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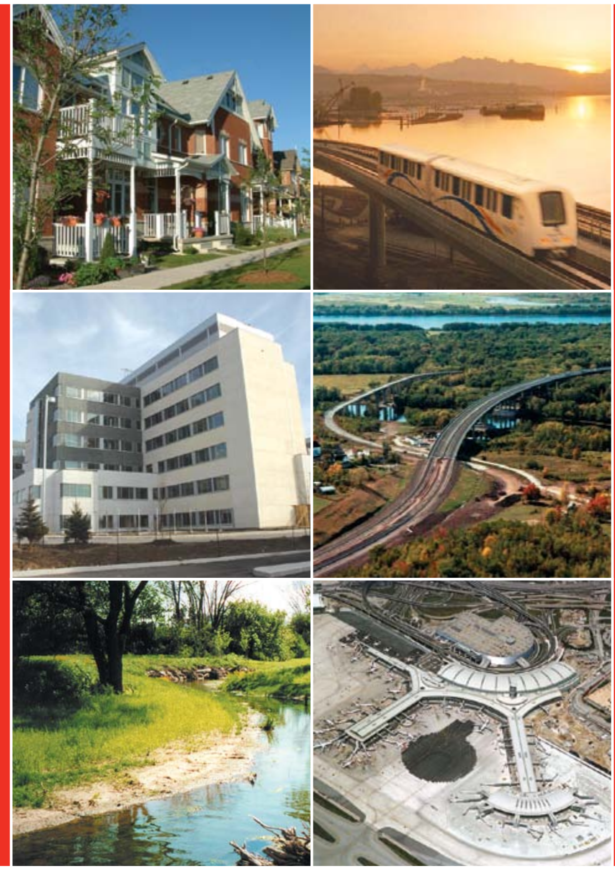

Draft Final Report

Etobicoke Creek Hydrology Update

14-11605-001

COMMUNITIES

TRANSPORTATION

BUILDINGS

INFRASTRUCTURE

April 2013

STANDARD LIMITATIONS

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1.0 INTRODUCTION

1.1 Background

The present study involved updating the hydrologic models for the Etobicoke Creek watershed (Phase I) and developing stormwater management quantity control criteria for the subject watershed (Phase II). The recommendations from the study will provide guidance to local, regional and provincial government agencies as well as the private sector in managing and planning existing and future developments. A map of the study area is presented on Figure 1.1.

The hydrologic model currently in use on the Etobicoke Creek watershed was originally established by Fred Schaeffer & Associates in 1996 along with a watershed management strategy developed for future and ultimate land use scenarios. Since then, the model was subsequently updated in 2003 and 2007 by Totten Sims Hubicki Associates (TSH) using subcatchment and stream delineation boundaries similar to the previous 1996 study. The Toronto and Region Conservation Authority (TRCA) recognizes the necessity to update the hydrology and stormwater management strategy for the following reasons:

- Drainage characteristics and watershed parameters used in the 2007 models (i.e., subcatchment boundaries, reach delineation, land use information, etc.) were similar to the previous 1996 study. Hence, the model needs to be updated to reflect the current drainage characteristics of the watershed.
- The calibration results presented in the 2007 study showed relatively poor correlation with observed data. Since the 2007 study, there have been additional precipitation events, which can be used for calibration.
- Environmental Canada’s Streamflow gauge located near the mouth of the creek at QEW provides the only observed flow data for the calibration in the 2007 models. Due to the different geographic characteristics of the watershed, especially for areas in the upper Etobicoke Creek watershed (headwatershed), calibration based on a single streamflow location is not sufficient to confidently calibrate the entire Etobicoke Creek watershed.
- The stormwater management quantity control strategy for Etobicoke Creek watershed has not been updated since 1996. Therefore, the quantity control strategy needs to be updated to incorporate state of the art stormwater best management practices (BMPs).

MMM Group Limited was retained by the Toronto and Region Conservation Authority (TRCA) to undertake the present study. Upon completion of the Phase I study, this Interim Report presents the methodology and the results of the hydrologic model development, calibration and validation. It also provides a discussion on the analysis to investigate the inconsistencies in the peak flows from the previous to the present studies.

1.2 Description of Study Area

As shown in Figure 1.1, Etobicoke Creek watershed is a long and narrow watershed that runs through Caledon, Brampton, Mississauga and Toronto. The majority of the watershed areas have been urbanized. The undeveloped rural areas within the watershed are primarily located in the headwaters. The entire watershed covers over 200 km^2 in area with relatively flat catchment slopes.

1.3 Scope of Work

As mentioned previously, the present study involved two phases: (1) to update the hydrologic models for the Etobicoke Creek watershed and (2) to develop stormwater management quantity control criteria for the subject watershed. The following fundamental tasks were identified in the Scope of Work (SOW) for the proposed study:

- Phase 1
  - Review existing available information provided by TRCA staff.
  - Confirm subcatchment delineation and develop a hydrologic model for the Etobicoke Creek watershed based on existing land use conditions.
  - Calibrate the model based on observed precipitation and streamflow data.
  - Develop existing and future condition models. Estimate peak flows for existing and future land use scenarios.

- Phase 2
  - Develop a stormwater quantity control strategy for the watershed to improve the management of existing flooding risks and to mitigate potential impacts as a result of predicted future land use changes.

1.4 Relevant Previous Studies

An extensive review of relevant studies was conducted for the present hydrologic update. The reviewed documents are summarized below:

- *"Flood Plain Criteria and Management Evaluation Study"*, M. M. Dillon Ltd. and James F. MacLaren Ltd.,
- *"Report on a Hydrologic Model Study Etobicoke and Mimico Creeks for the Metropolitan Toronto and Region Conservation Authority"*, March 1978, James F. MacLaren Limited.
- "*Snowmelt Hydrology – A Method of Modelling a T-Year Snowmelt Hydrograph*", March 1990, Rob Bishop and Harold Belore.
- *"Etobicoke Creek Flood Control Study, Watershed Management Strategy"*, September 1996, Fred Schaeffer & Associates Limited.

- *“City of Toronto Wet Weather Flow Management Plan (WWFMP), Area 2: Etobicoke and Mimico Creeks”*, 2003, Totten Sims Hubicki Associates.
- *“Summary of Rainfall Analysis Completed for the August 19th, 2005 Storm Event”,* June 2006, Clarifica.
- *“Etobicoke Creek Hydrology Update”*, March 2007, Totten Sims Hubicki Associates.

2.0 METHODOLOGY

2.1 General

The methodology used for the study was developed with the view of achieving the objectives specified in the Terms of Reference (TOR). Background information provided by TRCA pertinent to the study was reviewed and incorporated as necessary. The following sections describe the methodology used to complete different aspects of the model development.

2.2 Watershed Discretization

Watershed, subwatershed and catchment boundaries were carefully delineated based on the latest topographic information, up-to-date as-built information, detailed design drawings, and sewershed data. For modeling purposes, the entire Etobicoke Creek watershed was divided into 12 sub-basins (as shown in Figure 2.1). The discretization of the sub-basins into subcatchments was done with the view of achieving the best balance between the catchment size and the length of routing sections. This resulted in the watersheds being divided into more catchments than in the previous studies. A total of 280 subcatchments, ranging from 2 ha (e.g., small development site) to 500 ha (undeveloped rural area located in the headwatershed), with average area of approximately 80 ha, was created for the present model. A summary of the watershed discretization is presented in Table 2.1. The watershed delineation along with the stream network and topographic information are shown on Drawing 2.1 in the rear pocket of this report.

Table 2.1 Watershed Discretization Summary

Sub-Basins No.	Sub-Basin Name	TRCA Sub-Watershed Name	Drainage Area (ha)	No. of Catchments	Average Catchment Size (ha)
1	Etobicoke Headwater (Upstream)	Etobicoke Headwater	4716	62	76
2	Etobicoke Headwater (Downstream)		1416	23	62
3	Etobicoke West Branch (U/S of Downtown Brampton Flow Gauge)	Etobicoke West Branch	780	12	65
4	Etobicoke West Branch (D/S of Downtown BramptonnFlow Gauge)		2255	32	70
5	Tributary 3	Tributary 3	1306	20	65
6	Spring Creek (U/S of Spring Creek Flow Guge)	Spring Creek	3804	56	68
7	Spring Creek (D/S of Spring Creek Flow Gauge)		1162	14	83
8	Etobicoke Creek Main Branch	Etobicoke Creek Main Branch	2025	19	107
9	Tributary 4	Tributary 4	955	12	80
10	Little Etobicoke Creek	Little Etobicoke Creek	2260	15	151
11	Lower Etobicoke (U/S of Little Etobicike Confluence)	Lower Etobicoke	623	5	125
12	Lower Etobicoke (D/S of Little Etobicike Confluence)		969	10	97
Total	Entire Etobicoke Creek Watershed		22270	280	80

Watershed parameters for the hydrologic models (i.e., CN, imperviousness, catchment slope, catchment length, etc.) were derived from the DTM, aerial photographs and soils mapping. Such information was provided by TRCA, confirmed and reviewed by MMM. The following sections describe the methodology used to estimate the parameters for the hydrologic models.

2.3 Catchment Parameters

Consistent with the previous models, the SCS Curve Number method was used to model the rainfall-runoff relationship for the watersheds. The runoff curve number is a function of the soil type, land-use and antecedent moisture conditions (AMC). The antecedent moisture conditions of a soil are determined based on the total precipitation occurring in the five-day period preceding a storm event. Antecedent moisture condition II (AMC II) depicts the average condition, and AMC I and AMC III represent dry and wet soil conditions, respectively.

The availability of GIS data, coupled with a variety of geospatial data processing tools in GIS software (i.e., ARCVIEW), facilitated a more accurate and efficient approach to deriving model parameters. Most of the above tasks were automated by the software and a brief description of the steps involved is provided below.

2.3.1 Land Use

Land use maps of the study area were developed from high resolution aerial photographs and soils mapping, using an elaborate classification and clustering scheme in ARCVIEW. Using the Spatial Analyst tool, the maximum likelihood classifier was used to classify the aerial photographs into clusters (i.e., groups with some common feature) according to their reflectance values. Through visual inspection of the clusters, they were either merged or designated as one of the thirteen (13) categories as indicated in Table 2.2. The land use mapping was finalized by manually delineating residential and commercial areas, which are generally difficult to classify from high resolution images.

The land use maps are included under Appendix A, as Figures A.1 and A.2 for existing and future development conditions respectively.

2.3.2 Soils Mapping

Most of the soils within the study area had been pre-classified into one of the five hydrologic soil groups (HSG's), i.e., A, AB, B, C and D. The HSG's are indicative of the runoff potential of particular soil types, e.g., Group A soils have the lowest runoff potential, while Group D soils have the highest runoff potential. Soils that were not classified by the mapping, such as Bottom Land, were placed in Group D to reflect their often saturated state.

An overall soils map showing the hydrologic soil groups for soil types in the study area is included in Appendix A, as Figure A.3.

2.3.3 Runoff Curve Numbers (CNs)

The weighted average runoff curve number (CN) for each subcatchment was computed in GIS software. To do this, a “union” was created of the land-use and soils shape files in ARCVIEW and a lookup table created of Curve Numbers, which cross referenced land-use, hydrologic soil group and various CN values (see Table 2.2). The curve numbers used in the lookup table are for AMC II conditions, and were taken from standard published values. Using the tabulated CN values, a curve number grid was generated for the watershed. The weighted average curve number for each catchment was then determined from the curve number grid in ARCVIEW, on a cell-by-cell basis.

Table 2.2 Curve Number Lookup Table

Land Use Categories	Type	Code	A	AB	B	C	D
01	Forest	NCF	36	48	60	73	79
02	Agriculture/Meadow / Successional	AG, NCM, NCS	48	54	60	72	81
03	Open Water / Water Body /	OW	50	50	50	50	50
04	Wetland	NCW	50	50	50	50	50
05	Open Space / Parkland / Vacant / Golf Courses	OS	39	50	61	74	80
06	Rural/Estate Residential	RSES	51	59.5	68	79	84
07	Low Density Residential	RSL	61	68	75	83	87
08	Medium Density Residential	RSM	77	81	85	90	92
09	High Density Residential	RSHI	77	81	85	90	92
10	Institutional / School / Recreational	DAIS, DARC	77	81	85	90	92
11	Commercial / Industrial	DAID, DACM	89	90	92	94	95
12	Roadway / Railway	TRRD, TRRW	98	98	98	98	98
13	Airport Lands	TRAL	59	66.5	74	82	86

The weighted average curve numbers were used to determine the initial abstraction (*Ia*) for each catchment. The initial abstraction is that part of the rainfall that is intercepted by vegetation or surface depressions prior to the initiation of runoff. Numerous studies have found that the empirical equation, $Ia = 0.2\ S$, where *S* is the potential maximum retention of the soil defined as $S = 25400/CN - 254$, overestimates the abstractions, especially for lower values of curve numbers (e.g., Ponce, 1989). Therefore, the guidelines provided in the Visual OTTHYMO Model Hydraulic Reference for computing *Ia* were used for this study. The guidelines are as follows:

- $CN \leq 70$, IA = 0.075 S
- $70 < CN \leq 80$, IA = 0.1 S
- $80 < CN \leq 90$, IA = 0.15 S
- $CN > 90$, IA = 0.2 S.

Other pertinent information for the model included weighted average slope and time to peak (*Tp*) for the catchments, which were determined from the DTM and catchment geometry. The watershed parameters as computed will be reviewed and adjusted according to the results of calibration.

The initial watershed parameters are tabulated in Appendix B1.

2.4 Channel Routing

In general, flood or channel routing is required to appropriately represent flood wave travel times (translation) and reduction in peak discharge (attenuation) as flows propagate downstream along a reach. The routing of flows through the catchments of the study area required special consideration, in particular along reaches having relatively flat slopes (So < 0.0004). As channel slopes lessen, assumptions made to develop many of the common channel routing algorithms will be violated. Ponce (1978) established a numerical criterion to judge the likely applicability of various routing models. For example, a full dynamic wave solution would be required for channel routing, if the following criterion is not satisfied for channels with slopes (So) < 0.0004:

$$TS_o\left(\frac{g}{d_o}\right)^{1/2} \geq 30 \qquad \text{Eq.2.1}$$

Where T is the duration of the hydrograph, and d_o is a reference flow depth. There are a number of “flat” reaches within the study area that do not satisfy Eq. 2.1 and would require a full dynamic wave solution for channel routing, however, such a solution is outside the scope of the present study. Therefore, the best use was made of the available methods in the hydrologic models to minimize any errors in routing.

Two methods are available for flood routing in Visual OTTHYMO v2.0 (VO2 Model). The routing commands available in the VO2 Model are the Variable Storage Coefficient (VSC) (ROUTE CHANNEL 1) and the Muskingum-Cunge (MC) (ROUTE CHANNEL 2). Only the VSC channel routing command is available in the previous version of OTTHYMO known as OTTHYMO-89.

The Muskingum-Cunge algorithm uses a simplification for the kinematic-wave model, which is appropriate only if the channel slope exceeds 0.002 (0.2 %) (USACE, 2000). Furthermore, the Muskingum-Cunge algorithm in VO2 was found to be unstable and quite unpredictable according to initial trial runs performed for the present study. Therefore, the Variable Storage Coefficient method was adopted for all the models; however, this method also has limitations as described below.

