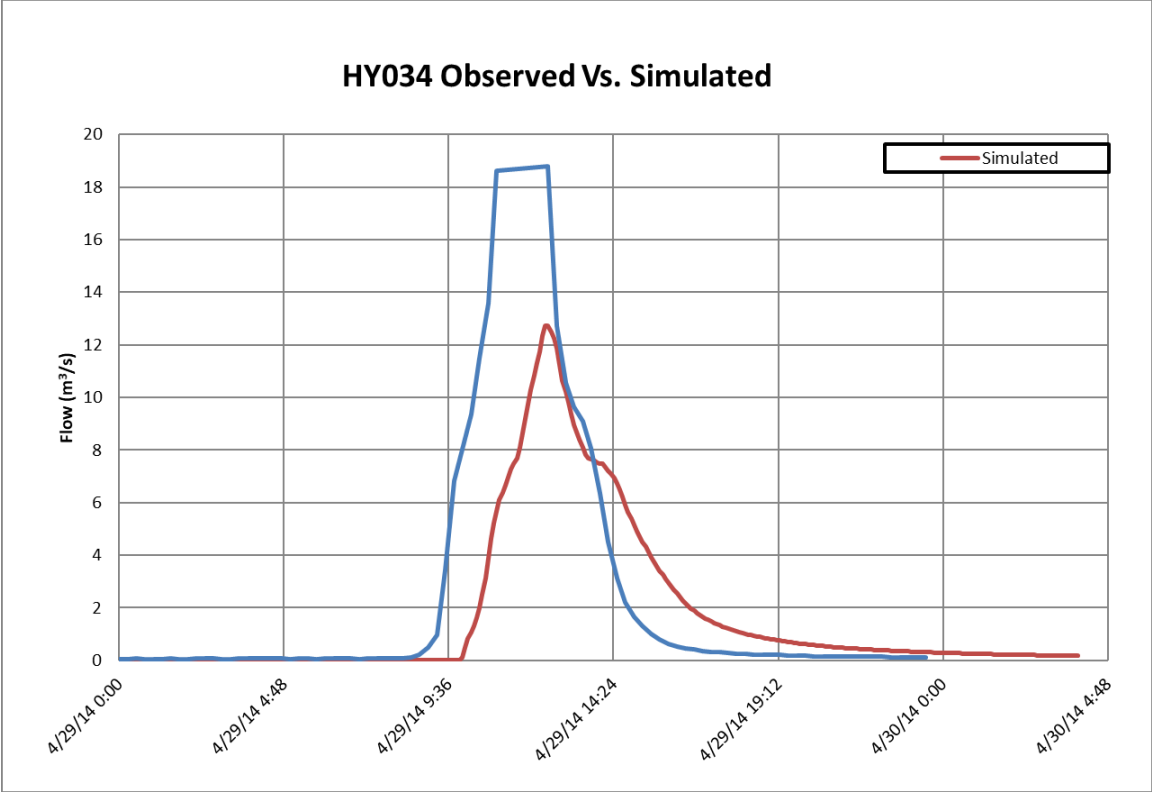
V6 - Validation - June 5, 2015

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HY034 Simulated

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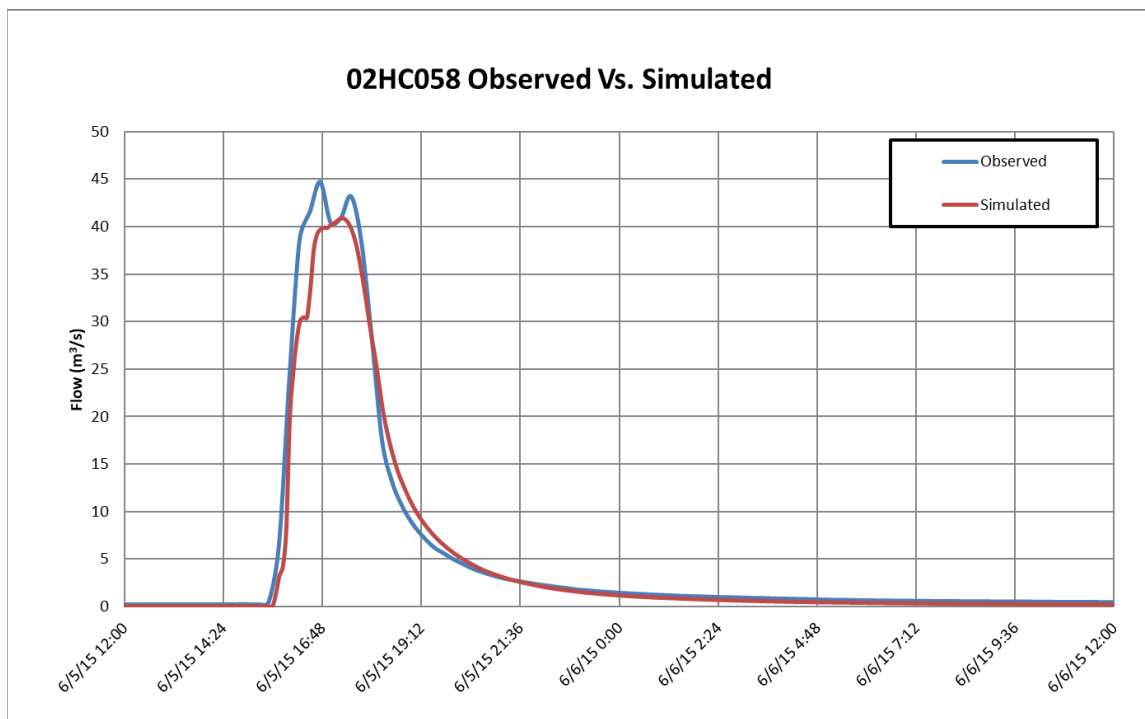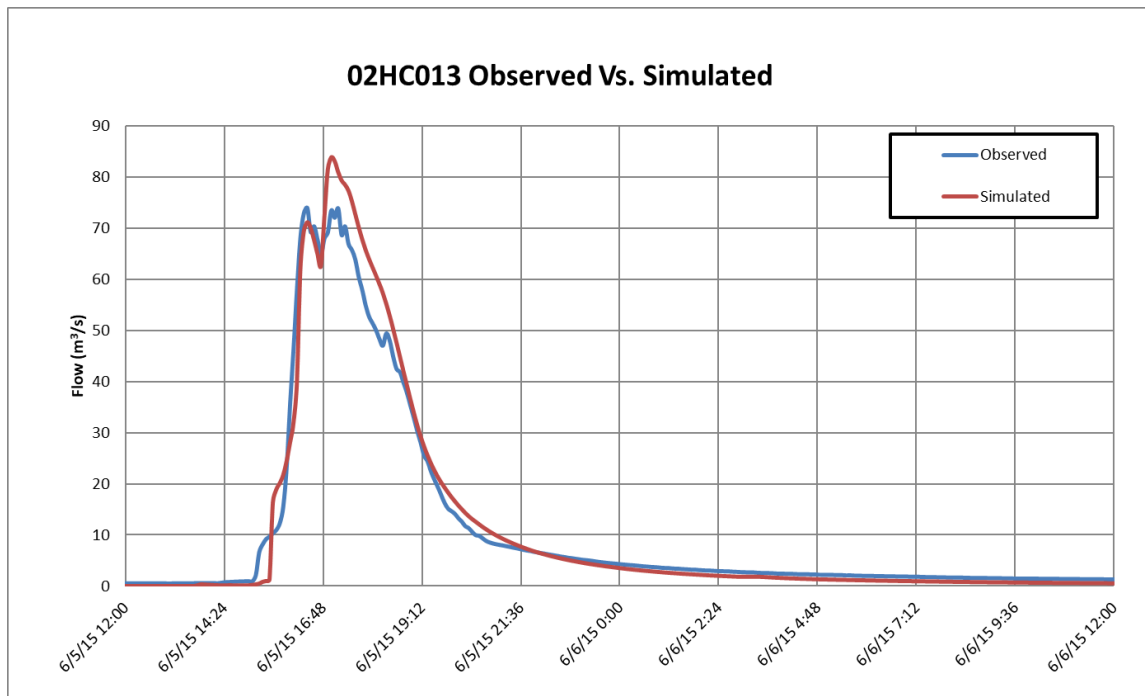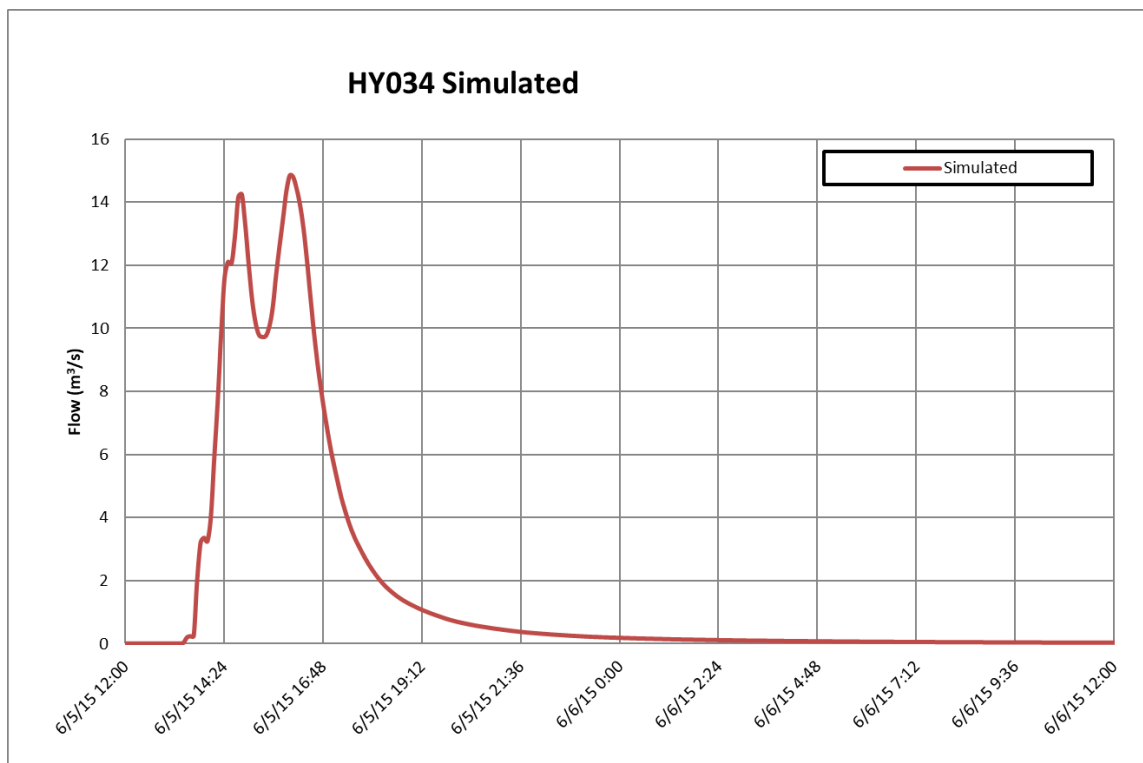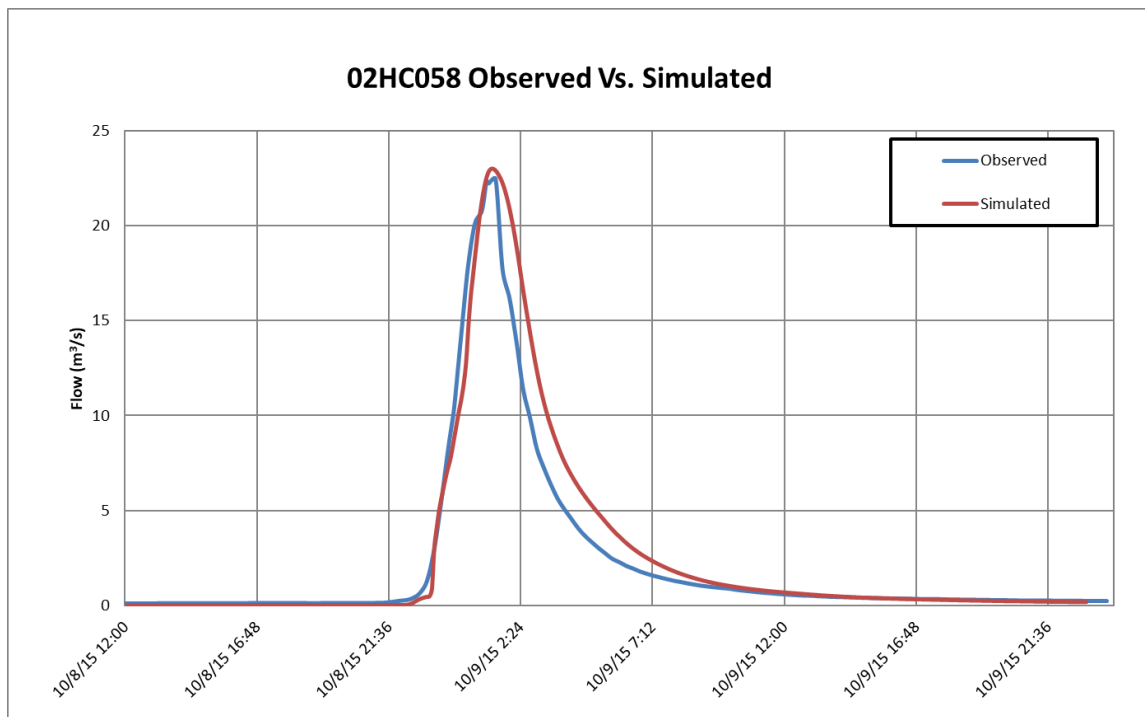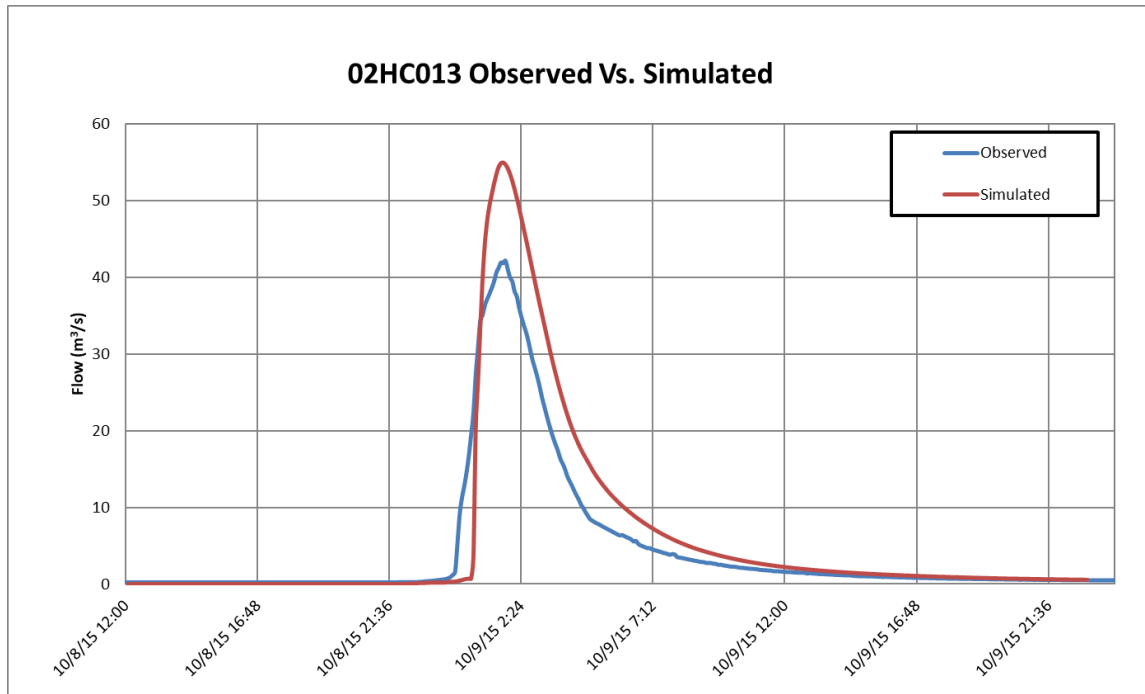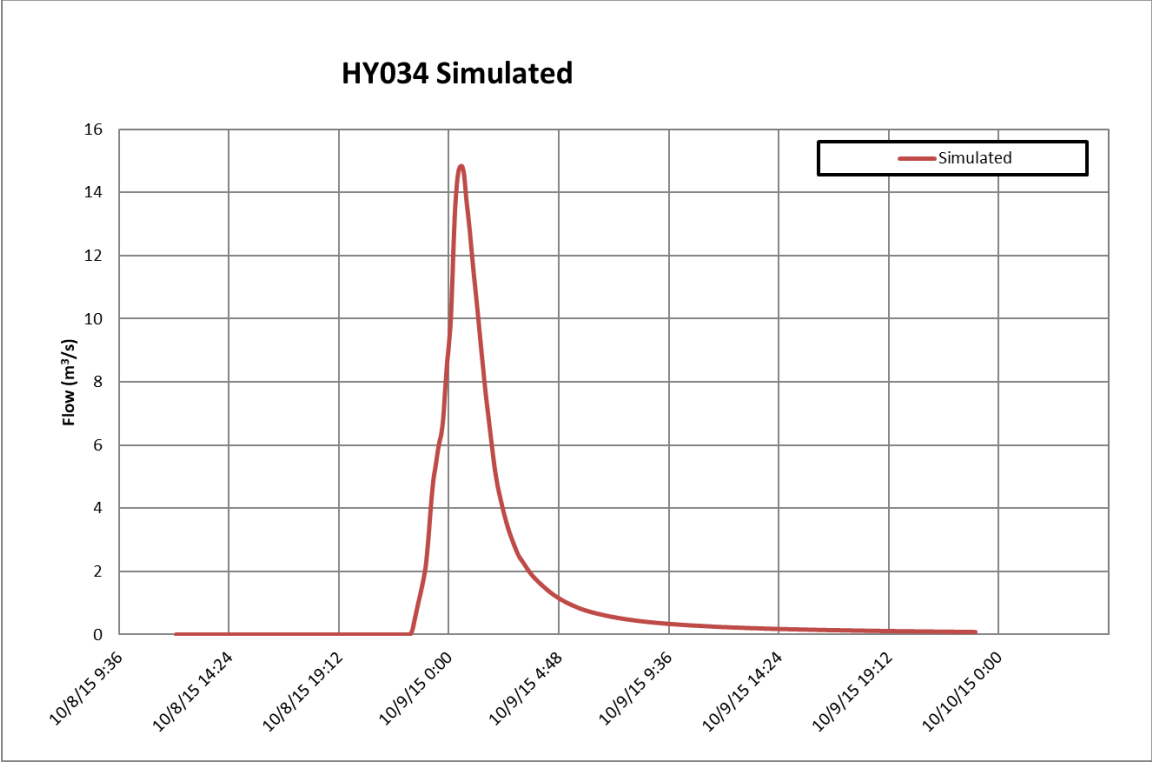
SVB - Small Event Validation - September 2, 2014

