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REVIEW OF STORMWATER MANAGEMENT IN ONTARIO AND A CASE STUDY ON THE ETOBICOKE EXFILTRATION SYSTEM

by

Sabrina Ternier, Bachelor of Science (Honours), University of Guelph, 2010

A thesis

presented to Ryerson University

In partial fulfilment of the

requirements for the degree of

Master of Applied Science

in the Program of

Environmental Applied Science and Management

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Review of Stormwater Management in Ontario and a Case Study on the Etobicoke Exfiltration System
Master of Applied Science, 2012
Sabrina Ternier
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Abstract

Stormwater management has transformed throughout the decades with the purpose of maintaining the pre-development hydrological cycle to protect humans and the environment. Despite the progress, Ontario's water bodies have continued to degrade. This research discusses and recommends three essential modifications to stormwater management to increase environmental and human protection. These include: 1) management based on the four seasons, 2) management based on regional conditions such as local climate and receiving water body characteristics, and 3) updating current stormwater management objectives to provide detailed direction.

The Etobicoke Exfiltration System is used as a case study to demonstrate some aspects of the proposed stormwater management modifications and to show the benefits of addressing the five stormwater characteristics (volume, peak flow, quality, duration, frequency) throughout the year. Modelling its performance under 2 to 100 year Chicago storms and use of previous EES studies show the wide range of objectives it can achieve. Future stormwater designs should look to the EES as insight into how stormwater can be properly managed.

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To everyone who played a hand in supporting me, Thank You!

In loving memory of my

Grandmother Nadia Haddad-Ternier

and

Grandfather Trong Dung Dao

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List of Abbreviations

BMP	Best Management Practice
CSO	Combined Sewer Overflow
EES	Etobicoke Exfiltration System
IDF	Intensity-Duration-Frequency
LID	Low Impact Development
MOE	Ministry of Environment
PAH	Polycyclic Aromatic Hydrocarbons
PWQO	Provincial Water Quality Objective
SWM	Stormwater Management
TSS	Total Suspended Solids

1.0 Introduction

1.1 Background

Humans rely on a reliable and safe supply of water for agricultural, industrial and domestic uses, thereby making it essential to protect. Throughout Ontario, this valuable resource is being threatened by the impacts of urbanization through a change of the hydrologic cycle. In an undeveloped scenario, precipitation could evaporate, become soil moisture or subsurface flow, or percolate deep into the water table and feed rivers and lakes through baseflow. However, under urbanization, the circulation of water is altered by impervious surfaces such as roads, sidewalks, parking lots and buildings, which can comprise a large portion of a city's physical landscape. Consequently, as urbanization expands, less precipitation is infiltrated into the ground and a larger portion of precipitation becomes runoff. To compound the problem, the traditional approach to stormwater management in Ontario involved creating an efficient underground stormwater sewer network with straight pipes and minimal bends to convey runoff from the development site as quickly as possible to a nearby water body. In older parts of a city, such as Toronto's downtown core, stormwater is conveyed with raw sewage in a combined sewer network to a wastewater treatment plant.

The increase in impervious surfaces combined with conventional stormwater management has significantly altered the hydrologic cycle of the affected watershed. The change in hydrology in terms of runoff peak flow rates, volumes, frequency and duration has had significant impacts on the receiving water body's geomorphology such as bank instability and erosion. Additionally, urban stormwater becomes highly polluted as it travels along the urban environment picking up substances ranging from hydrocarbons, heavy metals, pesticides and animal waste. This polluted water is mainly discharged into a water body untreated, and in the case of combined sewers, the flashy runoff response of large storms can result in combined sewer overflows (CSOs) in which raw sewage and polluted stormwater bypass the intended facility and instead discharge into a water body. These three impacted areas of hydrology, stream geomorphology and water quality consequently have negative impacts on the aquatic ecosystem.

To address these issues, Ontario has undergone a series of transformations regarding its approach to stormwater management to evolve from its traditional flood control approach. Stormwater management is now designed for runoff volume, peak flow, quality, while the adoption of runoff frequency and duration into design criteria has been slow. Despite the progress that has been made relative to the 1970s, the current approach has been unable to adequately achieve the stormwater management objectives set forth by the Ministry of Environment (MOE) in the '2003 Stormwater Management Planning and Practices Manual' and many of Ontario's water bodies remain degraded.

1.2 Problem Identification

As previously stated, Ontario's water bodies continue to be in a degraded state (TRCA, 2006b; TRCA, 2008b; TRCA, 2009a). This can be seen in several of the watersheds within the Greater Toronto Area's boundaries, such as the Rouge, Don, and Humber watersheds. The Don watershed remains to be one of the most degraded in the Greater Toronto Area, with the majority of rainfall becoming runoff. The lack of proper stormwater management has resulted in substantial channel degradation, damage to human structures, and unsuitable aquatic habitat.

Despite several progressive stormwater-related documents being published within the past twenty years, stormwater management has continued moving forward, as evident by the poor state of Ontario's water bodies (TRCA, 2007a; TRCA, 2009a). The 1991 Interim Water Quality Guidelines (MOE & MNR, 1991) have stated that runoff frequency and duration should also be addressed when dealing with stormwater, yet currently, only runoff peak flow, volume and quality are considered for management. We also see in the Trilogy of the Watershed documents (MOEE & MNR, 1993a, 1993b, 1993c) a call for land use planning and stormwater management to be based on the impacted environment or receiving water body, yet the current approach to stormwater has not truly achieved this, as seen with the removal efficiency targets of best management practices.

Stormwater management is not seasonally managed to account for the unique and variable climatic characteristics of each of Ontario's four distinct seasons: fall, winter, spring and summer. Also, the stormwater objectives in the 2003 Stormwater Management Planning and Practices Manual are due for a revision.

Lastly, the stormwater management practice known as the Etobicoke Exfiltration System requires examination as there is lack of research on it despite it being functional throughout the year and adequately able to address runoff volume, peak flow, quality, duration and frequency.

1.3 Objectives and Scope

The objective of this research is to review the evolution of stormwater management in Ontario to address any issues of concerns, and provide direction for the next step to be taken to protect and enhance Ontario's watersheds.

The specific research objectives are to:

1) Propose a revised stormwater management approach which will:
    a. Encompass four seasons.
    b. Be truly based on the regional conditions to account for climate, catchment characteristics and receiving water body requirements.
    c. Develop an updated set of stormwater management objectives divided into human and environmental categories.
2) Model the Etobicoke Exfiltration System to analyze its effectiveness under various synthetic storm events.
3) Determine which of the revised stormwater management objectives the Etobicoke Exfiltration System has addressed.

The ultimate goal of this research paper is to propose modifications to stormwater management, as listed in the first research objective. The Etobicoke Exfiltration System is used as a case study to demonstrate the benefits of including these changes and how it can broaden the range of stormwater management objectives addressed. Due to the limited research on this system, modelling will provide another source of information to analyze the EES's performance and to determine its fulfillment of stormwater management objectives.

1.4 Structure of the Report

Chapter 2 consists of an in-depth literature review detailing the history of Ontario's stormwater management and its effectiveness in protecting Ontario's watersheds, and a background of the Etobicoke Exfiltration System. Chapter 3 describes the methods taken to achieve the objectives of the research. Chapters 4 through 6 address the first specific objective, split into the corresponding subsections, while Chapters 7 and 8 consist of the EES modelling and how it fulfills the new stormwater management objectives. Chapter 9 ends the report with a conclusion and recommendations.

2. 0 Literature Review of Stormwater Management in Ontario

The purpose of this literature review is to discuss the impacts of urban stormwater and the history of stormwater management in Ontario. The effectiveness of stormwater management in protecting the province's water bodies is analyzed through the use of watershed case studies, the Environmental Commissioner of Ontario's Reports and reports on the impacts of stormwater ponds. Additionally, one of the structural systems designed for stormwater management is the Etobicoke Exfiltration System which has proven to be successful since its construction. Thus, a background on this system has been included to highlight the design considerations that have resulted in its success as well as the areas of research needed to increase the understanding of the system for future implementation. Stormwater management in non-Ontario jurisdictions has also been briefly reviewed to see if this research's proposed stormwater management modifications are already implemented in any jurisdictions.

2.1 Impacts of Urbanization

In order to understand the objectives and performance targets used in stormwater management practices, the numerous impacts of urban stormwater must first be realized. The transformation of land from pre-development to post-development impacts the watershed's hydrology, which in turn affects the receiving water body's stream geometry, water quality, and terrestrial and aquatic ecosystems.

2.1.1 Watershed Hydrology

A watershed's natural storage capacity for runoff through vegetation and natural land depressions can be reduced by construction, land grading, and impervious surfaces (Bradford & Denich, 2007). These land changes can alter the water hydrology in several aspects such as:

1. Producing higher and longer (in duration) runoff peak discharges into streams (Bradford *et al.*, 2007);
2. Lag time to peak flow is much lower in sites which use traditional stormwater practices compared to low impact development practices (Hood *et al.*, 2007), resulting in faster generation of runoff (MOE, 2003), and thus higher frequency of runoff (Walsh *et al.*, 2005). When combined with an efficient stormwater conveyance system (Aquafor Beech Ltd., 2006), runoff reaches a stream significantly quicker;

3. Increasing runoff volume and velocity (Deering *et al.*, 2003) due to imperviousness obstructing infiltration, such that land development increases the ratio of runoff generated from a storm (Sciera *et al.*, 2008). The amount of runoff produced can be so great that even in smaller urban streams, the annual stream flow volume can be 72% higher than a forested stream (Wahl *et al.*, 1997);
4. Increasing flood frequency and magnitude from high runoff peak discharge, volume and velocity, and consequently enlarging the flood plain size (Ku *et al.*, 1992); and
5. The effect of urbanization on groundwater recharge and baseflows has been inconsistent (Konrad and Booth, 2002). Some have reported poor groundwater recharge and decreasing baseflow due to low infiltration from imperviousness (Di Biase, 2005; Bradford *et al.*, 2007). While others have noted cases where natural streams may become dry during a dry year, but urban streams remained (Riley *et al.*, 2005) - this could be due to leaky water supply and sewer pipes or irrigation providing a source of water (Bradford & Denich, 2007).

The increase in runoff volume, peak flows, frequency and duration has led to peak flows from design storm events to occur more often than previously calculated. For instance, in a 30% impervious watershed, the peak flows associated with 1, 2, and 100 year storms have increased in frequency by 10.6, 3.3 or 1.5 times, respectively (Aquafor Beech Ltd., 2006). This translates into a 1 year storm peak flow occurring up to 10.6 times a year, instead of once per year. In effect, peak flows should no longer be traditionally associated with a certain sized storm event as imperviousness results in smaller storms producing larger peak flows than conventionally expected.

2.1.2 Stream Geology

The above changes in watershed hydrology can have great impacts on a stream's geometry. The first stream response includes downcutting of stream banks, which can result in the channel widening and straightening from the bank erosion, as well as deeper pools (Walsh *et al.*, 2005), ultimately leading to larger cross-sectional areas (McBride & Booth, 2005). The resulting sediment loading is composed of fine and coarse particulate, which fills any voids (imbedding) in the streambed, thus changing its sediment composition (Aquafor Beech Ltd., 2006).

2.1.3 Water Quality

Pollution in runoff can come from both atmospheric and non-atmospheric sources (Tsihrintzis & Hamid, 1997). The rise in pollutant concentrations can be up to ten times greater than those set by the

Provincial Water Quality Guidelines (MOE, 2003) and is the main cause for not meeting water quality standards in roughly 40% of U.S. water bodies (Arnone & Walling, 2007). The following categories of pollutants and their impacts are discussed below:

- High levels of suspended solids from erosion of stream banks, lawns and construction sites, pollute the receiving water body, with up to 66% higher annual sediment loading in urban streams than those that are forested (Wahl *et al.*, 1997). This can increase the turbidity of a stream, leading to less light penetration (MOE, 2003). Also, sediments are a common transport for other pollutants such as nutrients (CWP & MDE, 2009) or heavy metals (Clark & Pitt, 2007).
- Elevated levels of nutrient loading, mainly phosphorous and nitrogen (Wahl *et al.*, 1997) from fertilizer application on lawns and golf courses, as well as from attachment to suspended solids, can lead to the eutrophication of the receiving water body (He *et al.*, 2010) and can promote high levels of toxic cyanobacteria algae strains (i.e., microcystin) (MOE, 2011). In Chesapeake Bay in Maryland, U.S., extreme nutrient loading from urban runoff has led to water quality decline (CWP & MDE, 2009). Dissolved organic carbon and ammonium have also been positively correlated with imperviousness (Hatt *et al.*, 2004).
- Large amounts of organic matter from city vegetation are transported into water bodies (Miller & Boulton, 2005).
- Bacteria levels in urban waters have increased from discharging untreated stormwater, combined sewer overflows and sanitary sewer overflows (Arnone & Walling, 2007; He *et al.*, 2010) such that public health standards are occasionally not met (Nevers & Whitman, 2005).
- Toxic compounds including pesticides, hydrocarbons (MOE, 2003) and heavy metals such as zinc, iron, lead and cadmium (Hathhorn & Yonge, 1995) come from automobile use, roofs, lawn care and golf courses. The ability to support aquatic diversity decreases as tolerant species have better survival rates (Deering *et al.*, 2003).
- Chloride levels have dramatically increased due to the use of de-icing salts during winter (Meriano *et al.*, 2009), and could be the reason why electrical conductivity was positively associated with imperviousness (Hatt *et al.*, 2004). High concentrations have led to safety issues in terms for drinking and recreation (Nevers & Whitman, 2005).
- Elevated stream water temperatures can result from impervious surfaces absorbing heat which is transferred to runoff (Walsh *et al.*, 2005). This can have a negative impact on sensitive resident cold-water species (MOE, 2003).

2.1.4 Aquatic and Terrestrial Ecosystems

Riparian communities can be impacted through the changes in streamflow and baseflow levels (Nilsson & Svedmark, 2002), thereby limiting stream vegetation establishment and diversity, and may affect terrestrial species such as birds due to lost habitat and nesting areas.

The previous mentioned impacts of urban stormwater all negatively affect the aquatic ecosystem. Reduced baseflow affects the size of suitable aquatic habitat (Di Biase, 2005), while flow depth and velocity influence the aquatic species distribution within a stream (Bradford *et al.*, 2007). Poor water quality results in unsuitable aquatic habitat via depleted oxygen levels, and increased turbidity, temperature fluctuations and toxin concentrations (Deering *et al.*, 2003). Chloride levels are much higher than normal ranges that can be tolerated by many aquatic species (CWP & MDE, 2009). Sediment loading and imbedding restricts fish spawning areas and causes poor oxygen circulation in the sediment for aquatic insects (Aquafor Beech Ltd., 2006).

Overall, this can lead to decreased fish health (Helms & Feminella, 2005) through not only toxic pollutant exposure, but also from a higher rate of abrasions and clogging of gills and filters from suspended solids (MOE, 2003). It has also resulted in reduced fish reproduction (MOE, 2003), feeding and growth (Deering *et al.*, 2003) and a negative correlation has been identified between high peak flows and fish population and diversity (Helms *et al.*, 2009; Coleman II *et al.*, 2011). This is in part due to the effect of stream velocities on the aquatic species' swimming ability in each life stage (Bradford *et al.*, 2007). Additionally, fish diversity has diminished in response to sensitive species being unable to cope with the new changes, while the tolerant species thrive (Wang and Lyons, 2002). Consequently, fish index of biotic integrity in Ontario stream has been reported by Steedman (1987) to significantly reduce when imperviousness is greater than 10%.

A similar relationship exists with aquatic benthic macroinvertebrates. Diversity appears to be correlated with riparian forest cover, and as such, forested urban streams had levels of diversity observed in areas less developed (Moore & Palmer, 2005).

There have also been concerns over algae growth due to runoff. Algae biomass can increase from excess nutrients input and have been found to increase in streams with increasing drainage connections (Taylor *et al.*, 2004). Eutrophication can result from excess algae, with dissolved oxygen levels decreasing to levels unsuitable to sustain aquatic life and fish die-offs have been reported as a result (Albay *et al.*, 2005).

2.1.5 Summary

Overall, urban stormwater has been documented to impact the watershed's hydrology, stream geometry, water quality and ultimately terrestrial and aquatic ecosystems. Acknowledgement and understanding of these impacts provides direction for stormwater management.

2.2 History of Stormwater Management in Ontario

In order to mitigate these urbanization impacts on the affected watershed, Ontario has undergone a significant change in its approach to stormwater management. The history of stormwater management in Ontario is discussed in three time periods, as well as the current stormwater management objectives and practices used.

2.2.1 Prior to 1990

Before the 1970s, stormwater management involved the use of storm sewer networks to carry the high runoff volumes and peak flows downstream to a receiving water body. The sole purpose of stormwater management at this time was to provide flood control (Bui, 2003). These minor systems were designed by determining what peak flow the pipe had to accommodate which was relative to the design storm selected. Design storms used for a minor system were generally between 2 to 10 year storms. The peak discharge of these design storms were calculated using the rational method and applied in determining the sizing of the pipe (Watt *et al.*, 2003).

Between the 1970s and 1990, stormwater management was still mainly focused on how to control the runoff volume and peak flow. New approaches were developed which involved the use of stormwater ponds at the end of a storm sewer network, as well as the incorporation of major systems into stormwater management. This meant that minor systems (i.e., storm sewer) were designed for 10 year storms or less, while major systems (overland routing and ponds) were designed for 100 year storms (Watt *et al.*, 2003). Additionally, this was the beginning of requiring post-development runoff flows to match pre-development levels. Furthermore, at the end of this period, the impact of urban construction on erosion and sediment loading into water bodies via runoff was realized, and the 'Guidelines on Erosion and Sediment Control for Urban Construction Sites' were developed (MNR *et al.*, 1987).

2.2.2 The 1990's

The early 1990s saw a significant shift in stormwater management and urban planning which consisted of a more encompassing and integrated approach regarding land use and the resulting environmental effects. Firstly, the 1991 'Interim Stormwater Quality Control Guidelines for New Development' were developed to protect and enhance water quality and the predevelopment hydrological cycle (MOE and MNR, 1991). This document was the first of its kind to address the issue of water quality in runoff and its impacts to the receiving water body. It also highlighted the five main stormwater characteristics that are affected from development. These include runoff volume, peak flow, quality, frequency and duration. Including runoff frequency and duration to shape design criteria are still aspects that are often overlooked.

A significant change in the approach to stormwater management took place when the idea of integrated planning was introduced. This approach entailed integrating land use planning with stormwater management and the environment (MOE, 2003). In order to integrate these areas of interest, each stage of land use planning had to incorporate information from a corresponding environmental study or stormwater management report. The scale of the environmental study would depend on the stage of land use planning, i.e., a watershed study for a municipal official plan, or a stormwater management report to obtain a permit for a site plan (MOE, 2003).

As a result of integrated planning, the trilogy of the watershed planning documents, consisting of 'Water Management on a Watershed Basis: Implementing an Ecosystem Approach,' 'Subwatershed Planning' and 'Integrating Water Management Objectives into Municipal Planning Documents,' were published as supporting literature to this new strategy (MOEE & MNR, 1993a, 1993b, 1993c). These documents introduced the notion of watersheds as the natural boundary for land use planning, gave direction for the required environmental studies and required expertise, and designed a process that enabled agencies and practioners to work together.

Furthermore, MOE produced the '1994 Stormwater Management Planning and Practices Manual' which was intended as a guide for the selection and design of stormwater management practices and focused extensively on water quality, introducing facilities for water quality and erosion control (MOEE, 1994). This manual also introduced the concept of a treatment train approach when implementing stormwater management practices, which will be further discussed later in this paper. Overall, by the end of the 1990's stormwater management focuses included water quality, sediment and erosion control, aquatic habitat and baseflow maintenance (CVC & TRCA, 2010).

2.2.3 Beyond 2000

The last decade also saw new stormwater management areas of focus, such as fluvial geomorphology, terrestrial habitat, groundwater infiltration and water temperature (CVC & TRCA, 2010). For instance, there were concerns that runoff was replenishing the groundwater table at a lower rate in comparison to that of the pre-development. As a result, infiltration practices were developed which would direct the runoff into the ground in hopes of recharging the water table (Di Biase, 2005). In 2003, MOE updated its 'Stormwater Management Planning and Practices Manual' to incorporate a broader and more current array of technologies, methods and planning practices that dealt with sediment and erosion control, water balance, and water quality and quantity protection (MOE, 2003). The revision also included procedures which could assist practioners in developing design criteria based on local watershed and receiving water conditions, as well as documented the performance of existing stormwater management practices (Bradford & Gharabaghi, 2004). However, the manual does not mention the importance that Ontario's four unique seasons has on the design and effectiveness of the implemented practices. It also assumes that the climate and thus the rainfall characteristics are uniform through the entire province and will not affect the design and performance of practices.

Within the last few years, new developments to stormwater management include climate change, low impact developments and the water budget (CVC & TRCA, 2010). The '2003 Stormwater Management Planning and Practices Manual' was originally drafted in 1999; in 2007, MOE was summoned by an Environmental Bill of Rights request to review its stormwater management policies in light of climate change. The report was completed in 2010 and calls were made for a new policy framework which 'supports resilient municipal stormwater management systems and adaptation to climate change,' as well as an update to its manual (MOE, 2010b).

The change in stormwater management approach has also led to the diversity of professionals within that field. In the beginning, only water resource engineers were deemed necessary for stormwater management. However, with increasing environmental awareness and understanding of the impacts of urbanization on the receiving watershed, those involved in stormwater management began to diversify. As such, a water resource engineer now works with stream ecologists, limnologists and fluvial morphologist when designing a stormwater best management practice (BMP) (Bui, 2003).

2.2.4 Stormwater Management Objectives

As discussed previously, the objectives of stormwater management has shifted from flood control to a more all encompassing and holistic approach. The most current objectives have been listed within the MOE 2003 'Stormwater Management Planning and Practices Manual' (hereafter referred to as the 2003 SWM Manual) and consist of:

- "Preservation of groundwater and baseflow characteristics;
- Protection of water quality;
- Prevention of undesirable and costly geomorphic changes within the watercourse;
- No increase in flood damage potential; and
- Maintaining an appropriate diversity of aquatic life and opportunities for human uses."

This set of objectives does not encompass all the impacts that stormwater has on the environment and humans, and changes will be proposed as part of this research.