The VSC routing algorithm is essentially a storage routing method involving the use of a storage coefficient which is a function of the time increment (or time step) and the travel time of the flow in the reach. It has two distinct characteristics: the peak of the outflow hydrograph always falls on or within one time step of the recession limb of the inflow hydrograph and, the outflow begins one time step after the inflow starts, which is typical of reservoir routing. This is because the method assumes a very short reach as noted in the Flood Routing Sensitivity Study (FRS Study) prepared by Kouwen (1984). Therefore, if applied without modification, the method is not suited for routing flows through long reaches. Similarly, the FRS Study found that the VSC method resulted in over-attenuated peak flows on long “flat” reaches.

The effects of the two limitations of the VSC method can be mitigated with some adjustments to the routing approach. The delay in outflow, required to account for the travel time of the flood wave down a long reach, can be achieved by using the Lag-and-Route methodology employed by MMM for the 1980 hydrology study. In this approach, the inflow hydrograph is lagged by the travel time computed on the basis of the wave celerity ω (i.e., wave speed) before being routed using the VSC algorithm. The wave celerity or speed can be approximated as 1.5 times the average flow velocity within the reach (Chow, 1959). Because the average flow velocity changes with discharge, the lag time for the reaches would vary for the different calibration events.

The Lag-and-Route approach is not suitable, or necessary, for the routing of the flows along the relatively flat reaches within the study area. This is because on flat slopes (defined here as $S_o < 0.0004$), the effect of the "convective acceleration" term in the dynamic wave equation (which accounts for changes in flow velocity in the direction of flow) is pronounced and cannot be accounted for using formulas assuming uniform flow. Furthermore, the flat reaches act essentially as quasi-reservoirs, where the outflow is considered to be controlled by the channel geometry. Therefore, the Lag and Route methodology was only applied to reaches with slopes greater than 0.04% (i.e., $S_o \geq 0.0004$). The Lag-and-Route technique was applied only in those instances where the travel time was at least twice the time step.

The flat reaches (i.e., $S_o < 0.0004$) function as quasi-reservoirs for runoff events, therefore, the VSC method is directly applicable – in the sense that outflow would begin one time step after the inflow begins. The over attenuation of the peak flow observed by Kouwen (1984) can be minimized by dividing the reach into several sub reaches, where the outflow from one sub-reach becomes the inflow to the next downstream sub-reach. The FRS Study noted that the recommended routing reach lengths should be such that the travel time through the reach is smaller than 1/5th of the time to rise (*Tr*) of the inflow hydrograph. Though ideal, this recommendation would result in too many sub-reaches for practical applications. Therefore, in lieu of the above criterion, a maximum sub-reach length of 2.5 km was specified. The 2.5 km reach length was selected after several iterations, where the reaches were sub divided into different reach lengths to arrive at the optimum reach length that minimized both the number of required sub-reaches and peak flow attenuation.

The channel routing sections, reach lengths and reach slopes were derived directly from the DTM, while initial values for Manning's *n* to denote channel roughness and typical channel cross sections were obtained based on the existing HEC-RAS hydraulic models for the water courses. A total of 143 channel routing sections are included in the present model. The locations and overall length of the channel routing sections are provided in Appendix A, on Figure A.4. A list of the channel routing sections is included in Appendix B2.

2.5 Reservoir Routing

There are a number of online storage and stormwater management facilities (i.e., SWM pond or on-site control storages) within the study area. In previous 2007 study by TSH, the SWM ponds were lumped in such a way as to produce a combined facility representative of the collective performance of the individual ponds. The approach to lumping the ponds was simply achieved by directly adding the storage-discharge values of the individual ponds on a rainfall return period basis. Note that the lumped pond approach used in the 2007 Etobicoke Creek watershed study was different from that implemented in the Don River hydrologic study (1986 and 2004) and Rouge River watershed study by MMM, where a “scaling factor” was further applied to correct the discharges from the lumped pond instead of simply adding discharges from individual SWM ponds. A “cap” was also added to the “lumped” storage-discharge relations to avoid unrealistic outflows from the “lumped” pond when the storages are exceeded. The advantage of the “lumped” pond approach is to reduce the size of the hydrologic model, especially when there are a significant number of ponds in a watershed. However, it is obvious that the “lumped” pond is an estimating method and it doesn’t reflect the actual hydrological storage routing effects in the watershed. Based on the previous studies, it has been recognized that in some cases, the increase (rather than attenuation) of pond outflows were obtained due to instabilities arising from the abrupt increase in discharges in the “caps” and numerical computation error. Consequently, in the present study, all SWM facilities, including SWM ponds and on-site storages, are included in the hydrologic model individually to best reflect the hydrological storage routing effects.

The design details for each SWM facility in the watershed were carefully reviewed to establish the storage-discharge relationships for each individual storage routing command in the model. There are a total of 57 storages in the present model, including 33 SWM facilities designed for storm events up to 100-Year return period and 24 SWM facilities only providing quality and erosion control storages. A summary of SWM storage facilities are included in Appendix B3. It should be noted that in accordance with provincial flood plain management guidelines, these storages were not included in the model used to simulate the Regional Storm.

2.6 Modelling Methodology for Other Hydrological Features

Etobicoke Creek watershed has some unique hydrological features. The following describes the modeling methodology to reflect such hydrological features in the present model.

- **Brampton Esker System:**

  TRCA's recent research indicates that groundwater levels appear to be rebounding in the vicinity of the Brampton Esker in response to cessation of dewatering associated with aggregate extraction (TRCA, 2010). A study of the Peel Groundwater Levels – Follow Up Study is currently undertaking to investigate the groundwater level recovery and associated implications for management in the vicinity of the Brampton Esker. As such, a DuHYD command (Name: 9001) was added to the Brampton Esker location to provide an opportunity for the user to input the maximum flow rates from the Esker to the downstream surface water system via groundwater routes.

- **Downtown Brampton Bypass Channel:**

  The Downtown Brampton by-pass channel was constructed in 1952 and was designed to convey the 100 year storm and served to protect the City of Brampton from significant flooding. For hydrological modelling purpose, a DivertHYD command (Name: 1800) is included in the model to divert flow from upstream to downstream receiving water courses via the man-made by-pass channel. The rating curve of the DivertHYD can be easily revised for future uses, if necessary.

- **City of Toronto Storm Sewer System:**

  In order to better understand the minor and major drainage system within the part of the watershed which lies in the City of Toronto (i.e., Basins 671, 672 and 673), the City's storm sewer system model (InfoWorks CS) was reviewed. Based on the sewer model, there is no major system outlet to the receiving Etobicoke Creek via surface runoff route (i.e., water courses, ditches, etc.). The City's current storm sewer system was designed to convey 2-year flow rates and discharge to a downstream water course. As a result, due to the lack of major system outlet, three hypothetical storages (NHYDs # 6671, 6672 and 6673) are included in the model to control 100-year runoff (major flows) to 2-year levels (minor system) from drainage areas within the City of Toronto.

3.0 SETUP AND CALIBRATION OF BASE MODELS

3.1 General

Once the basin parameters were determined, base hydrologic models for the calibration phase were setup from schematics for the watershed.

The base models were setup both in VO2 and in OTTHYMO-89. The OTTHYMO-89 model was prepared because it was not feasible to interface Visual OTTHYMO with the automated calibration procedure used in the study. However, once the calibration/validation was approved, the calibrated model was imported into VO2 for the simulation of design storm events.

The catchments within the study watershed are predominantly developed to residential, industrial and commercial areas based on the land use mapping. Since such areas would have significant impervious cover, the STANDHYD command was used to model these catchments. The main input parameters for the STANDHYD command are Area, Total Imperviousness (*TIMP*), Impervious Area directly Connected (*XIMP*), Storage Coefficient (*SC*), slope of pervious and impervious areas (*SLPP* and *SLPI*), and *CN* values for the pervious portion of the areas. For those undeveloped “rural” catchments (primarily located in the headwaters), since such catchments generally have less 20% impervious cover, the NASHYD command was used in the VO2 and OTTHYMO-89 models. The input parameters of NASHYD include Area, *N* (number of linear reservoir), *CN* value, Initial Abstraction (*Ia)* and Time to Peak (*Tp*).

Due to the different geographic characteristics of the watershed, calibration based on a single streamflow location was not sufficient. As a result, in the present study, the entire Etobicoke Creek watershed was calibrated based on three different streamflow gauge locations, as shown in Figure 3.1: (1) Etobicoke Creek at Brampton - HY026/HC017; (2) Spring Creek Stream Gauge – HY059; and (3) Etobicoke Creek below Queen Elizabeth Highway – HC030. Table 3.1 provides a summary of the watershed calibration locations.

Table 3.1 Watershed Calibration Locations

Data from Stream Flow Gauge for Calibration	Sub-Basin No.	Drainage Area (ha)	Landuse
Etobicoke Creek at Brampton – HY026/HC017	Sub-Basins 1, 2 and 3	6912	Approximately 70% of Rural Area - 30 % of Urban Area
Spring Creek Stream Gauge – HY059	Sub-Basin 6	3804	Approximately 40% of Rural Area - 60 % of Urban Area
Etobicoke Creek Below QEW – HC030	Sub-Basins 4, 5, 7, 8, 9, 10, 11 and 12	11555	Approximately 5% of Rural Area - 95% of Urban Area

3.2 Streamflow and Rain Data

The calibration and validation process requires concurrent streamflow and rainfall data. There are a total of 6 precipitation gauges located within the vicinity of the study watershed, and 4 streamflow gauges located on the Etobicoke Creek water courses. Figure 3.2 shows the locations of these gauges. Tables 3.2 and 3.3 summarize the details of the streamflow gauges and precipitation gauges respectively.

Table 3.2 Streamflow Gauges

StationID	Parameter	LocationName	Available Data From	Available Data To	Time Step in min	Region	Municipality	Owner
HY024	Flow	Etobicoke at Dixie and Derry	24/07/2003 9:00	01/01/2009 0:00	60	Peel	Mississauga	TRCA
HY026*	Flow	Etobicoke Creek at Brampton	02/11/2007 14:00	06/06/2011 16:15	15	Peel	Brampton	TRCA
HY059*	Flow	Spring Creek	21/08/2003 10:00	01/01/2009 0:00	60	Peel	Mississauga	TRCA
HC030*	Flow	Etobicoke Creek Below Queen Elizabeth Highway	01/01/1969 0:00	01/01/2011 0:00	15	Toronto	Toronto	EC

* Data from the selected gauges for calibration

Table 3.3 Precipitation Gauges

StationID	Parameter	LocationName	Available Data From	Available Data To	Time Step in min	Region	Municipality	Owner
HY014	Rain	Claireville Dam	24/05/2002 1:00	06/06/2011 16:20	5	Toronto	Toronto	TRCA
HY025	Rain	Etobicoke at QEW	26/04/2005 12:00	10/12/2010 10:00	60	Toronto	Toronto	TRCA
HY033*	Rain	Heart Lake CA	22/05/2002 0:07	08/12/2010 12:25	5	Peel	Brampton	TRCA
HY041	Rain	Laidlaw Bus Depot	20/04/2005 14:35	06/06/2011 16:25	5	Peel	Caledon	TRCA
HY046*	Rain	Mississauga Works Yard	03/06/2005 11:15	08/12/2010 13:30	5	Peel	Mississauga	TRCA
HY076	Rain	Lawrence and Weston Rd	26/04/2005 12:00	21/12/2009 9:00	60	Toronto	Toronto	TRCA

* Data from the selected gauges for calibration

In order to improve the rainfall-runoff response accuracy, available sub-hourly data were given priority to be selected. As mentioned previously, Etobicoke Creek at Brampton (HY026), Spring Creek Stream Gauge (HY059) and Etobicoke Creek below Queen Elizabeth Highway (HC030) were selected as stream gauges for calibration and validation.

In general, the spatial distribution of the rainfall over the large scaled watershed area (i.e., Etobicoke Creek watershed) is highly non-uniform. Significant spatial variation of the rainfall may be observed at different rain gauge locations. As a result, precipitation gauges at Heart Lake (HY033) and Mississauga Works Yard (HY046) were selected for present study. Both gauges are located within the Etobicoke Creek watersheds and provide sub-hourly data for the model calibration and validation. The spatial distribution of the calibration and validation rainfall events was incorporated into the modeling by using the Thiessen Polygons method to assign the rain gauges to the different catchments, as shown in Figure 3.3.

Note that additional streamflow and precipitation information were obtained for further model validation, which will be discussed in detail in Section 4.5.

3.3 Calibration and Validation Events

The available hydrometric data for the study area were screened for suitable calibration and validation events. Since concurrent sub-hourly rainfall and streamflow data is required for the automated calibration routine, the screening process for calibration data was very stringent. The initial screening was performed based on the hydrometric data obtained from Etobicoke Creek below QEW rain and flow gauges (HC030 and HY025). Figures C.1 through C.6, included in Appendix C, plot the concurrent rain (in depth) and flow series during the 6-year record period (April 2005 to December 2010). The screening process focused on the observed rainfall-runoff responses. Spring snowmelt periods, i.e., during the period from December to May, were not included in the database, because the increased flows were not directly resulted from the concurrent storm events. Consequently, a total of 25 of the most significant rainfall events during the period were identified and deemed suitable for model calibration and validation. Once the 25 periods of rainfall events were identified, data from selected rain gauges (i.e., Heart Lake - HY033 and Mississauga Works Yard - HY046) and streamflow stations (i.e., Etobicoke Creek at Brampton - HY026, Spring Creek Stream Gauge - HY059 and Etobicoke Creek below Queen Elizabeth Highway - HC030) were further examined to determine the final rainfall events for the model calibration and validation. Table 3.4 shows the final selected rainfall events. The numbers of calibration and validation events for different calibration sets (location) are summarized in Table 3.5. Details of rainfall events and corresponding streamflow data used for the calibration and validation are summarized in Appendix C. Again, additional model validation was included in the study and will be discussed in detail in Section 4.5.