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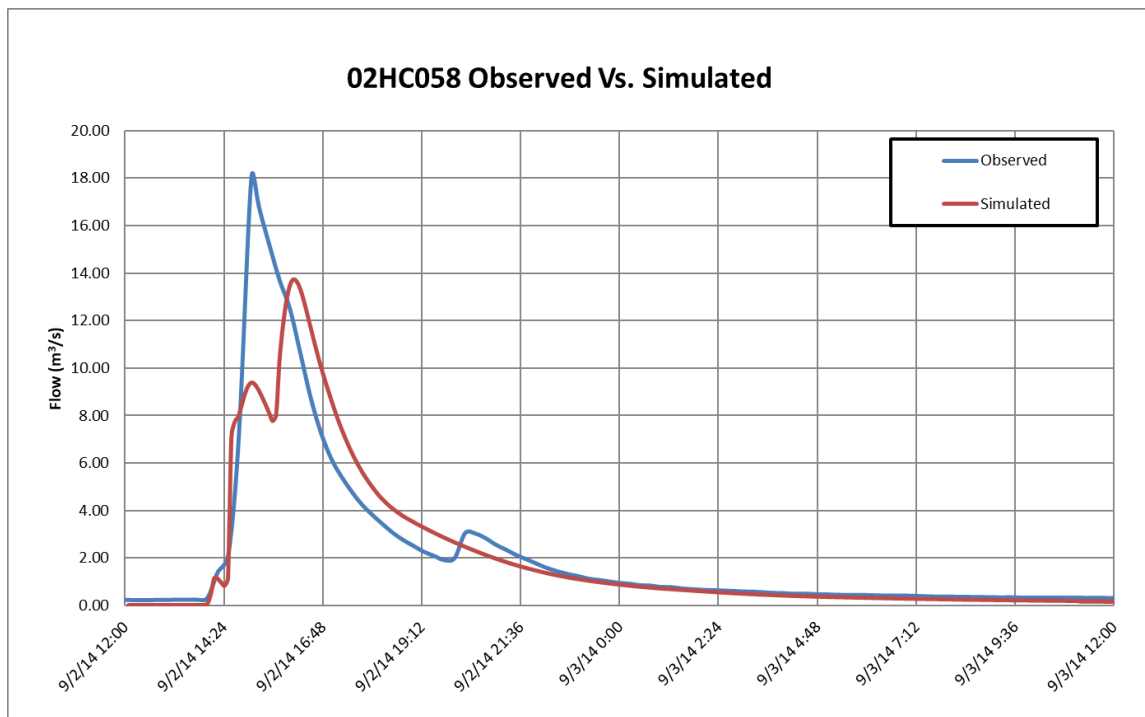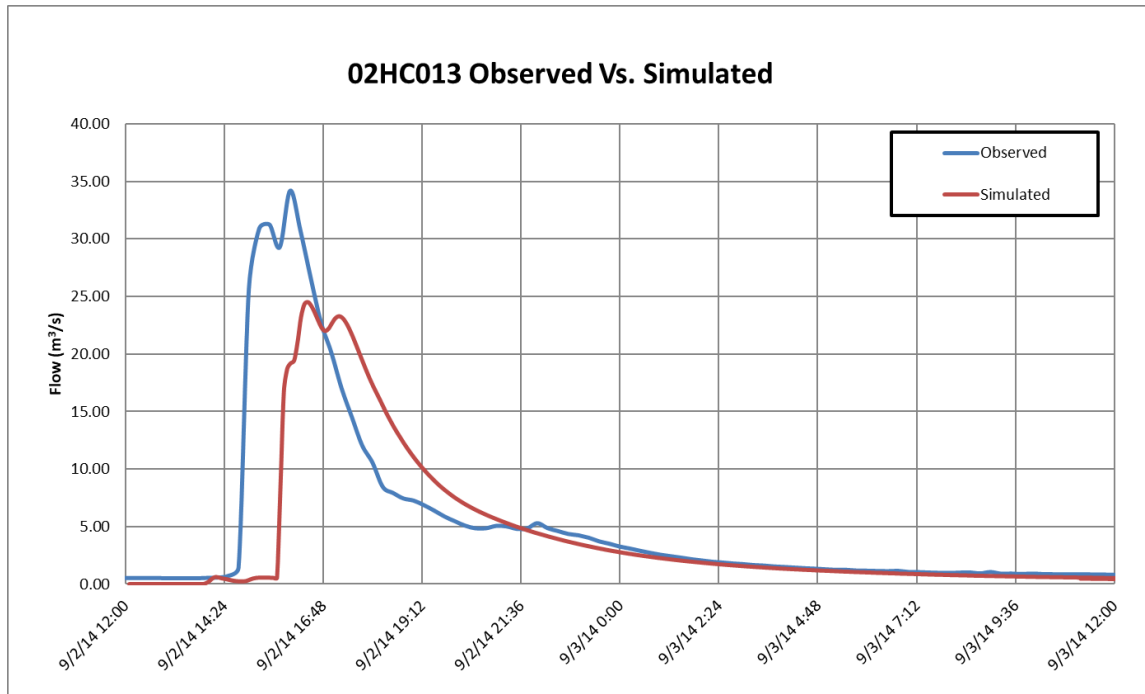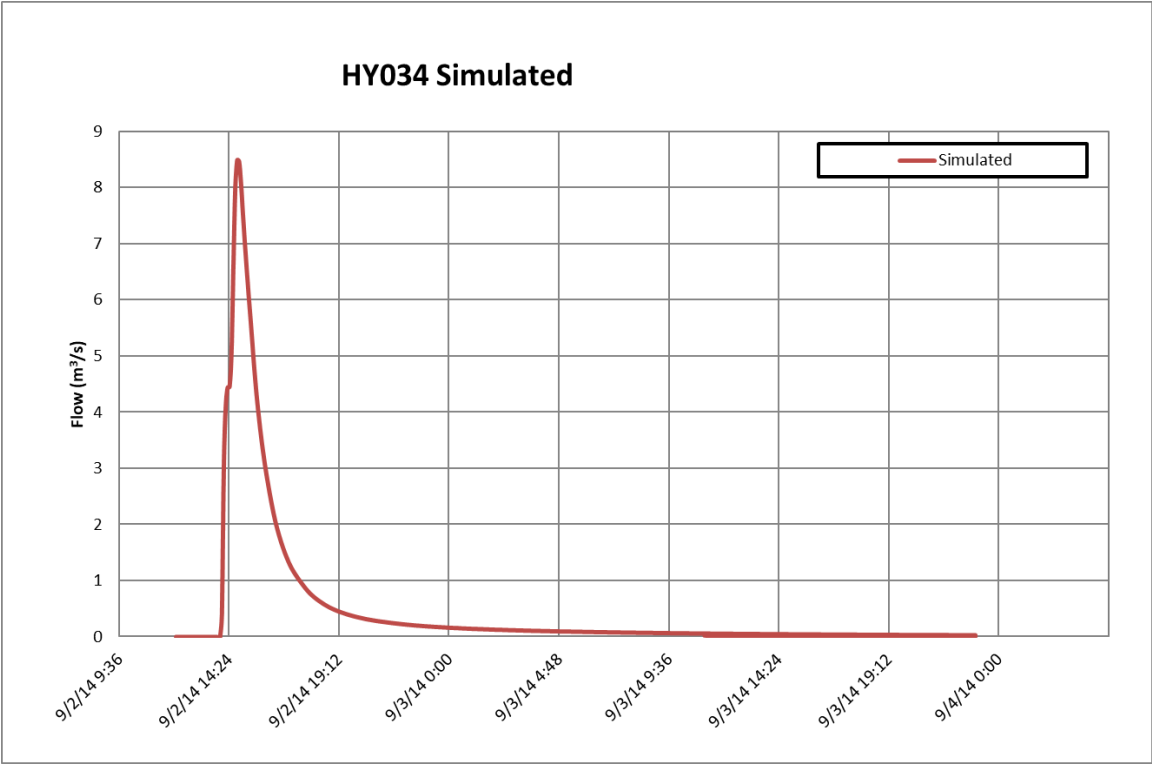
SVC - Small Event Validation - June 12, 2014