2.2.5 Stormwater Management Practices

The traditional storm sewer pipe network is unable to adequately manage the runoff from storm events while fulfilling these objectives of protecting the environment and watershed. As such, stormwater best management practices (BMPs) and low impact development (LID) practices have been developed to support or enhance the existing storm sewer pipe network. BMPs are techniques, measures or structural controls which provide quantity and quality control of stormwater runoff (US EPA, 1999b). These practices can be developed for source control (lot level), conveyance control, or end-of-pipe control (MOE, 2003). On the other hand, LIDs consist of BMPs solely for source control with the aim to restore the pre-development hydrological cycle within the site (CVC & TRCA, 2010).

Source control practices are the initial level of control and are developed within the site development's boundaries. They can be categorized into storage or infiltration-based control. Storage practices can be developed on the rooftop such as green roofs, and under parking lots and backyards (MOE, 2003). Infiltration-based practices can include reduced grading, downspout disconnections, infiltration trenches, grassed swales, open ditches, pervious pipe systems, vegetated filter strips, stream/valley corridor buffer strips, oil/grit separators, porous pavements and bioretention control (MOE, 2003; CVC & TRCA, 2010).

Conveyance control BMPs are facilities which are connected in-line with the stormwater conveyance system, and include over-sizing storm sewers to create extra storage, ditches and concrete basins (Dubyk, 1994; MOE, 2003).

End of pipe control BMPs are the last level of stormwater control. Stormwater from a conveyance system is received, treated and discharged into a water body. Facilities which are considered end-of-pipe include wet ponds, wetlands, dry ponds and infiltration basins (MOE, 2003).

The design of BMPs and LIDs must meet the criteria requirements to fulfill some of the stormwater management objectives listed above. BMPs are unable to accomplish all the stormwater objectives, and therefore it is recognized that an integrated approach is necessary during selection for a site (MOE, 2003). Therefore the use of a treatment train approach is emphasized such that source controls are the first group of stormwater control that the runoff encounters, followed by conveyance and end of pipe control (MOE, 2003). To aid in BMP selection according to performance of objectives, Table 1.3 of the MOE's 2003 'Stormwater Management Planning and Practices Manual,' displays which stormwater management objectives can be fulfilled by a specific BMP (Table 1).

2.2.6 Summary

Stormwater management in Ontario has evolved throughout the years as the understanding of stormwater and its impacts has increased. Stormwater management has transitioned from solely focusing on flood control, to also now incorporating control for volume, erosion, water quality and is theoretically based on a watershed concept. However, the design of practices have not accounted for the unique climate and stormwater characteristics of Ontario's four season, and they have not truly considered regional conditions and factors (discussed briefly in the section 2.4.7 Stormwater Ponds). Furthermore, current stormwater objectives do not include the explicit protection of human life and property, nor does it provide sufficient guidance for stormwater management as the objectives are vague (i.e., maintain an appropriate diversity of aquatic life).

Table 1: List of stormwater management practices to aid practioners in selecting practices according to the objectives they fulfill. (MOE, 2003).

SWMP	Water Balance	Water Quality	Erosion	Water Quantity
Lot Level and Conveyance Controls				
Rooftop storage	○	○	○	●
Parking lot storage	○	○	○	●
Superpipe storage	○	○	○	●
Reduced lot grading	●	•	•	○
Roof leader to ponding area	●	•	•	○
Roof leader to soakaway pit	●	•	•	○
Infiltration trench	●	●	•	○
Grassed swales	●	•	•	•
Pervious pipes	●	●	•	○
Pervious catchbasins	●	•	•	○
Vegetated filter strips	●	•	•	○
Natural buffer strips	•	•	•	○
Rooftop gardens	○	•	•	○
End-of-Pipe Controls				
Wet pond	○	●	●	●
Artificial Wetland	○	●	●	●
Dry pond	○	•	●	●
Infiltration basin	•	●	•	○
Filters*	○	●	○	○
Oil/grit separators*	○	•	○	○

● High Suitability • Medium Suitability ○ Low Suitability

2.4 Review of the Effectiveness of Ontario's Stormwater Management

The purpose of this section is to provide evidence of the state of some of Ontario's watersheds and how it is related to the stormwater management implemented. This evidence was discussed in three subsections. First, watersheds within Ontario were analyzed to show the state of stormwater management and its positive or negative impacts on the affected watershed. Second, a few of the Environmental Commissioner's Reports are included to highlight any progress or setbacks in stormwater management and how this consequently affected the receiving water bodies. Third, the widespread use of stormwater ponds is investigated to determine its effectiveness and impacts on the receiving water body. In all, the determination of the effectiveness of Ontario's stormwater management will be a basis as to whether or not modifications are warranted.

2.4.1 Ontario Watersheds

The watersheds researched include the Lake Simcoe watershed and the watersheds in the Greater Toronto Region as seen in Figures 1 and 2. Within the Greater Toronto Region, the Humber River, Don River, Etobicoke Creek and Mimico Creek watersheds were analyzed as they are heavily urbanized. The Rouge River watershed was also examined as it less developed and was used as a comparison. River The analysis of each watershed's state was based on information gathered from specific watershed reports and only measures which were stormwater-related were included. Examples of measures used are fish and macroinvertebrate diversity, riparian vegetation, level of stormwater management and quality of groundwater and surface water.

Figure 1: Map of watersheds within southwestern Ontario. (Conservation Authority, 2009b)

Figure 2: Map of watersheds in the Greater Toronto Region. H = Humber; M = Mimico; E = Etobicoke; D = Don; R = Rouge; Hi = Highlands; P = Petticoat; Du = Duffins; F = Frenchman's Bay; C = Caruthers. (TRCA, 2012).

2.4.1.1 Humber River Watershed

At 903 km^2, the Humber River Watershed covers several municipalities and towns with 27% urban land use, of which the majority is concentrated in the southern regions near Toronto and Mississauga (TRCA, 2008b). Prior to the use of stormwater management measures, many developments were vulnerable to flooding, as seen in the Black Creek Subwatershed and as such, concrete channels were utilized to efficiently move surface runoff downstream (TRCA, 2008b). Modifying the drainage networks and the increase of impervious area resulted in increased peak discharge, volume, frequency and duration of runoff. The change in surface hydrology has led to unstable stream banks and increased channel erosion (TRCA, 2008b).

At the time that the Humber River Watershed Plan was published in 2008, only 25% of the urbanized watershed had stormwater management, which consists of 6% quantity control, 15% quantity and quality control, and 4% retrofitted facilities of varying control (TRCA, 2008b). The remaining 75% consists of the urban areas that were developed prior to 1980, such as Black Creek and Lower Humber River Subwatersheds, and have none to very minimal stormwater management control. Even areas with some sort of stormwater management control have proven to be insufficient in improving or maintaining the river system's health (TRCA, 2008b).

The insufficient management of stormwater can be realized through its several impacts documented in the Humber River watershed. Accelerated stream erosion and unstable banks have made it harder for vegetation to establish, as seen with only 61% of the watercourses having natural riparian vegetation (TRCA, 2008b). As a result, fish habitat quality within the watershed has declined. According to fish monitoring data between 2001 and 2004, it appears that "good habitat" had lowered from 42% to 33%, while benthic invertebrate sampling in 2004 implied that only 36% of aquatic habitat was "unimpaired." (TRCA, 2008a) Consequently, a significant decrease of native fish species within the watershed has been observed. Historically, sixty-four native fish species were recorded; however thirty-nine were found in a 2004 survey, with seventeen species listed as a local concern showing that native fish species are in danger. Aquatic benthic invertebrates were also reported to be decreasing in community health between 2002 and 2004, while the invasive rusty crayfish (*Orconectes rusticus*) has been documented since 2003 and is believed to have spread (TRCA, 2008b).

In terms of water quality, groundwater quality has met the PWQO and Ontario Drinking Water Standards except for chloride which has become a growing concern. On the other hand, maintaining surface water quality has posed more difficulties (TRCA, 2008b). Within the northern region of the watershed, surface water quality has met standards due to clean input of groundwater from the Oak Ridges Aquifer. However, further south where urbanization is present, water quality is poor from lack of stormwater management and occurrence of combined sewer overflows (TRCA, 2008b). Amongst the concerns are bacteria levels which do not meet recreational swimming standards, and chloride concentrations which are increasing as the little stormwater management that is implemented is unable to remove it from water (TRCA, 2008b). Additionally, the temperature of surface water is generally cold to cool in the upper reaches as they are fed by the aquifer, but further south and to the west in the watershed, the water is found to be warmer (TRCA, 2008a) again, reflecting the impacts of urbanization and inadequate stormwater control.

Report cards have been published in 2000 and 2007 evaluating the Humber River's conditions. Since this section is directed towards the effectiveness of the 2003 Stormwater Management Practice and Design Manual (MOE, 2003), the assigned grades highlight any progress or failure in stormwater management between the publications, as summarized in Table 2. Additionally, only watershed indicators relevant to stormwater impacts and its management have been included, whilst others such as air quality or heritage resources have been omitted. As Table 2 shows, there is a range of grades between B and F, and overall, the watershed was assigned an average grade of C (TRCA, 2007a). It should also be noted that this average grade is for the entire watershed – a watershed which has varying degrees of urbanization between its northern and southern regions. Therefore it can be misleading and incorrect to assume that the overall grade of C represents the entire watershed, including the urbanized regions. Within the report cards, some indicators were assigned grades for each subwatershed and it has been observed for several indicators that the lower urbanized reaches had poorer grades than those of the rural and agricultural reaches in the north (TRCA, 2007a). It would be expected that an overall grade lower than C would be assigned if the southern urbanized areas of the watershed were analyzed separately. Furthermore, evidence has shown that the northern areas are beginning to exhibit signs of stress from increasing development, such as benthic invertebrate health (TRCA, 2007a).

Table 2: Humber River watershed 2000 and 2007 report card grades.

Indicator	Objectives	2000 Grade	2007 Grade	Comment
Groundwater Quantity	Sustainable use	C	B	No observed drop of water levels in wells
Groundwater Quality	Protection	D	B	Meets Ontario's Drinking Water Standards
River Flow	Stable flows	C	C	Median summer low flows in dry weather maintained since 2003
Stormwater Management	Urban runoff management	F	F	25% of urban area has stormwater management
Bacteria	Recreational protection	E	F	No improvement since 1990-1996. Between 2000 -2005, monitoring stations met PWQO standards for swimming only for 31% of the season, on average.
Conventional Pollutants	Suspended solids, Phosphorous, Nitrogen, Ammonia, Chlorides – PWQO's or other criteria	D	C	No significant increase since 1990 to 1996 period, except for chloride which has steadily risen.
Heavy Metals & Organic Contaminants	Lead, copper, zinc, cadmium, chromium, and iron – PWQO's	C	C	Met PWQO for 88% of samples on average.
Benthic Invertebrates	Health	B	C	68% of monitored stations in 'fair' or 'good' health
Fish Communities	Health	C	D	57% of monitored stations declined in fish habitat quality; 30% improved
Riparian Vegetation	Health and coverage	C	C	61% of riparian zone has natural vegetation
Wetlands	Protection	E	F	3.6 % of watershed is covered by wetlands

*Source: TRCA, 2007a

2.4.1.2 Don River Watershed

Similar to the Humber River Watershed, the Don River watershed is amongst the most deteriorated river ecosystems in the Greater Toronto Area, with 80% urbanized. The use of stormwater management ponds has been emphasized, with about 140 existing or in the works by 2006 (TRCA, 2006a). Other than these ponds, 80% of the watershed does not implement any stormwater management control and consequently stormwater continues to be the priority issue in terms of watershed health. Only 20% of the urbanized land utilizes stormwater control, of which 7% and 13% is for quantity and quality control, respectively (TRCA, 2009d). Therefore, basement flooding can still occur, as seen in the August 19th, 2005 storm where widespread basement flooding, property/infrastructure damage, and extreme channel bank erosion was reported (TRCA, 2006a).

Other stormwater impacts have been well documented throughout the Don River watershed. The hydrology of runoff has been changed such that average peaks flow of the 2, 5, 10, 25, 50 and 100 year storm events in the Don river were noted to have an overall increase of peak flows (TRCA, 2009d). This has negatively impacted the channels in the East and West Don river valleys which undergo severe levels of bank erosion and widening and requiring ongoing city maintenance (TRCA, 2009c). Surface water quality has also deteriorated as seen by the monthly grab samples of stream water at monitoring stations taken during 2002 to 2005 which repeatedly exceeded guidelines for total suspended solids, phosphorous, nitrate and chloride set by Canadian Water Quality Guidelines, Provincial Water Quality Objectives (PWQO) or Environment Canada/Health Canada (TRCA, 2009e). PWQO guidelines were also exceeded for metals such as zinc, lead, copper and aluminium. Although it is acknowledged that other sources (i.e., waste treatment plants) contribute to pollution levels, a 2005 wet weather study confirmed that runoff is a significant contaminant source (TRCA, 2009e). The study showed that during wet weather conditions, levels of chloride, phosphorous, faecal coliforms, aluminium, copper, iron and zinc consistently exceeded guidelines, notably phosphorous and faecal coliforms (TRCA, 2009e).

Lastly, according to 2002 to 2005 surveys, fish habitat quality has remained the same at 69% of the monitoring sites, declined at 9% of sites, and improved at 22% (TRCA, 2009a). Nonetheless, fish diversity of the Don River has not improved, with only 21 of the 42 originally documented fish species being reported in 2006. Even by 2009, majority of the fish species, as well as benthic invertebrates present at the monitoring stations, were considered generalists, and associated with degraded streams (TRCA, 2009a).

A summary of the grades assigned to the watershed indicators is presented in Tables 3 and 4 and shows the extent of watershed's deterioration. An overall grade to the watershed was not assigned in the reports, but it can be seen that a grade of D or lower is suitable considering the poor aquatic health, increased stream bank erosion and flood potential, pollutant levels exceeding guidelines and lack of stormwater management.

Table 3: Don River watershed 2005 report card grades for stormwater related indicators, part 1

Indicator	Target	Grade*	Comments	References
Benthic Invertebrates	10% of stations 'unimpaired' using aggregate assessment; of the 'potentially impaired' stations, at least 40% consist mainly of moderately tolerant families	F	All monitored stations 'potentially impaired.' 87% of stations mainly inhabited by pollutant tolerant families.	TRCA, 2009a
Fish Communities	100% of FMZ's[1] have an IBI score of 'Fair' or better	F	Only 2 out of 5 FMZ's monitored had 'fair' health or higher	TRCA, 2009a
	Target indicator species are abundant and well distributed compared to past conditions	D	4 out of the 6 monitored FMZ's were 'D'	TRCA, 2009a
Invasive Species	No new invasive/exotic species	A	None collected in 2005	TRCA, 2009a
Aquatic Habitat	At 100% of sites, thermal regime and stability supports target indicator species	A	90% of monitored stations achieved 'stable' or 'moderately stable' and had the appropriate thermal regime for that location	TRCA, 2009a
	100% of total potential riparian zone has natural cover	C	63% of potential riparian zone had natural vegetation in 2002	TRCA, 2009a
	10% of potential riparian zone to be wetlands	F	1.4% wetland cover in 2003	TRCA, 2009a
Swimming and body contact recreation	*E.coli* levels in water samples are lower than those of the 1991-1995 period	F	Bacteria levels between 2003 and 2005 were not statistically different than those between 1991 and 1995.	TRCA, 2009e
Conventional pollutants	Levels of suspended solids, phosphorous, nitrate, un-ionized ammonia, dissolved oxygen and chloride meet guidelines in 75% of samples	F	Conventional pollutants did not meet guidelines in 75% of the samples, notably nitrate, phosphorous and chloride.	TRCA, 2009e
Heavy metals and organic contaminants	Concentrations of the persistent organic contaminants, pesticides and heavy metals in surface water and in fish meet guidelines; restrictions on sport fish consumption have not increased since 1999	D	Heavy metals and organic contamination in waters given 'B', but tissue contamination in fish and sporting fish restrictions have increased and given 'F' and 'D,' respectively.[2]	TRCA, 2009e

*Assigned grades were based on data collected from 2005 and earlier.

[1]FMZs: Fish management zones

[2]Urban runoff is not the only source of pollutants

Table 4: Don River watershed 2005 report card grades for stormwater related indicators, part 2

Indicator	Target	Grade*	Comments	References
Baseflow	No negative trend in median daily baseflow rate from 1995 to 2005	C	Lower West and Lower Main Don given 'D' because baseflow decreased (<2%), but was within normal range of variance. Lower East Don – no data after 1996.	TRCA, 2009b
Stream flow	No increasing trend in average annual and seasonal stream flow volume; maintain flow volumes at 1997 levels	C	Slight reduction in flow volumes from 1997 - 2004, but this variance is not significant.	TRCA, 2009d
Flooding	Maintain baseline flow rates for 2 to 100 year storms	D	Overall general increase of peak flows of 2 to 100 yr storms	TRCA, 2009d
	Reduce/maintain existing flood vulnerable areas/roads (FVAs/FVRs)[1]		Digital flood line is hard to compare to pre-existing database of FVAs and FVRs. In 2009, more than 2,800 known FVA's and FVR's.	TRCA, 2009d
Channel Morphology	Maintain/restore natural channel structure	F[2]		TRCA, 2009c
Erosion Potential	Maintain baseline erosion potential at stable banks; decrease potential at unstable banks			TRCA, 2009c
	Maintain/restore natural rates of morphologic change			TRCA, 2009c
Stormwater Management	Increase % of urban areas with Level 1 stormwater controls	D	80% of urban area still lacks control	TRCA, 2009d

*Assigned grades were based on data collected from 2005 and earlier.

[1]FVAs and FVRs: Flood Vulnerable Areas and Flood Vulnerable Roads

[2]Lack of data to assign an individual grade, but an overall grade of F was given to represent the extreme physical degradation of the channels.

2.4.1.3 Etobicoke and Mimico Creeks Watershed

With roughly 63% of the land urbanized by 2002, the Etobicoke Creek watershed is another highly degraded watershed in the GTA (TRCA, 2010). Only 30% of the area has stormwater management control, which is mainly in the form of detention ponds, with 46 built by 2010. Within the urban areas, 21% of stormwater practices have quality control, 25% have erosion control, and 22% have quantity control (TRCA, 2010) (TRCA, 2010). The lack of adequate stormwater management is evident in stream flow data of over the last 40 years which shows that mean annual stream flow has increased by 44%, with a 60% increase in the last ten years (TRCA, 2010). Additionally, the floodlines may have also increased (TRCA, 2010). In contrast to chloride and bacteria which are increasing, concentrations of nutrients and metals have not risen (TRCA, 2010).

Adjacent to the Etobicoke Creek Watershed, is the Mimico Creek Watershed of which 88% of the land was urbanized by 2002 (TRCA, 2010). Only 30% of the urban area has stormwater control which is mainly in the form of detention ponds. In these urban areas, 8% of stormwater practices have quality control, 9% have erosion control, and 26% have quantity control (TRCA, 2010). Mimico Creek watershed has also seen an increase of mean annual stream flow by 27% in the last 40 years (TRCA, 2010). Floodlines have expanded as well, and nutrient, metal, chloride and bacteria levels are similar to those of the Etobicoke Creek watershed (TRCA, 2010). Stormwater runoff continues to have the most impact on surface water quality in these two watersheds (TRCA, 2010).

Report cards have been published in 2002 and 2006; however the latter uses data varying from 2002 to 2005, and consequently, will be the only report card included in the review. To understand the rating system, each watershed indicator had been assigned a grade based upon the percentage of the target achieved. Also, indicators were absent for groundwater quantity and quality, surface water quantity, and fluvial geomorphology and as such, are not present in Table 5. This includes recharging of groundwater levels, conventional pollutants in groundwater, stream flow (which can be broken down into baseflow, peak flow, flooding) stormwater management, channel morphology, flow regime and erosion potential, stream corridor and continuity, and risk to public/private property. These indicators are planned to be part of the analysis for the subsequent report card (TRCA, 2010).

Table 5: Etobicoke and Mimico Creek watersheds and 2006 report card grades for stormwater related indicators.

Indicator	Target	Etobicoke Grade	Comments	Mimico Grade	Comments
Fish Community	By 2025 – IBI rating at 3 sites in Etobicoke Creek should be 'fair;' Mimico Creek should have fish at all tested sites	Poor	Average species richness in 2004 was lower than the expected richness by nearly 50%. Median IBI calculated as 'poor'	Poor	Average species richness in 2005 is one tenth of the expected richness. No target species found at monitoring stations.
Benthic invertebrates	By 2012 – both Creeks should have an invertebrate community health of 'fair' or higher. This rating should become 'good' for 40% of the tested stations by 2025.	Fair[1]	In 2004, 79% of monitoring stations were 'fair' or higher. 43% of stations were 'good.'	Fair[1]	In 2004, 60% (3 out of 5) of monitored stations achieved 'fair' or higher. 20% of stations were 'good.'
Riparian Cover	By 2025 – 75% of potential riparian zone has natural vegetation	Poor	39% of the riparian zone is vegetated. 15% and 5% riparian zone consists of forest and wetlands, respectively.	Poor	49% has natural cover, with 16% forest and <1% wetlands.
Conventional Pollutants	By 2025 –PWQO's of conventional pollutants[2] should be met for 75% of samples	Poor	Phosphorous, chloride and nitrate levels exceeded guidelines repeatedly between 2002 – 2004.	Poor	Same as Etobicoke.
Heavy Metals and Organic Contaminants	By 2025 - Concentrations of seven metals of concern meet PWQO's in 75% of samples; levels of COA Tier 1 pollutants undetected. No restriction of sport fish consumption.	Poor	Persistent contaminant data unreliable. In 2003, five out of seven metals (not aluminium and zinc) met the PWQO in 75% of samples. Restrictions on consumption of some sport fish.	Poor	Three (chromium, cadmium, Cu) out of seven metals met the PWQO in 75% of samples in 2002. Restrictions on consumption of some sport fish.
Water Contact Recreation	By 2025 – *E.coli* levels meet PWQO for 95% of swimming season.	Poor	Grades for lakes were 'excellent,' and 'fail' for Marie Curtis Park. Bacteria levels slightly decreased in 2003 to 2005, but may be due to normal variance.	Poor	Same as Etobicoke.