Table 3.4 Calibration/Validation Events

Event No.	Event ID.	Date	Rainfall Depth (mm) at Rain Gauges		Streamflow Station					
			Heart Lake (HY033)	M. Works Yard (HY046)	Etobicoke Creek at QEW (HC030)		Spring Creek (HY059)		Etobicoke Creek at Brampton (HY026)	
					Max. Flow (m^3/s)	Calibration or Validation	Max. Flow (m^3/s)	Calibration or Validation	Max. Flow (m^3/s)	Calibration or Validation
1	Event ID1	02/08/2005	38.6	38.6	95.1	Calibration	24.8	Calibration	-	-
2	Event ID2	19/08/2005	105.0	67.0	95.8	Validation	47.2	Calibration	-	-
3	Event ID3	30/08/2005	33.2	33.2	53.6	Validation	2.4	-	-	-
4	Event ID4	15/11/2005	34.7	34.0	53.2	Validation	16.8	Validation	-	-
5	Event ID5	27/11/2005	39.4	30.8	60.2	Validation	14.2	Validation	-	-
6	Event ID6-1	10/07/2006	67.9	39.4	71.1	-	26.4	Calibration	-	-
7	Event ID6-2	12/07/2006	35.6	38.6	70.9	Calibration	18.0	Validation	-	-
8	Event ID7	17/10/2006	36.2	35.2	66.0	-	11.4	Validation	-	-
9	Event ID8	15/11/2006	33.2	33.2	63.8	-	16.9	-	-	-
10	Event ID9	30/11/2006	57.6	49.8	92.1	Validation	20.6	Validation	-	-
11	Event ID10	15/05/2007	56.1	56.1	75.3	Calibration	19.1	Calibration	-	-
12	Event ID11	18/07/2007	38.6	20.6	65.5	-	6.0	-	-	-
13	Event ID12-1	11/07/2008	10.9	13.2	29.0	-	7.1	-	3.0	-
14	Event ID12-2	08/07/2008	13.0	23.2	63.0	-	5.4	-	5.9	-
15	Event ID13	20/07/2008	45.6	56.0	86.0	Calibration	20.0	Calibration	17.2	Calibration
16	Event ID14	03/04/2009	33.0	41.2	78.9	-	-	-	21.3	-
17	Event ID15	09/05/2009	17.6	22.2	84.2	-	-	-	19.2	-
18	Event ID16	20/08/2009	38.0	13.8	-	-	-	-	22.2	Calibration
19	Event ID17	28/08/2009	9.2	14.0	75.9	-	-	-	2.2	-
20	Event ID18	07/05/2010	43.4	34.6	58.8	Calibration	-	-	14.6	Calibration
21	Event ID19	23/07/2010	38.0	36.8	73.0	Validation	-	-	13.0	Validation
22	Event ID20	24/07/2010	25.6	16.2	41.6	Validation	-	-	7.9	Validation
23	Event ID21	16/09/2010	27.0	28.2	65.2	Validation	-	-	7.3	Validation
24	Event ID22	28/09/2010	37.8	22.6	69.5	Calibration	-	-	14.1	Calibration
25	Event ID23	16/11/2010	30.2	29.8	60.1	Validation	-	-	7.2	Validation

Table 3.5 Summary of Calibration/Validation Events

Calibration Set (Stream Flow Location)	Calibration Events No.	Validation Events No.	Total Event No.
Etobicoke Creek at QEW (HC030)	6	9	15
Spring Creek (HY059)	5	5	10
Etobicoke Creek at Brampton (HY026)	4	4	8

3.4 Calibration Procedure

Since the calibration process can be very time consuming to complete manually, an automatic calibration procedure as part of the process was proposed to achieve the best fit. The automated calibration procedure using the Shuffled Complex Evolution (SCE) method was applied in the present study. The Shuffled Complex Evolution (SCE) method was tested by Peyron et al as part of a study of seven such procedures and it concluded that "the Multi-start and modified and original Shuffled Complex Evolution (SCE) methods are the best performing methods" (CWRA Annual Conference, 2004). In general, the calibration procedure involved the following:

- **Compute initial values for catchment parameters.**

  Initial values of catchment parameters were established using typical methods (i.e. Williams's or Airport formula for undeveloped areas and slope/length/Manning's n formula for urban areas). The initial values computed are summarized in Appendix B1.

- **Identify suitable rainfall events.**

  Identify significant rainfall events at each rain gauge. Once an event was identified, the concurrent streamflow data at the associated flow gauge was used to develop a flood (runoff) hydrograph.

  If applicable, base flow was separated from the flood hydrograph to determine the direct runoff hydrograph (DRH) using the "straight line" method.

- **Calibrate watershed runoff volumes.**

  For each calibration event, the runoff volume was calculated from the streamflow data at the gauges, based on the direct runoff hydrograph. The appropriate initial value of the SCS Curve Number (CN) for each catchment (NASHYD) was calculated to ensure that the modelled runoff volume would be close to that observed. This was achieved by estimating a basin wide value and prorating back to each sub-basin by comparing the calculated value to the basin wide average AMC II value. For urbanized catchments (STANDHYD), in order to ensure the matching runoff volume, imperviousness values were also adjusted for calibration purposes. Since OTTHYMO is a single event simulation model there is no other way of establishing antecedent conditions. In addition, for design event simulations, the initial conditions are prescribed (AMC II or AMC III). Hence there is no need to establish a predictive relationship for antecedent conditions.

- **Initiate automatic calibration procedure.**

  The automated calibration procedure (Shuffled Complex Evolution – SCE method) was initialized and allowed to search a possible range of parameters to find an optimum set for each event. The values optimized were: *Tp* and *N* (no. of linear reservoirs) for NASHYDs, *SC* (Storage Coefficient), including *SCI* and *SCP* for STANDHYDs and *RO* (Manning's n) for channel routing sections. As mentioned previously, the calibration for the Etobicoke Creek watershed was separated into three calibration sets based on three different streamflow gauge locations (1) Etobicoke Creek at Brampton for Sub-Basins 1, 2 and 3; (2) Spring Creek Stream Gauge for Sub-Basin 6; and (3) Etobicoke Creek below Queen

Elizabeth Highway for Sub-Basins 4, 5, 7, 8, 9, 10, 11 and 12. Figure 3.1 shows the locations of streamflow gauges and their associated sub-watersheds for the calibration. For each calibration set, the optimization was achieved by applying a multiplication factor (either greater than 1.0 or less than 1.0) uniformly across all catchments and routing reaches within the calibration sub-watershed to those parameters until an optimum multiplier was found for each type of parameter. Each optimization run completes the equivalent of thousands of model simulations to identify the optimum parameter set that translates into the best match between simulated and observed. Table 3.6 shows the multiplier parameter space used.

Table 3.6 Boundaries of Calibration Multiplier Coefficients

Parameter	Initial Value	Lower Limit	Upper Limit
SC	1	0.5	5
N	1	0.5	3
Tp	1	0.5	4
RO	1	0.5	3

- **Model validation.**

  Once optimum multipliers were found, the identified parameters were calibrated. The selected validation rainfall events were applied to provide a rigorous check on the "soundness" of the calibrated hydrologic model. Depending on calibration level of confidence, if required, further validations based on the data beyond the original streamflow and rainfall data provided by TRCA as indicated in the TOR were performed to provide further evidence that the SCE automated calibration routine was successful.

- **Simulation of design storms and Regional storms.**

  The calibrated and validated hydrological model was used to simulate a variety of design storms and identified Regional storms. Since the initial conditions are prescribed for design storms (AMC **II**) and Regional storms (AMC **III**), CN values were adjusted accordingly. Assigned imperviousness values for urban areas based on aerial photographs were also applied for design storms and Regional storm simulations.

- **Frequency analysis**

  At hydrometric stations with longer periods of record, frequency analyses were performed to derive flows of various return periods to compare with the 1 in 2 to 1 in 100 year flows simulated by the calibrated hydrologic model.

- **Sensitivity analysis**

  Sensitivity analysis was performed to further understand the calibrated watershed model and investigate the variations in flows from the previous to the present studies.

4.0 CALIBRATION RESULTS AND DISCUSSION

4.1 Calibration Results

In general, the calibration exercise was successful. The SCE automated calibration routine (SCE-ACR) yielded mixed results for the three different calibrations sets (streamflow gauge locations). Table 4.1 presents the parameter multiplier coefficients suggested by the SCE-ACR. All calibration data and results, including summary tables and detailed comparisons of the hydrographs are included in Appendices D1, D2 and D3.

Table 4.1 Calibration Multiplier Coefficient

Calibration Set (Streamflow Gauge Location)	Total Rain Event No. for Calibration	Total Optimization No. for SCE-ACR	Post-Calibration Multiplier Coefficients			
			SC (X1)	N (X2)	TP (X3)	RO (X4)
Etobicoke Creek at Brampton (HY026)	4	40	1.274	0.511	3.977	1.165
Spring Creek (HY059)	5	50	4.975	0.543	3.797	1.250
Etobicoke Creek at QEW (HC030)	6	60	4.983	1.692	2.096	1.391

The following are the main points and observations from the calibration process:

- The SCE-ACR yielded different results for three calibration sets (locations), as shown in Table 4.1. Generally, the multipliers for Time to Peak (*Tp*) values used in NASHYD command were obtained in a range from 2 to 4, which based on our experience, is typical for rural catchments calibration in Southern Ontario. The multiplier for the storage coefficient (SC) in the STANDHYD command for Etobicoke Creek at Brampton calibration location was smaller than those for the other two locations. This is because the majority of the catchments contributing to Etobicoke Creek at Brampton gauge are rural catchments, and the effect of the flows generated from urbanized catchment (i.e., STANDHYD) is smaller than those from the rest of the watershed. The suggested multipliers for Manning's *n*-values for channel routing are generally consistent for the entire watershed. As a result, the adopted *n*-values are 0.09~0.10 for flood plains and 0.04~0.05 for channel. These values are in good agreement with published values for streams of similar physical and flow characteristics provided in noted references (e.g., Chow (1959)).
- For all three calibration sets, the average runoff volumes (essentially forced by the CN values and imperviousness values) were within +/- 10% of the observed runoff volume for the calibration and validation events (as shown in Tables included in Appendix D3). An exact match of the runoff volumes was not achievable using the "lumped" model to back calculate the average basin wide CN. This was mainly due to the fact that for the overall model, two rain gauges were used for the simulations, which was not feasible when using a "lumped" model. Nonetheless, the calibrated volumes are close enough to the observed volumes for practical purposes.

- Excitingly, the observed hydrograph shapes were very well reproduced. Please refer to a complete set of hydrograph comparisons included in Appendix D1. Statistically, the average simulated peak flows for both calibration and validation events for these three calibration sets are within 10% of their respective observed values and time to peak values of the simulated hydrographs match well with those observed (as shown in Tables included in Appendix D3).

4.2 Model Validation

As shown in Table 3.5, in addition to the rainfall events for calibration, an additional 9, 5 and 4 rain events were selected separately for model validations at Etobicoke Creek at QEW (HC030), Spring Creek (HY059) and Etobicoke Creek at Brampton (HY026) respectively. The characteristics of validation rainfall events were different from the calibration events, and as such, provided a rigorous check on the "soundness" of the calibrated hydrologic model. The validation results are also provided in Appendix D2.

The validation results show that the calibrated model performed very well for the validation events. It is evident that the calibrated VO2 model for the Etobicoke Creek watershed gives acceptable predictions for peak flows and times to peak.

4.3 Further Model Validation

4.3.1 General

In order to ensure the reliability of the calibrated model, additional validation events based on the data beyond the original streamflow and rainfall data provided by TRCA as indicated in the TOR were performed to provide further evidence that the SCE automated calibration routine was successful.

Additional validations were performed at downstream Etobicoke Creek at QEW (for entire watershed) and upstream Etobicoke Creek at Brampton (for the bulk of rural areas within the headwatershed) locations. The following sections describe the further model validation for both locations in detail.

4.3.2 Further Validation at Etobicoke Creek at QEW

The calibrated model was further validated by simulating the May 2000 storm event, which is recognized as one of the significant storm events in Southern Ontario. Since the rain gauges at Heart Lake (HY033) and Mississauga Works Yard (HY046) were established after 2000, hourly rain data from Environment Canada's precipitation station at Pearson International Airport (# 6158733) were used. Concurrent hourly streamflow at Environmental Canada's streamflow station at Etobicoke Creek at QEW (# HC030) were also available during May 2000 storm events. The following Table 4.2 summarizes the details of the May 2000 storm events used for the calibration. Detailed information about the event can also be found in Appendix C. Detailed validation results are included in Appendices D2 and D3. Figures 4.1 and 4.2 present comparisons of the resulting hydrographs with observed data recorded at the QEW gauge.

Table 4.2 Further Validation Event at Etobicoke Creek at QEW Gauge

Event #	Event ID	Simulated Hyetograph from	Simulated Hyetograph to	Total Rain Depth (mm) at Pearson Int'l Airport	Max. Flow (m^3/s) at Etobicoke Creek under QEW gauge (HC030)
23	Event ID24	11/05/2000 17:00	14/05/2000 4:00	62.9	181.9
24	Event ID25	17/05/2000 23:00	18/05/2000 22:00	24.7	50.1

Figure 4.1 Hydrograph Comparison – Event ID 24 at QEW

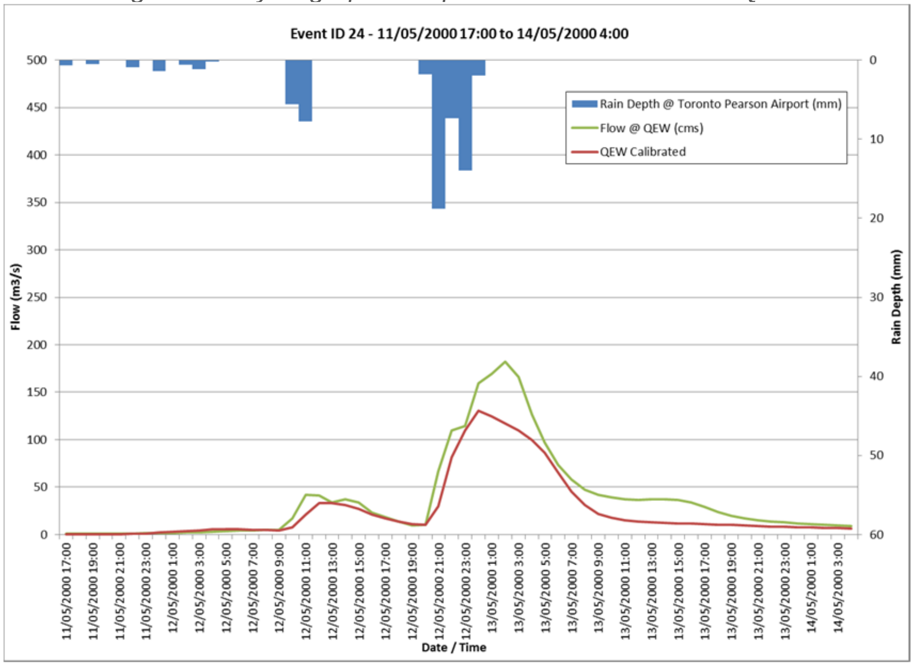
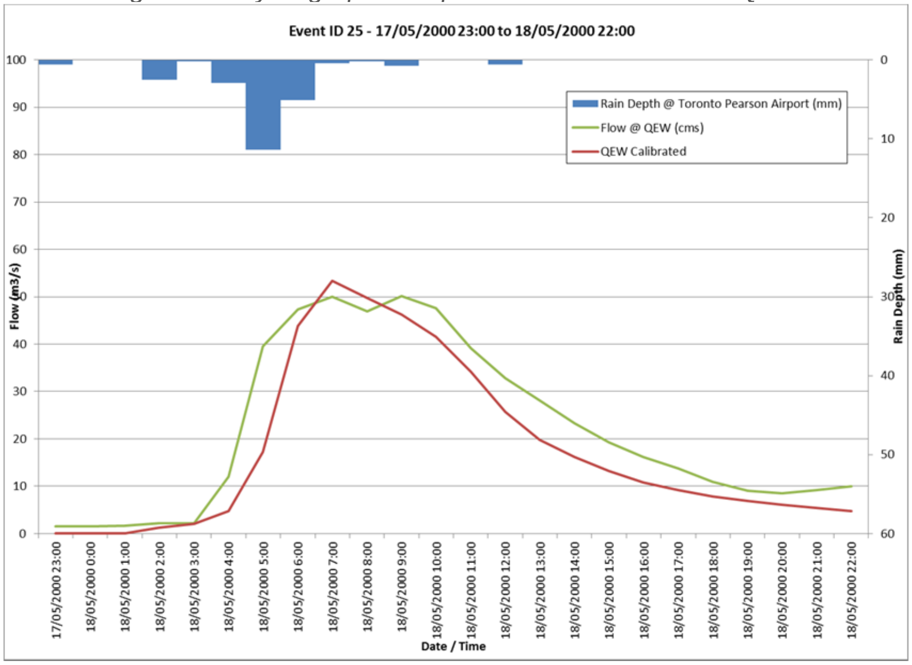


Figure 4.2 Hydrograph Comparison – Event ID 25 at QEW



As shown from the results, although the models generated an underestimated peak flow from the observed data for Event ID 24, the overall simulated hydrographs for May 2000 storm events reasonably agree with the observed data.