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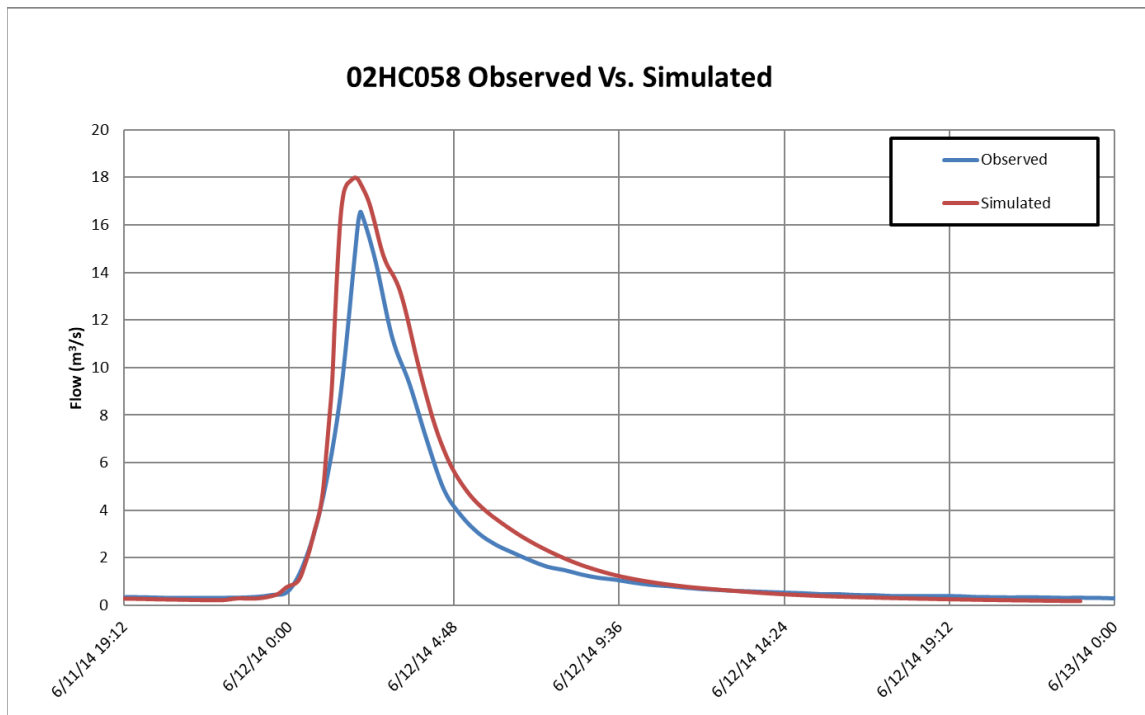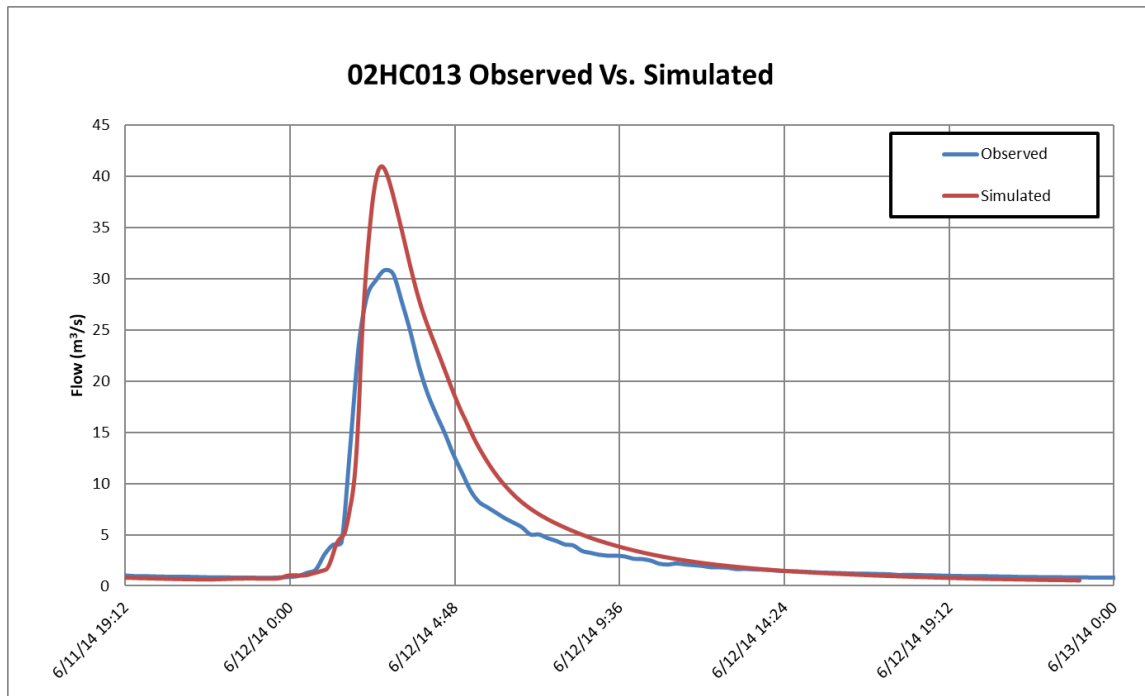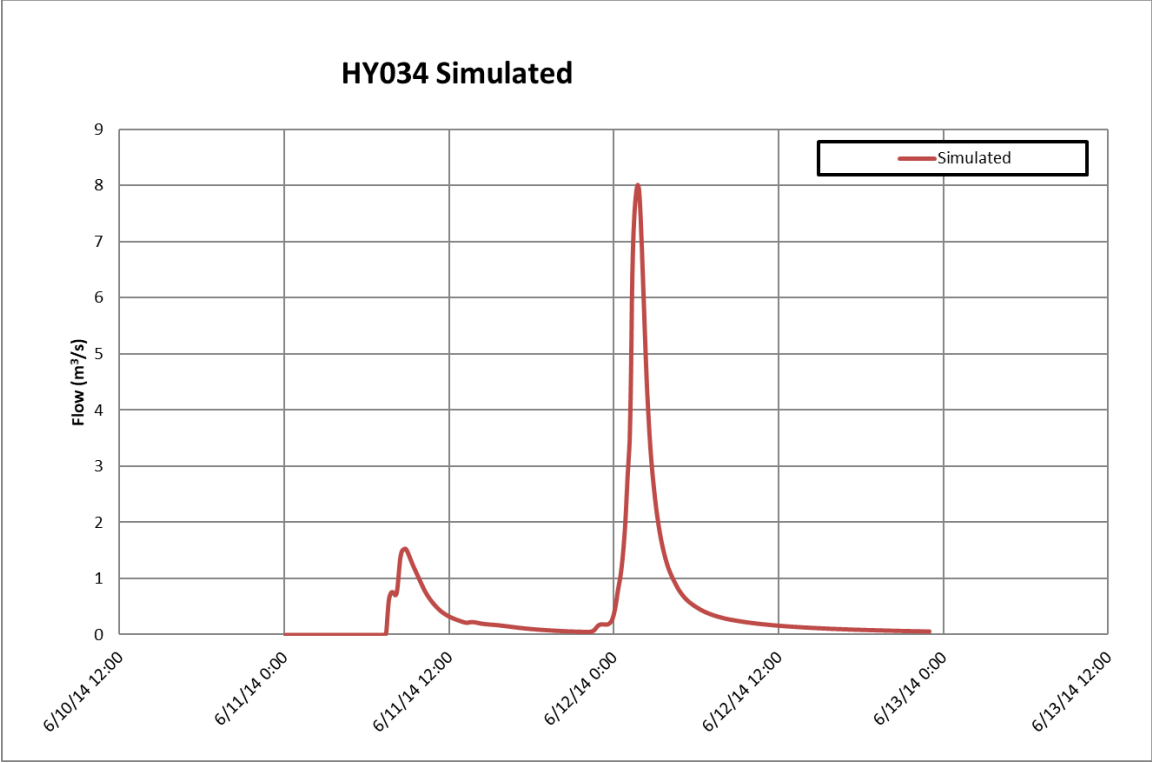
SVD - Small Event Validation - July 7, 2014

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02HC058 Observed Vs. Simulated

HY034 Simulated
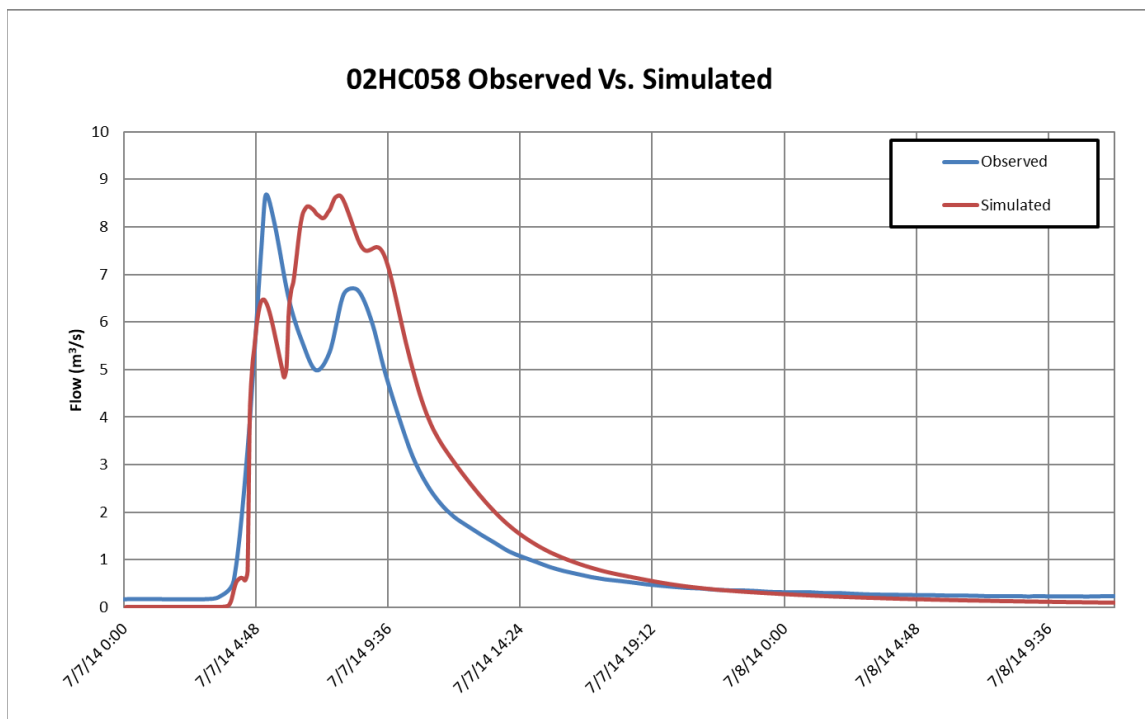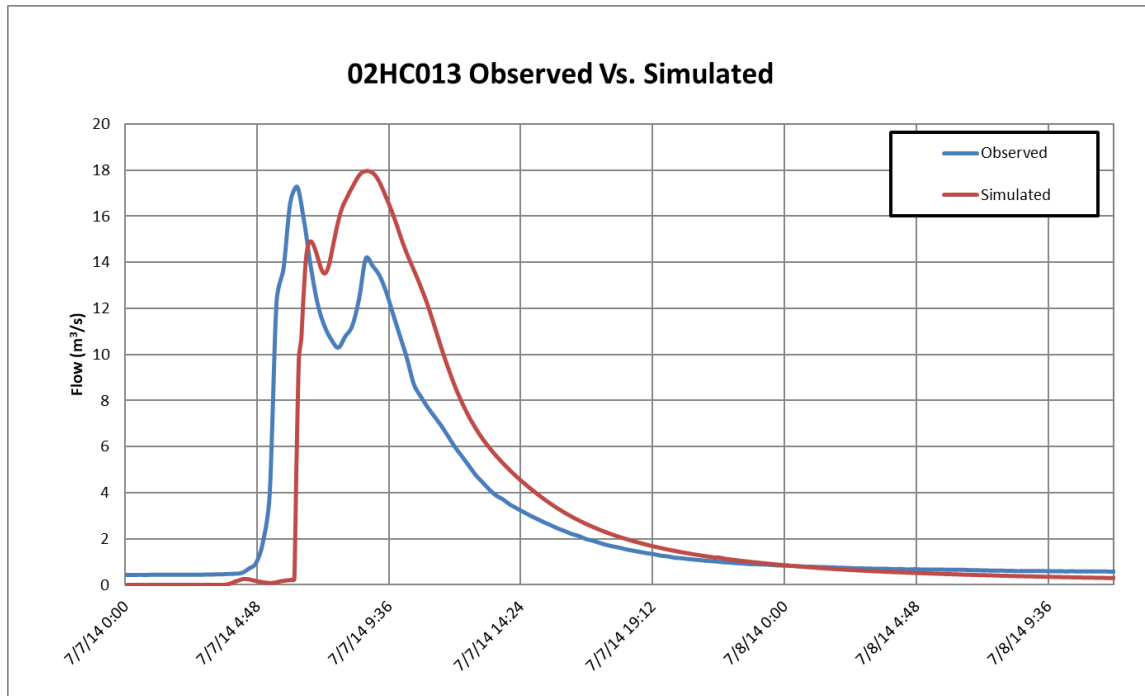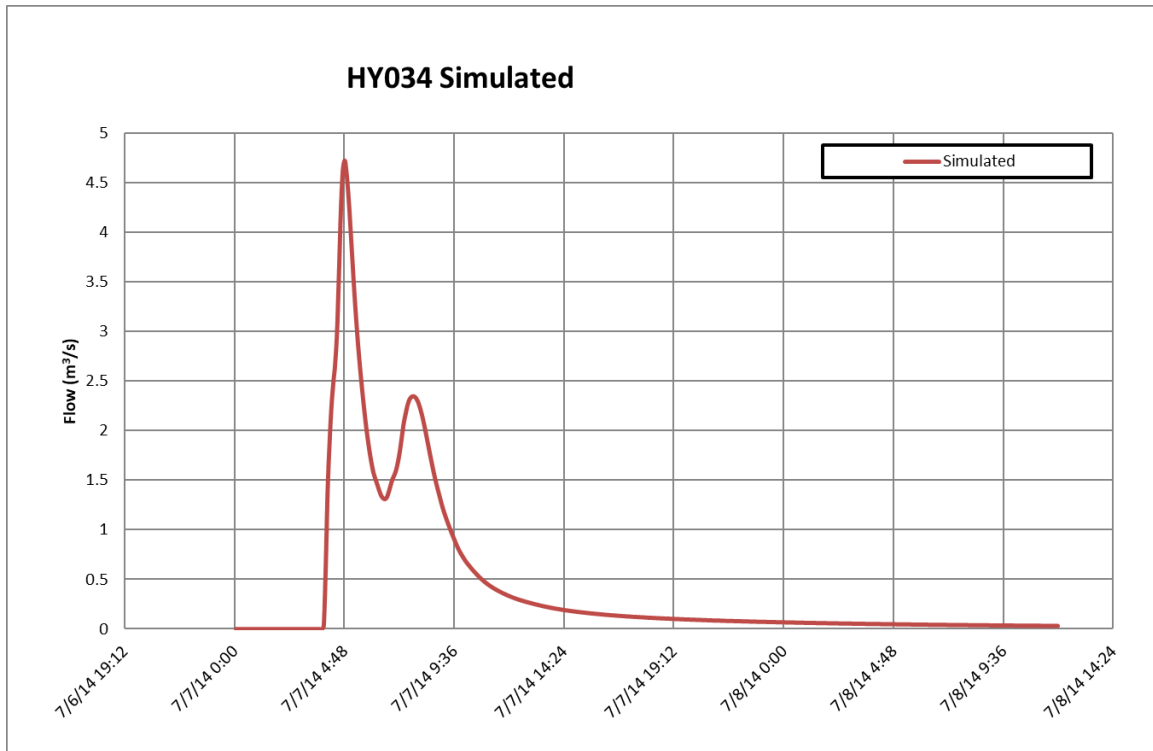
SVE - Small Event Validation - July 27, 2016

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02HC058 Observed Vs. Simulated