Source: TRCA, 2006b

[1]Although Etobicoke Creek had a healthier benthic invertebrate community, an overall single grade was given to both watersheds.

[2] Phosphorous, total suspended solids, chloride, unionized ammonia and nitrates

2.4.1.4 Lake Simcoe

The Lake Simcoe watershed is extremely large, comprised of eighteen subwatersheds and covering parts of the Oak Ridges Moraine, York and Durham Regions, City of Kawartha Lakes, Simcoe County and the lake itself (LSSAC, 2008). Over the last few decades, the area has experienced a rise in urbanization, specifically around the lake's shoreline. Since the 1970s, water quality has remained a serious issue, notably in terms of phosphorous loadings which at one point had triple the loadings of the pre-settlement era (32 tonnes/year) (LSSAC, 2008). Although reductions have been made from waste treatment plants and contributing tributaries (LSSAC, 2008) such that mean phosphorous loading is 72 tonnes/year (ECO, 2011), it is still higher than what is needed to sustain a healthy aquatic ecosystem. Additionally, many rivers have been reported to still exceed PWQO guidelines for phosphorous (LSSAC, 2008). As a result of the substantial amount of phosphorous in the water, dissolved oxygen concentrations had decreased to lower than 2 mg/L in the 1980s and 1990s, but progress has been made and is now above the 5 mg/L interim target (LSSAC, 2008). Chloride concentrations have also tripled those of the 1970s and were near 34 mg/L in 2003 (LSSAC, 2008). Urban runoff has also affected recreational activities through the closure of beaches which has increased since 2003 (LSSAC, 2008). Overall, urban stormwater impacts have not been mitigated adequately and are currently the largest source of phosphorous to the watershed at 31% of total annual phosphorous loadings (LSSAC, 2008).

In its latest watershed report card of 2008, several indicators were measured and analyzed for both the tributaries and lake itself (LSRCA, 2008). Amongst the tributary indicators, an 'A' grade was given to six subwatersheds whose stream buffer zone comprised of 75% or more vegetation, as recommended by Environment Canada (LSSAC, 2008). Meanwhile it was found that ten subwatersheds had less than 65% of their stream buffer containing vegetation. Phosphorous concentration within the tributaries was only monitored for eight subwatersheds, of which only two were given an 'A' as they met the PWQO of 0.03 mg/L. IBI scores were calculated for the fish community indicator and majority of the subwatersheds were assigned a 'fair' grade. A benthic invertebrate indicator was also measured and had mixed results with a range of grades between excellent to fair amongst the subwatersheds; overall the grade appears to be 'very good' indicating that the ecosystem is capable of supporting several types of invertebrates. Tributary indicators also included hardened surfaces and stormwater control. The majority of the watershed has an 'A' corresponding to less than 10% hardened surfaces, as recommended by Environment Canada. However, five subwatersheds were found to have between 10-

20% hardened surface area, and two subwatersheds with more than 20% (grade D and E), which were the highly developed urban areas of Barrie and the Aurora-Newmarket region. Stormwater control measures faired very poorly. Of the 18 subwatersheds monitored, only 12 are considered as urban, thus only 12 have been analyzed for stormwater control. Amongst these twelve, only one subwatershed had an ‘A’, equivalent to control greater than 70%, while two subwatersheds had between 30-50%, five were between 10-30%, and three had less than 10% (Grade E). It should also be noted that the type of stormwater measures used for this review included any level of stormwater control, and could consist of poor to good control, thus an indication of how much stormwater control there is cannot be correlated to how effective the control is on the receiving water bodies. Lastly, baseflow trends indicate that there has been a reduction in the amount of groundwater that feeds into streams in the last ten years.

In terms of lake indicators, grades were not assigned; however, general assessments were made for phosphorous, benthic invertebrates and coldwater fish. Phosphorous levels have reduced overall in the last four years prior to 2007 and it should be noted that concentrations were highest in the beginning of spring coinciding with snowmelt and spring rains (LSSAC, 2008). Benthic invertebrates were in “fairly good” health, while coldwater fish were in extremely poor conditions, such that lake trout continues to be annually stocked, and lake whitefish and lake herring populations continue to decline (LSSAC, 2008).

2.4.1.5 Rouge River Watershed

The Rouge River watershed is 35% urban and the variations in stormwater impacts can be seen in areas with high development in the south compared to that in the middle which is beginning to show degradation in the form of bank erosion, and Little Rouge river subwatershed in the north-east which has the hydrology of a rural setting (TRCA, 2007b). Unlike the previous watersheds discussed, there is a larger percentage of urban areas with some form of stormwater management, although it too is in the form of detention ponds (TRCA, 2007b). Urban areas with quantity, quantity and quality, or no stormwater management control are 10%, 60% and 20%, respectively (TRCA, 2007b). However, stormwater management is still inadequate as evident during wet weather flows when levels of suspended solids, metals, phosphorous and nitrates significantly increase (TRCA, 2007b). Furthermore, stormwater with no quality treatment is discharged into streams in 40% of the urbanized region (TRCA, 2007b).

Despite this, water quality is cleaner than that of other degraded GTA watersheds. Fish index of biotic integrity scores suggest “unimpaired”’ aquatic habitat in the headwaters and middle tributaries, while the lower urbanized watershed has "potentially impaired" and "impaired" aquatic habitat (TRCA, 2007b). Additionally, riparian cover consists of 65% of the stream length, of which 38% is forest (TRCA, 2007b).

2.4.1.6 Summary of Watershed Case Studies

Despite the progress made in stormwater management since the 1990s, the urban water bodies within the Humber River, Don River, Etobicoke Creek, Mimico Creek and Lake Simcoe watersheds continue to be in a degraded state. This is in part due to the minimal implementation of stormwater structural controls within these watersheds which has resulted in a large portion of the urbanized regions without adequate stormwater control. Stormwater control which does exist within these urban areas mainly comprise of stormwater ponds which is also another contributing factor to the decline of water body health. Overall, the degraded state of the water bodies in these urban watersheds provides the basis that modifications to stormwater management in Ontario are required.

2.4.2 Environmental Commissioner's Reports

To gain another perspective of the state of stormwater management and its effectiveness in protecting Ontario's water bodies, some of the Environmental Commissioner's Annual Reports were reviewed. Within these reports, there has been some assessment of the state of stormwater management and its problems. Firstly, it has been highlighted that there are over 100 Ontario municipalities which continue to use combined sewer systems and discharge raw sewage during heavy storms thereby polluting water bodies (ECO, 2011).

Additionally, the Commissioner has stated areas of concern related to monitoring of stormwater management facilities. Monitoring standards, in terms of which parameters should be included, have not been standardized by the Ministry of the Environment, and are instead developed according to a particular development site (ECO, 2011). Also, monitoring of the condition or performance of a proposed stormwater facility infrastructure is generally not needed for its approval (ECO, 2010), and most cases of non-compliance reported during an inspection of stormwater discharges were due to lack of monitoring (ECO, 2011). Ministry of the Environment also acknowledged that due to lack of monitoring and research, there is no province wide database which allows for assessment of progress, if any, in the affected water body (ECO, 2011). Overall, the Commissioner believes that without proper monitoring of the stormwater facilities and their performance, it will prove difficult for the Ministry of the Environment to identify and account for areas of concerns in the review and update of the 2003 SWM Manual (ECO, 2011).

Lastly, the need for stormwater management to include climate change has also been noted by the Commissioner, with the mention of the Environmental Bill of Rights (EBR) application in 2007 which called for a review of stormwater management infrastructure and its ability to accommodate different weather events in terms of climate change (ECO, 2011). This EBR was initiated by two 100-year storm events that occurred in Peterborough in 2002 and 2004. The lack of monitoring, as noted above, has also resulted in not knowing how vulnerable the province's stormwater infrastructure is to climate change. The Commissioner additionally pointed out that intensity duration frequency (IDF) curves being utilized by municipalities are based on outdated data and that there is a need for new climatic data to be incorporated in order to accommodate for the changing weather.

The perspective from the Environmental Commissioner of Ontario is in line with the analysis of the watershed case studies such that level of stormwater management that is currently being provided is not adequate.

2.4.3 Stormwater Ponds

As documented in the previous watershed case studies, the health of Ontario's urban water bodies has either continued to degrade, remained in the same poor state, or has not improved consistently. Despite the wide variety of stormwater practices and emphasis on a treatment train approach, stormwater management in Ontario has primarily used conveyance and end-of-pipe controls, with the main choice being detention ponds (Binstock, 2011). This can be seen in the primary use of ponds in the aforementioned watershed case studies. The heavy application of ponds as the main stormwater management solution has not remediated water bodies (Aquafor Beech Ltd., 2006; Bradford & Denich, 2007), but instead has exacerbated stormwater impacts.

The 1991 Interim Water Quality Control Guidelines explicitly state that fives characteristics of stormwater need to be addressed, that being volume, peak flow, quality, duration and frequency (MOE & MNR, 1991). Not only do stormwater ponds only focus on volume, peak flow and quality, but they are not able to even adequately mitigate those targeted areas, which is discussed below.

Ponds have had several designs for their outlet hydraulic performance. Some have been designed such that the outlet peak flow matches the pre-development peak flow (DOE, 2010). This approach only focuses on peak flow, and as such, does not account for the *duration* of the peak flow which is above the critical discharge of the mean particle size fraction. Consequently, although the post-development peak flow is reduced significantly to pre-development levels, this flow rate is not only above the critical discharge for the mean particle size fraction, but it is also prolonged in duration at this erosive flow (Fig. 3) (Tillinghast *et al.*, 2011). As a result, erosion has not been mitigated with these designs (Bradford & Denich, 2007). Southern Ontario's river channels have been impacted by the erosive forces created from detention ponds, leaving the silt and clay material, which is normally protected by the coarser sized particles, vulnerable to erosion. These smaller sized particles are also eroded and deposit large amounts of fine sediment into the stream (Aquafor Beech Ltd., 2006).

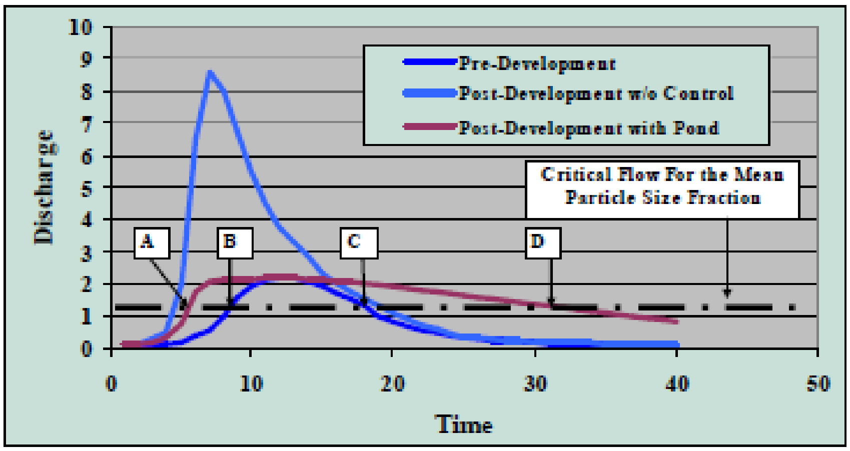


Figure 3: Comparison of runoff hydrographs between pre-development, post-development with no control, and post-development with pond control (Aquafor Beech Ltd., 2006).

Currently, ponds are designed using the "flow duration standard" whereby it is assumed that flows below the critical discharge will not erode and transport sediment. Under this concept, the stream's form would be protected since the mean particle size fraction would have less exposure to erosive flows (Aquafor Beech Ltd., 2006). Meanwhile, minor events, which have a lower peak flow than the critical discharge, are regulated with minimal control. These minor events have increased in both frequency and duration in urban areas and are capable of transporting particles smaller than the mean particle size fraction (Aquafor Beech Ltd., 2006). Therefore, although the mean particle size fraction has been controlled, the erosive potential for transporting finer particles has increased because the peak flows below the critical discharge have been extended and occur more often (Aquafor Beech Ltd., 2006).

Implementation of ponds also does not guarantee improved water quality of the receiving water body, despite the use of total suspended solids (TSS) percentage removal performance targets. While coarser sediments settle within the pond, the finer particles, which are a significant portion of the influent's suspended solids, are not sufficiently reduced at the outlet discharge (Braford & Gharabaghi, 2004). Other pollutants, such as nutrients (i.e., phosphorous, which has high binding affinity to fine particles) and heavy metals (i.e., copper and zinc) are often attached to the finer particles and thus the majority of these pollutants are able to escape treatment as well (Braford & Gharabaghi, 2004). Furthermore, ponds also have poor treatment of soluble pollutants (Bradford & Denich, 2007).

In addition, the water quality storage requirements of end of pipe controls (i.e., ponds) is based on US EPA soil data and have been standardized under the assumption that the provincial climate is uniform. Therefore, the design criteria used in these types of practices are not based on regional conditions (further explained in 5.0 Stormwater Management Based on Regional Conditions).

Lastly, a channel's geometry and stability are not only based on the hydrologic regime, but also the sediment regime, whereby the type of sediment that it receives from overland flow, or the pond facility, will dictate its stability and form. Since the larger suspended solids are the first to settle in the pond, the effluent is primarily dominated with finer particles, and consequently the stream bed composition can be affected downstream of pond facilities. Keeping in mind the increased erosive potential for finer particles below the mean particle size fraction, these particles from both the pond effluent and those exposed within the stream material, are eroded and transported downstream. This can leave a stream bed that is coarse (Aquafor Beech Ltd., 2006).

The use of stormwater ponds has not produced desired results to protect the receiving water body in terms of both biological and physical integrity. Even with conservative designs, ponds are incapable of reproducing the pre-development stream flow pattern (Konrad and Booth, 2005), and have minimal effect on reducing the frequency (Walsh *et al.*, 2005) and volume of runoff events (Hancock *et al.*, 2010).

2.4.4 Summary

It is evident that the current stormwater management in Ontario has not effectively mitigated the impacts of urban stormwater. Several urbanized watersheds within Ontario continue to have degraded water bodies due to the limited implementation of practices, of which consist mainly of stormwater ponds whose design has proven it challenging to adequately manage stormwater. Modifications to stormwater management are warranted in order to address the poor health of Ontario's urban water bodies and the threat that stormwater continues to pose towards human life and property. This is necessary to achieve the ultimate goal of protecting humans and environment from stormwater impacts.

2.5 Etobicoke Exfiltration System

The information for this section is provided from the "Draft Design Manual of the Etobicoke Exfiltration System" (Tran, 2011b), unless noted otherwise. The Etobicoke Exfiltration System (EES) is a stormwater management practice which was designed and constructed in 1991 for the former City of Etobicoke. The following sections discuss the EES's purpose and background, system description and system dynamics. The EES pilot projects are also mentioned to briefly detail their performance in stormwater management. Ultimately, the purpose of this section is to provide information on the EES and its success, and to highlight research gaps that are required for further understanding of the EES.

2.5.1 Purpose

The EES was developed to retrofit the Etobicoke's existing storm sewer network to rehabilitate the urban environment by restoring the natural hydrologic cycle through groundwater recharge. Previous attempts at recharging groundwater using traditional infiltration systems, such as the French drain, were unsuccessful due to performance and maintenance issues (Dubyk, 1994). These included clogging, being non-functional during winter and spring thaw, no recharging of groundwater aquifers, and lowering the groundwater table in areas of high groundwater levels (Dubyk, 1994). Another important factor for its development was to prove that the 1991 Interim Water Quality Control Guidelines (MOE & MNR, 1991) could truly be implemented through a stormwater management practice, such that it would incorporate and control for runoff intensity, volume, quality, duration and frequency (Tran, 2011a). Furthermore, contrary to existing stormwater management practices, the EES also had to be functional throughout the entire year (Tran, 2011a).

The EES engineers considered all these factors and made the following design criteria and restrictions:

- Exfiltrate 90% of the former City's annual rainfall events based on rainfall depth (equivalent to the 15 mm AES 1 hour storm which, with a time to peak of 20 minutes, has a maximum rainfall intensity around 50 mm/hr).
- Exfiltration must be completed within two days after a rainfall event in order to be ready for the next event (inter-event period calculated to be three days).
- The system must be constructed and maintained using existing equipment and techniques
- The system is not applicable in areas where groundwater is a drinking source, in commercial/industrial areas, or in heavy traffic corridors.

2.5.2 System Description

The EES was designed such that it retrofitted an existing storm sewer network by adding two perforated pipes in a gravel trench directly below the main storm sewer pipe, and sloped at the same angle. The perforations are located at 45° to the vertical. Figures 4 and 5 show the cross-section and profile of the EES. These specifications (perforation's location and pipe angle) would allow for sediment to travel towards the downstream end of the perforated pipe, with no clogging occurring. The perforated pipes are also wrapped in filter cloth to minimize pollutant mobility into the trench. The gravel trench consists of 19mm clear stone, a trench bed material commonly required for standard stormwater minor system projects. The trench is also wrapped in filter cloth to reduce surrounding soil from migrating in, which subsequently will prevent voids in surrounding soil and associated road failures. The two perforated pipes and voids in the gravel trench are capable of storing 90% of the City's annual rainfall events. Goss traps are added to catchbasins in case of accidental spills, particularly in older residential areas where spills can result from the refilling of oil furnaces. Additionally, cut-off walls are used to prevent the bedding material and the infiltrated runoff in the trench to migrate downstream. Mechanical plugs are utilized at the downstream end of the perforated pipe during system use, and can be removed during maintenance. Also, the entire system is located below the frost line.

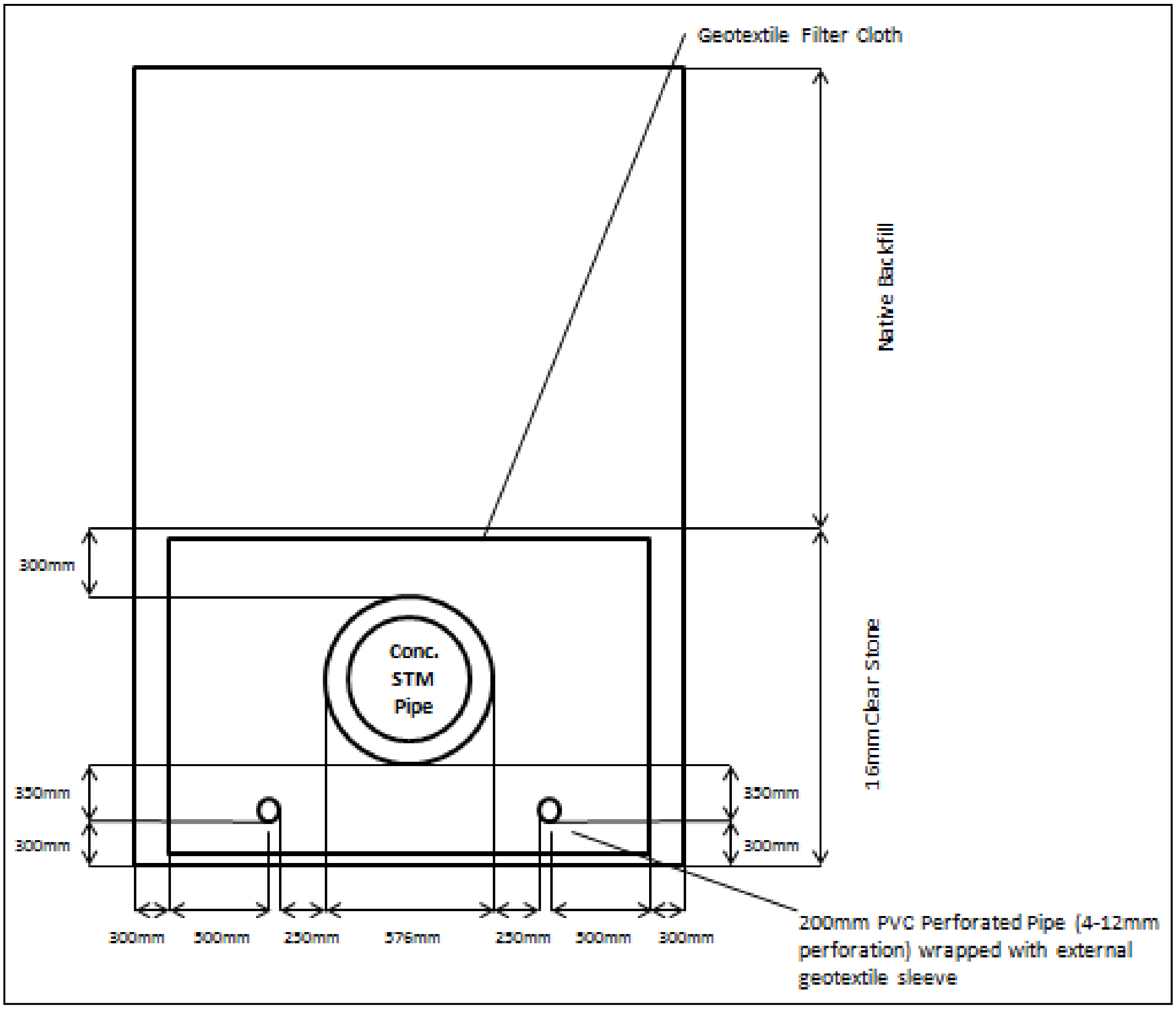


Figure 4: Cross-section of constructed EES. Adapted from Candaras (1997).