4.3.3 Further Validation at Etobicoke Creek at Brampton

In the previous 2007 hydrologic models, Environment Canada's streamflow gauge located near the mouth of the creek at QEW (HC030) was the only observed flow data used for the calibration. Due to the different geographic characteristics for areas in the Etobicoke creek headwatershed (rural areas), independent calibration at Etobicoke Creek at Brampton streamflow gauge would provide proper catchment parameters of such rural areas to reflect existing hydrology characteristics for the Etobicoke Creek headwatershed. Consequently, further validations were performed to ensure a reliable calibrated hydrologic model in the present study. The following describes the details of the additional validation performed at Etobicoke Creek at Brampton streamflow gauge location.

- **Event of June 27, 2010 (Event ID26) at Etobicoke Creek at Brampton**

  This event was originally included in the rain and flow database provided by TRCA, but was not selected for the model calibration and validation (as shown Table 3.4). As an additional event, June 27, 2010 event (named as Event ID26) was simulated for validation at Etobicoke Creek at Brampton. Detailed information of the event can also be found in Appendix C. Detailed validation results are included in Appendices D2 and D3. The hydrograph comparison figure indicates that the simulated flows matches well with observed data.

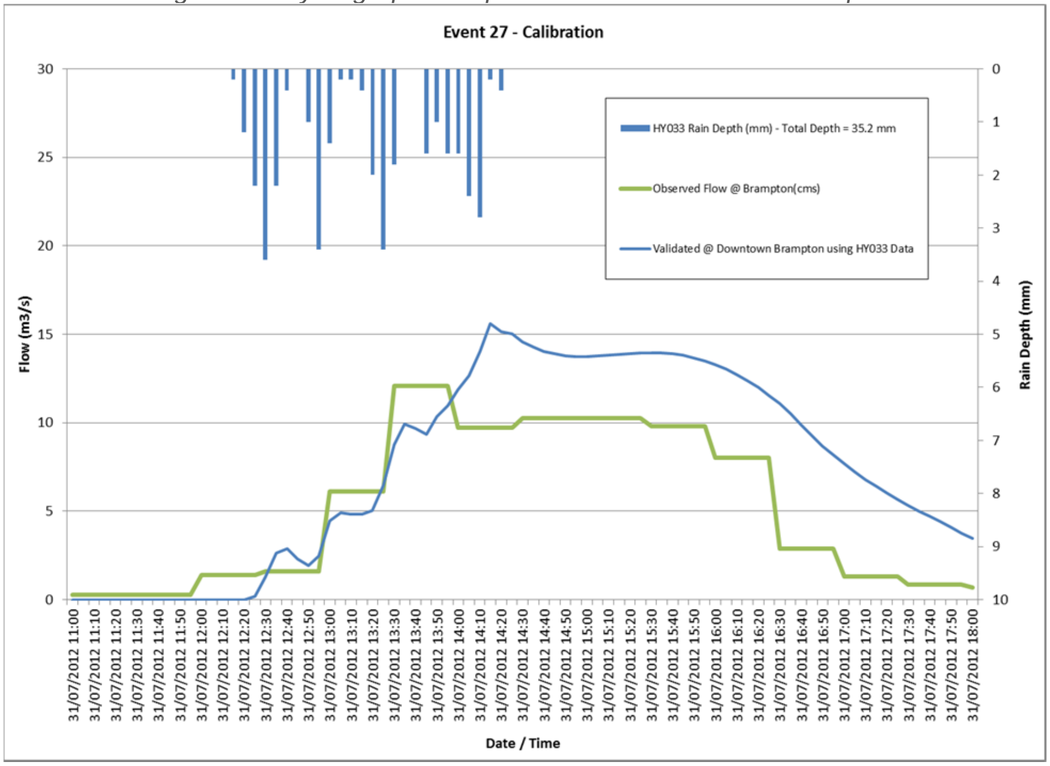
- **Event of July 31, 2012 (Event ID27) at Etobicoke Creek at Brampton**

  A severe thunderstorm hammered Toronto, York, Peel, Halton and Durham regions on July 31, 2012, with strong winds, heavy rain and lightning causing damage and knocking out power around the GTA. Environment Canada reported a significant rainfall event of more than 50 mm in depth for a certain region of the area. In order to test the calibrated model for this recent storm event, TRCA obtained the rain data from Heart Lake (HY033) rain gauge and concurrent streamflow data from Etobicoke Creek at Brampton streamflow gauge (HY026). Table 4.3 summarizes the details of the event on July 31, 2012. Figure 4.3 shows a comparison of resulting simulated hydrology with observed flows recorded at the gauge. Detailed information of the event can be found in Appendix C. Detailed validation results are included in Appendices D2 and D3.

Table 4.3 Validation Event of July 31, 2012 at Etobicoke Creek at Brampton

Event #	Event ID	Simulated Hyetograph from	Simulated Hyetograph to	Total Rain Depth (mm) at Heart Lake (HY033)	Max. Flow (m^3/s) at Etobicoke Creek at Brampton streamflow gauge (HY026)
29	Event ID27	31/07/2012 11:00	31/07/2012 18:00	35.2	12.1

Figure 4.3 Hydrograph Comparison – Event ID 27 at Brampton

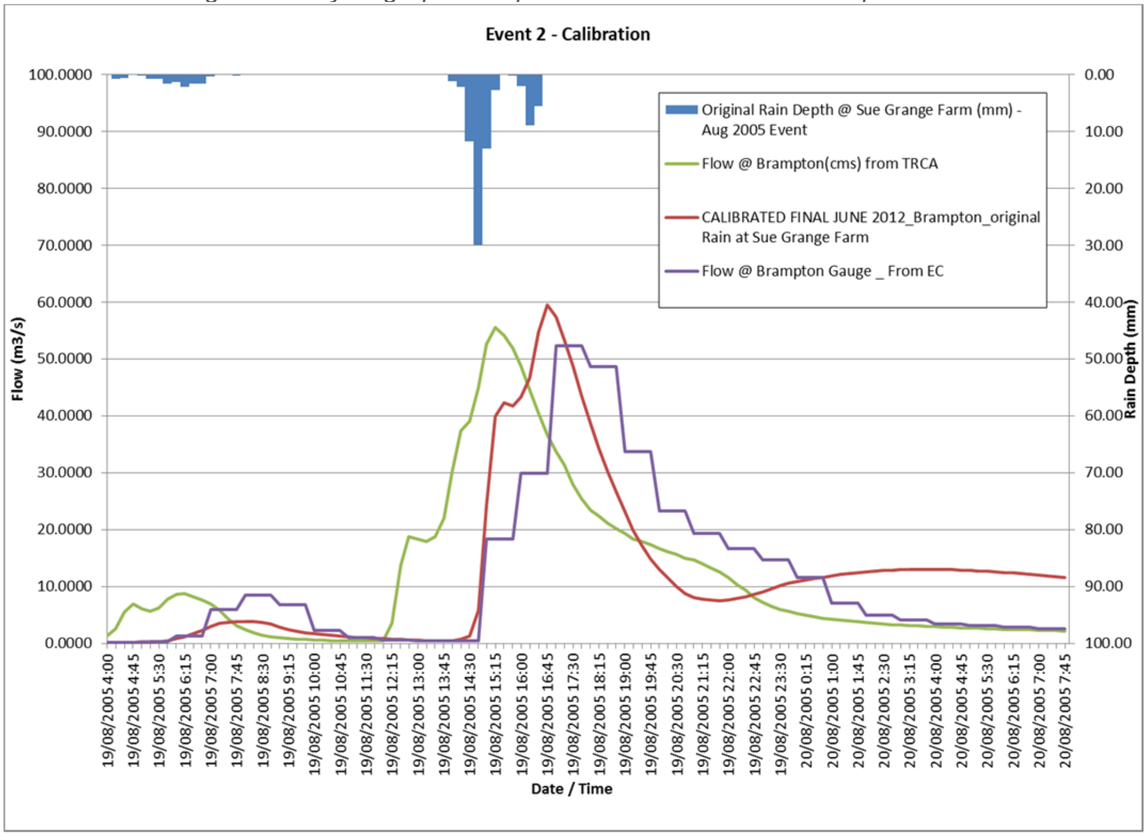


As shown in Figure 4.3, the calibrated model gives reasonable predictions for peak flows and times to peak for such event, although the model is expected to be slightly conservative in estimating the recession curves of the direct runoff hydrograph.

- **Event of August 19, 2005 (Event ID2) at Etobicoke Creek at Brampton**

The TRCA operated streamflow gauge located at Etobicoke Creek at Brampton (HY026) had started recording data before 2007. However, TRCA staff indicated the data recorded from this gauge before 2007 was not reliable for calibration. Hence the available data from this gauge provided by TRCA were from November 2007 to June 2011 for model calibration and validation purposes. As a result, for the event of August 19, 2005 (Event ID2) with a significant rain depth of more than 100 mm recorded at Heart Lake rain location (HY033), calibration was not carried out at Etobicoke Creek at Brampton location. However, MMM noted that Environment Canada had operated a separate streamflow gauge at the same location (# 02HC017) since 1971, with missing data during 1994 to 2003, when the gauge was temporally stopped and the data were not available. Although the data received from EC's gauge at this location were hourly-based, it was a very good event for the model validation. Furthermore, in June 2006, Clarifica prepared a study on the August 19, 2005 event, where a detailed investigation on this significant precipitation was performed. Based upon that study, the sub-hourly data from Sue Grange Farm rain gauge (HY061) was obtained. This rain gauge is located within the Etobicoke Creek headwatershed area (as shown in the figure included in Appendix D4) and recorded a total rainfall depth of 90mm. This provides a best rain input for the calibrated model to produce the corresponding runoff. Figure 4.4 presented below shows a comparison between the simulated hydrograph by the calibrated model, observed flows from both Environmental Canada (02HC017) and TRCA (HY026) gauges. All detailed information regarding the validation of this event is included in Appendix D4.

Figure 4.4 Hydrograph Comparison – Event ID 2 at Brampton



It is evident from Figure 4.4, the validation results indicate that by comparing the simulated hydrograph with recorded flows from EC gauge, the calibrated model gives very good predictions (+15%) for peak flow rates; and a very close time to peak values of the hydrograph. Interestingly, as shown in the figure, flows received from TRCA's gauge appear to be ahead of those from EC's gauge by roughly half an hour. This proves that data recorded by TRCA's gauge before 2007 was not reliable for calibration as previously indicated by TRCA staff.

4.4 Calibrated Model for Future Development Conditions

Once the hydrologic model for existing conditions was successfully calibrated and validated, the model was revised to reflect future development conditions based on the build-out of the Regional and local municipal Official Plans. Catchment parameters for future development models provided by TRCA were reviewed and confirmed by MMM. SWM facilities for areas not yet being developed were determined based on the approved engineering documents or standard SWM approaches. The future catchment parameters are included in Appendix B1. Appendix B3 includes all the related SWM facilities information.

5.0 DESIGN STORM AND REGIONAL STORM SIMULATIONS

5.1 General

The design storm approach was applied to estimate the peak flows for the study area for the 1:2 to 1:100 year return period design storms and Regional Storm (Hurricane Hazel). As requested by TRCA, the 1 in 350 year return period design storm was also generated and simulated in the present model. A total of 234 locations (Flow Nodes) were selected over the proposed study watershed area for flow comparison purposes. Tables in Appendix E summarize the details of the selected Flow Nodes. Figure 5.1 illustrates the locations of these Flow Nodes. For comparison purposes, Key Flow Nodes used in the previous 2007 TSH study are also shown in Figure 5.1. The peak flows of both existing and future land use conditions were determined by using the calibrated hydrology models established for the proposed study area. Drawing 2.1 (rear pocket) shows the detailed locations (with Node ID) of these 234 comparison flow points along the study watercourses.

For the streamflow gauging locations at Etobicoke Creek at Downtown Brampton (Environment Canada's streamflow gauge # 02HC017) and Etobicoke Creek under QEW (Environment Canada's streamflow gauge # HC030), since both hydrometric stations have longer periods of record, Section 5.2 discusses frequency analysis at both locations to derive the flows which would be compared with the simulated design flows (1 in 2 year through 1 in 100 year) by the calibrated hydrologic model.

In order to further understand the variations in flows, flow analysis was performed to investigate further all apparent inconsistencies in the peak flows during 100-year and Regional Storm from the previous to the present studies. Section 5.3 discusses the flow analysis in detail.

5.2 Simulation of Representative Design Storms

5.2.1 2 to 100-Year Return Period Design Storms

The amount of rainfall and its representative pattern, type and distribution in time and space are usually critical inputs to the hydrologic simulation in calculating runoff characteristics. In order to determine a storm distribution appropriate for the subject watershed, a list of potential 2 to 100-year storm distributions, as shown in Table 5.1, was simulated in the calibrated model. All the storm files used in the model were derived based on Toronto City (Bloor) gauge (# 6158350) and confirmed by TRCA. A detailed list of model simulations with their associated design storms is included in Appendix F1. A complete summary of the resulting 2 to 100-year peak flows are included in Appendix F2.

Table 5.1 Potential Storm Distributions for Etobicoke Creek

Return Period	Design Storms
2 to 100 Year	Chicago (3, 4 and 12 hours)
	AES (1, 6, 12 and 24 hours)
	SCS Type II (6, 12, and 24 hours)

Tables included in Appendix F2 present the resulting 100-year flows for all design storm distributions at all selected flow node locations. As seen from these Tables, the most conservative peak flow rates were generally found to be associated with the 12-hour AES rainfall distribution. Given that the 12-hour AES distribution is also used by TRCA in other urban watersheds (i.e., Humber and Rouge River watersheds), the present study recommends the 12-hour AES distribution for use in the Etobicoke Creek watershed for establishing peak flows. Tables 5.2 and 5.3 summarize the resulting 2 to 100-year peak flow rates by using selected 12-hour AES design storm distributions for existing and future conditions respectively.

It is recommended that for sites with small drainage areas (i.e., individual site) that the Chicago storm with 5 min time steps be used for hydrologic modelling.