HY034 Simulated
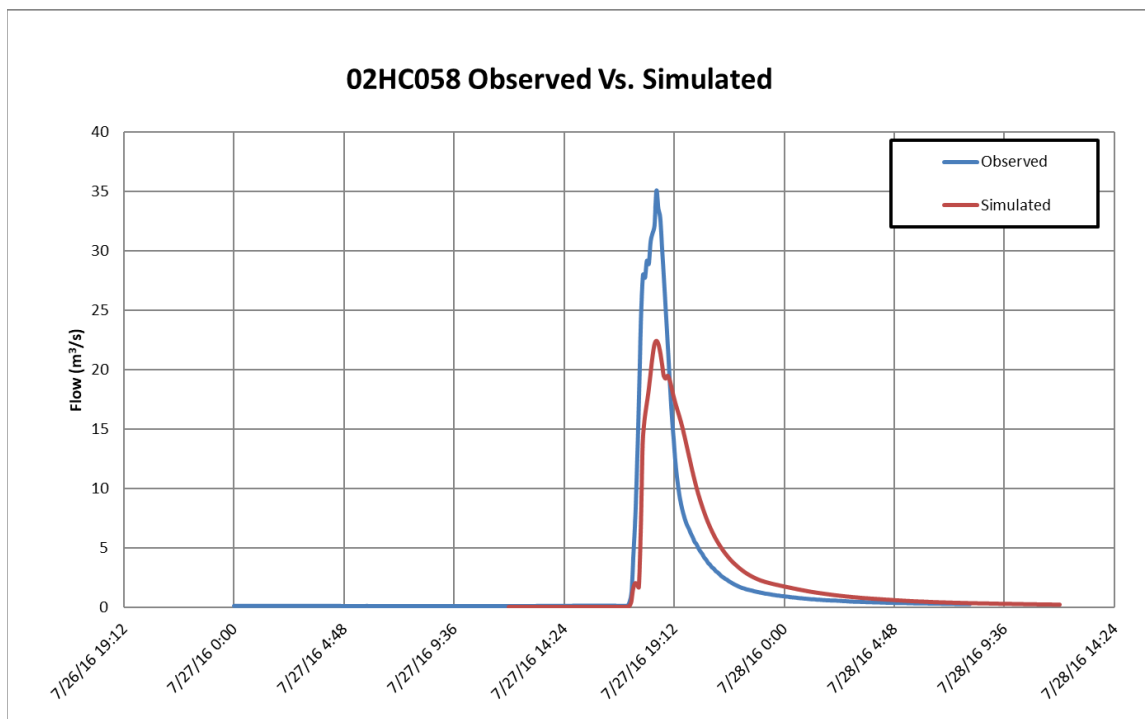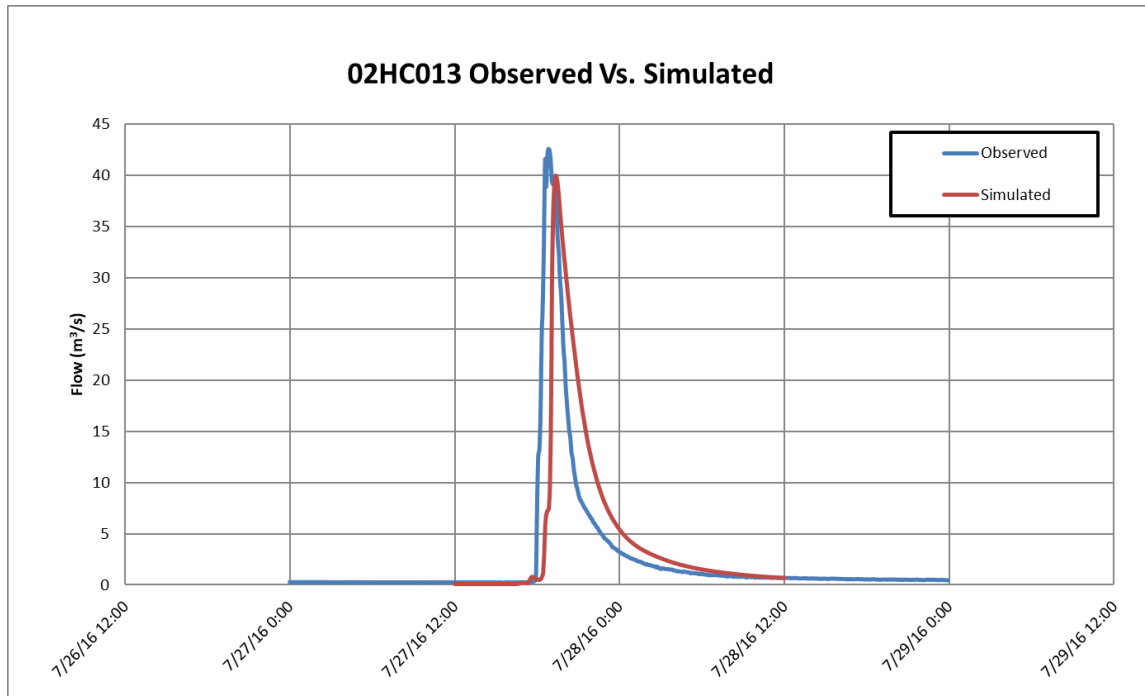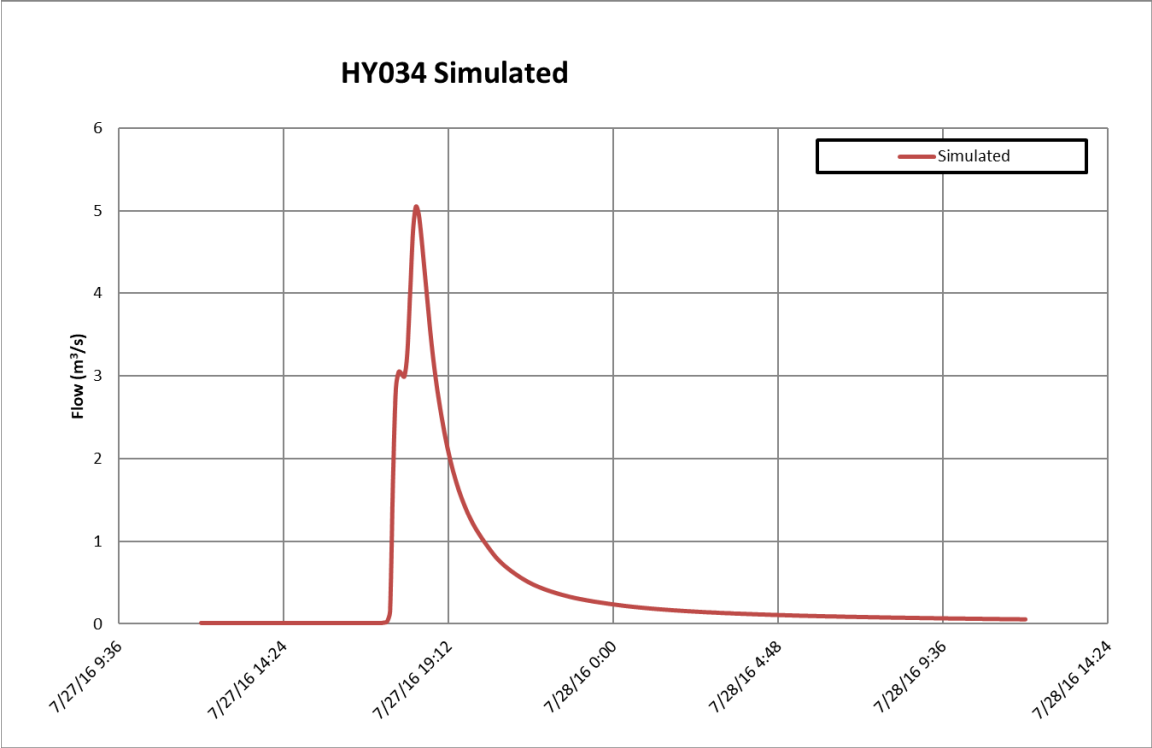
APPENDIX I
Design Storm Results and 2004 Comparison Study

Table I.1: Design Storm Flows - 1-hour AES Storm Distribution

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m3/s)						
					2-yr (24.1 mm)	5-yr (33.1 mm)	10-yr (39.0 mm)	25-yr (46.5 mm)	50-yr (52.1 mm)	100-yr (57.6 mm)	350-yr (72.7 mm)[1]
H0147	CJ12060	Bendale Branch	Reach 1	12060	5.62	8.41	11.21	16.21	20.65	25.26	58.07
H0035	CJ11573	Bendale Branch	Reach 1	12004	5.72	8.62	11.47	16.52	21.10	25.32	59.22
H0008	CJ11278	Bendale Branch	Reach 1	11581	5.17	7.97	10.88	15.51	19.54	24.22	58.84
H0069	CJ11152	Bendale Branch	Reach 1	11285	4.82	7.60	10.78	15.51	19.13	23.00	76.94
H0082	CJ11081	Bendale Branch	Reach 1	11152	4.77	7.60	10.78	15.51	19.13	23.01	77.08
H0090	CJ10702	Bendale Branch	Reach 1	11096	4.29	7.72	11.08	16.00	19.85	23.93	82.32
H0075	CJ10387	Bendale Branch	Reach 1	10711	4.28	7.71	11.05	15.94	19.78	23.88	82.66
H0024	CJ9975	Bendale Branch	Reach 1	10396	4.28	7.79	11.24	16.27	20.26	24.49	85.06
H0017	CJ9732	Bendale Branch	Reach 1	9996	4.30	7.86	11.37	16.46	20.52	24.81	86.92
H0028	CJ9372	Bendale Branch	Reach 2	9673	11.31	18.22	23.13	29.57	34.50	39.39	124.54
H0081	CJ8873	Bendale Branch	Reach 2	9379	11.73	18.99	24.04	30.51	35.22	39.70	126.48
H0005	CJ8629	Bendale Branch	Reach 3	8769	24.38	39.12	48.97	61.40	70.13	78.09	174.69
H0092	CJ8200	Bendale Branch	Reach 3	8629	25.15	40.23	50.47	63.59	72.55	81.15	180.58
H0025	CJ8031	Bendale Branch	Reach 3	8200	26.79	43.31	54.44	68.64	78.45	87.64	189.40
H0077	CJ7941	Bendale Branch	Reach 3	8038	26.93	43.66	54.87	69.26	79.15	88.23	187.35
H0098	CJ7606	Bendale Branch	Reach 3	7941	26.63	43.29	54.47	68.62	78.73	87.65	185.98
H0051	CJ7296	Bendale Branch	Reach 3	7630	27.29	44.44	55.60	68.74	78.22	86.93	185.13
H0034	CJ7069	Bendale Branch	Reach 3	7176	27.10	44.06	55.20	68.32	77.83	86.76	185.25
H0012	CJ6860	Bendale Branch	Reach 3	7086	27.32	44.41	55.62	68.68	77.94	87.43	186.83
H0039	CJ6649	Bendale Branch	Reach 3	6769	31.27	51.34	64.12	78.48	87.53	97.28	203.53
H0104	CJ6333	Bendale Branch	Reach 3	6598	31.17	51.16	64.06	77.97	86.65	95.77	203.80
H0109	CJ6100	Bendale Branch	Reach 3	6299	31.25	51.28	64.09	77.33	85.04	93.53	203.88
H0110	CJ5969	Bendale Branch	Reach 3	6120	31.48	51.67	64.54	77.68	85.30	93.54	204.82
H0064	CJ5860	Bendale Branch	Reach 3	5988	31.49	51.64	64.43	77.51	84.89	92.70	204.68
H0111	CJ5600	Bendale Branch	Reach 3	5876	31.79	52.16	64.99	78.36	85.94	98.74	204.28
H0112	CJ5442	Bendale Branch	Reach 3	5600	31.83	52.17	64.90	78.22	85.51	92.07	202.63
H0105	CJ5224	Bendale Branch	Reach 3	5442	31.73	51.86	64.46	77.96	85.29	91.67	202.37
H0106	CJ5048	Bendale Branch	Reach 3	5224	31.53	51.42	63.84	77.61	84.89	90.73	201.94
H0022	CJ4909	Bendale Branch	Reach 3	5048	31.50	51.25	63.62	77.32	84.67	90.36	201.68
H0113	CJ4676	Bendale Branch	Reach 3	4928	31.38	51.03	63.32	76.75	84.26	89.97	201.75
H0010	CJ4527	Bendale Branch	Reach 3	4676	31.48	51.15	63.42	76.78	84.30	89.94	202.00
H0114	CJ4199	Bendale Branch	Reach 3	4527	31.27	50.47	62.33	75.32	82.97	88.83	202.52
H0042	CJ3853	Bendale Branch	Reach 3	4142	30.55	49.10	60.96	74.34	82.22	88.41	202.65
H0052	CJ2230	Bendale Branch	Reach 3	3867	29.24	45.66	56.12	66.46	72.50	78.06	202.07
H0107	CJ2073	Bendale Branch	Reach 3	2278	29.10	45.47	55.84	66.19	72.25	77.80	202.15
H0232	CJ1104	Bendale Branch	Reach 3	2073	29.39	45.99	56.47	67.18	73.36	78.93	204.08
H0033	CJ918	Bendale Branch	Reach 3	1034	29.42	46.07	56.60	67.39	73.59	79.15	204.95
H0023	CJ639	Bendale Branch	Reach 3	885	29.35	46.02	56.58	67.33	73.55	79.16	204.76
H0196	CJ60_1	Bendale Branch	Reach 3	600	29.42	46.29	56.98	67.88	74.17	79.86	206.15
H0048	CJ266	Bendale Trib	Reach 1	624	9.03	14.36	18.10	23.00	26.78	30.55	42.46
H0002	CJ46	Bendale Trib	Reach 1	283	8.96	14.28	18.00	22.95	26.74	30.53	41.65
H0159	CJ1261	Bendale Trib 2	Reach 1	1261	7.32	11.50	14.38	18.16	21.02	23.93	32.93
H0031	CJ921	Bendale Trib 2	Reach 1	1066	7.28	11.45	14.29	17.93	20.64	23.08	34.18
H0016	CJ724	Bendale Trib 2	Reach 1	935	9.26	14.47	18.01	22.54	25.91	28.95	44.41
H0068	CJ423	Bendale Trib 2	Reach 1	733	11.64	18.09	22.46	27.75	31.80	35.51	57.27
H0080	CJ163	Bendale Trib 2	Reach 1	438	11.68	18.02	22.39	27.65	31.64	35.14	58.21
H0140	CJ5238	Centennial Creek	Reach 1	5341	0.95	1.79	2.39	3.16	3.54	3.54	6.68
H0136	CJ4980	Centennial Creek	Reach 1	5238	1.07	1.81	2.17	2.96	3.36	3.58	9.63
H0135	CJ4816	Centennial Creek	Reach 1	4980	0.68	1.14	2.13	3.04	3.48	3.74	10.30
H0134	CJ4728	Centennial Creek	Reach 1	4834	1.08	1.57	2.40	3.51	4.12	4.52	13.27
H0133	CJ4562	Centennial Creek	Reach 1	4740	1.45	2.25	2.76	3.80	4.53	5.09	15.05
H0132	OL1	Centennial Creek	Reach 1	4562	1.67	2.68	3.33	4.21	4.90	5.60	15.60
H0138	CJ3617_1	Centennial Creek	Reach 1	3852	8.10	14.55	19.19	22.81	23.00	23.26	56.37
H0131	CJ3405	Centennial Creek	Reach 1	3637	8.24	14.84	19.61	23.40	23.70	23.98	58.89
H0130	CJ3235	Centennial Creek	Reach 1	3423	8.25	14.94	19.67	23.34	23.72	24.12	58.07
H0027	CJ2996_1	Centennial Creek	Reach 1	3148	8.50	15.42	19.67	24.60	25.37	26.13	61.15
H0004	CJ2181	Centennial Creek	Reach 1	3004	8.73	16.00	20.69	26.07	27.36	28.53	64.69
H0137	CJ1582	Centennial Creek	Reach 1	2188	8.56	16.00	20.79	26.34	27.75	29.10	65.66