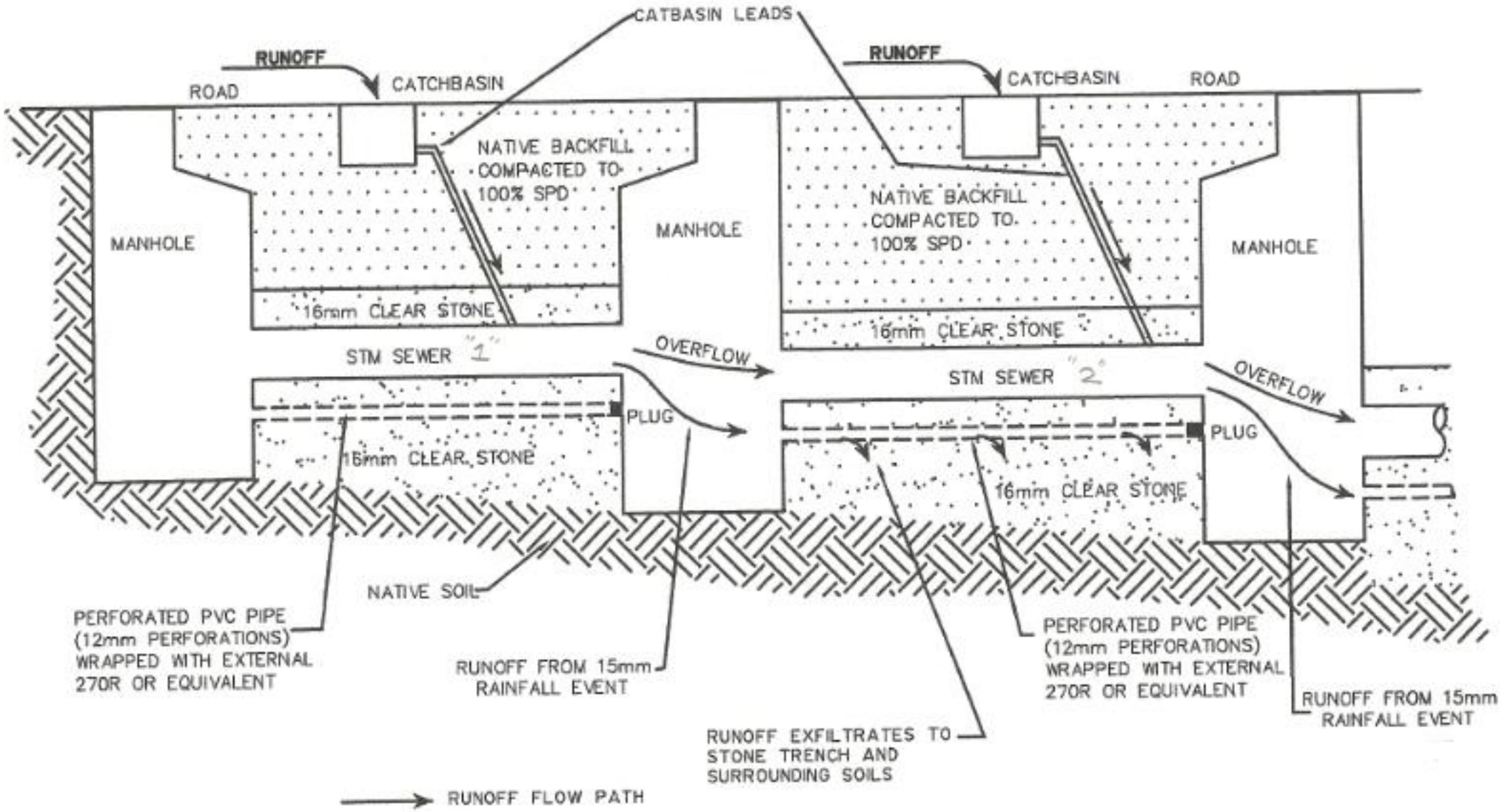


Figure 5: Typical profile of EES (Candaras, 1997).

2.5.3 System Dynamics

The EES is a very dynamic system, involving runoff capture, transportation, distribution, infiltration, exfiltration and recharge. Firstly, runoff produced above ground is captured through catchbasins. It is important to note that the runoff area is not cumulative, but instead corresponds to a particular contributing section of the EES as it moves downstream along the road, which is shown in Figure 6. For example, instead of the EES between manhole 2 and 3 to receive runoff from both the yellow and blue shaded drainage area, it only receives the runoff from the blue shaded drainage area. Therefore both peak flow and volume of runoff are not cumulative.

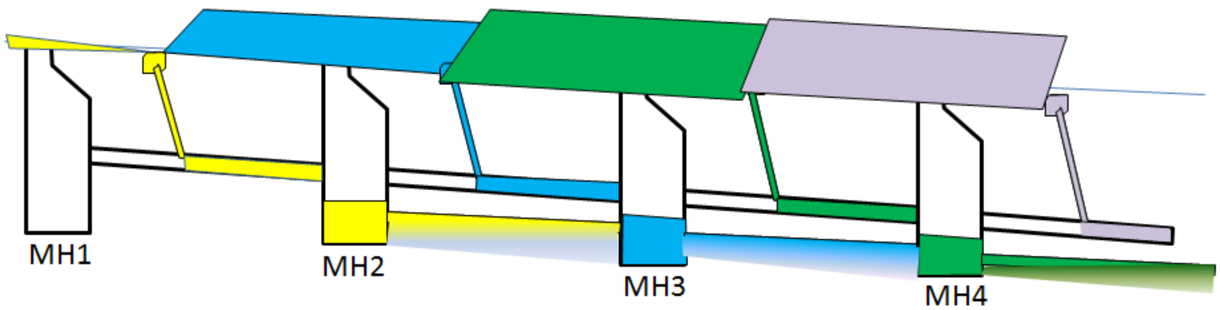


Figure 6: EES runoff inflow associated with a non-cumulative drainage area. (Tran 2011c).

Once the runoff is captured by the catchbasins, it is transported into the minor storm sewer pipes and manholes. The sizing of the minor pipe is determined by the Rational Method and Manning's formula, and takes into account peak flow amongst other factors. As the hydraulic head in the manhole rises, the water level of the runoff will eventually reach the upstream opening of the perforated pipes, where it will enter and be distributed downstream along the length of the gravel bed. The runoff will then infiltrate into the gravel bedding for temporary storage and slowly exfiltrate into the surrounding soil. The infiltration rate and storage capacity of the trench determines how well the EES can handle large storm events, therefore it is important to select the right material for the trench bedding, as well as the perforation size of the pipes. Additionally, the rainfall inter-event period for that region has an essential role as it determines the maximum amount of time allowed for the stored runoff to be exfiltrated completely to minimize overflow potential. In Etobicoke, the inter-event duration is three days, thus an exfiltration time requirement was set as two days. Once the runoff is exfiltrated into the soil, the details regarding recharging of the groundwater has not been research; however, observations of the pilot studies after 20 years from construction appear that a healthy variety of vegetation and mature trees are supported by adequate groundwater supply (discussed further in Section 2.5.4.2 Pilot Projects – Performance). Lastly, overflows of the perforated pipes can occur. This entails the volumes of the perforated pipes and trench being completely full, thus the hydraulic head in the manhole will rise such that it will eventually reach the entrance of the main storm sewer where it will then be transported to the downstream manhole. In these situations, the overflow hydrograph will be added on to the following downstream hydrograph.

2.5.4 Pilot Projects

This section consists of information regarding the two pilot projects of the EES that were constructed in 1991 in the former City of Etobicoke.

2.5.4.1 Description of Drainage Areas

Two sites were selected for the EES pilot studies: Queen Mary Drive and Princess Margaret Boulevard.

Queen Mary Drive (Fig. 7) is a high class residential area which had 0.44 km of storm sewer servicing a 13.3 ha drainage area. The soil type found in this neighbourhood was silty sand to clayey silt with a hydraulic conductivity (K) of 7×10^{-7} cm/s, and the groundwater table was 1.6 to 2.6 m below the ground surface. Most importantly, this site still had downspout roof connections to the storm sewer network. At this site, stream bank failure was present at the Queen Mary Drive/Kingsway Crescent intersection and was resulting in constant road maintenance.

The Princess Margaret Boulevard site (Fig. 8) is also in a high class residential neighbourhood, with 1.3 km of sewer servicing 30.5 ha of drainage area. There, the soil type is of silty clay ($K = 1 \times 10^{-7}$ cm/s) and silty sand ($K = 7 \times 10^{-7}$ to 2×10^{-7} cm/s), and roof downspouts are disconnected. Boreholes of up to 14 m did not indicate any groundwater near the drilled depths. Additionally, Princess Margaret Boulevard is a residential collector which was due for replacement at the time, as well as an upgrade to a curb and gutter system. The pilot study area is between Kipling Avenue and Islington Avenue and drains into the Humber River and Mimico Creek.

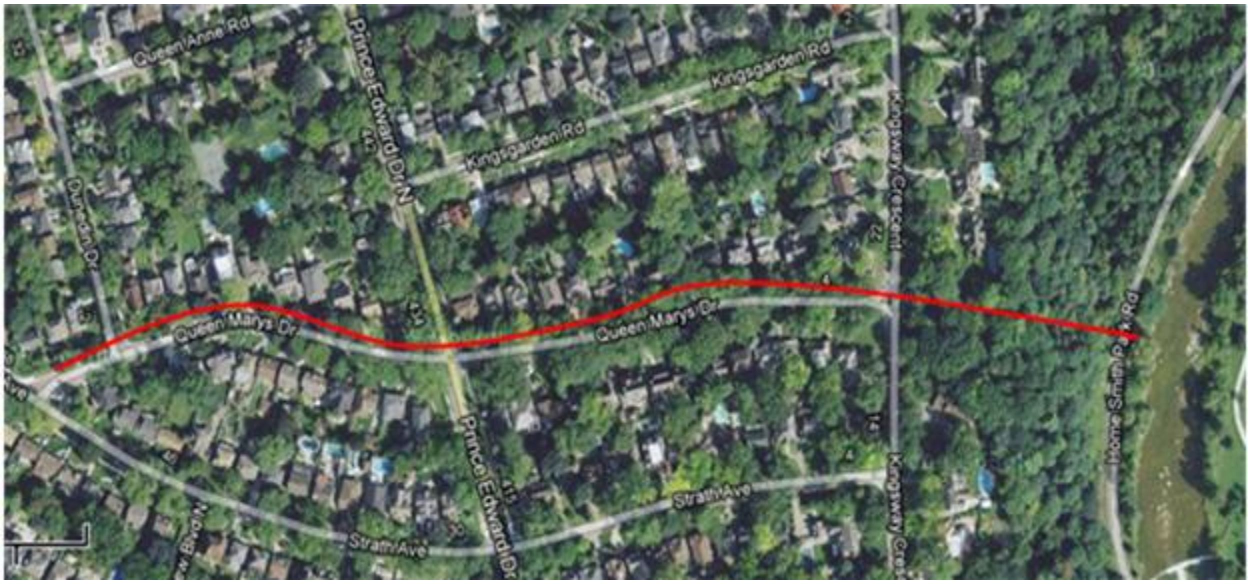


Figure 7: EES pilot site at Queen Mary Drive. Red arrow shows the downstream flow of runoff entering the Humber River.

Figure 8: EES pilot site at Princess Margaret Boulevard. Red arrow shows the downstream flow of runoff.

2.5.4.2 Maintenance

Monitoring has shown that minimal maintenance will be needed for the EES. The location of the pipe perforations and the slope of the pipes result in the perforations unclogged, and the sediment migrating towards the downstream. This sediment can be easily flushed manually with water into the manhole for removal. After 20 years of use, the EES is still performing well at both pilot study locations.

2.5.4.3 Performance and Observations

Two studies have been conducted on the performance of the EES. A.M. Candaras Associates Inc. monitored both pilot sites in 1994 and 1995, with one section of the EES analyzed (Candaras, 1997). Manhole 2 to 3 was monitored within the Princess Margaret Boulevard site, while manhole 14 to 15 was monitored at the Queen Mary's Drive site (Candaras, 1997). The hydraulic parameters that were monitored include the upstream and downstream head in the trench, and the upstream inflow and downstream outflow (overflow) relative to the EES section being monitored. Data from this study shows insight into the trench dynamics of the runoff and the upstream trench head level that is required for an overflow. Sediment quality was also analyzed and will be discussed below.

The Stormwater Assessment Monitoring and Performance (SWAMP) Program also studied both pilot sites between 1996 and 1998 (SWAMP, 2004). However, there is limited data that can be used from the SWAMP study. Firstly, monitoring for Queen Mary Drive took place at the intersection of Queen Mary Drive and Kingsway Crescent where the EES and a traditional storm sewer terminate at the last downstream manhole and discharge into the receiving stream. At this intersecting manhole, flow monitoring equipment was placed for the Kingsway Crescent main sewer pipe (no EES installed), the Queen Mary Dr. main sewer pipe, the relief pipe below the EES, and the manhole outlet. However, the flow monitoring equipment for the Queen Mary Drive main sewer pipe was placed downstream of the dropshaft and as such, any overflows that occur may enter the dropshaft and not be recorded. The groundwater interceptor pipes installed under the EES in this location were not analyzed for water quality, but this was done for the relief pipe water quality. The water quality data of this relief pipe represents the runoff exfiltrating from the trench and can be used in analyzing the impacts to groundwater quality. Secondly, the water level that was measured at the Princess Margaret Boulevard site was in the manhole and not the trench; therefore the performance of the trench hydraulics was not truly monitored. Water quality analysis at this site was for samples taken from the main sewer pipe and consisted mainly of catchbasin effluent because only one sample was taken during an overflow. This is of little use as there are no trench or groundwater samples to compare to for this site.

With the available data on the EES from the Candaras (1997) and SWAMP (2004) studies, determinations of its performance can still be made. Since the EES was developed to meet the 1991 Interim Water Quality Control Guidelines (MOE & MNR, 1991), it would be logical to base the EES's performance on how well it addresses the five areas of stormwater runoff characteristics: peak flow, volume, quality, duration, and frequency.

As mentioned before, both peak flow and volume of runoff are not cumulative when entering the EES, but instead are associated with the contributing drainage area. Therefore, each section of the EES (upstream manhole to downstream manhole) handles a smaller volume of runoff and lower peak flow then would be seen in a traditional storm sewer system where runoff from upstream drainage areas is accumulated along the minor pipe. When overflows do occur, the peak flow resulting from the overflow hydrograph is much lower than the peak flow from the downstream contributing area, and the peak flows do not coincide. Additionally, the cumulative volume controlled, in terms of depth (mm), is much larger than designed for (Candaras, 1997). This is seen by the October 5-6, 1995 event at Princess Margaret Boulevard where 63 mm of rainfall over 18 hours did not produce an overflow (Candaras, 1997). At the downstream end of the system, runoff from the last storm sewer section is discharged through the outlet untreated. But since this runoff is from a single contributing drainage area, the peak flow and volume of the outlet discharge is significantly reduced. Furthermore, the EES provided peak flow control for a 15mm, 1hr AES design storm which has about a 50 mm/hr intensity. Storms with higher peak flows can cause an overflow, such as the September 6, 1998 event at Princess Margaret Boulevard where during the storm, 9.7 mm of runoff depth accumulated within 10 minutes (SWAMP, 2004). Although this was for only ten minutes, it is equivalent to an intensity of 120 mm/hr – more than double the designed peak flow.

The EES provided adequate control in terms of frequency, as designed. Events which occurred at least within three days of a following event (inter-event period) were less likely to result in an overflow. However, when two back-to-back rain events occurred within two days of each other (the time required for the trench to exfiltrate all of the runoff), there may be an overflow. This is seen with the June 30, 1998 event at Princess Margaret Blvd. where a first event of 14.9 mm was then followed by a 11.9 mm event just five hours after, which caused an overflow (SWAMP, 2004). Additionally, the design criteria of exfiltrating 90% of the annual rainfall events was achieved as seen by the small number of overflows. With an average of 300 rainfall events per year, it was expected that about 30 events would produce an overflow (Tran, 2011b). However, monitoring has shown that the actual number of overflows is much lower than 10 overflows per year, therefore reducing the frequency of runoff that enters the stream from the EES outlet (Tran, 2011b).

Duration of runoff is also controlled indirectly through the reduction of overflows and the reduction of peak flow and volume. This is discussed in more detail in Chapter 7.

Overall, peak flow, volume, duration and frequency control can be observed through the small number of overflows that occurred. Large and long events (up to 50-year storms) were eliminated through exfiltration and did not create overflows, while events which were intense and short in duration, and thus exceeded the design criteria, produced overflows. It is important to note that overflows did not occur during the winter or spring where runoff volumes are highest. The successful exfiltration results in the groundwater being recharged while providing a high level of flood protection. After 20 years, the Queen Mary Drive site has a stable bank with no need for road maintenance, as well as producing a habitat similar to headwater reaches with mature trees and a diversity of vegetation providing shade to the stormwater discharging from the outlet.

In terms of water quality, the EES has proven that it is capable of capturing and significantly reducing pollutants (SWAMP, 2004), such that the resultant pollutant concentration in runoff is of better quality than that of stormwater pond effluent (Tran *et al.*, 2012). Monitoring of the Queen Mary Dr. site showed that pollutant concentrations in the runoff recharging the groundwater were significantly lower than that from stormwater ponds and their effluent. It was also found that the sediments captured within the EES's perforated pipes had much higher pollutant levels, notably lead, copper, zinc and cadmium, than from stormwater pond sediment (Tran *et al.*, 2012).

Despite the restrictions on soil type and groundwater/bedrock levels put forth by the 2003 Stormwater Management Planning and Design Manual (MOE, 2003), the EES at both pilot sites properly functioned with hydraulic conductivities significantly less than 15 mm/hr and with the groundwater level less than 1 m below the gravel bedding at Queen Mary Drive. Furthermore, a relief perforated pipe, such as the one installed at the Queen Mary Drive site, will allow the use of EES in sites with groundwater less than 1 m from the trench. Although the soil found at Queen Mary Drive was silty sand, while Princess Margaret Boulevard had silty clay, it was found that the latter site performed better because it had disconnected roof downspouts (Tran, 2011a). This shows the importance and influence of downspout disconnections for stormwater management, as both the peak flow and volume of runoff entering the storm sewer system decreased.

2.5.5. Cost Comparison

In addition to performing well at both pilot sites, the EES is an inexpensive option for stormwater management since it is simply installing two perforated pipes under a storm sewer pipe and wrapping the trench with filter cloth. In 1993, which was the time of EES construction, the cost of drainage works (sewers, manholes, labour) was $122,531.20 while the cost of road construction (including catchbasins, labour) was $533,990.60 (Tran *et al.*, 2012). The installation of the EES (including perforated pipes, filter cloth, plugs and labour) was $25,033.60, which brought the total cost of drainage and road works to be $681,555.40 (Tran *et al.*, 2012). The EES addition was only 4% of the total cost. Another benefit of the EES is that it can be implemented in conjunction with capital work projects such as repairs for existing roads, storm or sanitary sewers, or drinking water pipes.

The low cost of the EES is highlighted when comparing it to the cost of a stormwater pond. If a stormwater pond was constructed at the Princess Margaret Boulevard site, it would have to have a storage volume of 4,270 m^3 to accommodate a drainage area of 30.5 ha (Tran *et al.*, 2012). This storage volume is calculated according to the 2003 SWM Manual (MOE, 2003), using the 140 m^3/ha storage volume for a wet pond in a 35% impervious drainage area. The cost for a wet pond ranges from $20 to $30.50 per m^3; therefore the construction cost is between $85,400 to $130,235 (not including land and expropriation costs) (Tran *et al.*, 2012). This shows that the EES is 71-81% less expensive than the construction of a wet pond and when combined with the EES's high performance, ultimately shows that facility is very cost effective (Tran *et al.*, 2012).

2.5.6 Research Needed

The EES has proven to be successful in mitigating the impacts of urban stormwater. It has addressed the five stormwater characteristics throughout all of Ontario's seasons and accounts for regional conditions by basing its design criteria on local storm characteristics.

In order to further understand the system and how it can be applied at other locations, research is warranted in several areas. Firstly, research is needed into the chemical mechanisms involved in reducing the pollution concentration in the trench runoff, as well as the pollutant interaction with the sediment. Secondly, other than through observation of healthy vegetation, there is lack of information regarding the movement and effects of the exfiltrated runoff. Examples include how much exfiltrated runoff recharges the groundwater table; how much becomes baseflow; what are pollutant concentrations of the runoff as it migrates further away; how the soil and its microbes provide remediation (if any); and to what extent can drinking water sources be contaminated.

Additionally, modelling has not been conducted for various single size storm events, which would be essential in determining how well the EES performs for a range of synthetic storms. Modelling has also not been conducted for differing regions with different local climates and soil conditions. This is especially important if the EES is to become a more widely used stormwater practice.

2.6 Stormwater Management in Other Jurisdictions

In this section, the stormwater management manuals of British Columbia (Stephens *et al.*, 2002), Alberta (CH2M Gore & Storrie Limited, 1999) and State of Maryland (CWP & MDE, 2009) were investigated for their approach to stormwater management, with more focus on their goals and objectives, as well as which of the five runoff characteristics they address. The purpose of this is to know if other jurisdictions have already implemented the modifications that are proposed within this research paper (see the specific research objective in 1.3 Objectives and Scope).

2.6.1 British Columbia

The goal for British Columbia's stormwater management, although not explicitly stated as a "goal," is to "apply land use planning tools in order to protect property and aquatic habitat, while accommodating land development and population growth (Stephens *et al.*, 2002)."

The stormwater management objectives stated within the Guidebook (Stephens *et al.*, 2002) are, to the opinion of the author of this thesis, not properly organized, and as such, included some statements to be classified as objectives although they were not within any "objectives list." Some objectives were also found to be under the Guidebook's stormwater performance target section. It is important to distinguish the differences between an objective and a performance target, with the latter involving a desired numerical value to be achieved. As such, objectives which included a value were categorized solely as performance targets. Furthermore, some of these performance targets would be better suited as land use planning targets. Although it can be argued that stormwater management is interconnected with land use planning, targets such as "retain 65% forest cover across the watershed" and "preserve a 30m wide intact riparian corridor along all streamside areas" are more impacted by land use planning policies. A summary of British Columbia's stormwater management objectives are in Table 7.

The Guidebook (Stephens *et al.*, 2002) on stormwater management explicitly states that management should focus on runoff volumes and peak flows. Water quality is also targeted, as seen by the objectives of setting TSS loading rates and controlling pollution sources. Runoff frequency is also managed, indirectly, through the use of a three tier system that categorizes rainfall events relative to the Mean Annual Rainfall (MAR), which is an "event that occurs once per year, on average (Table 6)." Reducing runoff volume can be achieved by reducing all runoff events from the Tier A events which although are the smallest in volume, consist of approximately 90% of the annual rainfall events in British Columbia. Thus, minimizing runoff frequency by 90% will significantly lower runoff volume. In addition, a different method of control is suggested for the different tiers, with Tier A events being captured and infiltrated through source control measures, Tier B events being detained, and Tier C events undergoing flood control involving containment and conveyance.

Table 6: Rainfall spectrum for various locations in B.C. (Stephens et al., 2002).