Table 5.2 Summary of Resulting 2 to 100-Year Existing Peak Flow Rates (2012 MMM Calibrated Model)

Key Flow Nodes	MMM Flow Nodes	Drainage Area (ha)	12-Hr AES - Peak Flow Rates (m^3/s)					
			2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
			EXI.1.31	EXI.1.32	EXI.1.33	EXI.1.34	EXI.1.35	EXI.1.36
A	1.265	1471	1.45	2.53	3.39	4.54	5.45	6.40
B	1.285	2096	2.05	3.61	4.82	6.45	7.75	9.03
C	1.615	2307	2.32	4.06	5.42	7.31	8.84	10.45
D	1.620	4716	4.70	8.27	10.99	14.71	17.65	20.76
E	2.030	5241	5.16	9.08	12.06	16.03	19.21	22.57
F	2.090	6479	30.27	40.59	47.99	57.38	64.66	72.02
Brampton	2.140	6912	26.81	38.54	47.29	58.16	66.76	75.69
G	7.065	1332	10.89	15.13	18.06	21.88	24.82	27.86
H	2.190	7579	33.40	47.88	58.28	71.46	81.81	92.72
I	7.115	3289	42.78	58.91	70.12	84.97	96.38	107.60
J	7.145	3763	45.48	63.81	76.69	93.20	105.98	118.97
Spring Creek	7.150	3804	43.22	60.64	73.46	89.69	102.33	115.16
L	2.240	8941	41.58	57.13	67.66	82.10	92.85	104.70
M	2.255	10329	53.12	72.24	87.09	105.20	120.06	134.83
N	13.005	15437	103.19	143.58	174.09	213.81	243.82	275.47
O	12.030	445	7.00	9.28	10.86	12.82	14.21	15.69
P	13.030	16596	107.11	149.85	181.76	223.79	255.62	289.60
Q	11.055	487	13.57	18.36	21.68	25.94	29.14	32.38
R	13.050	17076	104.90	145.92	176.86	217.50	248.24	280.64
S	12.070	1778	41.68	55.21	64.37	75.96	84.64	93.27
T	13.075	18275	107.69	149.59	181.44	223.89	256.30	289.75
U	13.085	18882	110.41	153.35	185.98	229.52	262.54	296.95
V	13.090	19033	110.40	153.00	185.54	228.93	262.23	296.69
W	13.095	21293	124.50	167.61	204.69	254.32	292.47	334.29
X - QEW	13.110	21773	128.03	170.62	208.39	258.90	297.53	339.86
Y	13.120	22104	129.73	172.28	210.35	261.27	300.64	342.85
Z	13.150	22259	130.83	173.77	210.76	261.70	301.28	344.06

Table 5.3 Summary of Resulting 2 to 100-Year Future Peak Flow Rates (2012 MMM Calibrated Model)

Key Flow Nodes	MMM Flow Nodes	Drainage Area (ha)	12-Hr AES - Peak Flow Rates (m3/s)					
			2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr
			FUT.11.31	FUT.11.32	FUT.11.33	FUT.11.34	FUT.11.35	FUT.11.36
A	1.265	1471	1.44	2.52	3.37	4.51	5.42	6.37
B	1.285	2096	2.04	3.59	4.80	6.44	7.73	9.01
C	1.615	2296	2.30	4.02	5.37	7.23	8.75	10.40
D	1.620	4706	4.57	8.03	10.65	14.24	17.09	20.09
E	2.030	5230	5.45	9.58	12.60	16.47	19.59	22.82
F	2.090	6460	30.16	41.28	48.94	58.70	66.12	73.44
Brampton	2.140	6893	27.19	39.14	47.91	58.81	67.47	76.32
G	7.065	1324	16.43	22.96	27.54	33.50	38.07	42.65
H	2.190	7560	33.47	48.03	58.44	71.51	81.88	92.74
I	7.115	3281	44.09	60.52	71.99	87.15	98.77	110.12
J	7.145	3755	47.02	65.70	78.79	95.52	108.89	122.66
Spring Creek	7.150	3796	44.55	62.66	75.66	92.15	104.89	117.78
L	2.240	8921	42.62	57.33	67.82	82.08	92.75	104.49
M	2.255	10310	54.34	74.84	89.13	108.87	123.83	138.64
N	13.005	15410	105.99	147.95	178.85	218.98	250.17	281.80
O	12.030	445	6.92	9.18	10.74	12.70	14.08	15.53
P	13.030	16570	109.98	154.02	186.78	229.13	262.15	296.24
Q	11.055	487	13.25	17.95	21.22	25.41	28.57	31.76
R	13.050	17049	107.49	149.50	180.89	222.30	253.42	286.69
S	12.070	1778	42.32	56.04	65.31	77.05	85.85	94.57
T	13.075	18248	110.22	153.29	185.66	228.98	261.35	296.10
U	13.085	18855	112.98	156.91	190.04	234.47	268.04	303.44
V	13.090	19006	112.92	156.61	189.76	233.92	267.72	303.22
W	13.095	21266	126.04	171.45	209.14	259.68	298.37	341.18
X - QEW	13.110	21746	129.53	174.38	212.76	264.20	303.55	346.60
Y	13.120	22077	131.22	176.01	214.81	266.55	306.65	349.97
Z	13.150	22232	132.30	176.38	215.18	267.11	307.12	351.04

5.2.2 Regional Storm

As requested by TRCA, in addition to the typical final 12-hours of Hurricane Hazel used as the Regional Storm to determine the Regional peak flows, different scenarios for Regional Storm simulations were performed. Typically, when applying the final 12-hours of Hurricane Hazel, the saturated antecedent moisture condition (AMC III) is used to simulate the wet soil condition at the beginning of the design rainfall. This accounts for the increase in soil moisture caused by the first 36 hours of the storm. Additional scenarios were carried out by applying the complete 48-hour Hurricane Hazel rainfall with AMC II used for initial soil conditions. Furthermore, according to the MNR Technical Guide, 2002, all SWM facilities should be removed for a Regional Storm simulation. For investigation purposes, additional simulations were performed based on different storage routing included in the model (i.e., with and without the 100-year storage provided by 100-year SWM facilities). Table 5.4 summarizes the Regional Storm scenarios applied in the model. As mentioned previously, a detailed list of model simulations with their associated design storms is included in Appendix F1.

According to the MNR Technical Guide, 2002, for flow points with a contribution area greater than 25 km^2, the total rainfall depth should be reduced by applying an areal adjustment factor (as shown in Table 5.5) based on the ***equivalent circular area method***. Note that the equivalent circular area should be determined by using the longest length of the watershed as a diameter (Page 39, Technical Guide – River and Stream Systems: Flooding Hazard Limit, MNR, 2002). The equivalent circular area is different from the watershed drainage area, however, which was applied in the previous 2007 studies to determine the Regional Storm flows. Complete tables presenting the resulting Regional Storm flows at all selected flow node locations for both existing and future development conditions are included in Appendix F3. As seen from the results, the most conservative Regional Storm flows were produced by Scenarios 5 (existing) and 15 (future) at some downstream flow node locations. However, provincial policy dictates that Regional Storm flows should be based upon Scenarios 3 (existing) and 13 (future), where the last 12-hours of Hurricane Hazel are used with AMC III soil conditions and all SWM facilities removed. Hence those scenarios (#3 and 13) were selected to determine the recommended Regional Storm flows. Tables 5.6 and 5.7 summarize the resulting Regional Storm flows for existing (Scenario 3) and future conditions (Scenario 13) respectively.

Table 5.4 Regional Storm Scenarios

VO2 Scenario #	Development Scenario (Existing or Future)	Return Period	Distribution	Duration (Hrs)	Areal Reduction Factor (Y or N)	CN AMC (II or III)	100-Year Quantity Control SWM Pond (Y/N)
2	Existing	Regional Storms	Hurricane Hazel	12	Y	III	Y
3				12	Y	III	N
4				48	Y	II	Y
5				48	Y	II	N
12	Future	Regional Storms	Hurricane Hazel	12	Y	III	Y
13				12	Y	III	N
14				48	Y	II	Y
15				48	Y	II	N

Table 5.5 Areal Adjustment Factor for Regional Storm

Watershed Longest Length		Equivalent Circular Area (up to)		Reduction Factor Percentage
km	m	km2	ha	%
5.6	5642	25	2500	100.0
7.6	7569	45	4500	99.2
9.1	9097	65	6500	98.2
10.7	10705	90	9000	97.1
12.1	12101	115	11500	96.3
13.4	13351	140	14000	95.4
14.5	14494	165	16500	94.8
15.8	15757	195	19500	94.2
16.7	16737	220	22000	93.5
17.7	17662	245	24500	92.7
18.5	18541	270	27000	92.0
23.9	23937	450	45000	89.4
27.1	27058	575	57500	86.7
29.9	29854	700	70000	84.0
32.9	32898	850	85000	82.4
35.7	35682	1000	100000	80.8
39.1	39088	1200	120000	79.3

Table 5.6 Summary of Resulting Regional Flow Rates for Existing Conditions (2012 MMM Calibrated Model)

TSH Flow Node	MMM Flow Node	Drainage Area (ha)	Areal Reduction Factor (%)	Peak Flow Rates (m^3/s)
				12Hr Hurricane Hazel - Without Pond
				EXI.3.01
A	1.265	1471	100.0	30.9
B	1.285	2096	100.0	44.1
C	1.615	2307	100.0	51.4
D	1.620	4716	99.2	100.8
E	2.030	5241	97.1	106.2
F	2.090	6479	94.8	149.5
Brampton	2.140	6912	93.5	171.0
G	7.065	1332	100.0	79.0
H	2.190	7579	89.4	198.1
I	7.115	3289	96.3	257.3
J	7.145	3763	95.4	292.9
Spring Creek Gauge	7.150	3804	94.8	288.7
L	2.240	8937	89.4	250.4
M	2.255	10329	89.4	342.7
N	13.005	15437	86.7	659.5
O	12.030	444	100.0	51.1
P	13.030	16596	84.0	686.4
Q	11.055	487	100.0	51.9
R	13.050	17076	82.4	670.2
S	12.070	1777	99.2	177.8
T	13.075	18275	82.4	711.1
U	13.085	18882	80.8	712.7
V	13.090	19033	80.8	711.1
W	13.095	21293	80.8	841.5
X - QEW	13.110	21773	80.8	855.8
Y	13.120	22104	79.3	851.5
Z	13.150	22259	79.3	857.6

Table 5.7 Summary of Resulting Regional Flow Rates for Future Conditions (2012 MMM Calibrated Model)

TSH Flow Node	MMM Flow Node	Drainage Area (ha)	Areal Reduction Factor (%)	Peak Flow Rates (m^3/s)
				12Hr Hurricane Hazel - Without Pond
				FUT.13.01
A	1.265	1471	100.0	30.8
B	1.285	2096	100.0	43.9
C	1.615	2296	100.0	50.3
D	1.620	4706	99.2	96.5
E	2.030	5230	97.1	94.5
F	2.090	6460	94.8	163.5
Brampton	2.140	6893	93.5	186.5
G	7.065	1324	100.0	115.7
H	2.190	7560	89.4	212.7
I	7.115	3281	96.3	292.5
J	7.145	3755	95.4	323.9
Spring Creek Gauge	7.150	3796	94.8	320.0
L	2.240	8918	89.4	266.6
M	2.255	10310	89.4	357.5
N	13.005	15410	86.7	700.1
O	12.030	444	100.0	50.8
P	13.030	16570	84.0	725.7
Q	11.055	487	100.0	51.4
R	13.050	17049	82.4	708.2
S	12.070	1777	99.2	178.1
T	13.075	18248	82.4	749.8
U	13.085	18855	80.8	750.6
V	13.090	19006	80.8	750.7
W	13.095	21266	80.8	882.4
X - QEW	13.110	21746	80.8	891.3
Y	13.120	22077	79.3	880.3
Z	13.150	22232	79.3	884.4

5.2.3 350-Year Return Period Design Storms

As requested by TRCA, the 1 in 350 year return period design storms were established and simulated in the calibrated model for reference purposes. The following procedure was used to determine the 350-Year design storm for the Etobicoke Creek watershed.

- Frequency Analyses (by using Environment Canada's CFA v3.1 program) were performed at two Environment Canada-AES precipitation stations located in the vicinity of the subject watershed area: Toronto City - Bloor (# 6158350) and Pearson International Airport (# 6158733). The result of the frequency analysis was used to statistically estimate the 1 in 350 year return period rain depth. Table 5.8 shows the resulting 1 in 350-year return period rainfall depths. All detailed information can be found in Appendix F4.

Table 5.8 Estimated 1 in 350-Year Return Period Rainfall Depth (mm)

Return Period	Exceedance Probability	Gauge Location	Data Available	Event Duration (hr)	Estimated Depth (mm)
350 -Yr	0.00286	Toronto City - Bloor	1941-2003	6	101
				12	114
				24	130
		Pearson Int'l Airport	1950-2003	6	126
				12	172
				24	184

- As requested by TRCA, different scenarios were performed for the 350-Year storm events based on the inclusion of the SWM facilities in the model. A detailed list of model simulations for 350-year events in Appendix F1. Tables included in Appendix F4 provide a complete set of simulation results for all scenarios identified.
- In order to be consistent with the selected 2 to 100-year design storm events generated based on the Toronto City – Bloor gauge, 12-hr duration AES design distribution storms from the same rain station were used with the hydrologic model to simulate the 1 in 350-year event flows. By considering the effect of attenuation of the 100-Year stormwater management facilities, it was also recommended that 100-year SWM ponds should be included in the model. Tables 5.9 and 5.10 summarize the resulting 1 in 350-year flows at all key flow node locations for both existing and future development conditions respectively.
- The resulting 350-year flows were compared with the frequency analysis results as described in the following section.

Table 5.9 Estimated 1 in 350-Year Return Period Flows for Existing Conditions (2012 MMM Calibrated Model)

TSH Flow Node	MMM Flow Node	Drainage Area (ha)	350-Year Event based on Toronto City AES 12Hr EXI.6.08
A	1.265	1471	9.8
B	1.285	2096	13.9
C	1.615	2307	16.1
D	1.620	4716	31.7
E	2.030	5241	34.2
F	2.090	6479	100.2
Brampton	2.140	6912	107.1
G	7.065	1332	38.1
H	2.190	7579	128.1
I	7.115	3289	153.3
J	7.145	3763	171.3
Spring Creek Gauge	7.150	3804	165.8
L	2.240	8936	148.6
M	2.255	10329	187.5
N	13.005	15437	393.2
O	12.030	445	20.8
P	13.030	16596	417.2
Q	11.055	487	43.3
R	13.050	17076	403.9
S	12.070	1777	122.8
T	13.075	18275	421.8
U	13.085	18882	432.7
V	13.090	19033	432.8
W	13.095	21293	494.9
X - QEW	13.110	21773	499.1
Y	13.120	22103	502.2
Z	13.150	22258	504.3

Table 5.10 Estimated 1 in 350-Year Return Period Flows for Future Conditions (2012 MMM Calibrated Model)

TSH Flow Node	MMM Flow Node	Drainage Area (ha)	350-Year Event based on Toronto City
			AES 12Hr
			FUT.16.08
A	1.265	1471	9.8
B	1.285	2096	13.9
C	1.615	2296	15.9
D	1.620	4706	30.7
E	2.030	5230	33.2
F	2.090	6460	102.5
Brampton	2.140	6893	108.8
G	7.065	1324	62.3
H	2.190	7560	129.1
I	7.115	3281	156.0
J	7.145	3755	175.0
Spring Creek Gauge	7.150	3796	169.7
L	2.240	8917	148.9
M	2.255	10310	190.5
N	13.005	15410	400.5
O	12.030	444	20.7
P	13.030	16570	424.7
Q	11.055	487	42.5
R	13.050	17049	410.9
S	12.070	1777	124.5
T	13.075	18248	430.1
U	13.085	18855	441.1
V	13.090	19006	441.1
W	13.095	21265	503.8
X - QEW	13.110	21745	507.8
Y	13.120	22076	510.7
Z	13.150	22230	513.0

5.3 Non-Hydrographic Methods (Frequency Analysis)

5.3.1 General

Single Station Frequency Analysis is one of the basic methods to determine the magnitude of a design flood at hydrometric station locations. With this method, peak annual floods recorded at these gauges are statistically analysed to provide reasonably accurate means of estimating a design flow. The computer program Consolidated Frequency Analysis (CFA) version 3.1 by Environment Canada (EC) was used to conduct a frequency analysis and calculate frequency curves and statistics characteristics of the flows at the following two hydrometric stations located within study watersheds.

- Etobicoke Creek at Downtown Brampton (EC gauge # 02HC017) – MMM Flow Node # 2.140.
- Etobicoke Creek under QEW (EC gauge # HC030) – MMM Flow Node # 13.110.

Four theoretical distributions were examined to determine the return period peak flows, including:

1. General extreme value distribution (GEV),
2. Three-parameter lognormal distribution (3PLN),
3. Log Pearson type III distribution (LP3); and
4. Wakeby Distribution.

Detailed CFA program outputs are included in Appendix G1.