Table I.1: Design Storm Flows - 1-hour AES Storm Distribution

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m3/s)						
					2-yr (24.1 mm)	5-yr (33.1 mm)	10-yr (39.0 mm)	25-yr (46.5 mm)	50-yr (52.1 mm)	100-yr (57.6 mm)	350-yr (72.7 mm)[1]
H0197	CJ743	Centennial Creek	Reach 2	1438	10.74	22.28	29.19	36.77	39.50	41.84	87.30
H0184	CJ44	Centennial Creek	Reach 2	641	11.30	20.86	27.26	34.64	37.46	39.43	79.16
H0191	CJ330	Centennial Trib	Reach 1	387	5.46	8.47	10.63	13.50	15.72	17.97	24.75
H0102	CJ166	Centennial Trib	Reach 1	274	6.25	9.72	12.18	15.45	18.00	20.58	28.39
H0179	CJ686_1	Curran Hall Cree	Reach 1	808	1.24	1.92	2.42	3.09	3.61	4.14	5.64
H0185	CJ269_1	Curran Hall Cree	Reach 1	585	2.96	4.98	6.42	8.29	9.83	11.41	16.03
H0139	CJ7039	Dorset Park Bran	Reach 1	7039	1.74	2.67	3.34	4.23	4.91	5.58	7.60
H0118	CJ6622_1	Dorset Park Bran	Reach 1	6842	6.06	9.05	9.85	10.58	11.00	12.88	27.36
H0117	CJ6112	Dorset Park Bran	Reach 1	6642	6.88	10.18	11.17	11.95	12.39	13.37	31.03
H0071	CJ5909	Dorset Park Bran	Reach 1	6122	7.21	10.68	11.77	12.69	13.20	14.13	35.91
H0065	CJ5571	Dorset Park Bran	Reach 1	5925	7.41	11.03	12.26	13.29	13.93	14.42	33.97
H0073	CJ5046	Dorset Park Bran	Reach 1	5593	9.99	15.70	18.56	20.16	20.97	22.01	58.65
H0078	CJ4725	Dorset Park Bran	Reach 1	5046	10.73	16.75	19.71	21.73	22.72	23.79	63.26
H0116	CJ4532	Dorset Park Bran	Reach 1	4725	11.50	17.91	21.06	23.25	24.21	25.23	68.07
H0041	CJ4002	Dorset Park Bran	Reach 1	4532	18.71	28.57	33.46	37.81	40.09	42.85	107.11
H0101	CJ3806	Dorset Park Bran	Reach 1	4016	19.27	29.40	34.35	38.77	41.10	44.27	109.85
H0014	CJ3231	Dorset Park Bran	Reach 1	3820	19.85	30.11	34.55	38.90	41.61	44.86	112.20
H0115	CJ2990	Dorset Park Bran	Reach 1	3231	20.53	31.12	35.61	40.11	42.94	46.37	113.07
H0205	CJ2804	Dorset Park Bran	Reach 1	2990	21.11	32.07	36.69	41.41	44.42	47.93	115.71
H0070	CJ2097	Dorset Park Bran	Reach 1	2642	25.19	38.42	44.88	51.49	55.34	58.46	134.45
H0165	CJ1996	Dorset Park Bran	Reach 1	2097	25.63	39.15	45.84	52.67	56.59	59.65	136.64
H0021	CJ1422	Dorset Park Bran	Reach 2	1923	29.84	44.52	52.54	60.99	66.13	70.32	158.76
H0053	CJ1154	Dorset Park Bran	Reach 2	1422	31.14	46.38	54.98	64.88	70.56	75.14	166.07
H0166	CJ50	Dorset Park Bran	Reach 2	1126	31.17	46.24	55.25	64.88	70.93	75.95	167.01
H0164	CJ815	Dorset Park Inte	Reach 1	815	7.04	11.05	13.83	17.48	20.28	23.06	31.65
H0001	CJ447	Dorset Park Inte	Reach 1	627	7.47	11.83	14.59	18.36	21.16	23.96	33.85
H0195	CJ105	Dorset Park Inte	Reach 1	447	7.82	12.20	15.22	19.15	22.10	25.00	35.42
H0019	CJ2320	East Highland Creek	Reach 1	3211	74.12	121.07	152.70	192.25	221.63	247.34	456.01
H0037	CJ1656	East Highland Creek	Reach 1	2320	77.10	124.74	155.85	192.73	222.17	248.01	456.36
H0186	CJ110	East Highland Creek	Reach 1	1620	73.52	120.33	151.76	191.99	222.04	248.23	454.97
H0153	CJ1874	Ellesmere Ravine	Reach 1	1890	2.06	3.17	3.97	5.10	5.98	6.87	9.43
H0043	CJ861	Ellesmere Ravine	Reach 1	1433	4.02	6.50	8.22	10.44	12.14	13.75	19.44
H0154	CJ290	Ellesmere Ravine	Reach 1	888	2.08	3.91	5.29	7.34	9.17	11.09	17.50
H0128	CJ202	Ellesmere Ravine	Reach 1	244	2.21	4.25	5.81	8.09	10.11	12.20	18.79
H0047	CJ202	Ellesmere Ravine	Reach 1	211	2.21	4.25	5.81	8.09	10.11	12.20	18.79
H0084	CJ46_2	Ellesmere Ravine	Reach 1	141	2.22	4.25	5.81	8.09	10.12	12.21	18.98
H0152	CJ5926	Highland Creek	Reach 1	6917	104.18	165.80	207.74	261.10	298.72	335.24	548.99
H0061	CJ5703	Highland Creek	Reach 2	5884	105.44	168.00	210.71	265.31	303.65	340.43	557.44
H0259	CJ4340	Highland Creek	Reach 2	5686	104.98	167.04	208.61	262.68	299.26	336.65	542.37
H0086	CJ4097	Highland Creek	Reach 2	4276	104.96	166.73	208.10	262.02	298.67	335.99	541.08
H0085	CJ3665	Highland Creek	Reach 2	4113	104.84	166.53	207.90	261.42	297.94	335.28	537.94
H0091	CJ3128	Highland Creek	Reach 2	3624	104.75	166.15	207.31	260.84	297.44	334.89	536.42
H0088	CJ1692	Highland Creek	Reach 2	3128	104.04	165.27	205.29	258.11	293.79	328.57	524.83
H0198	CJ1090	Highland Creek	Reach 2	1663	103.35	163.74	202.62	254.96	289.79	322.60	516.06
H0188	CJ636	Highland Creek	Reach 2	1006	95.79	151.95	185.57	228.57	258.37	286.46	481.23
H0162	CJ379_1	Highland Creek	Reach 3	513	90.03	139.53	171.97	209.29	238.21	267.20	468.81
H0175	CJ171	Highland Creek	Reach 4	248	88.67	135.56	167.32	204.77	233.80	262.63	470.40
H0129	CJ26	Highland Creek	Reach 5	78	114.08	135.55	167.36	204.88	233.96	262.91	471.31
H0194	CJ439	Highland Trib 1	Reach 1	439	1.85	2.76	3.39	4.21	4.84	5.48	7.48
H0193	CJ121	Highland Trib 1	Reach 1	295	1.58	2.47	3.09	3.91	4.56	5.22	7.17
H0170	CJ5163	Malvern Branch	Reach 1	5221	0.90	1.66	2.29	3.20	3.94	4.74	33.97
H0054	CJ4945	Malvern Branch	Reach 1	5071	3.60	5.42	6.57	8.04	9.10	10.16	53.86
H0125	CJ4608	Malvern Branch	Reach 1	4961	4.47	6.78	8.28	10.22	11.64	12.92	57.85
H0124	CJ4418	Malvern Branch	Reach 1	4627	7.03	10.80	13.33	16.65	18.97	21.05	69.44
H0126	CJ4072	Malvern Branch	Reach 2	4305	21.67	33.25	40.56	49.42	55.26	60.79	144.44
H0094	CJ3873	Malvern Branch	Reach 2	4098	21.73	33.39	40.76	49.53	55.59	61.14	145.38
H0049	CJ3757	Malvern Branch	Reach 2	3922	22.02	33.90	41.39	50.31	56.48	62.14	147.45
H0103	CJ2938	Malvern Branch	Reach 2	3757	30.99	48.66	60.00	73.98	83.68	92.86	179.43

Table I.1: Design Storm Flows - 1-hour AES Storm Distribution

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m3/s)						
					2-yr (24.1 mm)	5-yr (33.1 mm)	10-yr (39.0 mm)	25-yr (46.5 mm)	50-yr (52.1 mm)	100-yr (57.6 mm)	350-yr (72.7 mm)[1]
H0100	CJ2765	Malvern Branch	Reach 2	2765	34.68	54.85	67.91	84.20	95.69	106.63	206.16
H0100	CJ2450	Malvern Branch	Reach 2	2572	36.21	57.55	71.54	88.92	101.08	112.54	230.85
H0013	CJ2171	Malvern Branch	Reach 2	2450	36.39	58.09	72.16	89.26	101.42	112.83	233.24
H0044	CJ1902	Malvern Branch	Reach 2	2092	36.70	58.68	73.04	90.44	102.82	114.43	236.92
H0026	CJ1634_1	Malvern Branch	Reach 2	1946	37.73	60.48	75.40	93.49	106.36	118.42	245.02
H0003	CJ1347	Malvern Branch	Reach 2	1634	37.81	60.66	75.65	93.83	106.76	118.89	246.00
H0083	CJ1102	Malvern Branch	Reach 2	1347	38.21	61.37	76.57	95.04	108.19	120.52	249.52
H0127	CJ935_3	Malvern Branch	Reach 2	1178	41.19	66.54	83.21	103.62	118.12	131.12	272.65
H0127	CJ531_1	Malvern Branch	Reach 2	935	42.85	69.54	86.92	108.11	123.17	133.97	284.20
H0172	CJ59	Malvern Branch	Reach 2	562	43.06	70.17	87.76	109.35	124.70	135.75	287.76
H0160	CJ1113	Malvern Trib	Reach 1	1113	7.02	10.71	13.35	16.88	19.59	22.31	35.16
H0059	CJ823	Malvern Trib	Reach 1	951	9.30	14.20	17.73	22.39	25.96	29.55	45.85
H0032	CJ382	Malvern Trib	Reach 1	823	9.79	15.00	18.73	23.68	27.50	31.32	48.71
H0161	CJ197_1	Malvern Trib	Reach 1	411	13.86	21.44	26.54	33.23	37.87	42.89	68.96
H0144	CJ7852	Miliken Branch	Reach 1	7895	6.02	8.35	9.80	11.85	13.57	15.54	66.23
H0018	CJ7417_1	Miliken Branch	Reach 1	7799	6.23	8.74	10.37	12.73	14.71	16.93	71.50
H0063	CJ7195	Miliken Branch	Reach 1	7429	6.29	8.87	10.57	13.04	15.11	17.43	73.17
H0020	CJ6709	Miliken Branch	Reach 1	7153	6.40	9.10	10.92	13.58	15.79	18.27	75.45
H0011	CJ6262	Miliken Branch	Reach 1	6709	6.80	9.81	11.98	15.17	17.81	20.73	85.68
H0045	CJ5811	Miliken Branch	Reach 1	6291	6.85	9.95	12.19	15.50	18.25	21.27	87.21
H0074	CJ5517	Miliken Branch	Reach 1	5817	7.37	11.15	14.34	18.59	21.89	25.24	100.40
H0096	CJ5342	Miliken Branch	Reach 1	5540	7.43	11.89	15.32	19.86	23.37	26.93	103.06
H0121	CJ4866	Miliken Branch	Reach 1	5358	7.48	12.44	16.06	20.88	24.61	28.36	110.76
H0122	CJ4663	Miliken Branch	Reach 1	4881	7.57	12.74	16.47	21.43	25.28	29.14	107.24
H0079	CJ4513	Miliken Branch	Reach 1	4688	7.65	12.84	16.59	21.69	25.50	29.42	107.33
H0007	CJ4121	Miliken Branch	Reach 2	4455	30.36	49.11	62.14	76.50	87.55	97.82	218.15
H0015	CJ3809	Miliken Branch	Reach 2	4141	30.46	49.35	62.46	76.86	87.58	97.85	219.45
H0093	CJ3363	Miliken Branch	Reach 2	3838	30.71	49.37	61.48	75.53	84.84	97.13	223.67
H0123	CJ3027	Miliken Branch	Reach 2	3312	32.58	52.33	65.33	80.48	89.85	101.45	220.72
H0087	CJ2833	Miliken Branch	Reach 2	3027	34.98	56.22	70.15	86.24	95.67	107.41	216.29
H0006	CJ2581	Miliken Branch	Reach 2	2833	35.07	56.41	70.42	86.69	96.25	107.81	217.69
H0057	CJ2191	Miliken Branch	Reach 2	2581	35.55	57.34	71.59	88.17	98.03	109.36	221.78
H0089	CJ1704	Miliken Branch	Reach 2	2191	36.68	59.49	74.59	92.20	102.60	114.01	229.99
H0089	CJ1153	Miliken Branch	Reach 2	1632	37.29	60.55	75.98	93.96	104.75	115.90	240.63
H0143	CJ71	Miliken Branch	Reach 2	1169	37.43	61.01	76.71	95.06	106.14	117.36	239.73
H0142	CJ3313	Miliken Trib	Reach 1	3313	14.20	22.42	28.11	35.65	41.42	47.19	64.46
H0072	CJ2947	Miliken Trib	Reach 1	3158	13.77	21.43	26.83	33.78	38.99	44.10	64.34
H0062	CJ2465	Miliken Trib	Reach 1	2961	13.77	21.29	26.61	33.44	38.43	43.32	64.33
H0036	CJ2011	Miliken Trib	Reach 1	2479	15.43	24.01	30.00	37.72	43.36	48.87	73.37
H0097	CJ1545	Miliken Trib	Reach 1	2018	16.27	25.35	31.64	39.82	45.92	51.85	77.99
H0119	CJ812	Miliken Trib	Reach 1	1573	19.78	31.07	38.80	47.50	54.27	60.67	83.27
H0119	CJ417	Miliken Trib	Reach 1	701	19.57	30.89	38.48	47.28	53.90	60.15	96.29
H0055	CJ15	Miliken Trib	Reach 1	445	24.41	38.13	47.35	57.51	65.13	72.21	111.83
H0149	CJ3316_1	Thornton Creek	Reach 1	3449	0.19	0.30	0.37	0.47	0.54	0.60	0.78
H0200	CJ2649	Thornton Creek	Reach 1	3246	1.97	3.05	3.84	4.92	5.77	6.63	8.82
H0050	CJ2649	Thornton Creek	Reach 1	3156	1.97	3.05	3.84	4.92	5.77	6.63	8.82
H0040	CJ2153	Thornton Creek	Reach 1	2659	3.72	5.80	7.29	9.28	10.83	12.43	16.59
H0040	CJ1698	Thornton Creek	Reach 1	2053	4.72	7.37	9.24	11.76	13.72	15.74	20.92
H0009	CJ1202	Thornton Creek	Reach 1	1704	9.93	15.66	19.56	24.53	28.00	31.35	49.62
H0187	CJ404	Thornton Creek	Reach 1	1219	9.75	15.54	19.53	24.62	28.14	31.54	44.11
H0183	CJ96	Thornton Creek	Reach 2	167	10.71	16.69	20.88	26.24	29.98	33.40	56.75
H0150	CJ1011	Thornton Trib	Reach 1	1011	3.22	4.68	5.40	6.23	6.67	6.89	15.84
H0151	CJ225	Thornton Trib	Reach 1	441	1.16	1.40	1.59	1.86	2.78	3.93	17.11
H0066	CJ6235	West Highland Cr	Reach 1	6565	44.96	68.81	89.04	110.57	122.42	132.78	283.31
H0189	CJ6017	West Highland Cr	Reach 1	6258	44.92	68.79	89.00	110.50	122.40	132.77	283.29
H0056	CJ5034	West Highland Cr	Reach 2	5943	45.37	69.32	89.06	110.06	122.41	133.24	285.81
H0058	CJ3335	West Highland Cr	Reach 2	5060	45.46	69.65	89.42	110.45	123.11	134.12	286.61
H0182	CJ1937	West Highland Cr	Reach 2	3313	45.60	69.92	89.64	110.63	123.38	134.56	287.03