Location	Tier A Events (less than 50% of MAR)	Tier B Events (between 50% of MAR and MAR)	Tier C Events (Greater than MAR)
Vancouver (North Shore)	< 40 mm	40 to 80 mm	> 80 mm
Chilliwack	< 30 mm	30 to 60 mm	> 60 mm
Nanaimo	< 20 mm	20 to 40 mm	> 40 mm
Kelowna	< 10 mm	10 to 20 mm	> 20 mm

Table 6 also shows that rainfall distribution, and thereby rainfall volume and frequency, can vary across regions. This is important to note since the 2003 Ontario SWM manual (MOE, 2003) does not include this.

The B.C. Guidelines (Stephens *et al.*, 2002) also point out that policies, objectives, goals and performance targets should be customized to each watershed and catchment depending on their situation. As such, some objectives may be prioritized over others if warranted. Also, the guidelines emphasize adaptive management for stormwater and state that monitoring of the facility's performance relative to the target condition will enable determination of modifications, if any, to the performance targets.

Additionally, British Columbia has an extremely diverse climate across the province with the coastal side having warm to mild temperatures, while the interior portion has continental climate. Despite this, there is no mention of snow or snowmelt in their Stormwater Guidebook (Stephens *et al.*, 2002) other than in reference to the need for large storage volumes to lower peak runoff rates from 5-year winter storms.

Upon further inspection of the Guidelines (Stephens *et al.*, 2002), it appears that there is a lack of specific emphasis on the protection of fish, with only one relevant objective being to preserve in-stream features (i.e., channel complexity and adequate spawning gravel) essential to aquatic ecosystems. The protection of fish migratory corridors or rearing grounds has not been included. Without this addition, having the correct ratio of spawning gravel will have minimal effect as fewer adult fish will reach the spawning grounds, or once eggs have hatched, the fry or juveniles may fair poorly if there is not proper habitat to facilitate their maturation into adulthood.

2.6.2 Alberta

The goal of Alberta's stormwater management is to "develop effective drainage systems that balance the objectives of maximizing drainage efficiency and minimizing adverse environmental impacts," and to "preserve the natural hydrologic cycle (CH2M Gore & Storrie Limited, 1999)." The runoff characteristics targeted for control are peak flow, volume and quality.

The objectives of stormwater management were not explicitly stated in the manual (CH2M Gore & Storrie Limited, 1999). However, four water quality issues or areas of concern were listed and the author has modified them into objectives. These areas of concern were then linked to supporting aquatic diversity and geomorphologic changes and thus these concerns were also categorized as objectives. These objectives are extremely close in nature to those of Ontario's and are found in Table 7.

Snowmelt is mentioned several times throughout their SWM Manual (CH2M Gore & Storrie Limited, 1999) which states that the maximum annual flows occur from snowmelt. However, rural snowmelt is seen to be a bigger concern than that of urban watersheds stating that urban stormwater systems rarely exceed design capacity. With that said, high flows are said to occur once in spring due to snowmelt, and multiple times in summer. Furthermore, it is suggested that after sizing a facility for a design storm, it should also be able to accommodate up to one month or two weeks of snowmelt within the freeboard of the pond.

Two snowmelt calculation methods are briefly described. The degree-day method quantifies snowmelt through a relationship between mean daily temperature and a coefficient, while the energy budget method associates the rate of snowmelt to atmospheric inputs such as shortwave/longwave radiation, condensation and convection, heat content of rain, and heat conduct of the ground. However, practical issues are expressed because the majority of the inputs can only be estimated, including snow depth and snow density, and because the equations are applicable to uniform snow packs which is generally not found in urban environments. The manual also states that although snowmelt runoff simulation models are available, they are generally not used for estimating runoff in urban areas. This is because it is believed that Alberta's critical runoff events mainly consist from rain events.

Additionally, winter operation issues are discussed, such as ice blockages and recommends orientating facilities such that the sun can help reduce ice formation. De-icing agents are also mentioned briefly as a stormwater quality problem.

2.6.3 Maryland

The goal of Maryland's stormwater management is "to maintain after development, as nearly as possible, the pre-development runoff characteristics, and protect natural resources (CWP & MDE, 2009)." The runoff characteristics targeted are peak flow, volume and quality, and it does not appear that duration or frequency are a focus or acknowledged.

Maryland's manual (CWP & MDE, 2009) did not specifically state stormwater management objectives. However, the sizing criteria used for BMPs were categorized into five sections which the author has now modified into objectives, which are presented in Table 7. Maryland's objectives are more comprehensive than the other manuals in terms of protection of aquatic species, especially fish, with the explicit mention of protecting cold water streams by preventing rising water temperatures and preserving the riparian corridor for a source of shade. However, there is still no mention of protection of spawning or rearing grounds, which is essential for truly protecting fish. Furthermore, the objective to preserve riparian corridors should not be solely for cold water or sensitive streams, as it essential for the health of all aquatic species.

Similarly to the Ontario 2003 SWM Manual (MOE, 2003), stormwater management in the State of Maryland appears to be more concerned with the maintenance and operation of the facility, rather than accounting for the varieties in seasonal runoff events in the design (CWP & MDE, 2009). However, road salts and their high concentrations in snowmelt runoff were acknowledged to be a concern due to their toxicity to freshwater aquatic species (CWP & MDE, 2009).

2.6.4 Summary of Non-Ontario Stormwater Management

In general, it appears that stormwater management in British Columbia, Alberta and State of Maryland do not include the proposed modifications stated in the first specific research objective. The unique characteristics of each of their seasons are not accounted for in the design of their practices except the acknowledgement of chloride contamination, nor are the stormwater management objectives very different from those of Ontario. Although Alberta acknowledges that snowmelt occurs, snowmelt models have not been applied for urban stormwater management due to the belief that rainfall is more predominant. Additionally, some regional conditions appear to be considered for British Columbia as it is acknowledged that storm characteristics vary throughout the province.

The absence of this research's proposed modifications in these jurisdictions suggests that these regions may also benefit from the proposals made in this research paper.

Table 7: Stormwater management objectives for B.C., Alberta and State of Maryland.

British Columbia	Alberta	Maryland
Preserve and protect the water absorbing capabilities of soil, vegetation and trees	Provide water quantity control	Meet water quality pollutant removal goals
Prevent the frequently occurring small rainfall events from becoming surface runoff	Protect water quality	Maintain groundwater recharge
Provide runoff control so that the MAF approaches that for natural conditions	Maintain erosion potential	Reduce channel erosion
Minimize the number of times per year that the flow rate corresponding to the natural MAF is exceeded after urbanization	Maintenance of baseflow, including groundwater reaches and in-stream low flow	Prevent overbank flooding
Establish a TSS loading rate that matches pre-development conditions	Ensure waters can support an appropriate diversity of life	Extreme flood management
Maintain or restore the natural water balance as re/development proceeds	Ensure channels do not undergo damaging geomorphical change	Prevent stream warming [1]
Protection of property, aquatic resources and water quality		Preserve the natural riparian corridor [1]
Preserve or restore natural vegetation along riparian corridors		Prevent groundwater contamination [2]
Preserve or restore natural features (ie wetlands) that play a key role in maintaining the hydrologic and water quality characteristics of healthy streams		Protect aquatic resources
Preserve or restore in-stream features that are key to the health of aquatic ecosystems (ie channel complexity and adequate spawning gravel)		
Control point and non-point sources of water pollution		

Additional objectives for: [1] cold water and sensitive streams; [2] wellhead protection.

2.7 Gaps

The state of Ontario's watersheds shows that there is still much progress to be made in the field of stormwater management. Several gaps have been identified which warrant investigation into how it could beneficially impact Ontario's water bodies.

The important influence that our four seasons have on stormwater management has not been acknowledged, and as such our stormwater infrastructure has not been adequately designed to handle each of these season's unique storm and runoff characteristics.

Regional conditions have not been wholly accounted for when designing stormwater practices as seen by the assumption that Ontario's climate is uniform across the province. This is also seen by the use of standardized TSS pollutant percentage removals to gauge the success of a BMP despite its performance not being positively correlated to the health of the receiving water body.

Current stormwater management objectives in Ontario are very simple in nature and need to be expanded to provide further direction into what stormwater management must protect. This should entail developing more specific objectives of how to maintain aquatic diversity, and the inclusion of human objectives.

Furthermore, the EES has proven to be a successful stormwater practice but requires much research to understand its pollutant removal mechanisms and its hydraulic performance on a range of single event design storms as well as back to back events. Analysis has also never been carried out to determine which stormwater management objectives the EES is able to fulfill. Since there are many areas that need to be investigated for the EES, this research will only address the hydraulic performance under single event synthetic storms, and which stormwater objectives are fulfilled.

3.0 Methods

3.1 Introduction to Methods

As previously discussed in 2.7 Gaps, several areas of concerns and deficiencies have been identified which warrant modifications to stormwater management in Ontario. It is without doubt, that the current approach is not alleviating or protecting Ontario's water bodies as it was intended to do so, and thus changes must be made. With this understanding, new approaches can be proposed to head stormwater management in the right direction.

An extensive literature search of academic, institutional and/or professional opinions was conducted to support or disprove (if any) the proposed modifications listed in the first specific research objective. As listed in 1.3 Objectives and Scope, the proposed modifications were for stormwater management to account for Ontario's four seasons and regional conditions, and to update the stormwater management objectives. Practical suggestions for the modifications were also briefly indentified. Once the literature search was concluded, logic and reasoning was used to analyse the evidence to decide if each new modification to stormwater management is justified. In addition, the purpose of this research was to highlight the problem of stormwater management in Ontario and give the direction which needs to be taken – it is not to provide the solutions, technologies or practices in line with the new proposed modifications. This will require separate research on its own.

Along with the literature search, a case study on the EES was included as it has fulfilled two of the proposed modifications by being functional throughout all seasons and accounting for regional conditions, and to date has performance well. Computer modeling and analysis of its performance was carried out to provide evidence that following these proposed modifications will give the desired watershed outcome that stormwater management has been striving to achieve for the past decades.

Overall, there are three main objectives. The first objective entails proposing a new approach to stormwater management in Ontario, which is split into three sections, whilst the second and third objectives focus on the EES as the benchmark practice for stormwater management.

3.2 Four Seasons based Stormwater Management

The first section of the first research objective is to provide reasoning for stormwater management to account for Ontario's four seasons. To do this, the literature review first identified climatic and stormwater characteristics associated with each season in Ontario to show how the seasons vary. Stormwater management practices (if any) from the 2003 SWM Manual (MOE, 2003) that account for the season's varying characteristics are discussed to identify any deficiencies in Ontario regarding seasonal management.

The stormwater impacts on the receiving water body resulting from not adequately addressing the four season's stormwater characteristics in Ontario will be discussed, along with briefly identifying some measures that could be taken to adequately manage each season's runoff. This section is ended with a conclusion that is based on the seasonal management literature review to justify that stormwater needs to be managed on a seasonal basis for the entire year.

3.3 Stormwater Management Based on Regional Conditions

The second part of the first objective entailed mining the literature to search for practices in Ontario's stormwater management which are not based on regional conditions. This section identified stormwater performance targets or practices which were not based on local climate, receiving water body and drainage area characteristics. These characteristics were chosen as they are not uniform throughout the province. The stormwater impacts on the receiving water body that result from not accounting for regional conditions were also discussed and used as the basis for justification to have stormwater management based on regional conditions.

3.4 Revision of Stormwater Management Objectives

The last section of the first objective consisted of the introduction of new stormwater management objectives as proposed by Tran (2011b). These proposed objectives either elaborate upon current 2003 SWM objectives (MOE, 2003) or are entirely new. These proposed stormwater management objectives have been categorized into two groups: environmental and aquatic habitat, and human habitat. The reasoning for this separation will be explained in 6.0 Proposed Stormwater Management Objectives.

Each new proposed objective was analyzed for inclusion of an updated stormwater management objectives list through a literature review. The importance of the proposed objective was discussed, as well as its connection to stormwater management. However, it was not expected for the proposed stormwater objectives to be explicitly stated within literature, and as such, an attempt was made to establish a link between stormwater management and each of the proposed objectives through a holistic approach. This means that stormwater management may directly or indirectly impact the fulfillment of the proposed objectives, and for those objectives which are indirectly impacted, there may be several layers of connections that need to be identified. If a connection was established between stormwater management and the proposed objective, then the proposed objective was included in the updated stormwater management objectives list.

3.5 EES Modelling

The second research objective was to model the EES to analyze how the system performs in regards to a variety of single synthetic storms. For the purpose of this objective, performance was based on whether overflows occurred from an event, and how much of the outflow volume was reduced by the system. The details of the synthetic storms' parameters and the basis for their selection are discussed later in this section. Only the Princess Margaret Boulevard location was used for modelling for three main reasons: 1) the groundwater table was consistently low; 2) downspouts in this residential area were disconnected, and; 3) the soil type consisted of silty sand to clayey silt. Modelling of this pilot site enabled analysis of how well the EES performed under clayey silt conditions, as well as the impact that disconnecting downspouts had on the imperviousness of the drainage area. Furthermore, modelling was only carried out between manhole 2 (MH2) and manhole 3 (MH3) of the EES because it was the only section of the system at Princess Margaret Boulevard that has all the monitoring data required for calibration.

The following sections discuss in detail the several steps taken to select the stormwater model, to select the historic storm events, and to calibrate the model parameters which were then used to model and analyze how the EES performed under specified synthetic storms.

3.5.1 Model Selection

Several hydrologic and hydraulic models exist and they can be categorized as continuous or single event, and rural or urban. Event based modelling allows the user to input a few or individual storm events for short term simulation (MNR, 2002b) and estimates runoff generation by using several hydrologic processes such as infiltration, overland flow, channel flow, interception and detention storage (Knapp *et al.*, 1991). Additionally, event based modeling is generally used for designing stormwater infrastructure as it is able to model the stormwater flow in detail through the facility, as well as for operational modelling (Zoppou, 1999). In contrast, continuous modelling allows the user to input precipitation events and inter-event watershed conditions for long term simulation (MNR, 2002b). In addition to the hydrologic parameters used for event based modelling, evapotranspiration, shallow subsurface flow and groundwater flow are also included for runoff generation estimation (Knapp *et al.*, 1991) and thus allows the analysis of a catchment's water balance over a long time period (Zoppou, 1999). Antecedent soil moisture conditions present before and between storm events are also included to account for the effect it has on soil infiltration rates and ultimately runoff generation (Knapp *et al.*, 1991). Furthermore, continuous modelling is often used for planning modelling of water resources (Zoppou, 1999).

In terms of land use (rural vs. urban), the parameters that control runoff characteristics are influenced by the stormwater management system used. For example, urban regions utilize curb and gutters, streets for overland flow, sewer systems, roof top storage, natural or channelized watercourses, etc. Additionally, runoff is generated much faster in urban areas due to the high imperviousness. As such, different models have been developed to specifically address stormwater in either rural or urban catchments (Zoppou, 1999). Regardless of the type of stormwater model, the basic components involved are precipitation, rainfall-runoff modelling and transport modelling (Zoppou, 1999).

The MIDUSS model (Version 2.00, Rev200) was the stormwater model selected and was developed to analyze the hydrological and hydraulic parameters from a specified single event storm in order to help practioners design storm sewers and BMP's (Smith, 2004). MIDUSS was selected for this research because it is the only stormwater model available which includes a design option for the EES. This design option was included when A. Smith, the model developer, was asked to peer-review the design and calculations of the EES. Once the design was verified, the original EES design and calculations were incorporated into the model as a design option (Tran, 2011a). MIDUSS allows the user to modify both catchment and EES trench design parameters until the respective hydrographs are deemed satisfactory, which is necessary for the calibration portion of this modelling objective.

3.5.2 Selection of Historic Events

Before modelling could occur, MIDUSS was first calibrated to a historic storm event that the EES underwent to ensure that the model would behave similarly in function to real life.

To calibrate the model, a historic event was first selected in which there were monitoring data. Candaras (1997) documented the monitoring data for the Princess Margaret Boulevard location for four historic events and included the rainfall hyetographs, and the system hydrographs detailing the inflow, outflow and upstream/downstream trench head between MH2 and MH3, for each event. However, only one of the four historic events resulted in monitoring data which had measured values for head in the upstream portion of the trench. It is important that the upstream trench head is available for calibration because it is this water level that determines whether or not an overflow is produced. Since the modelling was being used to analyze overflows, only the October 5-6, 1995 event was used for calibration. This storm was monitored at the Toronto Lester B. Pearson International Airport rainfall station (Climate ID 6158733) and was 18 hours in duration with a total rainfall depth of 63 mm (Fig. 9).

The data of the hyetograph of the selected storm were not available through table format, but only through a graph (Fig. 9). As such, the graph was utilized by manually determining the rainfall intensities for each five minute time scale from the beginning to the end of the storm. This created a table from which to work with.

In MIDUSS, under 'Time Parameters,' the storm duration was 1120 min (to account for time before and after the storm), the time step was 5 minutes, and the maximum storm hydrograph was set at 1500 min (to allow for the hydrograph to continue after the storm stopped). Next, the 'Storm Parameters' were entered by selecting the 'Historic Event' option and using the rainfall data which was manually determined from Figure 9. The re-created hyetograph (Fig. 10) was an 18 hour storm with a 5 min time step, and had a 13.3 mm/hr maximum rainfall intensity and a total depth of 63.903 mm, which was only 0.903 mm or 1% higher than the monitored storm data. As such, the re-created and original hyetographs of the Oct 5-6, 1995 storm were very similar.

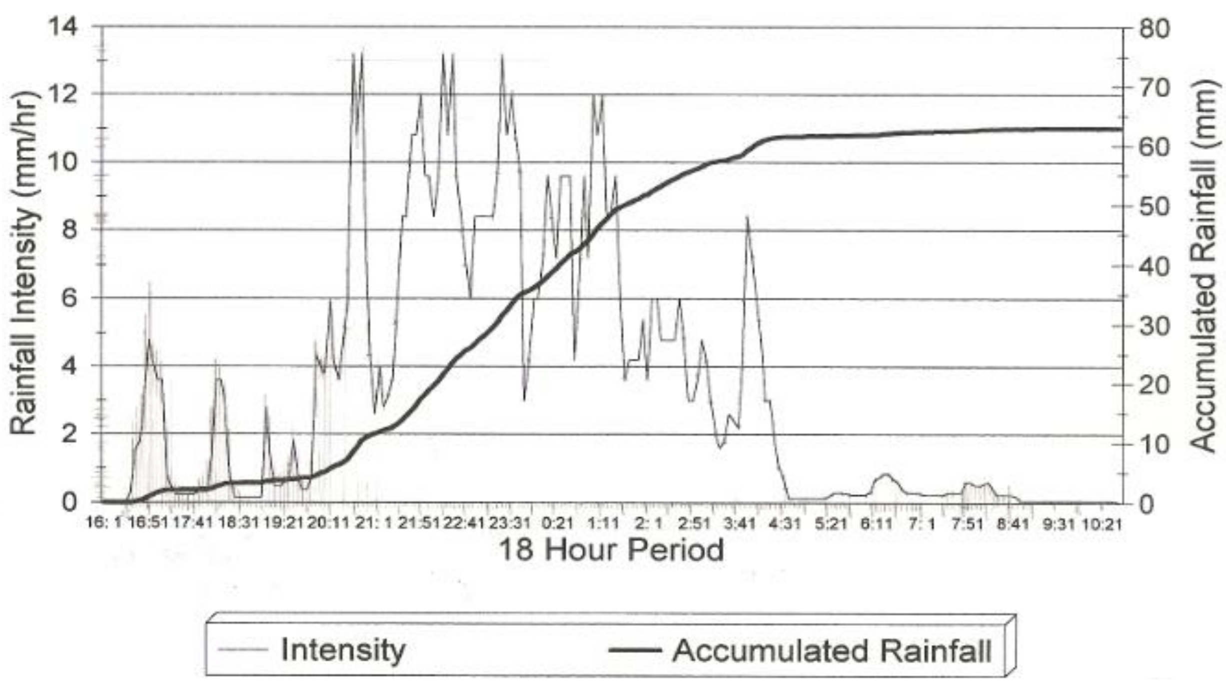


Figure 9: Rainfall hyetograph of October 5-6th, 1995 event (Candaras, 1997).

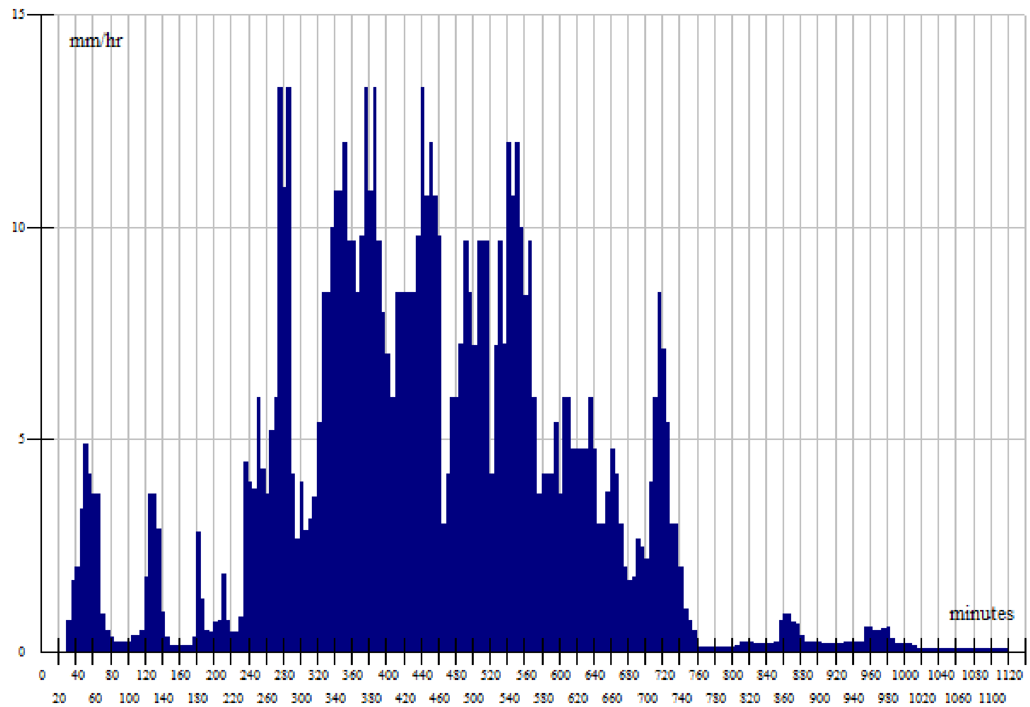


Figure 10: Re-created hyetograph of October 5-6th, 1995 event using MIDUSS.