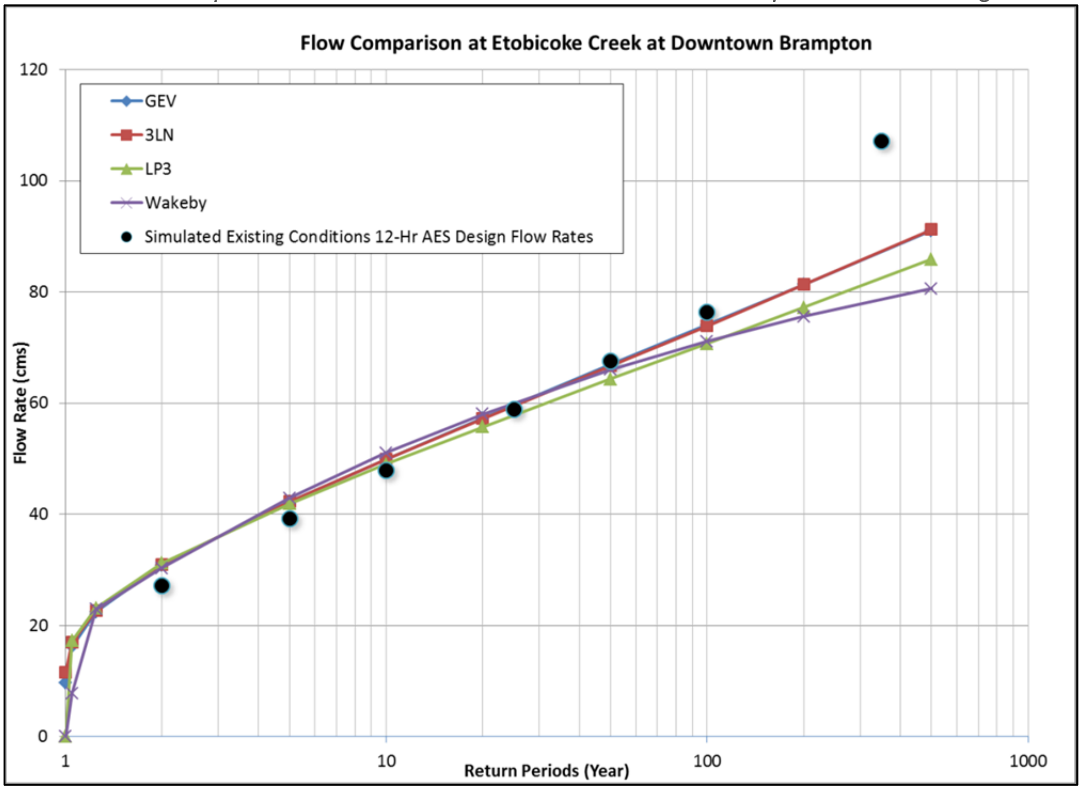
5.3.2 Analysis Results at Downtown Brampton Stream Gauge

Table 5.1 summarizes the frequency analysis results based on the data obtained from the Downtown Brampton stream gauge. Figure 5.2 presents a comparison of the frequency analysis results and calibrated existing design flows for a full range of return periods (including 2 to 100-year and 350-year) at the Downtown Brampton stream gauge location.

Table 5.11 Frequency Analysis Results at Downtown Brampton Stream Gauge (EC Station # 02HC017)

Return Period (Yr)	Resulting Flood (m^3/s)			
	GEV	3LN	LP3	Wakeby
1.003	9.68	11.6	-	-
1.05	16.1	16.9	17.2	7.7
1.25	22.4	22.7	23.1	22.9
2	30.8	30.9	31.2	30.3
5	42.3	42.3	41.9	42.9
10	49.9	49.9	49	51
20	57.3	57.2	55.7	58
50	66.9	66.7	64.3	66
100	74.1	73.9	70.7	71.1
200	81.3	81.3	77.2	75.6
500	91	91.2	85.9	80.6

Figure 5.2 Flow Comparison at Etobicoke Creek at Downtown Brampton Stream Gauge Location



As indicated by the above figure, the simulated design flows from the calibrated hydrologic model match very well with those resulting from the frequency analysis at Etobicoke Creek at the Downtown Brampton stream flow gauge location (EC gauge # 02HC017). The 1:350 year simulated flow exceeds the equivalent flow from the frequency analysis by about 25%. This would be anticipated since all the flows used in the frequency analysis were below the 1:100 year return period and would therefore be controlled by the numerous stormwater management facilities in the watershed. In contrast, the 1:350 year event would only be partially controlled by the SWM facilities.

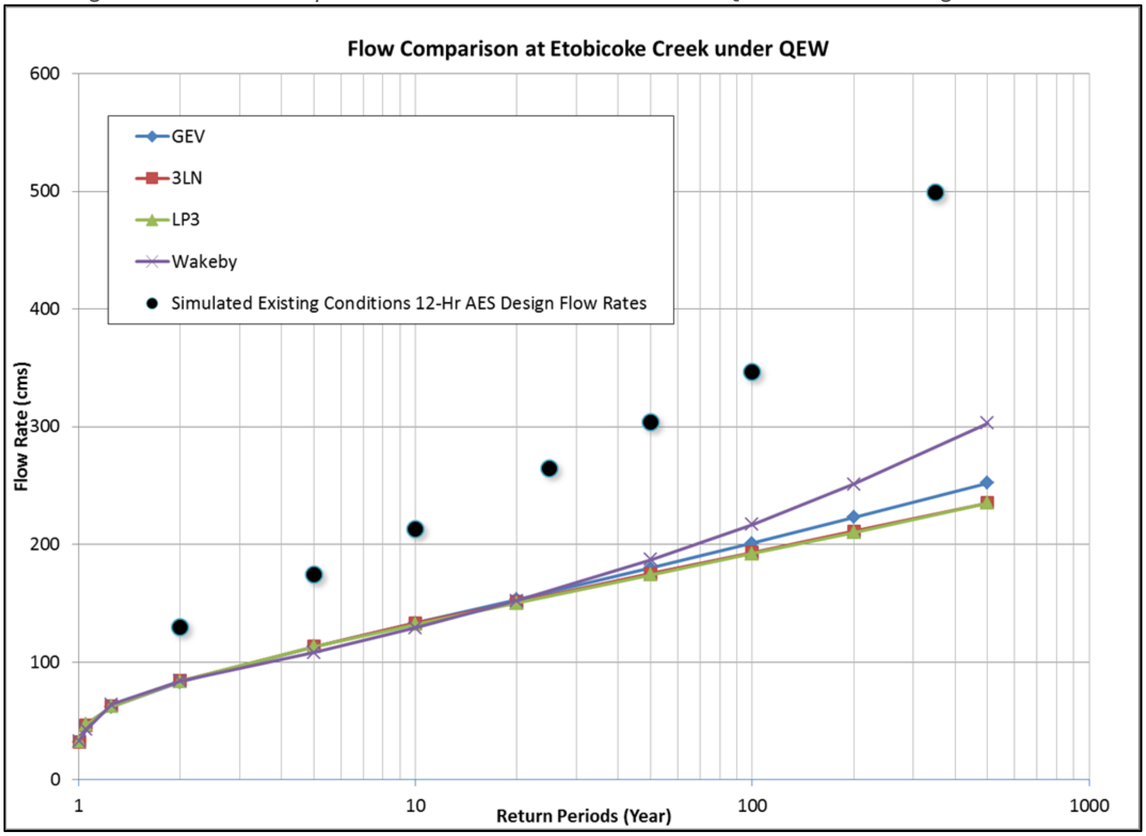
5.3.3 Analysis Results at Etobicoke Creek QEW Stream Gauge

Similar to the analysis performed for the Downtown Brampton location, the data obtained from Etobicoke Creek at QEW stream gauge (EC gauge # HC030) was also analysed. Table 5.12 summarizes the results of the frequency analysis. Figure 5.3 shows a comparison of the frequency analysis results and calibrated existing design flows for a full range of return periods (including 2 to 100-year and 350-year) at Etobicoke Creek at QEW stream gauge location.

Table 5.11 Frequency Analysis Results at Etobicoke Creek QEW Stream Gauge (EC Station # HC030)

Return Period (Yr)	Resulting Flood (m^3/s)			
	GEV	3LN	LP3	Wakeby
1.003	31.8	31.7	32.3	32.9
1.05	46.9	46.4	46.8	42.5
1.25	62.1	62.2	62.4	64
2	83	83.9	83.8	84
5	11	113	113	108
10	133	133	132	129
20	153	151	150	152
50	180	175	174	187
100	201	193	192	217
200	223	211	210	251
500	252	235	235	303

Figure 5.3 Flow Comparison at Etobicoke Creek under QEW Stream Gauge Location



As shown in Figure 5.3, the existing flows at the Etobicoke Creek at QEW stream gauge location by using the calibrated hydrologic model are almost double the values resulting from frequency analysis. Actually, such significant increases in the flows are expected. Frequency analysis at Etobicoke Creek under QEW gauge was performed based on the annual peak runoff rates recorded for a period from 1967 to 2009. Unlike the Etobicoke Creek headwatershed where the majority of the area remains undeveloped, the middle and downstream portions of Etobicoke Creek watershed have been dramatically developed over the past decades. By considering that most of the flows used in the frequency analysis were generated based on much less developed land use during previous years, the underestimated flows are expected.

5.4 Analysis of Resulting Peak Flows

Because the Regional Storm flows generated by the calibrated hydrologic model in the present study will be used to determine or revise the existing Regulatory floodlines along Etobicoke Creek and develop design criteria (policy) for its associated road crossings, a successfully calibrated model which reflects the actual hydrologic characteristics of the Etobicoke Creek watershed is crucial. Consequently, in order to further understand the variations in flows between different studies, additional analysis comparing the Regional Storm flows resulting from the previous and the present models was performed to investigate further all apparent inconsistencies.

In order to provide a proper comparison, the major differences between the model setup/calibration methodologies used to develop the previous 2007 model by TSH and the present model (MMM 2012 model) were first identified. Table 5.12 summarizes the identified differences and the revisions made to the present models. Then, based on these identified inconsistencies, revisions were made to the MMM 2012 model to establish a test hydrologic model developed by a similar methodology which was adopted in the previous 2007 TSH model. That test model was named as Scenario #18 and was listed in the simulation list in Appendix F1. Scenario #18 was simulated by using the Regional Storm. The detailed results are summarized in the tables included in Appendix G2. Table 5.13 presents a summary of the comparison of resulting Regional Storm peak flows from all available previous to the present models. Detailed comparison results can be found in Appendix G3.

In conjunction with TRCA staff, a sensitivity analysis has also been carried out for rural areas in the headwaters. The un-calibrated subcatchment parameters were used for the rural areas in the headwaters (Sub-Basins #1, #2 and #3 only), but the calibrated parameters were applied for the remaining areas of the watershed. The resulting flows are presented in Table 5.13.

Table 5.12 Summary of Identified Major Model Differences between 2007 TSH model and 2012 MMM model

Item	MMM 2012 Model	TSH 2007 Model
Catchment Delineation	280 Sub-Catchments	41 Sub-Catchments
Drainage Connectivity	Area 221 in the 2007 TSH model was revised to discharge to the main Etobicoke Creek. Various revisions to the model connectivity were made to best reflect the existing conditions.	Area 221 was incorrectly connected to Spring Creek.
Streamflow Data	In order to reflect different geographic characteristics of the watershed, the Etobicoke Creek watershed was calibrated based on three different streamflow gauge locations: (1) Etobicoke Creek at Brampton (Headwatershed) - HY026/HC017; (2) Spring Creek Stream Gauge – HY059; and (3) Etobicoke Creek below Queen Elizabeth Highway – HC030.	Observed flow data from EC's Etobicoke Creek under QEW station was the only flow gauge used to calibrate the entire watershed.
Calibration Events	A total of 25 of the most significant rainfall events were identified and used for model calibration and validation. Additional 5 events were added for further model validation.	A total of 6 rainfall events were selected, but only 2 events were further used for model calibration and validation.
Calibration Parameters	The initial values of CN for NASHYD and Imperviousness for STANDHYD were adjusted first to ensure that the modelled runoff volume close to that observed. The values optimized were: Tp and N (no. of linear reservoirs) for NASHYDs, SC (Storage Coefficient), including SCI and SCP for STANDHYDs and RO (Manning's n) for channel routing sections.	The adjusted parameters for calibration includes: CN, Imperviousness, Ia and Runoff travel length, including L, Tc, Tp.
SWM Facilities	All SWM facilities, including SWM ponds and on-site storages, are included in the hydrologic model individually to best reflect the hydrological storage routing effects.	The SWM ponds were lumped in such a way as to produce a combined facility representative of the collective performance of the individual ponds. The approach to lump the ponds was simply achieved by directly adding the storage-discharge values of the individual ponds on a rainfall return period basis.
Calibration Procedure	The automated calibration procedure by using Shuffled Complex Evolution (SCE) method was applied in the present study. Shuffled Complex Evolution (SCE) method was tested by Peyron et al for seven such procedures and it concluded that "the Multi-start and modified and original Shuffled Complex Evolution (SCE) methods are the best performing methods" (CWRA Annual Conference, 2004).	Manually adjust calibration parameters to achieve best fit.
Areal Reduction Factor applied for Regional Storm	For flow points with the contribution area greater than 25 km^2, an areal adjustment factor was applied to the Regional Storm depth based on the equivalent circular area, which was determined by using the longest length of the watershed as a diameter (Page 39, Technical Guide – River and Stream Systems: Flooding Hazard Limit, MNR, 2002).	For flow points with the contribution area greater than 25 km^2, an areal adjustment factor was applied to the Regional Storm depth based on watershed drainage area.