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PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	AES 1-Hour Design Storm Flows (m3/s)						
					2-yr (24.1 mm)	5-yr (33.1 mm)	10-yr (39.0 mm)	25-yr (46.5 mm)	50-yr (52.1 mm)	100-yr (57.6 mm)	350-yr (72.7 mm)[1]
H0099	CJ1344	West Highland Cr	Reach 3	1650	46.92	71.38	91.23	112.43	125.49	136.99	292.35
H0180	CJ749	West Highland Cr	Reach 3	1298	46.62	71.36	90.88	112.22	125.31	136.84	290.16
H0171	CJ77	West Highland Cr	Reach 4	585	47.05	71.99	91.34	112.69	125.95	137.52	291.87
H0146	CJ884	West Highland T1	Reach 1	884	1.13	1.75	2.19	2.78	3.22	3.67	5.09
H0095	CJ646	West Highland T1	Reach 1	797	1.47	2.24	2.78	3.48	4.01	4.54	6.54
H0076	CJ541	West Highland T1	Reach 1	656	2.39	3.66	4.53	5.66	6.52	7.38	10.53
H0030	CJ377	West Highland T1	Reach 1	541	2.67	4.10	5.10	6.38	7.36	8.34	11.83
H0029	CJ225_1	West Highland T1	Reach 1	383	2.97	4.57	5.68	7.11	8.21	9.30	13.17
H0167	CJ149	West Highland T1	Reach 1	154	4.23	6.47	8.02	10.01	11.51	13.04	18.27
H0181	CJ1594	West Highland T2	Reach 1	1594	9.19	14.43	18.05	22.81	26.45	30.26	41.37
H0038	CJ968_1	West Highland T2	Reach 1	1280	10.07	15.87	19.88	25.19	29.37	33.62	45.74
H0046	CJ407	West Highland T2	Reach 1	1012	13.19	20.68	25.85	32.96	38.55	44.13	59.99
H0190	CJ147	West Highland T2	Reach 1	428	13.61	21.52	26.98	34.39	40.30	46.21	62.85

Notes:

1. The 350-Year design storm flows were simulated using the Regional hydrology model (no structures or stormwater management facilities) and do not nesessarily align with the PCSWMM Conduits listed for the other design storms.

Table I.2: Design Storm Flows - 2004 and 2020 Comparison

2004 Hydrology Report[1]									2020 Hydrology Update[2]								
2004 Flow Node	Location	Drainage Area (km²)	Design Storm Flows (m3/s)						2020 Flow Node - Subcatchment	Location	Drainage Area (km²)	Design Storm Flows (m3/s)					
			2-yr	5-yr	10-yr	25-yr	50-yr	100-yr				2-yr	5-yr	10-yr	25-yr	50-yr	100-yr
104.1	Dorset Park Interceptor	3.24	12.3	17.2	20.9	25.7	29.3	33.7	H0073	Dorset Park Bran	3.3	10.0	15.7	18.6	20.2	21.0	22.0
100.1	Dorset Park Interceptor	10.77	34.9	50.3	61.7	76.2	87.1	99.6	H0021	Dorset Park Bran	13.4	29.8	44.5	52.5	61.0	66.1	70.3
100.2	Dorset Park Interceptor	13.82	34.4	50.4	62.1	76	87.5	100.7	H0166	Dorset Park Bran	15.2	31.2	46.2	55.3	64.9	70.9	75.9
206.1	Bendale Branch	7.28	20.7	30.7	37.9	46.7	54.7	62.3	H0028	Bendale Branch	7.8	11.3	18.2	23.1	29.6	34.5	39.4
205.1	Bendale Branch	14.64	35.7	53.3	65.8	82.8	96.9	110.9	H0104	Bendale Branch	17.5	31.2	51.2	64.1	78.0	86.7	95.8
204.1	Bendale Branch	16.19	35.6	53.2	66	82.7	96.9	110.9	H0111	Bendale Branch	18.4	31.8	52.2	65.0	78.4	85.9	98.7
201.1	Bendale Branch	21.16	44	65.8	81.7	102	119.7	136.4	H0042	Bendale Branch	19.8	30.6	49.1	61.0	74.3	82.2	88.4
200.1	Bendale Branch	25.34	34	50.5	62.3	78.7	92.1	106.3	H0023	Bendale Branch	23.4	29.3	46.0	56.6	67.3	73.5	79.2
608.1	West Branch Upstream	39.16	61.5	89.3	110.4	139	162.3	185.6	H0066	West Highland Cr	39.2	45.0	68.8	89.0	110.6	122.4	132.8
608.2	West Branch	49.48	62.8	90.5	108	130.8	151.4	171.5	H0099	West Highland Cr	47.3	46.9	71.4	91.2	112.4	125.5	137.0
606.1	West Branch	50.23	62.8	90.6	108.3	131.3	151.8	171.9	H0171	West Highland Cr	48.6	47.0	72.0	91.3	112.7	125.9	137.5
302.1	Markham Branch	5.89	17.8	26.7	33	40.7	46.3	52.5	H0055	Miliken Trib	7.5	24.4	38.1	47.3	57.5	65.1	72.2
304.1	Markham Branch	7.37	22.2	33	42.2	52	60.1	68.4	H0122	Miliken Branch	5.7	7.6	12.7	16.5	21.4	25.3	29.1
301.1	Markham Branch	13.26	40	59.7	75.1	92.6	106.3	120.8	H0007	Miliken Branch	13.6	30.4	49.1	62.1	76.5	87.6	97.8
301.2	Markham Branch	16.95	52.9	76.5	95.5	119.7	139.5	158.2	H0123	Miliken Branch	15.3	32.6	52.3	65.3	80.5	89.9	101.4
300.1	Markham Branch	21.25	53.6	79.1	97.9	120.6	140.3	159.1	H0143	Miliken Branch	19.9	37.4	61.0	76.7	95.1	106.1	117.4
402.1	Malvern Branch	5.29	21.1	29.8	37	45.9	52.3	60.7	H0126	Malvern Branch	6.8	21.7	33.2	40.6	49.4	55.3	60.8
401.1	Malvern Branch	11.21	39.5	56.4	69.7	87.7	101.5	115.9	H0044	Malvern Branch	12.3	36.7	58.7	73.0	90.4	102.8	114.4
400.1	Malvern Branch	14.11	45.4	66.2	81.4	102.4	118.6	135.8	H0172	Malvern Branch	15.7	43.1	70.2	87.8	109.4	124.7	135.8
605.1	Malvern Branch	38.02	98.5	145.4	180	223.3	260.3	296.9	H0186	East Highland Creek	37.8	73.5	120.3	151.8	192.0	222.0	248.2
604.1	Highland Creek	88.26	153.5	223.4	272.7	337.1	389.7	441.8	H0152	Highland Creek	86.7	104.2	165.8	207.7	261.1	298.7	335.2
603.1	Highland Creek	96.6	147	211.6	257.1	321.2	368.7	417.3	H0086	Highland Creek	90.5	105.0	166.7	208.1	262.0	298.7	336.0
600.1	Highland Creek	97.58	127.6	173.3	213.2	271.9	318.3	365.4	H0198	Highland Creek	92.1	103.3	163.7	202.6	255.0	289.8	322.6
601.1	West Hill Creek	2.98	9.6	13.6	16.5	21.2	24.3	27.5	H0183	Thornton Creek	4.0	10.7	16.7	20.9	26.2	30.0	33.4
501.1	Centennial Creek	1.73	5.7	8.2	9.9	12.4	14.2	16	H0131	Centennial Creek	3.9	8.2	14.8	19.6	23.4	23.7	24.0
501.2	Centennial Creek	4.79	15.7	22.3	26.9	34	39.4	44.7	H0197	Centennial Creek	6.9	10.7	22.3	29.2	36.8	39.5	41.8
600.2	Highland Creek	105.35	130.8	180.2	222.7	285.4	333.7	383.3	H0175	Highland Creek	103.3	88.7	135.6	167.3	204.8	233.8	262.6

Notes:
1. 2004 design storm flows were simulated using a 6-hour AES design storm distribution.
2. 2020 design storms flows were simulated using the 1-hour AES design storm distribution.

APPENDIX J
Regional Storm Results

Table J1: Regional Storm Flows

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	Regional ARF	Flows (m3/s)									Final Flow (m³/s)
						100.0%	99.2%	98.2%	97.1%	96.3%	95.4%	94.8%	94.2%	93.5%	
H0147	CJ11623	Bendale Branch	Reach 1	12060	100.0%	30.20	29.94	29.61	29.24	28.98	28.68	28.48	28.29	28.06	30.20
H0035	CJ11573	Bendale Branch	Reach 1	12004	100.0%	31.35	31.08	30.74	30.36	30.09	29.78	29.57	29.37	29.13	31.35
H0008	CJ11390	Bendale Branch	Reach 1	11581	100.0%	32.30	32.02	31.67	31.28	31.01	30.70	30.47	30.31	30.07	32.30
H0069	CJ11194	Bendale Branch	Reach 1	11285	100.0%	46.73	46.32	45.81	45.24	44.84	44.39	44.09	43.81	43.47	46.73
H0082	CJ11121	Bendale Branch	Reach 1	11152	100.0%	46.82	46.41	45.90	45.33	44.93	44.48	44.18	43.90	43.56	46.82
H0090	CJ10702	Bendale Branch	Reach 1	11096	100.0%	50.90	50.45	49.89	49.26	48.82	48.32	47.99	47.67	47.30	50.90
H0075	CJ10387	Bendale Branch	Reach 1	10711	100.0%	51.26	50.80	50.22	49.58	49.14	48.63	48.29	47.97	47.60	51.26
H0024	CJ10074	Bendale Branch	Reach 1	10396	100.0%	54.14	53.65	53.04	52.35	51.88	51.34	50.98	50.64	50.23	54.14
H0017	CJ9810	Bendale Branch	Reach 1	9996	100.0%	55.89	55.38	54.75	54.04	53.55	53.00	52.62	52.27	51.86	55.89
H0028	CJ9372	Bendale Branch	Reach 2	9673	100.0%	88.00	87.21	86.21	85.10	84.32	83.43	82.84	82.28	81.62	88.00
H0081	CJ8906	Bendale Branch	Reach 2	9379	100.0%	90.36	89.55	88.52	87.38	86.58	85.67	85.06	84.48	83.80	90.36
H0005	CJ8702	Bendale Branch	Reach 3	8769	100.0%	130.16	128.99	127.52	125.89	124.76	123.44	122.57	121.75	120.74	130.16
H0092	CJ8250	Bendale Branch	Reach 3	8629	100.0%	137.57	136.35	134.80	133.05	131.83	130.44	129.51	128.61	127.56	137.57
H0025	CJ8106	Bendale Branch	Reach 3	8200	100.0%	148.18	146.86	145.19	143.30	141.97	140.46	139.45	138.49	137.32	148.18
H0077	CJ7941	Bendale Branch	Reach 3	8038	99.2%	149.64	148.35	146.67	144.76	143.39	141.87	140.85	139.86	138.68	148.35
H0098	CJ7630	Bendale Branch	Reach 3	7941	99.2%	150.08	148.78	147.10	145.19	143.81	142.30	141.28	140.29	139.11	148.78
H0051	CJ7212	Bendale Branch	Reach 3	7630	99.2%	156.29	154.92	153.16	151.16	149.74	148.14	147.07	146.04	144.81	154.92
H0034	CJ7121	Bendale Branch	Reach 3	7176	99.2%	156.87	155.49	153.73	151.72	150.29	148.69	147.62	146.59	145.35	155.49
H0012	CJ6860	Bendale Branch	Reach 3	7086	99.2%	160.08	158.67	156.89	154.83	153.37	151.73	150.65	149.62	148.35	158.67
H0039	CJ6598	Bendale Branch	Reach 3	6769	99.2%	187.64	185.91	183.83	181.46	179.75	177.85	176.58	175.39	173.94	185.91
H0104	CJ6363	Bendale Branch	Reach 3	6598	99.2%	189.48	187.72	185.58	183.14	181.40	179.49	178.21	177.03	175.58	187.72
H0109	CJ6155	Bendale Branch	Reach 3	6299	99.2%	191.38	189.63	187.44	184.97	183.19	181.22	179.93	178.77	177.37	189.63
H0110	CJ5988	Bendale Branch	Reach 3	6120	99.2%	193.78	192.01	189.80	187.29	185.51	183.47	182.17	180.99	179.59	192.01
H0064	CJ5908	Bendale Branch	Reach 3	5988	99.2%	194.11	192.34	190.13	187.63	185.84	183.79	182.47	181.29	179.88	192.34
H0111	CJ5759	Bendale Branch	Reach 3	5876	99.2%	198.53	196.74	194.48	192.00	190.18	188.08	186.71	185.11	183.58	196.74
H0112	CJ5475	Bendale Branch	Reach 3	5600	99.2%	199.60	197.82	195.55	193.02	191.25	189.15	187.67	186.25	184.69	197.82
H0105	CJ5224	Bendale Branch	Reach 3	5442	98.2%	200.84	199.07	196.77	194.24	192.45	190.34	188.87	187.46	185.89	196.77
H0106	CJ5048	Bendale Branch	Reach 3	5224	98.2%	202.65	200.89	198.57	196.03	194.21	192.09	190.63	189.24	187.65	198.57
H0022	CJ4955	Bendale Branch	Reach 3	5048	98.2%	203.23	201.46	199.13	196.60	194.77	192.64	191.17	189.79	188.20	199.13
H0113	CJ4751	Bendale Branch	Reach 3	4928	98.2%	204.29	202.51	200.18	197.63	195.80	193.67	192.19	190.81	189.21	200.18
H0010	CJ4494	Bendale Branch	Reach 3	4676	98.2%	205.90	204.10	201.75	199.19	197.35	195.21	193.72	192.33	190.73	201.75
H0114	CJ4199	Bendale Branch	Reach 3	4527	98.2%	210.06	208.21	205.81	203.20	201.32	199.16	197.66	196.27	194.63	205.81
H0042	CJ3903	Bendale Branch	Reach 3	4142	98.2%	212.11	210.24	207.82	205.19	203.30	201.12	199.61	198.21	196.56	207.82
H0052	CJ2327	Bendale Branch	Reach 3	3867	97.1%	219.12	217.15	214.66	211.92	209.96	207.73	206.18	204.75	203.06	211.92
H0107	CJ2113	Bendale Branch	Reach 3	2278	97.1%	219.85	217.88	215.38	212.62	210.66	208.42	206.86	205.44	203.74	212.62
H0232	CJ1085_1	Bendale Branch	Reach 3	2073	97.1%	234.24	232.13	229.47	226.53	224.44	222.04	220.39	218.91	217.15	226.53
H0033	CJ918	Bendale Branch	Reach 3	1034	97.1%	238.62	236.48	233.76	230.77	228.64	226.19	224.53	223.03	221.25	230.77
H0023	CJ630	Bendale Branch	Reach 3	885	97.1%	240.46	238.30	235.56	232.55	230.42	227.97	226.30	224.80	223.02	232.55
H0196	CJ60_1	Bendale Branch	Reach 3	600	97.1%	244.01	241.82	239.05	236.01	233.91	231.39	229.69	228.16	226.35	236.01
H0048	CJ320	Bendale Trib	Reach 1	624	100.0%	28.38	28.12	27.79	27.42	27.16	26.85	26.64	26.45	26.22	28.38
H0002	CJ124	Bendale Trib	Reach 1	283	100.0%	28.40	28.14	27.81	27.45	27.18	26.88	26.67	26.47	26.23	28.40
H0159	CJ1261	Bendale Trib 2	Reach 1	1261	100.0%	19.69	19.51	19.29	19.04	18.87	18.67	18.53	18.40	18.25	19.69
H0031	CJ968	Bendale Trib 2	Reach 1	1066	100.0%	20.30	20.12	19.89	19.64	19.46	19.25	19.11	18.98	18.82	20.30