3.5.3 Calibration

With the historic event accepted in MIDUSS, calibration of the model parameters could start. This involved calibrating both the catchment and the trench design parameters, and accounting for the runoff flow diversion due to the grate's and storm sewer pipe's inlet capacity. Trench design parameters were calibrated under two different C factor values, 0.63 and 1, (reasons to be further discussed) and created two different sets of trench design parameters.

3.5.3.1 Catchment

The first step in model calibration was to determine the catchment parameters which produced the runoff during the time of the historic event. To do this, the MIDUSS hydrograph that was produced from the catchment parameters had to be similar to the measured MH2 inflow hydrograph (Fig. 11) that was monitored for that event. In order to be able to compare these two hydrographs, the measured MH2 inflow hydrograph (Fig. 11) was opened in the XY Extract Graphic Digitizer programme in order to generate a table of the MH2 inflow data points.

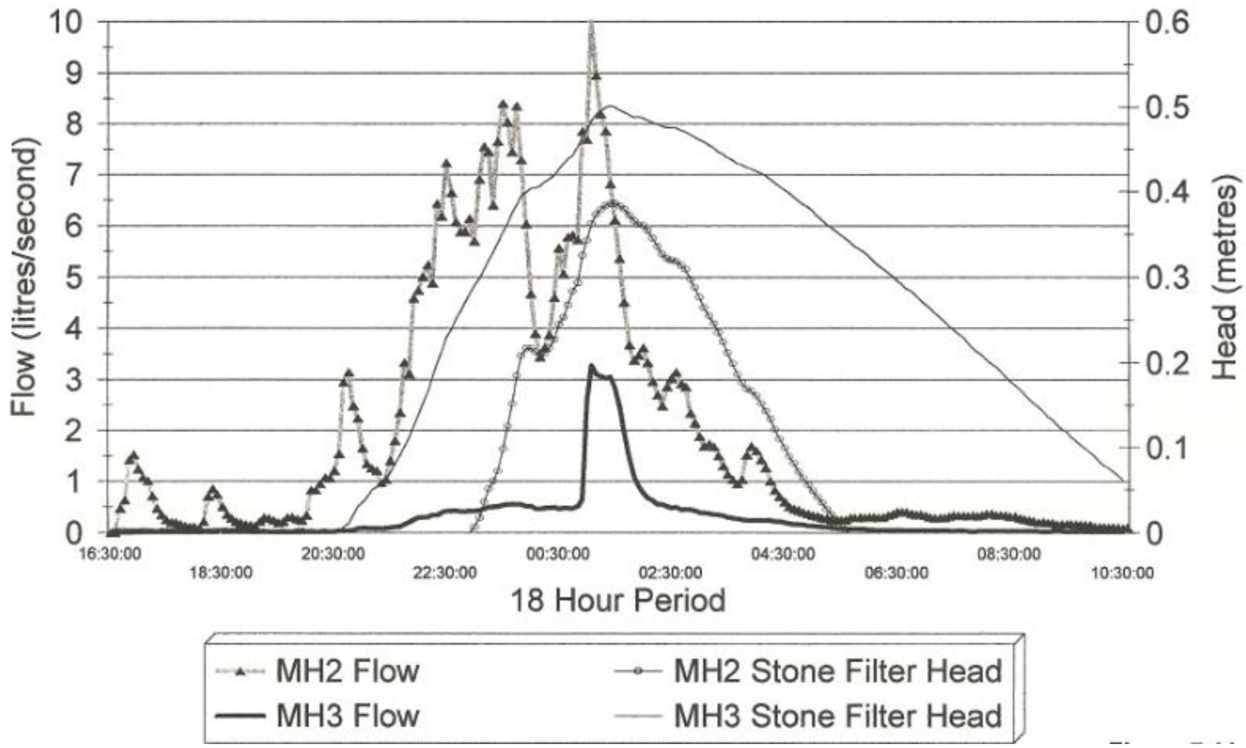


Figure 11: Measured trench hydraulics of the EES for the Oct. 5-6, 1995 historic event. Shows hydrographs of inflow, outflow and upstream/downstream trench head in the EES between MH2 and MH3 (Candaras, 1997).

The XY Extract programme generated a data table of flow vs. time, with time starting from 0 min. For these data to be useable, the flow values had to be converted from litres/second to m^3/sec using the following equation:

$$Flow\left(\frac{litres}{second}\right) \times \frac{1\text{ m3}}{1000\ litres} = Flow\left(\frac{\text{m3}}{second}\right) \qquad \text{Eq. 1}$$

Also, the measured rainfall hyetograph (Fig. 9) began at time 16:01 (hrs) and the measured MH2 inflow hydrograph (Fig. 11) started at time 16:30 (hrs), which indicated that there was a 29 min lag by the time runoff entered the system. However, the XY Extract data began the inflow hydrograph at time 0, which translated to 16:01 (hrs) and as such removed the lag. To correct for this, 29 min were added at the beginning of the XY Extract data, such that the re-created MH2 inflow hydrograph could start at the correct time.

With the measured MH2 inflow re-created, the catchment parameters could be modified until the resulting runoff hydrograph was similar. The following parameters that could be changed are seen in Table 8. Other routing methods available were Triangular SCS, Rectangular and Linear Reservoir, and the pervious and impervious flow length options consisted of equal length or proportional to the percentage. Additionally, infiltration options included Horton's equation, the SCS method and the Green and Ampt method. All of the parameters in Table 8, with the exception of a few, were modified to see which would produce the best fit. Parameters that were fixed include the drainage area and overland slope as these are set values. Also, the infiltration method was fixed as Horton's equation as this is the only method which accounts for both pervious and impervious parameters, which was ideal since the model was simulating urban runoff.

To determine which set of catchment parameters had the best fit, the resulting runoff hydrograph was first analyzed for peak flow and total runoff volume. Measured peak flow was 0.01001 m^3/s and a measured value for total runoff volume was not provided. However, the total runoff volume was determined in the following trench design step and was calculated by MIDUSS to be 129.53 m^3. If it was found that the modelled peak flow and total runoff volume were +/- 10% of the measured values, the model's flow data table was further analyzed for similarity in runoff distribution. This was done by copying and pasting the flow data into Excel, and then creating one graph with two data sets – one with the re-created measured inflow hydrograph and one using the modeled runoff hydrograph. This allowed for the two hydrographs to be easily compared for runoff distribution.

With the exception of a few, all of the catchment parameters were modified several tens of times until the runoff hydrograph was satisfactory and had similar runoff volume, peak flow and distribution. The catchment parameters established and the resulting runoff hydrograph are seen in Table 8 and Figure 12, respectively. Although the runoff hydrograph is the flow above ground while the inflow hydrograph is the flow found within the storm sewer pipe, it was assumed (and subsequently proven in the trench design step) that the runoff hydrograph had minimal changes after being routed through a storm sewer pipe.

Table 8: Calibrated catchment parameter values used in MIDUSS.

Catchment Parameters	
% Impervious	15
Total Area[1]	0.88
Flow Length	300
Overland Slope %[1]	0.45
Routing Method	SWMM method
Pervious & Impervious Flow Length	Prop. to %
Pervious Parameters	
Pervious Slope %	0.45
Manning 'n'	0.03
Max. Infiltration (mm/hr)	80
Min. Infiltration (mm/hr)	5.8
Lag constant (hr)	0.2
Depression storage (mm)	2
Infiltration Method[1]	Horton Eq.
Impervious Parameters	
Impervious Slope %	0.45
Manning 'n'	0.013
Max. Infiltration (mm/hr)	0
Min. Infiltration (mm/hr)	0
Lag constant (hr)	0
Depression storage (mm)	0.5

[1] Fixed parameters (not modified)

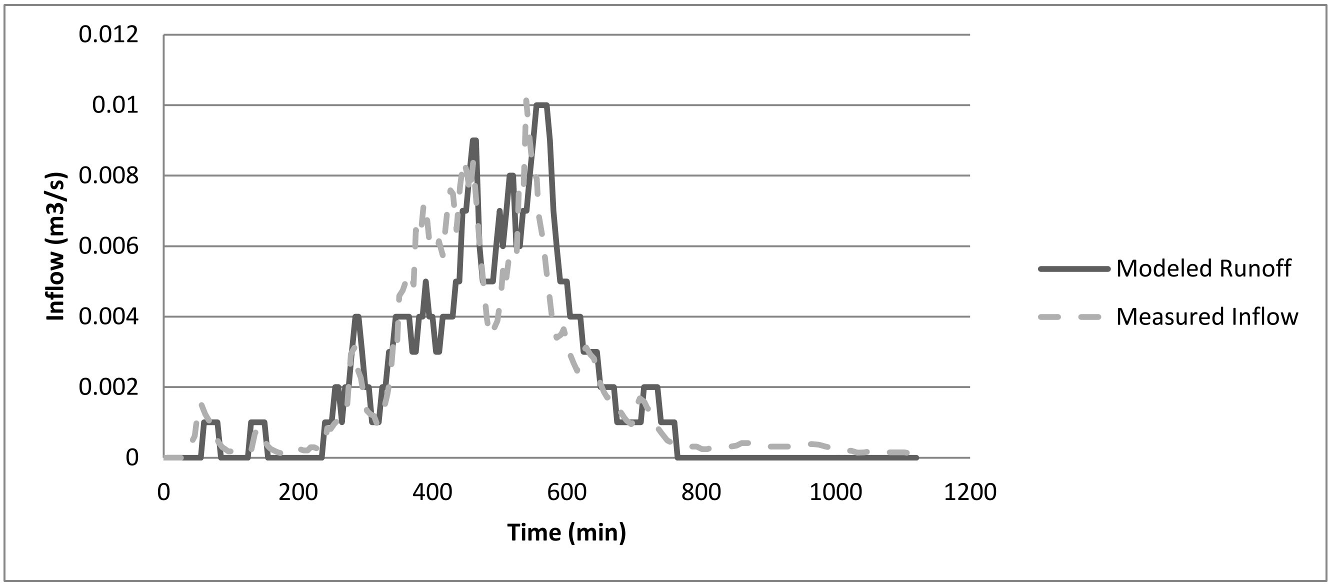


Figure 12: Comparison of measured inflow and modelled runoff for the October 5-6, 1995 event using original catchment parameters.

3.5.3.2 Storm Sewer Pipe Design and Flow Diversion

For this step, the runoff generated from the catchment had to be routed through a storm sewer pipe (from MH1 to MH2) before it could enter the EES at MH2. To do this, the storm sewer pipe had to be designed according to the City of Etobicoke (1992) Works Department drawing specifications (Appendix A), and the inflow into the EES had to account for any runoff diversion that may occur. This diversion was attributed to the inlet capacity of the above-ground grates to capture runoff and the storm sewer's pipe capacity to handle the resulting inflow.

First, instead of using the modelled runoff hydrograph, the measured MH2 inflow hydrograph data were used as input into the system. This ensured accuracy as both calibrated steps were based on measured data. The measured MH2 inflow had been previously re-created; however it had to be converted into a 5 min time step so that it was consistent with the time step used for catchment calibration and could also be entered into MIDUSS. This was done manually by using Excel and closely replicating the measured inflow by creating one graph with two data sets– one with the measured inflow, and one with the 5 min time step measured inflow. As each value was entered for the second data set (5 min time step), it would automatically show on the graph for comparison to the measured inflow and the value could be modified if necessary. The result was a new data table for the MH2 inflow with a 5 min time step.

The MH2 inflow was then entered into MIDUSS by starting with a new model run. Time parameters were entered as similar to that under 3.5.2 Selection of Historic Events and the 'Edit Test

Hydrograph' option was selected from the 'Hydrograph' tab. The new data table for the MH2 inflow was copied and pasted into the table displayed in the 'Edit Test Hydrograph.' When accepted, this created the MH2 inflow without setting any storm or catchment parameters (Fig. 13). The table also displayed the total runoff volume of 129.53 m^3 which was used in the catchment calibration and the peak flow of 0.01 m^3/s. This file was saved as a hydrograph (hyd.) file so that it could be used for future runs.

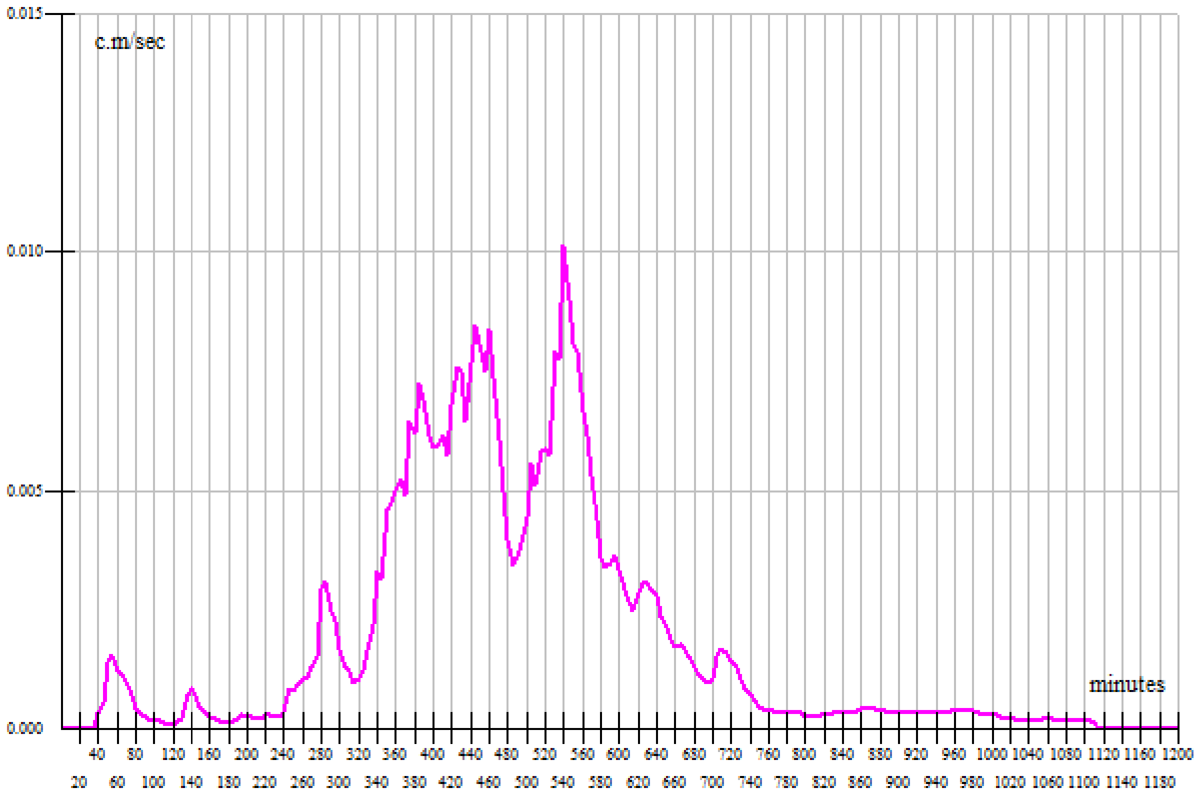


Figure 13: Re-created MH2 inflow of the October 5-6, 1995 event using MIDUSS.

With a new run, the saved hyd. file was loaded to start trench calibration. In reality, flow diversion of the runoff would first occur at the grate where catchment runoff is captured, followed by any reduction of flow (diversion) when the runoff is routed through the storm sewer pipe due to the pipe's capacity. However, MIDUSS was unable to allow flow diversion to occur in this order without several error messages. Instead, the catchment runoff was routed through the designed storm sewer pipe and then underwent a flow diversion threshold according to the calculated total of the grate inlet's capacity. This resulted in the inflow into the EES to have a maximum flow equal to the sum of four of the grate inlet's capacity. The design of the storm sewer pipe and the flow diversion calculations are discussed in detail.

3.5.3.2.1 Storm Sewer Pipe Design

Under the 'Design' tab, the 'Pipe' command was selected. The design of this pipe was according to specifications of the storm sewer pipe between MH1 and MH2 as this was the first section that the catchment runoff was routed through before it entered the monitored section of the EES between MH2 and MH3. Manning's 'n' was set to 0.013 (for concrete smooth storm sewer pipe (FishXing, 2006)), the pipe diameter to 0.375 m, and the pipe gradient as 0.73%. The storm sewer pipe diameter value was determined from the Works Department drawing (City of Etobicoke, 1992) of the EES, but no pipe gradient was displayed in the drawing for the area upstream of MH2. Therefore, the pipe gradient between MH1 and MH2 was assumed to be the same as MH2 and MH3, which was 0.73%. After this pipe design was accepted, the 'Route Pipe' command under the 'Design' tab was selected to route the inflow hydrograph through the pipe. A reach length of 96.95 m was entered as specified by the Works Department (City of Etobicoke, 1992), and the pipe's peak outflow was slightly reduced to 0.00938 m^3/s (Fig. 14).

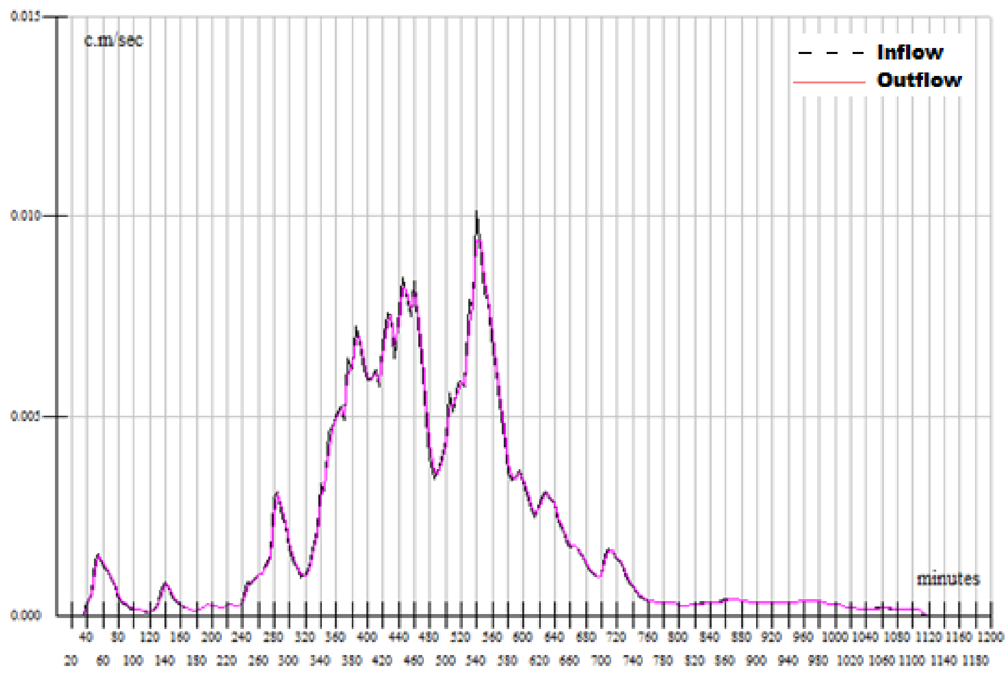


Figure 14: Inflow and outflow hydrograph before and after pipe routing.

3.5.3.2.2 Flow Diversion

Once the runoff was routed through the designed pipe, the 'Next Link' command was selected under the 'Hydrograph' tab. Under the 'Design' tab, the 'Diversion' command was chosen to input the grate inlet's capacity. A message popped up saying that the last pipe was not surcharged; however the diversion was selected to be continued. In order to calculate the inlet capacity of the grates present at the Princess Margaret Boulevard site, several steps were conducted.

First, the grates used at the site were the round frame herring bone style (Fig. 15).

Figure 15: Round frame herring bone grate at Princess Margaret Boulevard site.

The inlet capacity of this type of grate was calculated in a research study by the Ministry of Transportation for "Road and Bridge Deck Drainage Systems" (MOT, 1982). However, its inlet capacity was shown in relative terms to the DD-713 grates of which one has the rectangular herring bone style, as seen in Figure 16.

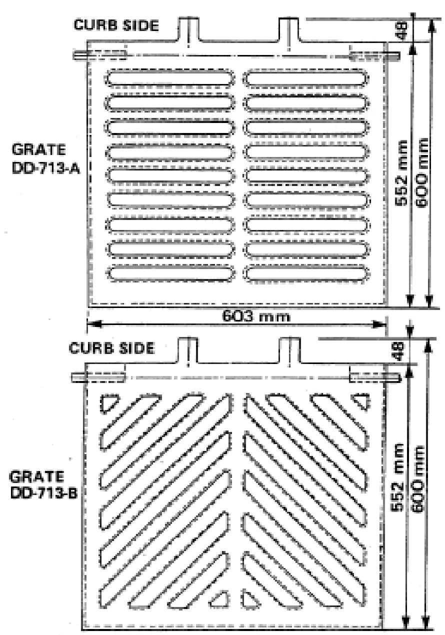


Figure 16: Grate types DD-713-A and DD-713-B. (MOT, 1982).

The round frame herring bone grate was calculated to be 90% of the DD-713 grates at a 0.003 m/m road grade (MOT, 1982). Therefore, the DD-713 grate inlet capacities had to be determined. The DD-713 Type B grate was selected for comparison as it was of similar herring bone style. The inlet capacity of the DD-713 Type B grate was made available in graph format under several scenarios, reflecting various values for the spread, crossfall and road grades tested in the research (MOT 1982). In addition, the DD-713 Type B grate was tested with different curb and gutter styles. The parameter values selected to determine the inlet capacity of the DD-713 Type B grate were the curb and gutter type B, a crossfall of 0.02 m/m, a road grade of 0.003 m/m and a spread of 2.0 m. A crossfall of 0.02 m/m was chosen as the Works Department drawings shows that the slope between the crown and the shoulder of the road is 2% (City of Etobicoke, 1992). A road grade of 0.003 m/m was selected because that is the grade that is used in the research for comparison between the round frame grate and the rectangular DD-713 type B grate (MOT, 1982). A spread of 2.0 m was selected as it is the middle range of the tested values (0.5 to 3 m). Lastly, the curb and gutter type B was chosen because it was the type experimented with the round frame herring bone grate, and because it is the closest resembling style present at the Princess Margaret Boulevard site as seen in Figure 17.