Table 5.13 Summary of Analysis of Resulting Peak Flows

Key Flow Nodes	MMM Flow Nodes	TSH VO2 NHYD	MMM VO2 NHYD	Drainage Area (ha)		Resulting Regional Storm Peak Flow Rates (cms)					
				TSH 2007	MMM 2012	1978 Report	Schaffer 1996	TSH-2007-Future Ultimate Scenario	MMM-2012-Future Scenario	MMM-2012-Future Conditions - Test Scenario # 18	MMM-2012-Future Conditions – Headwaters Un-Cal.
A	1.265	2341	1105	1432	1471	37	-	101	34	83	108
B	1.285	2321	1084	1997	2096	107	63	139	48	118	151
C	1.615	2301	1049	2285	2305	-	-	146	55	136	181
D	1.620	2303	1039	4589	4714	272	-	291	105	251	325
E	2.030	2285	2051	5144	5241	-	-	278	103	248	306
F	2.090	2276	2091	6325	6479	302	303	304	181	260	284
G	7.065	4234	1073	1427	1323	-	108	136	116	127	118
H	2.190	2268	2242	7678	7560	369	353	404	227	312	304
I	7.115	2223	1150	2910	3280	-	275	263	292	359	293
J	7.145	2206	1179	4210	3755	292	308	396	323	406	325
L	2.240	2255	2431	8533	8942	-	-	454	281	371	340
M	2.255	2195	1226	9417	10318	-	-	517	370	479	394
N	13.005	2157	1717	13866	15419	863	-	847	711	965	736
O	12.030	2174	2299	450	444	-	-	61	51	61	51
P	13.030	2182	1603	15499	16578	903	915	958	736	1021	761
Q	11.055	2123	1428	248	487	-	-	24	51	67	51
R	13.050	2184	2606	16491	17076	922	937	1003	718	1021	739
S	12.070	2165	2349	1731	2001	-	191	198	177	222	177
T	13.075	2103	1335	17332	18248	969	1026	1029	761	1074	780
U	13.085	2092	2346	17732	18882	-	-	1050	762	1103	779
V	13.090	2063	2355	18150	19006	981	-	1070	763	1107	779
W	13.095	2083	1365	20441	21266	-	-	1231	897	1287	912
X - QEW	13.110	2053	2372	20778	21773	1087	1214	1244	907	1307	923
Y	13.120	2023	2374	21102	22104	-	-	1260	894	1305	907
Z	13.150	2012	2395	21273	22259	1105	1233	1271	898	1309	912

The main conclusions and recommendations are summarized as follows,

- Regional flows from all previous studies (i.e., 1978 Report, Schaeffer 1996 and TSH 2007) are relatively consistent at key flow locations. This is because all the previous studies applied similar calibration methodology, i.e. based on single calibration gauge at Etobicoke Creek under QEW streamflow station. In additional, incorrect areal reduction factors based on watershed drainage areas were applied for these studies.
- By comparing with flows from the previous TSH 2007 study, the present study (MMM, 2012) generates roughly 25% ~ 30% decreases in Regional flows at flow nodes located within the middle and downstream areas of the watershed; while significant decreases of approximately 60% in flows were found at flow nodes located within the upstream watershed (headwatershed area). This is because a state-of-the-art calibration procedure was adopted and more comprehensive rain and flow data (especially, calibration at the upstream Etobicoke Creek at Downtown Brampton streamflow gauge location) were applied for calibration and validation in the present study. The resulting calibrated hydrologic model reflects the actual hydrologic characteristics of the entire subject Etobicoke Creek watershed. However, on the contrary, the flows simulated by the previous studies are overestimated (especially for the upstream Etobicoke Creek headwatershed) due to the limited calibration procedure and insufficient calibration/validation events.
- However, it should also be noted that at the Brampton flow station, the majority of the storm events available for calibration and validation produced flows in the range of the 1-year return period. The August 19, 2005 event was the only significant storm event available for validation. This storm event produced a flow equivalent to an approximately 25-year return period.
- In order to eliminate the differences between previous and present models and provide an appropriate comparison result, an additional test Scenario (# 18) was developed based on the MMM 2012 model to simulate the Regional flows. The present MMM model for the test Scenario (# 18) was revised to adopt the similar model setup and calibration methodology used in the development of the previous 2007 TSH model. As shown in the Table 5.13, it is expected that, once a similar model setup and calibration methodology was used, the test Scenario (# 18) gives very reasonably matching flows to those from the previous 2007 TSH model. This is evidence that the calibration procedure applied in the present study (MMM 2012) was successful, and a reliable calibrated model was developed to reflect the actual hydrologic characteristics of Etobicoke Creek.
- A sensitivity analysis indicated that
  - Peak flows for the upper Etobicoke creek (Sub-Basins 1, 2 and 3, as upstream of Downtown Brampton) are sensitive to the calibrated Tp and N values.
  - Peak flows for the middle portions of the watershed are less sensitive to Tp and N values.
  - At the QEW and the river mouth, the Regional Flows are not sensitive to Tp and N values.

  It can be summarized that Tp and N values for the headwaters (Sub-Basins 1, 2 and 3) do not have impacts on the Regional Storm peak flows for the downstream reach. However, they have significant impacts on areas immediately downstream, such as the headwaters and Downtown Brampton.

- TRCA has concluded that although the calibrated model provided good predictions of peak flows across the watersheds, there is a possibility that the model might underestimate peak flows for the Regional storm event in the headwater areas. This is due to limited confidence in the flow data collected at the Brampton and Spring Creek stream gauges (e.g., events used for calibration and validation at Brampton gauges were small and only one event was considered significant). Consequently, it was decided that the final 2013 model developed by MMM and adopted by TRCA for Etobicoke Creek Watershed should include the un-calibrated Tp and N values used for NASHYD areas located upstream of Brampton and Spring Creek stream gauges (i.e., Sub-Basins 1, 2, 3 and 6) while applying calibrated parameters for the remaining areas of the watershed.

Tables 5.14 and 5.15 summarize the flows of all simulated storm events (i.e. 2 to 100 year, Regional and 350-year) generated by the 2013 final hydrological model for existing and future development scenarios respectively. The parameters for 2013 final existing and future conditions models are included in Appendix H1. Complete sets of the flow results are included in Appendix H2.

Table 5.14 Summary of 2013 Final Etobicoke Creek Model Results for Existing Conditions

Key Flow Nodes	12-Hr AES - Peak Flow Rates (m^3/s) 2013 Final Model						Hurricane Hazel (m^3/s)	350-Year Event based on Toronto City
	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	12Hr w/o Pond	AES 12-Hr
	EXI.1.31	EXI.1.32	EXI.1.33	EXI.1.34	EXI.1.35	EXI.1.36	EXI.3.01	EXI.6.08
A	6	10	14	18	22	26	113	40
B	8	13	18	24	29	35	158	55
C	8	15	21	29	36	43	192	69
D	15	27	35	49	60	71	346	115
E	15	25	33	44	53	64	330	106
F	30	41	48	57	65	72	300	101
Downtown Brampton	27	39	47	58	67	76	290	108
G	13	21	27	35	41	47	129	68
H	33	48	58	72	82	93	272	129
I	43	59	70	85	97	108	305	157
J	46	64	77	93	106	119	334	174
Spring Creek	43	61	74	90	103	116	329	169
L	42	57	68	82	93	105	293	149
M	53	72	87	105	120	135	357	188
N	103	144	174	214	244	276	706	397
O	7	9	11	13	14	16	51	21
P	107	150	182	224	256	290	733	421
Q	14	18	22	26	29	32	52	43
R	105	146	177	218	249	282	711	408
S	42	55	64	76	85	93	178	123
T	108	150	182	224	257	291	750	425
U	110	154	186	230	263	298	750	436
V	110	153	186	229	263	298	749	436
W	125	168	205	255	293	335	877	497
X - QEW	128	171	209	259	298	341	885	502
Y	130	172	211	262	301	344	875	505
Z	131	174	211	262	302	345	880	507

Table 5.15 Summary of 2013 Final Etobicoke Creek Model Results for Future Conditions

Key Flow Nodes	12-Hr AES - Peak Flow Rates (m^3/s) 2013 Final Model						Hurricane Hazel (m^3/s)	350-Year Event based on Toronto City
	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	12Hr w/o Pond	AES 12-Hr
	FUT.11.31	FUT.11.32	FUT.11.33	FUT.11.34	FUT.11.35	FUT.11.36	EXI.13.01	EXI.16.08
A	6	10	14	18	22	26	112	40
B	8	14	18	24	30	35	157	55
C	8	15	21	29	35	42	187	67
D	15	27	36	49	60	72	339	114
E	16	27	35	46	56	67	313	106
F	30	41	49	58	66	73	287	102
Downtown Brampton	27	39	48	59	67	76	279	109
G	18	26	32	39	45	51	134	75
H	33	48	58	71	82	92	271	129
I	44	61	72	87	99	110	312	159
J	47	66	79	96	109	123	341	178
Spring Creek	45	63	76	92	105	118	336	172
L	43	57	68	82	93	104	300	149
M	54	75	89	109	124	139	367	191
N	106	148	179	220	251	283	722	404
O	7	9	11	13	14	16	51	21
P	110	154	187	230	263	297	749	428
Q	13	18	21	25	29	32	51	43
R	108	150	181	223	254	288	728	414
S	42	56	65	77	86	95	178	124
T	110	154	186	230	262	297	767	433
U	113	157	191	235	269	305	767	444
V	113	157	190	235	269	304	767	444
W	126	172	210	260	299	342	897	506
X - QEW	130	175	213	265	304	348	906	510
Y	131	176	215	267	307	351	892	513
Z	132	177	216	268	308	352	897	516

5.5 Ultimate and Full Development Scenarios

For hydrological study purposes, the final future conditions model was further revised to reflect two additional development conditions:

- Ultimate Development Conditions (Figure 5.4) – Areas beyond Official Plan (OP) boundary within the headwatershed are developed, while Environmental Protection Area (EPA) and Greenbelt area remain in their existing condition.
- Full Development Conditions (Figure 5.5) – This is a hypothetical scenario where entire areas within headwatershed are development including EPA and Greenbelt areas. Furthermore, all watercourses within headwatersheds are removed, e.g., there are no channel routing commands within headwatershed in the VO2 model.

Table 5.16 provides a comparison of the resulting 100-year and Regional Storm peak flows for existing, future, ultimate and full development conditions. The catchment parameters for both ultimate and full development scenarios are included in Appendix I1. Detailed simulation results are included in Appendix I2.

As seen from Table 5.16, there are significant increases in peak flows resulting from ultimate and full development conditions at upstream flow node locations. However, the effect of impacts reduces gradually downstream of the watershed. The Terms of Reference (TOR) specifies the requirement to establish a quantity control strategy for Etobicoke Creek watershed for the 2- to 100- year design storm and Regional Storm to eliminate the impacts of the flows due to the developments. Section 6 discusses this topic in details.

Table 5.16 Comparison of 100-year and Regional Peak Flows for Existing, Future, Ultimate and Full Development Conditions

Key Flow Nodes	12-Hr AES Design Storm – 100-Year Return Period				Hurricane Hazel			
	Existing	Future	Ultimate	Full Development	Existing	Future	Ultimate	Full Development
	EXI.1.36	FUT.11.36	ULT.21.06	FUL.31.06	EXI.3.01	FUT.13.01	ULT.22.01	FUL.32.01
A	26	26	50	132	113	112	140	206
B	35	35	62	187	158	157	192	295
C	43	42	74	206	192	187	214	322
D	71	72	111	419	346	339	400	654
E	64	67	104	259	330	313	374	533
F	72	73	96	208	300	287	350	516
Downtown Brampton	76	76	96	203	290	279	342	512
G	47	51	51	51	129	134	134	134
H	93	92	96	203	272	271	340	499
I	108	110	110	110	305	312	312	312
J	119	123	123	123	334	341	341	341
Spring Creek	116	118	118	118	329	336	336	336
L	105	104	106	200	293	300	363	512
M	135	139	139	206	357	367	402	532
N	276	283	283	283	706	722	752	876
O	16	16	16	16	51	51	51	51
P	290	297	297	298	733	749	774	890
Q	32	32	32	32	52	51	51	51
R	282	288	288	289	711	728	749	860
S	93	95	95	95	178	178	178	178
T	291	297	297	299	750	767	787	894
U	298	305	305	306	750	767	784	888
V	298	304	304	306	749	767	784	886
W	335	342	342	343	877	897	914	1002
X - QEW	341	348	348	348	885	906	922	1009
Y	344	351	351	351	875	892	909	993
Z	345	352	352	353	880	897	911	997

6.0 DEVELOPMENT OF STORMWATER QUANTITY CONTROL STRATEGY

6.1 Methodology

The Term of Reference (TOR) identify that a “Unit Flow Rates” approach should be adopted as the quantity control strategy for the subject watershed. Such an approach has been practically implemented for the Humber, Duffins and Don Watersheds within TRCA’s jurisdiction. Based on discussion with TRCA staff, a quantity control strategy for Etobicoke Creek watershed was developed based on Ultimate Development Conditions (e.g., for developments within the Etobicoke Creek Headwatersheds, exclusive of the Greenbelt and EPA areas, and infill re-developments within the rest of the downstream watersheds). The quantity control targets are summarized as follows,

- Developments are required to be controlled so that there are no increases of peak flows from existing levels for Etobicoke Creek water courses for 1 in 2 to 1 in 100-year design storm events (12-hr AES); and
- Developments are required to be controlled so that there are no increases in peak flows from those generated from future development models for the Etobicoke Creek water courses for the Regional storm event (final 12-hours of Hurricane Hazel).

Figure 6.1 shows a flow chart in order to better describe the study procedure. The entire watershed was divided into three strategic areas: (1) Headwatersheds (Sub-Basin #1); (2) Mid-Basins and Tributaries (Sub-Basins # 2 to 7, 9 and 10); and Low-Basins (Sub-Basins # 8, 11 and 12). The following sections describe the details of establishing unit flow rates based upon identified strategic watersheds and provides our recommendations. Drawings J.1 and J.2 show existing and future catchment boundaries for the Etobicoke Creek watershed respectively.

6.2 Development of Unit Flow Rates for 1 in 2 to 1 in 100 year Design Storms

6.2.1 Headwatersheds (Sub-Basin # 1)

There are a total of more than 50 ultimate development catchments (STANDHYDs) within the headwatersheds. Due to the large number of subcatchments, it is impractical and extremely time-consuming to develop storage-discharge curves for each individual STANDHYD. Hence, five representative ultimate development catchments were selected to calculate the unit controlled hydrograph (i.e., a hydrograph per unit drainage hectare) based on the following criteria:

- 100% of the catchment will be developed in the ultimate conditions, i.e., areas of NASHYDs in the base scenario are equal to those of the STANDHYDs in the ultimate scenario.

- Based on a statistical data analysis (e.g. Histogram), the sizes of the selected catchments are representative for the headwatershed.

It is known from previous studies in other watersheds (e.g. the Don River watershed) that in order to control flows at a downstream point to a target unit flow level (l/s/ha), it is necessary to “overcontrol” the discharges from upstream catchments. In other words, the unit flow rates in the distributed subcatchments must be lower than at the target location downstream. Hence various control levels (e.g. 100% of base levels, 75% of base levels and 60% of base levels, etc.) were investigated to identify the applicable control level. Such investigation involved iterative modifications of the models. A comparison of the resulting peak flows at all key FPs is shown in Table 6.1. Detailed comparison results are included in Appendix J1. As shown in Table 6.1, it can be concluded that, as anticipated, controlling peak flows within the headwatersheds only to their existing levels is not sufficient. For instance, the 100-year peak flow at FP #D is 84.9 m^3/s if headwater flows are only controlled to 100% of their existing levels (Run 1) vs. the required flow of 71.4 m^3/s to match existing conditions at FP #D. Consequently, more conservative control levels were investigated to control ultimate headwater subcatchment peak flows to 75% of base levels and to 60% of base levels. As shown in the result table, if the flows from ultimate development catchments were controlled to 60% of base levels (Run 3), there would be no impact to the flows at downstream flow nodes.

6.2.2 Mid-Basins and Tributaries (Sub-Basins # 2 to 7, 9 and 10)

TRCA’s policy allows 20% increases of imperviousness for infill re-development. Based on our experience on similar watersheds (e.g., Don River), for the middle part of the watershed (Sub-Basins #2 to 7) and the tributary drainage areas (Basins # 9 and 10), “control of post development peak flows to pre development peak flows” is typically implemented. For the lower/downstream part of the watershed (Sub-Basins #8, 11 and 12), no controls are typically required. These strategies will be discussed in the following section. Hence, for mid basins (Sub-Basins #2 to 7), investigations have been carried out to confirm the use of a “control post to pre” strategy.

There are a total of more than 170 infill re-development catchments (STANDHYDs) within the mid part of the watershed and the tributaries (Sub-Basins # 2 to 7, 9 and 10). Again, due to the large number of the catchments, it is impractical and extremely time-consuming to develop storage-discharge curve individually for each of the STANDHYDs. Since the increases of the imperviousness of the re-development are limited to 20%, investigations were carried out to compare the hydrograph (i.e., peak flow, time to peak) between existing and controlled conditions. In order to have representative hydrographs to compare, three catchments were selected: (1) hypothetical catchment with average drainage area (the most frequent catchment in size according to the statistical results); (2) Catchment #306 (representative large catchment in size) and (3) Catchment #605 (representative small catchment in size). The comparison results are included in Appendix J2. As shown, based on the comparison results, the changes to the hydrographs, especially, time to peak values are negligible. Consequently, for investigation purposes, runoff hydrographs generated from existing catchments are used to present the controlled hydrographs for the infill re-development areas within the mid part and tributaries of the watersheds.