Table J1: Regional Storm Flows

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	Regional ARF	Flows (m3/s)									Final Flow (m³/s)
						100.0%	99.2%	98.2%	97.1%	96.3%	95.4%	94.8%	94.2%	93.5%	
H0016	CJ771	Bendale Trib 2	Reach 1	935	100.0%	**26.27**	26.04	25.74	25.41	25.17	24.91	24.73	24.55	24.35	**26.27**
H0068	CJ494	Bendale Trib 2	Reach 1	733	100.0%	**33.43**	33.13	32.75	32.33	32.04	31.69	31.46	31.25	30.98	**33.43**
H0080	CJ199	Bendale Trib 2	Reach 1	438	100.0%	**34.29**	33.98	33.60	33.17	32.86	32.50	32.26	32.04	31.77	**34.29**
H0140	CJ5305	Centennial Creek	Reach 1	5341	100.0%	**3.07**	3.04	3.00	2.96	2.94	2.90	2.88	2.86	2.84	**3.07**
H0136	CJ5014_1	Centennial Creek	Reach 1	5238	100.0%	**4.76**	4.71	4.64	4.57	4.53	4.47	4.43	4.39	4.35	**4.76**
H0135	CJ4858	Centennial Creek	Reach 1	4980	100.0%	**5.10**	5.05	4.98	4.90	4.85	4.79	4.75	4.71	4.66	**5.10**
H0134	CJ4770	Centennial Creek	Reach 1	4834	100.0%	**6.43**	6.36	6.27	6.17	6.10	6.01	5.96	5.91	5.85	**6.43**
H0133	CJ4592	Centennial Creek	Reach 1	4740	100.0%	**7.31**	7.22	7.12	7.01	6.92	6.83	6.77	6.70	6.63	**7.31**
H0132	CJ4219	Centennial Creek	Reach 1	4562	100.0%	**8.16**	8.06	7.95	7.82	7.73	7.62	7.55	7.48	7.40	**8.16**
H0138	CJ3617_1	Centennial Creek	Reach 1	3852	100.0%	**31.68**	31.22	30.69	30.33	29.96	29.54	29.26	28.99	28.67	**31.68**
H0131	CJ3485.5	Centennial Creek	Reach 1	3637	100.0%	**32.54**	32.07	31.53	31.17	30.79	30.35	30.06	29.79	29.45	**32.54**
H0130	CJ3175	Centennial Creek	Reach 1	3423	100.0%	**33.12**	32.63	32.10	31.72	31.34	30.90	30.61	30.33	29.99	**33.12**
H0027	CJ3066	Centennial Creek	Reach 1	3148	100.0%	**35.23**	34.71	34.16	33.77	33.36	32.90	32.60	32.30	31.95	**35.23**
H0004	CJ2281	Centennial Creek	Reach 1	3004	100.0%	**38.05**	37.50	36.96	36.51	36.07	35.58	35.25	34.93	34.55	**38.05**
H0137	CJ1534_1	Centennial Creek	Reach 1	2188	100.0%	**39.08**	38.52	37.98	37.50	37.05	36.54	36.20	35.87	35.47	**39.08**
H0197	CJ743	Centennial Creek	Reach 2	1438	99.2%	57.92	**57.34**	56.57	55.69	55.05	54.30	53.80	53.33	52.75	**57.34**
H0184	CJ44	Centennial Creek	Reach 2	641	99.2%	53.49	**53.08**	52.33	51.51	50.88	50.04	49.56	49.11	48.55	**53.08**
H0191	CJ270	Centennial Trib	Reach 1	387	100.0%	**12.17**	12.02	11.84	11.63	11.48	11.31	11.20	11.09	10.97	**12.17**
H0102	CJ66	Centennial Trib	Reach 1	274	100.0%	**14.67**	14.50	14.28	14.05	13.88	13.68	13.55	13.43	13.28	**14.67**
H0179	CJ686_1	Curran Hall Cree	Reach 1	808	100.0%	**2.65**	2.63	2.60	2.57	2.54	2.52	2.50	2.48	2.46	**2.65**
H0185	CJ269_1	Curran Hall Cree	Reach 1	585	100.0%	**7.90**	7.83	7.74	7.63	7.56	7.48	7.42	7.37	7.30	**7.90**
H0139	CJ7039	Dorset Park Bran	Reach 1	7039	100.0%	**3.51**	3.48	3.45	3.40	3.37	3.34	3.32	3.30	3.27	**3.51**
H0118	CJ6702	Dorset Park Bran	Reach 1	6842	100.0%	**13.78**	13.67	13.52	13.35	13.24	13.10	13.01	12.93	12.83	**13.78**
H0117	CJ6502	Dorset Park Bran	Reach 1	6642	100.0%	**15.64**	15.50	15.34	15.15	15.02	14.86	14.76	14.66	14.55	**15.64**
H0071	CJ5953	Dorset Park Bran	Reach 1	6122	100.0%	**16.79**	16.64	16.46	16.26	16.12	15.95	15.84	15.74	15.61	**16.79**
H0065	CJ5617	Dorset Park Bran	Reach 1	5925	100.0%	**17.68**	17.53	17.34	17.12	16.97	16.80	16.68	16.57	16.44	**17.68**
H0073	CJ5261	Dorset Park Bran	Reach 1	5593	100.0%	**38.68**	38.33	37.88	37.39	37.03	36.63	36.36	36.10	35.79	**38.68**
H0078	CJ4796	Dorset Park Bran	Reach 1	5046	100.0%	**41.90**	41.52	41.04	40.50	40.12	39.68	39.39	39.11	38.77	**41.90**
H0116	CJ4584	Dorset Park Bran	Reach 1	4725	100.0%	**45.25**	44.84	44.32	43.74	43.33	42.86	42.55	42.24	41.88	**45.25**
H0041	CJ4101	Dorset Park Bran	Reach 1	4532	100.0%	**74.28**	73.60	72.77	71.83	71.17	70.39	69.87	69.37	68.79	**74.28**
H0101	CJ3846	Dorset Park Bran	Reach 1	4016	100.0%	**77.32**	76.60	75.72	74.76	74.08	73.27	72.72	72.20	71.59	**77.32**
H0014	CJ3439	Dorset Park Bran	Reach 1	3820	100.0%	**83.76**	82.96	81.98	80.88	80.12	79.25	78.67	78.11	77.44	**83.76**
H0115	CJ2990	Dorset Park Bran	Reach 1	3231	100.0%	**87.85**	87.03	86.03	84.90	84.09	83.17	82.56	81.98	81.29	**87.85**
H0205	CJ2804	Dorset Park Bran	Reach 1	2990	100.0%	**92.05**	91.20	90.14	88.97	88.13	87.17	86.53	85.93	85.20	**92.05**
H0070	CJ2136	Dorset Park Bran	Reach 1	2642	100.0%	**116.78**	115.72	114.38	112.88	111.82	110.60	109.79	109.02	108.10	**116.78**
H0165	CJ1996	Dorset Park Bran	Reach 1	2097	100.0%	**119.46**	118.37	117.00	115.47	114.38	113.14	112.31	111.52	110.58	**119.46**
H0021	CJ1511	Dorset Park Bran	Reach 2	1923	100.0%	**143.47**	142.16	140.52	138.68	137.38	135.89	134.90	133.95	132.82	**143.47**
H0053	CJ1194	Dorset Park Bran	Reach 2	1422	99.2%	154.42	**153.01**	151.23	149.25	147.86	146.25	145.18	144.16	142.94	**153.01**
H0166	CJ50	Dorset Park Bran	Reach 2	1126	99.2%	156.02	**154.60**	152.78	150.72	149.27	147.60	146.47	145.42	144.15	**154.60**
H0164	CJ815	Dorset Park Inte	Reach 1	815	100.0%	**19.87**	19.69	19.46	19.20	19.02	18.81	18.67	18.53	18.37	**19.87**
H0001	CJ474	Dorset Park Inte	Reach 1	627	100.0%	**21.20**	21.00	20.76	20.48	20.29	20.07	19.92	19.78	19.61	**21.20**
H0195	CJ105	Dorset Park Inte	Reach 1	447	100.0%	**22.00**	21.80	21.54	21.27	21.07	20.84	20.69	20.54	20.37	**22.00**
H0019	CJ2327_1	East Highland Creek	Reach 1	3211	97.1%	405.86	401.88	397.59	**392.80**	389.34	385.15	382.30	379.68	376.31	**392.80**

Table J1: Regional Storm Flows

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	Regional ARF	Flows (m3/s)									Final Flow (m³/s)
						100.0%	99.2%	98.2%	97.1%	96.3%	95.4%	94.8%	94.2%	93.5%	
H0037	CJ1656	East Highland Creek	Reach 1	2320	97.1%	408.78	404.79	400.46	**395.62**	392.10	387.88	385.00	382.33	378.95	**395.62**
H0186	CJ110	East Highland Creek	Reach 1	1620	96.3%	413.52	409.60	405.19	400.20	**396.65**	392.37	389.38	386.64	383.24	**396.65**
H0153	CJ1874	Ellesmere Ravine	Reach 1	1890	100.0%	**4.87**	4.83	4.77	4.70	4.66	4.61	4.57	4.54	4.50	**4.87**
H0043	CJ965	Ellesmere Ravine	Reach 1	1433	100.0%	**12.55**	12.41	12.24	12.05	11.91	11.76	11.65	11.55	11.43	**12.55**
H0154	CJ290	Ellesmere Ravine	Reach 1	888	100.0%	**13.67**	13.52	13.33	13.12	12.98	12.82	12.70	12.60	12.47	**13.67**
H0128	CJ202	Ellesmere Ravine	Reach 1	244	100.0%	**16.66**	16.48	16.26	16.01	15.83	15.63	15.49	15.36	15.20	**16.66**
H0047	CJ202	Ellesmere Ravine	Reach 1	211	100.0%	**16.66**	16.48	16.26	16.01	15.83	15.63	15.49	15.36	15.20	**16.66**
H0084	CJ46_2	Ellesmere Ravine	Reach 1	141	100.0%	**16.49**	16.27	16.04	15.80	15.63	15.48	15.34	15.21	15.05	**16.49**
H0152	CJ5926	Highland Creek	Reach 1	6917	95.4%	808.25	800.25	790.74	780.49	773.16	**769.77**	763.82	758.21	751.32	**769.77**
H0061	CJ5723	Highland Creek	Reach 2	5884	95.4%	824.38	816.51	806.78	796.25	788.75	**784.91**	778.93	773.23	766.20	**784.91**
H0259	CJ4340	Highland Creek	Reach 2	5686	95.4%	825.52	816.79	807.07	796.42	788.82	**784.87**	778.87	773.11	766.08	**784.87**
H0086	CJ4097	Highland Creek	Reach 2	4276	94.8%	826.97	818.13	808.38	797.68	790.05	786.03	**780.02**	774.25	767.19	**780.02**
H0085	CJ3665	Highland Creek	Reach 2	4113	94.8%	828.68	819.66	809.87	799.11	791.43	787.32	**781.29**	775.52	768.42	**781.29**
H0091	CJ3128	Highland Creek	Reach 2	3624	94.8%	828.71	819.62	809.82	799.04	791.37	787.22	**781.20**	775.43	768.32	**781.20**
H0088	CJ1739_1	Highland Creek	Reach 2	3128	94.2%	828.00	818.43	808.66	797.81	790.10	785.67	779.61	**773.82**	766.68	**773.82**
H0198	CJ1090	Highland Creek	Reach 2	1663	94.2%	823.65	813.78	804.09	793.31	785.67	781.07	774.99	**769.12**	762.03	**769.12**
H0188	CJ636	Highland Creek	Reach 2	1006	93.5%	811.72	801.00	791.31	780.66	773.14	767.86	761.84	756.14	**749.19**	**749.19**
H0162	CJ379_1	Highland Creek	Reach 3	513	93.5%	817.76	807.20	797.41	786.50	778.81	772.40	766.24	760.44	**753.37**	**753.37**
H0175	CJ171	Highland Creek	Reach 4	248	93.5%	841.02	830.66	820.35	808.83	800.74	793.51	787.10	781.07	**773.79**	**773.79**
H0129	CJ26	Highland Creek	Reach 5	78	93.5%	845.25	834.89	824.47	812.82	804.63	797.37	790.92	784.83	**777.49**	**777.49**
H0194	CJ439	Highland Trib 1	Reach 1	439	100.0%	**3.94**	3.91	3.86	3.81	3.78	3.74	3.71	3.68	3.65	**3.94**
H0193	CJ121	Highland Trib 1	Reach 1	295	100.0%	**3.87**	3.85	3.80	3.75	3.72	3.67	3.64	3.61	3.57	**3.87**
H0170	CJ5221	Malvern Branch	Reach 1	5221	100.0%	**19.87**	19.69	19.47	19.22	19.05	18.84	18.71	18.58	18.42	**19.87**
H0054	CJ5000	Malvern Branch	Reach 1	5071	100.0%	**30.04**	29.78	29.45	29.08	28.82	28.51	28.31	28.12	27.88	**30.04**
H0125	CJ4655	Malvern Branch	Reach 1	4961	100.0%	**31.83**	31.55	31.20	30.81	30.53	30.22	30.00	29.80	29.55	**31.83**
H0124	CJ4418	Malvern Branch	Reach 1	4627	100.0%	**37.66**	37.33	36.92	36.45	36.13	35.75	35.50	35.26	34.97	**37.66**
H0126	CJ4136	Malvern Branch	Reach 2	4305	100.0%	**81.69**	80.97	80.05	79.03	78.31	77.49	76.93	76.39	75.75	**81.69**
H0094	CJ4006	Malvern Branch	Reach 2	4098	100.0%	**82.18**	81.45	80.53	79.50	78.77	77.94	77.37	76.83	76.19	**82.18**
H0049	CJ3823	Malvern Branch	Reach 2	3922	100.0%	**83.26**	82.52	81.58	80.54	79.81	78.96	78.39	77.84	77.18	**83.26**
H0103	CJ2835	Malvern Branch	Reach 2	3757	100.0%	**103.00**	102.09	100.94	99.66	98.75	97.70	96.99	96.32	95.51	**103.00**
H0100	CJ2765	Malvern Branch	Reach 2	2765	100.0%	**123.45**	122.35	120.97	119.42	118.33	117.07	116.22	115.41	114.44	**123.45**
H0100	CJ2477	Malvern Branch	Reach 2	2572	100.0%	**139.84**	138.59	137.02	135.25	134.00	132.57	131.60	130.68	129.57	**139.84**
H0013	CJ2130	Malvern Branch	Reach 2	2450	100.0%	**141.35**	140.08	138.49	136.70	135.43	133.97	132.99	132.06	130.94	**141.35**
H0044	CJ1968	Malvern Branch	Reach 2	2092	99.2%	144.00	**142.71**	141.08	139.26	137.96	136.48	135.48	134.53	133.39	**142.71**
H0026	CJ1664	Malvern Branch	Reach 2	1946	99.2%	149.92	**148.57**	146.88	144.98	143.63	142.08	141.04	140.05	138.86	**148.57**
H0003	CJ1390	Malvern Branch	Reach 2	1634	99.2%	150.71	**149.35**	147.65	145.74	144.38	142.82	141.78	140.78	139.59	**149.35**
H0083	CJ1260	Malvern Branch	Reach 2	1347	99.2%	153.52	**152.14**	150.40	148.46	147.07	145.48	144.42	143.41	142.19	**152.14**
H0127	CJ935_2	Malvern Branch	Reach 2	1178	99.2%	170.09	**168.56**	166.62	164.44	162.90	161.14	159.95	158.82	157.81	**168.56**
H0127	CJ739	Malvern Branch	Reach 2	935	99.2%	178.37	**176.76**	174.72	172.44	170.83	168.98	167.74	166.55	165.17	**176.76**
H0172	CJ59	Malvern Branch	Reach 2	562	99.2%	182.41	**180.74**	178.65	176.31	174.66	172.76	171.48	170.27	168.76	**180.74**
H0160	CJ1113	Malvern Trib	Reach 1	1113	100.0%	**21.23**	21.04	20.79	20.52	20.33	20.11	19.96	19.82	19.65	**21.23**
H0059	CJ902	Malvern Trib	Reach 1	951	100.0%	**26.86**	26.62	26.31	25.97	25.73	25.45	25.26	25.08	24.87	**26.86**
H0032	CJ459	Malvern Trib	Reach 1	823	100.0%	**28.06**	27.80	27.48	27.13	26.88	26.59	26.39	26.21	25.98	**28.06**