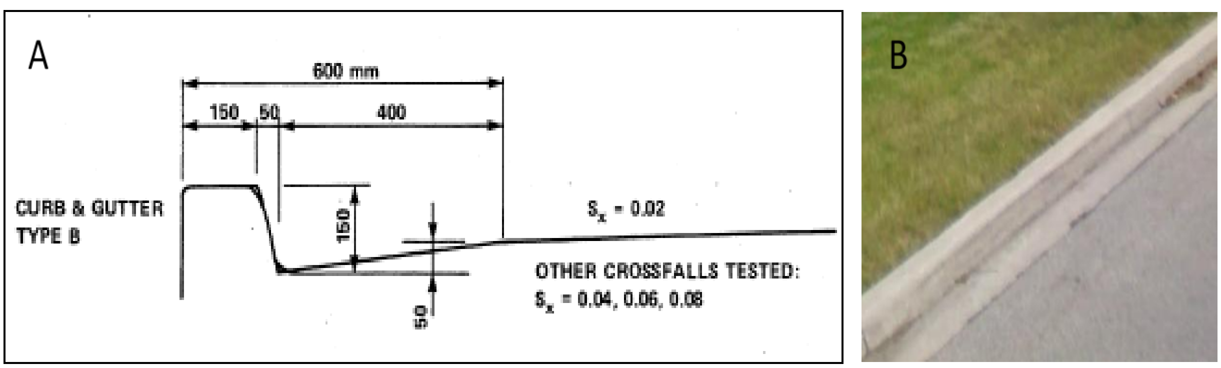


Figure 17: Curb and gutter style. A: Tested curb and gutter type B; B: Curb and gutter at site.

Under these selected parameter values, the inlet capacity of the DD-713 type B grate was estimated to be 0.043 m^3/s (Fig. 18). Therefore, the inlet capacity of the round frame herring bone grate was determined to be around 0.0387 m^3/s. However, this is the inlet capacity of a single grate. Since there are four grates between MH1 and MH2 (Candaras, 1997), the total inflow into the storm sewer pipe between MH1 and MH2 is 0.1548 m^3/s. As such, the overflow threshold in the 'Diversion' window was inputted as 0.1548 m^3/s. When this overflow threshold was accepted, it did not alter the October 5-6, 1995 measured inflow hydrograph because its peak flow of 0.01 m^3/s was much smaller than the total sum of the inflow from the grates (0.1548 m^3/s).

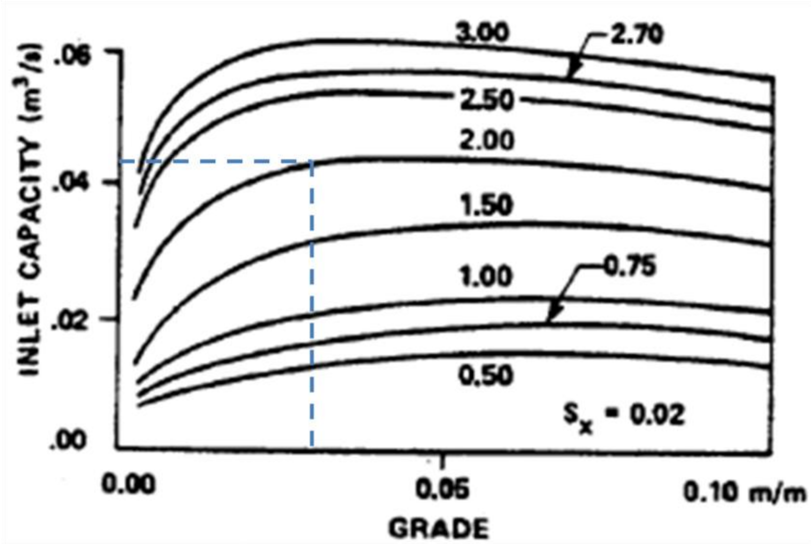


Figure 18: Inlet capacity of DD-713-B grate (MOT, 1982).

3.5.3.3 Trench

With the storm sewer pipe inflow generated, the 'Next Link' command was selected under the 'Hydrograph' tab, to allow for the design of the trench between MH2 and MH3. The 'Trench' command under the 'Design' tab was chosen and two windows were displayed: 'Trench Design' and 'Trench Data'.

The constructed EES is functioning under an orifice discharge (C factor) coefficient of 1 for the perforated pipes (Tran, 2011a). However, the C factor in MIDUSS has been fixed as 0.63 and cannot be modified (Smith, 2004). This means that the modelled trench hydraulics in MIDUSS does not have the same dynamics as that in the constructed EES. Under a C factor of 0.63, the rate of runoff and thus volume of runoff entering the perforate pipes will be less than under a C factor of 1. Therefore, the trench parameters were calibrated twice (under two separate trench calibration runs) to generate two sets of trench parameters in which one functions with a C factor of 0.63 and the other with a C factor of 1. This allowed for accurate modelling of the EES to account for the difference in C factor values, and also showed how the C factor impacts the EES performance.

3.5.3.3.1 C Factor 0.63

The majority of the trench parameters' values were based on the City of Etobicoke Works Department (Cit of Etobicoke, 1992) drawing for the Princess Margaret Boulevard EES between MH2 and MH3. The original trench parameters used in the 'Trench Data' window are shown in Table 9.

The ground elevation, trench gradient and length between MH2 and MH3 were directly taken from the Works Department drawing (City of Etobicoke, 1992); however downstream trench invert, trench height and trench top/bottom width were calculated based on the drawing. To do so, the thickness of the concrete storm sewer pipe was first determined. Knowing that the concrete pipe had an inside diameter of 450 mm (City of Etobicoke, 1992), the thickness was calculated:

$$Concrete\ pipe\ inside\ dia. = 450\ mm\ \times \left(\frac{1\ inch}{25.4\ mm}\right) \quad \text{Eq. 2}$$

$$= 17.72\ inches$$

$$Concrete\ pipe\ thickness = \left(\frac{17.72\ inches}{12}\right) +\ 1 \quad \text{Eq. 3}$$

$$= 2.48\ inches$$

$$= 62.9\ mm\ (0.0629m)$$

Downstream trench invert:

The downstream invert of the concrete pipe was 154.879 m (City of Etobicoke, 1992.) and was measured at the invert of the inside of the pipe. Additionally, there was a 0.35 m distance between the concrete pipe invert and the perforated pipe invert below, and there was 0.3 m depth below the perforated pipes. Therefore, the downstream trench invert was calculated by:

$$Downstream\ trench\ invert = 154.879\ m - 0.0629\ m - 0.35\ m - 0.3\ m \quad \text{Eq. 4}$$

$$= 154.17\ m$$

Trench height:

From the Candaras (1997) cross-section diagram (Fig. 4) and the City of Etobicoke (1992) Works Department drawing, the following parameters were known: height above concrete pipe (0.3 m), concrete pipe inside dia. (0.45 m), perforated pipe dia. (0.2 m), distance between inverts of concrete pipe and perforate pipe (0.35 m), and depth below perforated pipe (0.3 m). The thickness of the perforated pipe was insignificant as it was a small pipe. Using the thickness of the concrete pipe (0.0629 m), the trench height was determined:

$$Trench\ Height = 0.3\ m + 0.45\ m + 2(0.0629)\ m + 0.35\ m + 0.3\ m \quad \text{Eq. 5}$$

$$= 1.5258\ m$$

Trench top/bottom width:

Similarly to trench height, the following inputs were already known: distance between trench boundary and middle of perforated pipe (0.5m), perforated pipe dia. (0.2m), distance between closest edges of perforated pipe and concrete pipe (0.25m) and concrete pipe inside dia. (0.45m). Coupled with the thickness of the concrete pipe, the trench width was:

$$Trench\ width = 2\left[0.5\ m + \frac{0.2m}{2} + \ 0.25\ m\right] + 0.45\ m + 2(0.0629\ m) \qquad \text{Eq. 6}$$

$$= 2.2758\ m$$

The exact depth of the water table elevation in this location was not determined as boreholes were still dry at depths of 14 m (Candaras, 1997); therefore the water table elevation input was set at 10 m (in reference to the datum) which was much greater than a depth of 14m.

Boreholes were tested for hydraulic conductivity and borehole 6 (closest to MH2 and MH3) was found to be of sandy silt to silty sand soil type with a hydraulic conductivity (K) of 7 x 10^{-7} cm/s. To convert the K from cm/s to mm/hr for use in MIDUSS:

$$K = \left(\frac{7\ x\ 10^{-7} cm}{sec}\right)\ x\ \frac{60\ sec}{1\ min}\ x\ \frac{60\ min}{1\ hr}\ x\ \frac{10\ mm}{1\ cm} \qquad \text{Eq. 7}$$

$$= 0.0252\ mm/hr$$

The trench volume was automatically calculated by MIDUSS, and accounted for the trench dimensions, but also the volume of the perforated pipes. Additionally, the access riser diameter was assumed to be 1.2 m as it is a standard value for this parameter (Smith, 2004). Additionally, the options to use perforated pipes to distribute the inflow, and as well to have the inflow to the main pipe at the upstream end of trench, were selected. A summary of the original values of the trench design parameters is shown in Table 9.

Table 9: Original trench design parameters between MH2 and MH3 used in MIDUSS.

Trench Data:		Reference
Ground elevation (m)	158	City of Etobicoke, 1992
Downstream trench invert (m)	154.17	Eq. 4
Trench height (m)	1.5258	Eq. 5
Water table elevation (m)	10	Candaras, 1997
Trench top width (m)	2.2758	Eq. 6
Trench bottom width (m)	2.2758	Eq. 6
Voids ratio (%)	40	Candaras, 1997
K (mm/hr)	0.0252	Borehole #6, Candaras, 1997
Trench gradient (%)	0.73	City of Etobicoke, 1992
Trench length (m)	96.95	City of Etobicoke, 1992
Trench volume (m^3)	134.8	MIDUSS
Access riser diameter (m)	1.2	Smith, 2004

Once the trench data were accepted, the 'Outflow Pipes' was chosen from the 'Outflow Control' tab. This allowed details of the concrete storm sewer pipe to be entered. The values used are in Table 10.

Table 10: Outflow control parameters between MH2 and MH3 used in MIDUSS.

Outflow Data (Storm Sewer):		Reference
Upstream invert level (m)	155.589	City of Etobicoke
Downstream invert level (m)	154.879	City of Etobicoke
Pipe length (m)	96.95	City of Etobicoke
Pipe diameter (m)	0.45	City of Etobicoke
Manning's 'n'	0.013	FishXing, 2006
Entry loss Ke	0.5	Smith, 2004

All of the inputs for outflow data were taken from the Works Department drawing (City of Etobicoke, 1992), except for the Entry Loss Ke value which is standard (Smith, 2004) and Manning's 'n' which is for smooth concrete pipes (FishXing, 2006).

Next, the 'Pipes' command was selected from the 'Geometry' tab to input details about the perforated pipes in relation to the concrete pipe. The values used are in Table 11. The downstream invert of the perforated pipes were calculated using the downstream invert of the concrete pipe (154.879 m), the distance between the inverts of the concrete and perforated pipe (0.35 m) and the thickness of the concrete pipe (0.0629 m).

$$Downstream\ invert\ of\ perf.pipe = 154.879\ m - 0.35\ m - 0.0629\ m \qquad \text{Eq. 8}$$

$$= 154.47\ m$$

Table 11: Pipe parameters between MH2 and MH3 used in MIDUSS.

Trench pipes:	Pipe 1	Pipe 2	Pipe 3
Downstream Invert (m)	154.879	154.47	154.47
Pipe Length (m)	96.95	96.95	96.95
Pipe Diameter (m)	0.45	0.2	0.2
Pipe Grade (%)	0.73	0.73	0.73
Perforated?	No	Yes	Yes

The remaining input parameters in Table 11 were taken from the City of Etobicoke (1992) Works Department drawing. The cross-section of the EES design is seen in Figure 19.

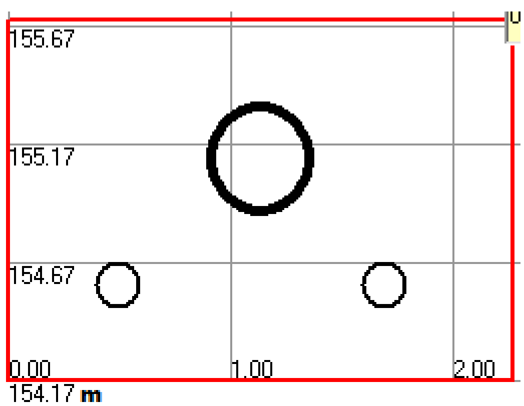


Figure 19: Cross-section of EES in MIDUSS.

Once the pipe geometry was entered, the trench volume was recomputed to account for the volume taken up by the perforated pipes. The pipe inflow was then routed into the system, with MIDUSS giving details about the hydraulics. Figure 20 shows the profile of the EES with the inflow into the system, while Figure 21 is the system hydrograph showing the inflow and outflow of the system, as well as the exfiltration. Both figures show that an overflow of 42.2 m^3 occurred with a peak flow of 0.005 m^3/s.

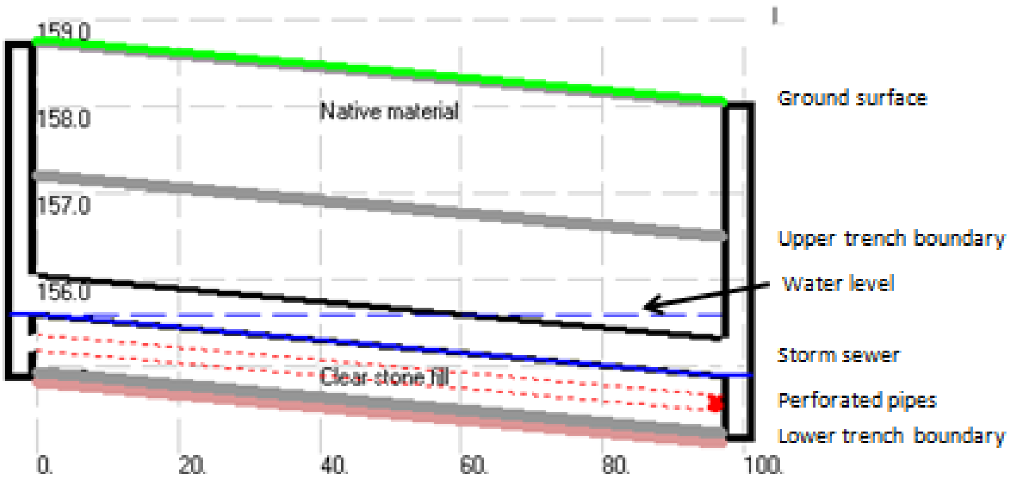


Figure 20: Profile of EES in MIDUSS before calibration showing a system overflow.

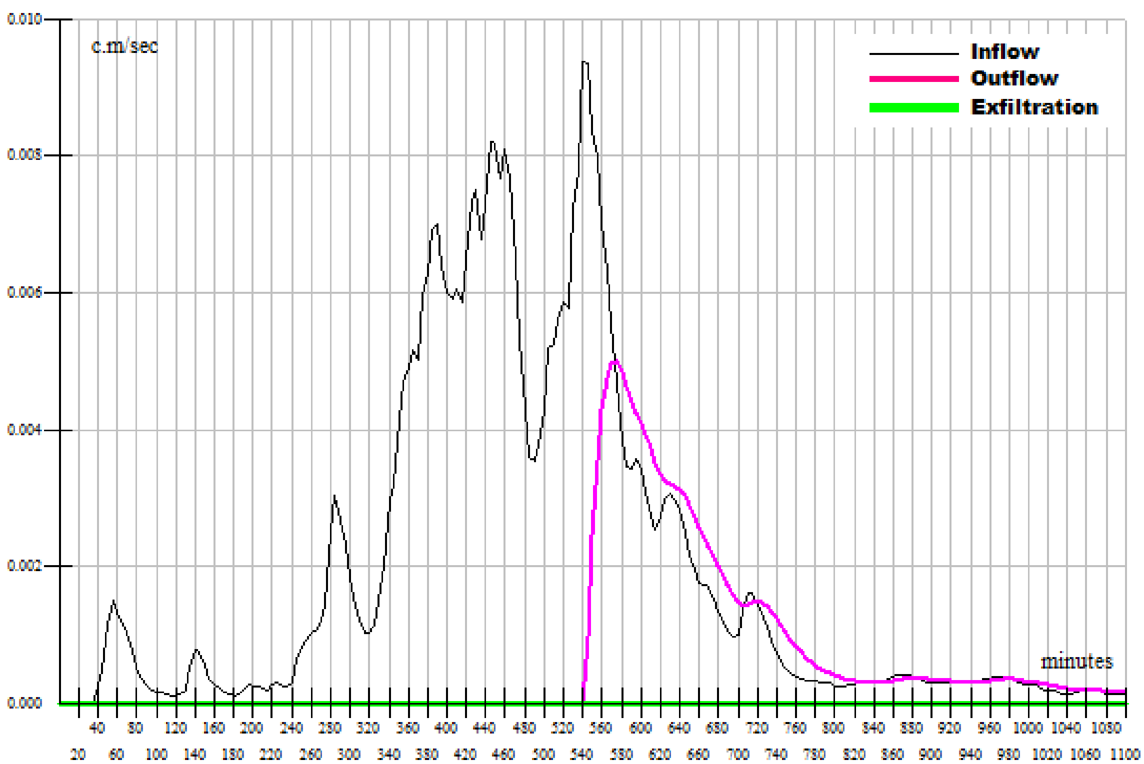


Figure 21: EES trench hydraulics using original soil hydraulic conductivity (K) of 0.0252 mm/hr. Overflow is produced.

Additionally, the maximum head within the system's upstream trench was given by MIDUSS and reached 155.6 m. To compare this number to the measured upstream trench head of 0.38 m, the upstream trench invert was calculated. This was done by using the downstream trench invert (154.17 m) of the system from Eq. 4 and adding the difference between the downstream and upstream trench inverts which was determined using the trench length and the trench gradient.

$$Difference\ in\ trench\ invert\ level = 96.95\ m\ x\ \left(\frac{0.73\%}{100}\right) \qquad \text{Eq. 9}$$

$$= 0.708\ m$$

$$Upstream\ trench\ invert = 154.17\ m + 0.708\ m \qquad \text{Eq. 10}$$

$$= 154.878\ m$$

With the upstream trench invert, the head level within the upstream trench was determined:

$$Upstream\ trench\ head = 155.6\ m - 154.878\ m \qquad \text{Eq. 11}$$

$$= 0.722\ m$$

The modelled upstream trench head of 0.722 m was much higher than that measured of 0.38m. Therefore, changes were required in the design of the trench to calibrate the upstream trench head to 0.38m. The majority of the values used in Tables 9, 10, and 11 are the actual constructed values and as such could not be modified. However, the hydraulic conductivity K was altered for calibration as it was the only design input that was not fixed.

The K value was increased to 27.4mm/hr which gave a maximum water level of 155.258 m and thus, an upstream trench head of 0.38 m. The EES trench results of the calibration are shown in Figures 22 and 23 which indicate that no overflow occurred. Although the calibrated K value was much higher than that measured, it was still within an accepted range of K values for soil and was equivalent to clay loam which has a K of 20-70 mm/hr (Hazleton & Murphy, 2007). Reasons for the difference between the measured and calibrated K may include variability within or between soil layers (Oosterbaan & Nijland, 1994) or the occurrence of fractures which may have widened after 20 years (Fitts, 2002).

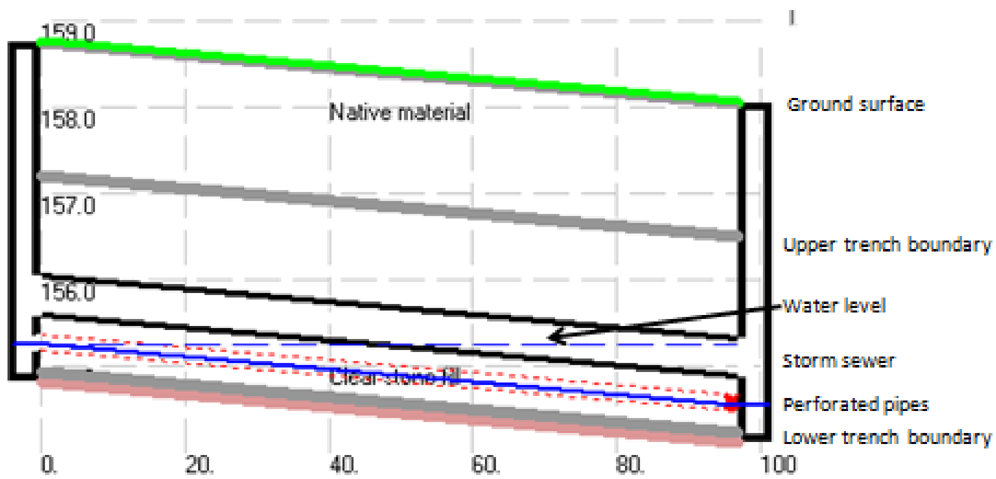


Figure 22: Trench system showing no overflow after trench calibration.