6.2.3 Lower-Basins (Sub-Basins # 8, 11 and 12)

As mentioned previously, for the downstream part of the watershed (Sub-Basins #8, 11 and 12), no controls are typically required. This is because if storages are provided for the infill re-development areas (with increased imperviousness) to attenuate the peak flows to the existing levels, such controls (storage routing) will delay the peak flows (i.e., longer time to peak values) from infill areas. For large sized watersheds (e.g., Etobicoke Creek watershed has a total drainage area more than 200 km^2), such delayed peak flows from the downstream watersheds will be added to the peak flows in the main branch coming from the upstream watersheds which typically occur later. As such, the peak flows in the main branch of the water course will increase due to this "timing effect" if the infill re-developments within the lower downstream part of the watershed (Sub-Basins #8, 11 and 12) are controlled. Detailed information for the Lower-Basins is included in Appendix J3.

6.2.4 Summary of Established Unit Flow Rates for 1 in 2 to 1 in 100 year Design Storm Events

In order to examine the identified quantity control strategies on an overall watershed basis, the entire Etobicoke Creek hydrology model was modified to reflect:

- Headwatersheds (Sub-Basin #1) – Control peak flows from ultimate development areas to 60% of the existing levels.
- Mid-Basins and Tributaries (Sub-Basins # 2 to 7, 9 and 10) - Control peak flows from infill re-development lands (maximum 20% increases of imperviousness) to existing levels; and
- Lower-Basins (Sub-Basins # 8, 11 and 12) – No quantity controls are required.

A summary of the resulting flows is presented in Table 6.1. As shown in the Table, by implementing the identified quantity control strategy (1 in 2 to 1 in 100 year) for the Etobicoke Creek watershed under ultimate development conditions, there will be no hydrological impact to the flows in the Etobicoke Creek watercourses (e.g.see results from Run 4 vs. target flows for existing conditions).

Consequently, the recommended Unit Flow Rates (UFRs) for 2- to 100-year design storm events (12hr AES) for Etobicoke Creek watershed are summarized in Appendix J4. The existing catchment numbers are shown in Drawing J.1 in the rear pocket.

Table 6.1 Development of Unit Flow Rates – 100-year Peak Flow Rates

Flow Node #	Locaton	12-Hr AES – 100-Year Peak Flow Rates (m3/s)									
		ULT.21.06 – Ultimate Conditions	EXI.1.36 Base - Target - Existing Condition	Run 1		Run 2		Run 3		Run 4	
				Only HW UFR Controlled (100%)		Only HW UFR Controlled (75%)		Only HW UFR Controlled (60%)		100-Yr - HW UFR Controlled (60%) - LOW (20% Imp Increase)	
				Only HW UFR Controlled (100%)	Diff. to Base (%)	Only HW UFR Controlled (75%)	Diff. to Base (%)	Only HW UFR Controlled (60%)	Diff. to Base (%)	HW Controlled (60%) - LOW (20% Imp Inc.)	Diff. to Base (%)
1.265	TSH FP# A	50.0	25.9	29.4	13.8%	24.4	-5.6%	21.4	-17.0%	21.4	-17.0%
1.285	TSH FP# B	62.1	34.7	39.4	13.5%	34.4	-1.0%	31.4	-9.4%	31.4	-9.4%
1.615	TSH FP# C	73.9	42.8	48.9	14.2%	43.6	1.9%	40.2	-6.3%	40.2	-6.3%
1.620	TSH FP# D	111.8	71.4	84.9	18.9%	75.2	5.2%	69.0	-3.4%	69.0	-3.4%
2.030	TSH FP# E	104.5	63.7	76.7	20.4%	68.2	6.9%	62.4	-2.1%	62.4	-2.1%
2.090	TSH FP# F	96.5	72.0	72.8	1.1%	72.1	0.0%	72.1	0.0%	72.1	0.0%
2.140	Etobicoke Creek Flow Gauge	96.0	75.7	75.9	0.2%	75.8	0.1%	75.8	0.1%	75.8	0.1%
2.190	TSH FP# H	95.9	92.8	92.9	0.1%	92.9	0.1%	92.8	0.1%	92.8	0.1%
2.240	TSH FP# L	106.5	104.6	104.8	0.2%	104.8	0.1%	104.7	0.1%	104.7	0.1%
2.255	TSH FP# M	138.6	134.5	134.5	0.0%	134.5	0.0%	134.5	0.0%	134.5	0.0%
7.065	TSH FP# G	51.0	47.4	47.4	0.0%	47.4	0.0%	47.4	0.0%	47.4	0.0%
7.115	TSH FP# I	109.7	108.0	108.0	0.0%	108.0	0.0%	108.0	0.0%	108.0	0.0%
7.145	TSH FP# J	123.1	119.3	119.3	0.0%	119.3	0.0%	119.3	0.0%	119.3	0.0%
11.055	TSH FP# Q	31.8	32.4	32.4	0.0%	32.4	0.0%	32.4	0.0%	32.4	0.0%
12.030	TSH FP# O	15.5	15.7	15.7	0.0%	15.7	0.0%	15.7	0.0%	15.7	0.0%
12.070	TSH FP# S	94.6	93.3	93.3	0.0%	93.3	0.0%	93.3	0.0%	93.3	0.0%
13.005	TSH FP# N	282.4	275.6	275.6	0.0%	275.6	0.0%	275.6	0.0%	275.6	0.0%
13.030	TSH FP# P	296.9	289.7	289.7	0.0%	289.7	0.0%	289.7	0.0%	287.8	-0.6%
13.050	TSH FP# R	287.5	281.1	281.1	0.0%	281.1	0.0%	281.1	0.0%	279.0	-0.7%
13.075	TSH FP# T	296.9	290.3	290.3	0.0%	290.3	0.0%	290.3	0.0%	287.9	-0.8%
13.085	TSH FP# U	304.2	297.5	297.5	0.0%	297.5	0.0%	297.5	0.0%	295.5	-0.7%
13.090	TSH FP# V	304.0	297.1	297.1	0.0%	297.1	0.0%	297.1	0.0%	295.2	-0.6%
13.095	TSH FP# W	341.7	334.5	334.5	0.0%	334.5	0.0%	334.5	0.0%	332.7	-0.5%
13.110	TSH FP#X	347.2	340.1	340.1	0.0%	340.1	0.0%	340.1	0.0%	338.4	-0.5%
13.120	TSH FP# Y	350.5	343.2	343.2	0.0%	343.2	0.0%	343.2	0.0%	341.7	-0.4%
13.150	TSH FP# Z	351.6	344.3	344.3	0.0%	344.3	0.0%	344.3	0.0%	342.9	-0.4%

6.3 Development of Unit Flow Rates for Regional Storms

Based on discussion with TRCA staff, for Regional Storm (final 12-hours of Hurricane Hazel), ultimate developments are required to be controlled so that there are no increases of peak flows from future development models for the Etobicoke Creek water courses.

Similar to the approaches applied to establish Unit Flow Rates for 1 in 2 to 1 in 100 year design storms, the following control strategies were implemented in the Etobicoke Creek watershed model for Regional Storms:

- Headwatersheds (Sub-Basin #1) – Control peak flows from ultimate development areas to 60% of resulting flows from the future conditions model.
- Mid-Basins and Tributaries (Sub-Basins # 2 to 7, 9 and 10) - Control peak flows from infill re-development lands (maximum 20% increases of imperviousness) to those from base model; and
- Lower-Basins (Sub-Basins # 8, 11 and 12) – No quantity controls are required.

A summary of the resulting flows is presented in Table 6.2. As shown in Table 6.2, by implementing the identified quantity control strategy for Regional Storm for the Etobicoke Creek watershed under ultimate development conditions, there will be no hydrological impact to the flows in the Etobicoke Creek watercourses (e.g. results from Run 8 vs. target flows for future conditions).

Consequently, the recommended Unit Flow Rates (UFRs) for Regional Storms (final 12-hours of Hurricane Hazel with no SWM ponds) for Etobicoke Creek watershed are summarized in Appendix J5. The future catchment numbers are shown in Drawing J.2 in the rear pocket.

Required Additional Storages for Regional Controls

Hurricane Hazel is a 48-hr duration historical storm. As discussed previously, final 12-hours of Hurricane Hazel has been identified as Regional Storm for Etobicoke Creek watershed. The saturated antecedent moisture condition (AMC III) is required to be applied for the catchment to simulate the wet soil conditions resulting from the first 36-hours of Hurricane Hazel. As such, when determining the required detention storage for regional controls, it is necessary to provide additional storage to accommodate the first 36-hours of Hurricane Hazel. Since no distribution was recorded during first 36-hour Hurricane Hazel historical storm, two hypothetical distributions (constant intensities and increased intensities, both with a total depth of 73mm) were applied in the existing model to determine the storage volumes used by the existing SWM ponds within the Etobicoke Creek watershed. All study results are included in Appendix J6. As indicated, a unit storage volume of 214 m^3/ha will be required as additional storages for Regional controls. Such storages should be added to the calculated storage volumes to control the post-development peak flows to the identified Unit Flow Rates for the Regional Storm.

Table 6.2 Development of Unit Flow Rates – Regional Storm Flow Rates

Flow Node #	Locaton	Final 12-hr Hurricane Hazel Regional Storm - Peak Flow Rates (m3/s)									
		ULT.22.01 - Ultimate	FUT.13.01 - Base Target Future Condition	Run 5		Run 6		Run 7		Run 8	
				Only HW UFR Controlled (100%)		Only HW UFR Controlled (75%)		Only HW UFR Controlled (60%)		HW UFR Controlled (60%) - LOW (20% Imp Increase)	
				Only HW UFR Controlled (100%)	Diff. to Base (%)	Only HW UFR Controlled (75%)	Diff. to Base (%)	Only HW UFR Controlled (60%)	Diff. to Base (%)	HW Controlled (60%) - LOW (20% Imp Inc.)	Diff. to Base (%)
1.265	TSH FP# A	140.3	112.3	114.8	2.2%	94.7	-15.7%	79.2	-29.5%	79.2	-29.5%
1.285	TSH FP# B	191.9	157.0	158.8	1.2%	138.9	-11.5%	123.8	-21.2%	123.8	-21.2%
1.615	TSH FP# C	213.8	187.4	186.3	-0.6%	168.2	-10.2%	156.5	-16.5%	156.5	-16.5%
1.620	TSH FP# D	400.1	339.3	342.6	1.0%	306.3	-9.7%	279.6	-17.6%	279.6	-17.6%
2.030	TSH FP# E	373.6	312.8	318.7	1.9%	284.9	-8.9%	259.2	-17.1%	261.3	-16.5%
2.090	TSH FP# F	350.4	287.4	294.0	2.3%	263.2	-8.4%	237.9	-17.2%	239.1	-16.8%
2.190	TSH FP# H	340.0	270.8	292.2	7.9%	270.3	-0.2%	256.7	-5.2%	256.2	-5.4%
2.240	TSH FP# L	363.3	300.3	321.6	7.1%	302.7	0.8%	293.5	-2.2%	293.5	-2.3%
2.255	TSH FP# M	402.4	367.4	377.8	2.8%	371.2	1.0%	368.2	0.2%	367.4	0.0%
7.065	TSH FP# G	134.1	134.0	134.1	0.1%	134.1	0.1%	134.1	0.1%	134.1	0.1%
7.115	TSH FP# I	312.0	311.9	312.0	0.1%	312.0	0.1%	312.0	0.1%	312.0	0.1%
7.145	TSH FP# J	340.9	340.8	340.9	0.0%	340.9	0.0%	340.9	0.0%	340.9	0.0%
11.055	TSH FP# Q	51.4	51.4	51.4	0.0%	51.4	0.0%	51.4	0.0%	51.4	0.0%
12.030	TSH FP# O	50.8	50.8	50.8	0.0%	50.8	0.0%	50.8	0.0%	50.8	0.0%
12.070	TSH FP# S	178.1	178.1	178.1	0.0%	178.1	0.0%	178.1	0.0%	178.1	0.0%
13.005	TSH FP# N	752.2	722.4	734.6	1.7%	726.9	0.6%	723.6	0.2%	722.9	0.1%
13.030	TSH FP# P	774.2	749.4	760.8	1.5%	754.2	0.6%	751.1	0.2%	746.6	-0.4%
13.050	TSH FP# R	748.8	727.6	737.6	1.4%	732.0	0.6%	729.5	0.3%	724.1	-0.5%
13.075	TSH FP# T	786.7	767.2	776.7	1.2%	771.5	0.6%	769.1	0.3%	760.3	-0.9%
13.085	TSH FP# U	784.3	767.5	776.4	1.2%	771.6	0.5%	769.5	0.3%	761.6	-0.8%
13.090	TSH FP# V	784.4	766.8	775.9	1.2%	771.0	0.5%	769.0	0.3%	761.3	-0.7%
13.095	TSH FP# W	913.8	897.4	906.7	1.0%	902.0	0.5%	900.0	0.3%	894.9	-0.3%
13.110	TSH FP#X	921.6	905.6	915.0	1.0%	910.0	0.5%	908.1	0.3%	901.7	-0.4%
13.120	TSH FP# Y	908.5	892.4	902.2	1.1%	898.0	0.6%	895.1	0.3%	888.3	-0.5%
13.150	TSH FP# Z	910.8	897.2	905.3	0.9%	901.4	0.5%	899.3	0.2%	892.3	-0.5%

REFERENCE

Chow, V. T. 1959. *Open Channel Hydraulics*, McGraw-Hill Book Company, New York.

Clarifica, June 2006, *Summary of Rainfall Analysis Completed for the August 19th, 2005 Storm Event*.

Fred Schaeffer & Associates Limited, September 1996, *Etobicoke Creek Flood Control Study, Watershed Management Strategy.*

James F. MacLaren Limited, March 1978. *Report on a Hydrologic Model Study Etobicoke and Mimico Creeks for the Metropolitan Toronto and Region Conservation Authority*.

Kouwen, N.1984. *Flood Routing Sensitivity Study*, Waterloo Research Institute, Final Report, Project No. 111-11, University of Waterloo, Waterloo, Ontario.

Ministry of Transportation Ontario, 1997. *MTO Drainage Management Manual*.

Ministry of Natural Resources Ontario, 2002. *Flood Plain Management in Ontario, Technical Guidelines*.

M. M. Dillon Ltd. and James F. MacLaren Ltd., *Flood Plain Criteria and Management Evaluation Study*.

National Research Council Canada, Associate Committee on Hydrology, 1989. *Hydrology of Floods in Canada, A Guide to Planning and Design*.

Ponce, V. M. 1989. *Engineering Hydrology: Principles and Practices*, Prentice-Hall.

Ponce, V. M. 1978. *Muskingum-Cunge method with variable parameters*. ASCE Journal of the Hydraulics Division, 104(HY12): 1663-1667.

Rob Bishop and Harold Belore., March 1990, *Snowmelt Hydrology – A Method of Modelling a T-Year Snowmelt Hydrograph*.

Totten Sims Hubicki Associates, 2003, *City of Toronto Wet Weather Flow Management Plan (WWFMP), Area 2: Etobicoke and Mimico Creeks.*

Totten Sims Hubicki Associates, March 2007, *Etobicoke Creek Hydrology Update*.

US Army Corps of Engineers (USACE). 2000. *HEC-HMS hydrologic modeling system user's manual*. Hydrologic Engineering Center, Davis, CA.

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