Table J1: Regional Storm Flows

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	Regional ARF	Flows (m3/s)									Final Flow (m³/s)
						100.0%	99.2%	98.2%	97.1%	96.3%	95.4%	94.8%	94.2%	93.5%	
H0161	CJ62	Malvern Trib	Reach 1	411	100.0%	**41.43**	41.06	40.58	40.06	39.69	39.26	38.97	38.70	38.37	**41.43**
H0144	CJ7852	Miliken Branch	Reach 1	7895	100.0%	**40.48**	40.11	39.65	39.13	38.77	38.35	38.06	37.80	37.48	**40.48**
H0018	CJ7471	Miliken Branch	Reach 1	7799	100.0%	**43.57**	43.18	42.68	42.12	41.73	41.28	40.97	40.69	40.34	**43.57**
H0063	CJ7195	Miliken Branch	Reach 1	7429	100.0%	**44.57**	44.17	43.66	43.09	42.68	42.22	41.91	41.62	41.26	**44.57**
H0020	CJ6771	Miliken Branch	Reach 1	7153	100.0%	**46.84**	46.41	45.87	45.27	44.85	44.36	44.03	43.72	43.35	**46.84**
H0011	CJ6352	Miliken Branch	Reach 1	6709	100.0%	**52.67**	52.19	51.58	50.91	50.43	49.88	49.52	49.17	48.75	**52.67**
H0045	CJ5876_1	Miliken Branch	Reach 1	6291	99.2%	53.85	**53.36**	52.74	52.05	51.56	51.00	50.63	50.27	49.84	**53.36**
H0074	CJ5616	Miliken Branch	Reach 1	5817	99.2%	62.13	**61.56**	60.85	60.05	59.49	58.85	58.42	58.00	57.51	**61.56**
H0096	CJ5398	Miliken Branch	Reach 1	5540	99.2%	63.65	**63.07**	62.34	61.52	60.95	60.29	59.85	59.43	58.92	**63.07**
H0121	CJ4921	Miliken Branch	Reach 1	5358	99.2%	65.06	**64.47**	63.72	62.89	62.30	61.63	61.18	60.75	60.23	**64.47**
H0122	CJ4780	Miliken Branch	Reach 1	4881	99.2%	65.94	**65.34**	64.58	63.74	63.14	62.47	62.01	61.57	61.05	**65.34**
H0079	CJ4556	Miliken Branch	Reach 1	4688	99.2%	66.27	**65.66**	64.91	64.06	63.46	62.78	62.32	61.88	61.35	**65.66**
H0007	CJ4178	Miliken Branch	Reach 2	4455	99.2%	154.98	**153.57**	151.80	149.83	148.43	146.83	145.75	144.73	143.50	**153.57**
H0015	CJ3868	Miliken Branch	Reach 2	4141	99.2%	156.31	**154.89**	153.10	151.11	149.70	148.09	147.00	145.97	144.73	**154.89**
H0093	CJ3387	Miliken Branch	Reach 2	3838	98.2%	160.25	158.80	**156.96**	154.92	153.48	151.82	150.71	149.64	148.37	**156.96**
H0123	CJ3152	Miliken Branch	Reach 2	3312	98.2%	173.84	172.29	**170.32**	168.18	166.72	165.06	164.01	162.90	161.53	**170.32**
H0087	CJ2889	Miliken Branch	Reach 2	3027	98.2%	188.03	186.36	**184.26**	181.96	180.44	178.74	177.68	176.51	175.05	**184.26**
H0006	CJ2622	Miliken Branch	Reach 2	2833	98.2%	190.09	188.41	**186.29**	183.98	182.44	180.74	179.68	178.50	177.02	**186.29**
H0057	CJ2246	Miliken Branch	Reach 2	2581	98.2%	195.67	193.94	**191.76**	189.39	187.81	186.08	185.01	183.77	182.25	**191.76**
H0089	CJ1704	Miliken Branch	Reach 2	2191	97.1%	208.22	206.37	204.04	**201.52**	199.83	197.97	196.80	195.48	193.86	**201.52**
H0089	CJ1208	Miliken Branch	Reach 2	1632	97.1%	219.98	218.01	215.55	**212.87**	211.07	209.09	208.30	207.65	206.34	**212.87**
H0143	CJ71_1	Miliken Branch	Reach 2	1169	97.1%	220.81	218.86	216.39	**213.72**	211.92	209.95	208.67	207.20	205.51	**213.72**
H0142	CJ3313	Miliken Trib	Reach 1	3313	100.0%	**39.14**	38.79	38.35	37.85	37.51	37.11	36.84	36.58	36.28	**39.14**
H0072	CJ2984	Miliken Trib	Reach 1	3158	100.0%	**39.85**	39.49	39.04	38.54	38.18	37.77	37.50	37.24	36.93	**39.85**
H0062	CJ2547	Miliken Trib	Reach 1	2961	100.0%	**40.77**	40.40	39.94	39.43	39.07	38.65	38.37	38.10	37.78	**40.77**
H0036	CJ2011	Miliken Trib	Reach 1	2479	100.0%	**48.56**	48.12	47.56	46.94	46.50	46.00	45.66	45.34	44.96	**48.56**
H0097	CJ1634	Miliken Trib	Reach 1	2018	100.0%	**53.88**	53.39	52.77	52.09	51.60	51.04	50.66	50.31	49.88	**53.88**
H0119	CJ812	Miliken Trib	Reach 1	1573	100.0%	**59.79**	59.24	58.55	57.79	57.25	56.62	56.21	55.81	55.33	**59.79**
H0119	CJ686	Miliken Trib	Reach 1	701	100.0%	**70.43**	69.79	68.98	68.08	67.45	66.72	66.23	65.77	65.21	**70.43**
H0055	CJ63	Miliken Trib	Reach 1	445	100.0%	**84.34**	83.57	82.61	81.53	80.77	79.89	79.30	78.75	78.07	**84.34**
H0149	CJ3316_1	Thornton Creek	Reach 1	3449	100.0%	**0.45**	0.44	0.43	0.43	0.42	0.41	0.41	0.40	0.40	**0.45**
H0200	CJ2649	Thornton Creek	Reach 1	3246	100.0%	**4.29**	4.24	4.17	4.10	4.04	3.98	3.94	3.90	3.85	**4.29**
H0050	CJ2649	Thornton Creek	Reach 1	3156	100.0%	**4.29**	4.24	4.17	4.10	4.04	3.98	3.94	3.90	3.85	**4.29**
H0040	CJ2153	Thornton Creek	Reach 1	2659	100.0%	**8.08**	7.98	7.86	7.72	7.63	7.51	7.44	7.37	7.28	**8.08**
H0040	CJ1761	Thornton Creek	Reach 1	2053	100.0%	**10.50**	10.37	10.20	10.00	9.87	9.71	9.60	9.50	9.38	**10.50**
H0009	CJ1253	Thornton Creek	Reach 1	1704	100.0%	**24.19**	23.89	23.51	23.09	22.79	22.44	22.20	21.98	21.72	**24.19**
H0187	CJ404	Thornton Creek	Reach 1	1219	100.0%	**24.36**	24.05	23.68	23.27	22.95	22.60	22.36	22.13	21.86	**24.36**
H0183	CJ96	Thornton Creek	Reach 2	167	100.0%	**29.62**	29.33	28.88	28.41	28.02	27.58	27.30	27.01	26.65	**29.62**
H0150	CJ1011	Thornton Trib	Reach 1	1011	100.0%	**6.49**	6.41	6.30	6.18	6.10	6.00	5.93	5.87	5.80	**6.49**
H0151	CJ225	Thornton Trib	Reach 1	441	100.0%	**7.44**	7.35	7.21	7.08	6.99	6.87	6.79	6.72	6.63	**7.44**
H0066	CJ6310	West Highland Cr	Reach 1	6565	96.3%	393.47	389.96	385.58	380.72	**377.29**	373.35	370.65	368.26	365.40	**377.29**
H0189	CJ6017	West Highland Cr	Reach 1	6258	96.3%	393.81	390.31	385.92	381.06	**377.62**	373.67	370.98	368.58	365.72	**377.62**
H0056	CJ5083	West Highland Cr	Reach 2	5943	96.3%	405.61	402.02	397.57	392.64	**389.16**	385.20	382.45	379.90	376.92	**389.16**

Table J1: Regional Storm Flows

PCSWMM Subcatchment	PCSWMM Conduit	River Name	Reach Name	River Station	Regional ARF	Flows (m3/s)									Final Flow (m³/s)
						100.0%	99.2%	98.2%	97.1%	96.3%	95.4%	94.8%	94.2%	93.5%	
H0058	CJ3335	West Highland Cr	Reach 2	5060	96.3%	413.38	409.76	405.23	400.22	**396.65**	392.58	389.80	387.21	384.16	**396.65**
H0182	CJ1937	West Highland Cr	Reach 2	3313	96.3%	419.68	416.00	411.38	406.27	**402.64**	398.49	395.66	393.02	389.88	**402.64**
H0099	CJ1344	West Highland Cr	Reach 3	1650	96.3%	440.85	436.96	432.11	426.77	**422.97**	418.65	415.68	412.90	409.56	**422.97**
H0180	CJ749	West Highland Cr	Reach 3	1298	96.3%	441.35	437.44	432.58	427.19	**423.33**	418.96	415.98	413.20	409.89	**423.33**
H0171	CJ77	West Highland Cr	Reach 4	585	96.3%	448.32	443.63	438.54	432.98	**429.10**	425.63	422.60	419.74	416.46	**429.10**
H0146	CJ884	West Highland T1	Reach 1	884	100.0%	**2.76**	2.73	2.70	2.66	2.64	2.61	2.59	2.57	2.55	**2.76**
H0095	CJ699	West Highland T1	Reach 1	797	100.0%	**3.63**	3.60	3.55	3.51	3.47	3.44	3.41	3.39	3.36	**3.63**
H0076	CJ594	West Highland T1	Reach 1	656	100.0%	**5.64**	5.59	5.53	5.45	5.40	5.35	5.31	5.27	5.22	**5.64**
H0030	CJ377	West Highland T1	Reach 1	541	100.0%	**6.54**	6.48	6.40	6.32	6.26	6.19	6.15	6.11	6.05	**6.54**
H0029	CJ187	West Highland T1	Reach 1	383	100.0%	**7.25**	7.18	7.10	7.01	6.94	6.87	6.82	6.77	6.71	**7.25**
H0167	CJ52	West Highland T1	Reach 1	154	100.0%	**9.80**	9.70	9.59	9.46	9.39	9.28	9.22	9.15	9.09	**9.80**
H0181	CJ1594	West Highland T2	Reach 1	1594	100.0%	**24.93**	24.69	24.40	24.07	23.84	23.57	23.39	23.22	23.02	**24.93**
H0038	CJ1065	West Highland T2	Reach 1	1280	100.0%	**27.82**	27.56	27.23	26.87	26.61	26.31	26.11	25.92	25.70	**27.82**
H0046	CJ531	West Highland T2	Reach 1	1012	100.0%	**36.39**	36.05	35.62	35.15	34.81	34.43	34.17	33.92	33.63	**36.39**
H0190	CJ147	West Highland T2	Reach 1	428	100.0%	**38.43**	36.04	35.62	35.14	34.81	36.32	36.04	35.77	35.45	**38.43**