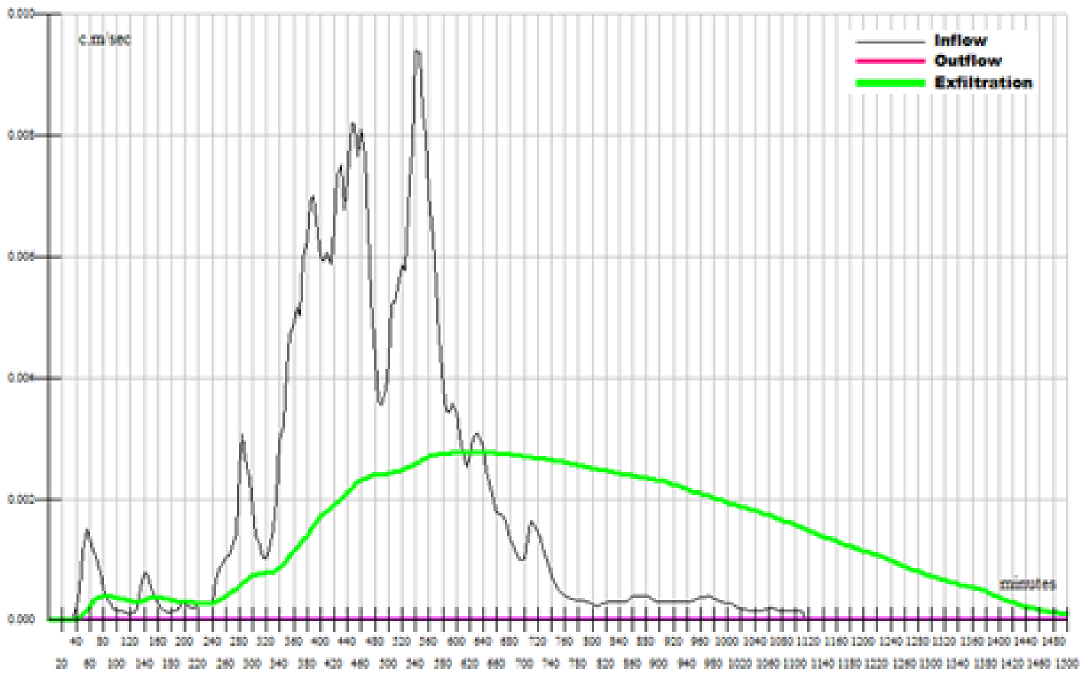


Figure 23: Trench hydraulics after calibration showing inflow and exfiltration rate, with no outflow occurring.

3.5.3.3.2 C Factor 1

The previous set of trench parameters were calibrated with the trench hydraulics functioning under a C factor of 0.63. In order for the MIDUSS model to act similarly in trench dynamics as the constructed EES, the trench design parameters were modified such that they would simulate a C factor of 1. This was carried out in a series of steps.

First, the level of head required for an overflow in the constructed EES was determined to be 0.713 m. This was done using the EES cross-section diagram (Fig. 4) to calculate the height between the upstream invert of the storm sewer pipe and the invert of the upstream trench (0.65 m), and adding the concrete pipe thickness of 0.0629 m. This level of head would determine the amount of pressure exerted on the runoff at the bottom of the manhole, and thus affect the flow rate into the perforated pipes.

Second, the flow rate of the runoff entering the perforated pipes was calculated under a C factor of 1 and using the orifice equation (Q = flow (m^3/s), C = coefficient of discharge (C factor), A = area of perforated pipe (m^2), g = gravitational force 9.81 m^2/s, H = head (m):

$$Q = CA\sqrt{2gH} \qquad \text{Eq.12}$$

The area of the perforated pipe was calculated to be 0.0314 m^2 by using the 0.2 m diameter of the perforated pipe. Therefore, the runoff flow rate entering a single perforated pipe with a C factor of 1 and under 0.713 m of head was determined to be 0.117 m^3/s. However, the runoff flow rate under a C factor of 0.63 was calculated to be 0.074 m^3/s. This showed that the trench hydraulics under the MIDUSS model was not simulating the real dynamics that occurred with a C factor of 1.

Third, the flow rate of 0.117 m^3/s needed to be recreated under the C factor of 0.63, which is fixed within MIDUSS. To do this, the level of head required to generate a flow rate of 0.117 under a C factor of 0.63 was calculated by using Equation 12 and solving for H which revealed that 1.7964 m of head in the upstream trench was required. This meant that under MIDUSS conditions of a C factor of 0.63, an overflow would have to occur with a head of 1.7964 m (to simulate a C factor of 1), and not 0.713 m which was the current model trench dynamics.

Last, the trench design parameters were adjusted to reflect a C factor of 1 such that an overflow would occur at 1.7964 m head and not 0.713 m. This was done by subtracting 1.7964 m from the upstream trench invert (154.878 m), downstream trench invert (154.17 m) and downstream perforated pipe invert (154.47 m) (Table 12). In essence, the bottom half of the EES (trench invert and perforate pipe invert) were replaced 1.7964 m further down, while keeping the top half (storm sewer pipe) in the same location. Also, the trench height was adjusted to reflect this change and was calculated to be 2.6093 m (upstream trench invert to upstream storm sewer pipe invert (1.7964 m), storm sewer pipe diameter (0.2 m), thickness of storm sewer pipe (0.0629 m), top of storm sewer pipe to vertical boundary of trench (0.3 m). The trench design parameters that were modified to simulate a C factor of 1 are shown in Table 12.

Table 12: Modified trench parameters to simulate a C factor of 1.

	C Factor 0.63	C Factor 1
Upstream trench invert (m)	154.878	153.7926
Downstream trench invert (m)	154.17	153.0826
Downstream perforated pipe invert (m)	154.47	153.3826

The values of the remaining trench design parameters found in Tables 9, 10 and 11 that have not been revised in Table 12, were used as part of the trench design data, including the original K value of 0.0252 mm/hr. With this data inputted, it was found that although no overflow occurred, the maximum head level in the upstream trench was 1.0694 m (1.7964 m required for an overflow). Since the measured head level was 0.38 m (Candaras, 1997), the K parameter was calibrated to 26.5 mm/hr which produced an upstream trench head of 0.38 m.

A summary of the two calibrated sets of trench design parameters to model under a C factor of 0.63 and 1 can be found in Appendix A.

3.5.4 Modeling

With the catchment, pipe and trench parameters calibrated, modelling of the EES could then be carried out. For the purpose of this modeling research, the EES was analyzed on how well it performed under specific single event synthetic storms, for each of the two calibrated trench parameters (C factor of 0.63 and 1). Therefore, each synthetic storm was run twice using the same catchment and pipe parameters but with different trench parameters. The performance was based on if overflows occur and how much the overflow volume and peak flow was reduced.

3.5.4.1 Synthetic Storms

The synthetic storms used were the 2-, 5-, 10-, 25-, 50-, and 100-yr storms based on the Chicago distribution. This range of return periods for storms was used as it is frequently used for designing and modelling stormwater management practices (MOE, 2003; City of Mississauga, 2009). The Chicago method was used because the distribution of the storm generates high peak intensities and consequently higher runoff flows which warrants its use for designing urban stormwater management practices (CH2M Gore & Storrie Limited, 1997). Additionally, the Transportation and Works Department in Mississauga uses this range of return periods, as well as the Chicago method. Not only does this provide the Chicago storm A, B, and C parameters, but the IDF curves are based on rainfall data taken from the Pearson International Airport rainfall station (City of Mississauga, 2009). This is the same rainfall station used for the calibration of the model using the October 5-6, 1995 storm (Candaras, 1997). It is essential to use rainfall data from similar locations as rainfall data can vary across regions, and consequently affect the design and performance of stormwater management practices.

The Chicago storm parameters associated with the return period are seen in Table 13. The 'r' input of 0.4 is a standard value for Chicago storms (Smith, 2004). The duration of each synthetic storm is also given. The 2-yr storm had a duration of one hour because 25mm synthetic storms are often used for designing stormwater management practices (MOE, 2003). The 1 hour 2-yr Chicago storm for Mississauga was a storm of nearly 25 mm total rainfall depth, and was therefore reasonable to use. Meanwhile, the 5- to 50-yr storms were four hours in duration because this duration for these return periods is also commonly used for designing and modelling practices (MOE, 2003). However, the 100-yr storm was given a duration of 12 hours. Under the Conservation Authorities Act, flood prone areas are identified as those which would be affected by the Timmins Flood Event Standard and other extreme 100-yr event standards. The Timmins Flood was a 100-yr flood event which produced a total rainfall depth of 193 mm over a 12 hour duration (MNR, 2002b). Therefore, a duration of 12 hours for a 100-yr storm was suitable for modelling an extreme event.

A two minute time step was used for all synthetic storms because a 5 min time step for the 100-yr Chicago storm resulted in the model automatically modifying the time step to 2.5 min during the trench design. Thus to round off the number and to be conservative, a 2 min time step was used. This is an important factor in understanding the performance of the EES under these synthetic storms. Using a 2 min time step had modified the storms such that the total rainfall depth was the same, but the peak rainfall intensity was much higher than that of a storm with a 5 min or 10 min time step. Therefore, the synthetic storms used for modelling were the extreme scenarios of each return period.

3.5.4.2 Running the Model

With the time and storm parameters entered for a specific Chicago storm, the model was then run with the catchment parameters and the pipe and trench parameters that were previously calibrated. A threshold diversion of 0.1548 m^3/s was also used, as done in Section 3.5.3.2.2 Flow Diversion. Once the inflow hydrograph was routed through the trench system, the values for peak exfiltration, infiltrated volume, maximum water level, maximum storage, and the total volume and peak flow of the outflow (if any) were recorded. The upstream trench head was calculated using Equation 13, and the reduction percentage of overflow volume was determined by:

$$Runoff\ volume\ reduction\ (\%) = 1 - \left(\frac{Total\ overflow\ volume\ (m^3)}{Total\ runoff\ volume\ (m^3)}\right) x\ 100 \qquad \text{Eq. 13}$$

The reduction percentage of the outflow's peak flow was also determined using the peak flow of the catchment runoff and the system's outflow:

$$Runoff\ peak\ flow\ reduction\ (\%) = 1 - \left(\frac{Peak\ outflow\ (m^3/s)}{Peak\ catchment\ runoff\ (m^3/s)}\right) x\ 100 \qquad \text{Eq. 14}$$

Table 13: Time and storm parameters for Mississauga's 2- to 100-yr Chicago storms

Design storm	Time Parameters			Chicago Storm Parameters				
	Time Step (min)	Duration (min)	Max Storm Hydrograph (min)	A	B (min)	C	r	Duration (min)
2-yr	2	60	500	610	4.6	0.78	0.4	60
5-yr	2	240	1000	820	4.6	0.78	0.4	240
10-yr	2	240	1500	1010	4.6	0.78	0.4	240
25-yr	2	240	1500	1160	4.6	0.78	0.4	240
50-yr	2	240	1500	1300	4.7	0.78	0.4	240
100-yr	2	720	1500	1450	4.9	0.78	0.4	720

These modelling steps were carried out for all of the return periods of the Chicago storm between 2- to 100-year events. However, when modeling the 100-year Chicago storm, a slightly different method had to be taken during the pipe design. The maximum total runoff inflow that can enter the storm sewer pipe between MH1 and MH2 is 0.1548 m^3/s (due to diversion). But the storm sewer pipe from MH1 to MH2 has a diameter of 375 mm and gradient of 0.73%, and thus a pipe capacity is 0.15 m^3/s, which is slightly smaller than the runoff inflow into the pipe. When the pipe was designed for the 100-yr synthetic storm using the original pipe parameters mentioned, an error message stated that the pipe was surcharged and the option to separate major and minor flow was selected. Thereafter, the 'Diversion' command window was automatically opened with the overflow threshold value already set at 0.148 m^3/s to reflect the pipe's capacity. This threshold was accepted and resulted in an inflow hydrograph (Appendix A) with a peak flow cut-off at 0.148 m^3/s and a new runoff volume of

476.83 m^3. Once accepted, the ‘Pipe’ command window automatically reopened where the original pipe parameters were then entered and able to accommodate the new adjusted inflow. The ‘Route Pipe’ command was then selected, followed by the ‘Next Link’ command which led to the design of the trench.

3.5.5 Pre-Development Runoff

The runoff generated under a pre-development scenario of the modeled catchment was also carried out for all of the modelled synthetic storms (2- to 100-yr). The catchment parameters previously calibrated were used except for the impervious percentage which was set to zero to simulate pre-development. This was done to compare the pre-development and post-development EES outflow hydrographs in terms of runoff duration, time to peak, peak flow, and volume.

3.6 Objective 3: EES Fulfilment of New Stormwater Management Objectives

The stormwater management objectives that are addressed by the EES have never been analyzed. Little research has been conducted on the EES; however, a few reports such as those by Candaras (1997) and SWAMP (2004), and the EES Design Manual (2011b) provided information which was used to determine which objectives the EES may achieve. The MIDUSS modelling from this research also provided insight for hydraulic and hydrologic mitigation. Additionally, in lieu of limited data, observations of the environment and road infrastructure at the two pilot study sites were used. Overall, based on the documents, modelling and observations, a holistic approach was used to rationalize which objectives the EES has fulfilled.

4.0 Four Seasons based Stormwater Management

4.1 Characteristics of Ontario's Seasons

Ontario's four distinct seasons, fall, winter, spring and summer, each have their unique climate and rainfall patterns in regards to precipitation volume, intensity, frequency, duration, and direction (Singh, 1997). Each season's conditions and the associated stormwater characteristics will be discussed below, and although categorized into four subsections, information about one season may be found in another subsection for comparison.

4.1.1 Summer

Summer (mid June to August) is characterized as the season with the hottest temperatures and high intensity short duration storms (MOE, 2003), which are sometimes observed as thunderstorms. This season has most of the severe rainfall events (Cao & Ma, 2009). A study by Dickinson (2010) of Southern Ontario seasonal rainfall extremes (omitting winter data) showed that the return period for an event with a specific rainfall volume and duration decreased in summer, in comparison to spring or fall. In other words, a 20mm rainfall event lasting 30 minutes in summer had a return period of around 10 years, while the chance of that same event occurring in fall or spring was more than once in a hundred years. This seasonal pattern occurred for all storm durations between 10 to 1440 minutes. Additionally, it was found that the range of seasonal variability in extreme rainfalls decreased as the storm duration increased. This means that the mean summer extreme event with a short 5 minute duration is larger than the April mean by more than two-fold, while a mean summer extreme event with a long 24 hour duration was much closer to the April mean. Overall, most extreme rainfall events occur during summer.

According to the 2003 SWM Manual (MOE, 2003), peak stream flows are increased during summer; however this is in contrast to one study which reported differently. Vink and Chin (2004) analyzed flow data from 1955 to 1997 for four streams in the Greater Toronto Area: Etobicoke Creek, Humber River, Rouge River and Duffin Creek. The precipitation of both rainfall and snow, and snowmelt were accounted for. It was found that for all the studied streams, spring had the highest peak mean daily flows, comprising of between 46% to 62% of the peak mean daily flows (Fig. 24). This was in contrast to summer which had the least peak mean daily flows, but instead the most minimum mean daily flows (55 to 85%). This comes as no surprise because the researchers also found that spring had the highest cumulative mean seasonal flow (up to 71% in Etobicoke Creek) which is mainly due to snowmelt, and summer had the lowest (as little as 4% in Etobicoke Creek). The cumulative mean seasonal flow in just spring and winter alone accounted for 74% and more of the total cumulative annual flow in the analyzed streams. The distribution of cumulative mean seasonal flows for the four studied streams is shown in Figure 25.

Furthermore, while we know that precipitation patterns vary across the seasons, the same is to be said for soil erodibility, K, which describes how resistant a type of soil is to the water erosion processes (detachment, entrainment, and transport) (Wall *et al.*, 19887). Wall *et al*. (1988) found that not only does K vary throughout the year, but the range of variation is influenced by the soil type. Summer had the lowest K values and the end of winter until spring had the highest.

4.1.2 Fall

Fall (September to November) is similar to summer during in September such that is also has high intensity and short duration storm events (MOE, 2003). While later in fall such as in November, the temperature begins to lower and events have medium intensity and long duration. In addition to what has been discussed above regarding fall storm and stormwater characteristics, Dickinson (2010) also showed that November had the least rainfall extremes for events under six hours. This most likely signifies the transition into winter.

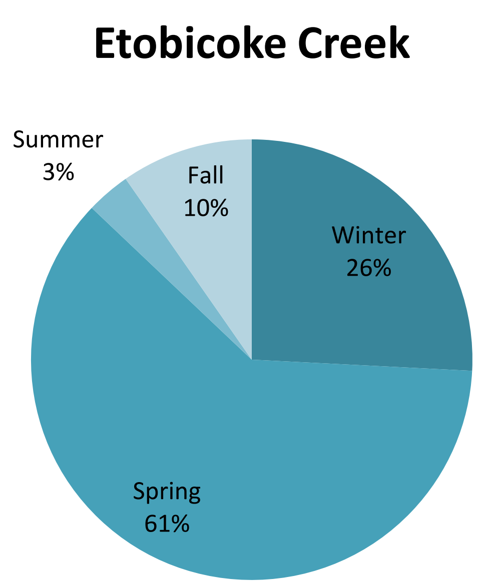


Figure 24: Seasonal distribution of peak mean daily flow between 1967-1997. (Vink & Chin, 2004).

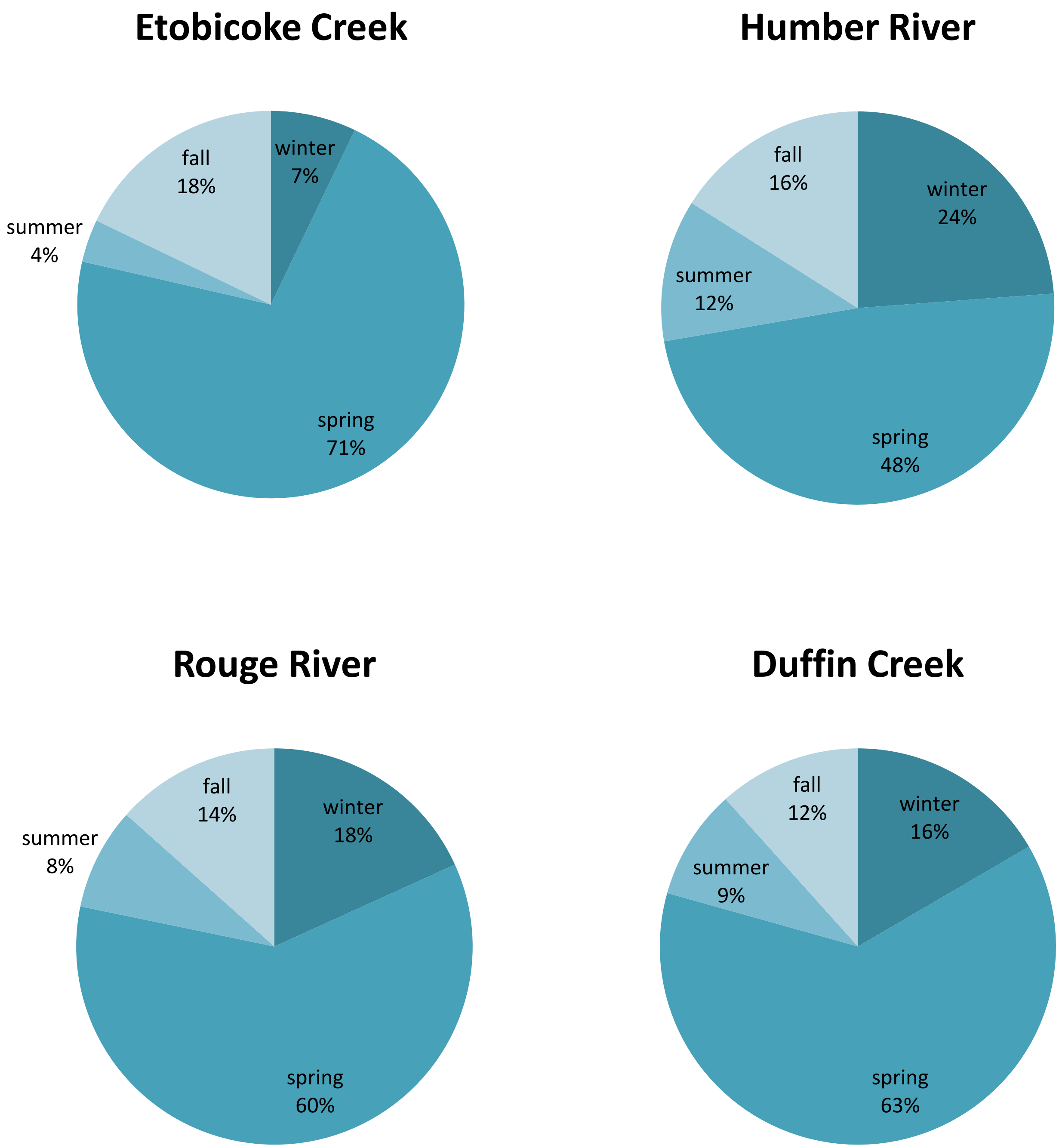


Figure 25: Distribution of cumulative mean seasonal flow between for four streams in the Greater Toronto Region: Etobicoke Creek (1967-1997), Humber River (1957-1997), Rouge River (1962-1997) and Duffin Creek (1955-1989). (Tran *et al.*, 2012).

4.1.3 Winter and Spring

Winter (December to mid March) and spring (mid March to mid June) in Ontario is generally in the form of low intensity and long duration events (MOE, 2003). These two seasons will be discussed together because the winter hydrology significantly influences that of spring.

During winter, the drop in temperature results in large amounts of snow covering the ground with a frost layer at the top of the soil profile. As long as the snow remains in its frozen state, there are no runoff problems. However, once melting begins, snowmelt must be managed. To do this, the snowmelt process in an urban setting must be well understood.

Snowmelt can occur through different means, and has three stages (Oberts, 2000). First, there is 'pavement melt', which involves the melting of snow by deicers (i.e. NaCl) and/or the effect of the sun's heat. Second, there is 'roadside melt' consisting of roadside snow piles melting periodically. Third, the largest runoff contributor of snowmelt is the 'pervious area melt' whereby snow piles on non-paved areas (i.e. lawns) melt quickly. The last two stages can occur throughout winter on a small scale, but as the temperatures becomes warmer at the end of winter these two stages are responsible for the 'largest single annual runoff event in northern climates' which can be accelerated and magnified with rain on snow events (Roseen *et al.*, 2009). This is understandable considering the previous study showing that winter and spring contribute the majority of the annual stream flow. The 2003 SWM Manual (MOE, 2003) states that 'winter and spring runoff may not change dramatically because pre-development runoff may be high due to frozen or saturated soils.' However, it does not account for the high levels of imperviousness in an urban setting, which compound the effect of frozen soils (Maksimovic *et al.*, 2000). It is also important to note that in urban communities, the heat produced (urban heat island effect) can also hasten the snowmelt process (Maksimovic *et al.*, 2000) whereby runoff is produced quicker than soils are able to handle.

It is also important to understand the dynamics of pollutants attached to snowflakes and within the snow pack to understand the pollutant loading in stormwater associated with the different phases of snowmelt. Snow is able to accumulate pollutants from both the air and through contamination on the ground. As a snow pack melts, the soluble pollutants percolate downwards and accumulate at the bottom (Oberts, 2000). At the beginning of the last snowmelt, these soluble pollutants are unloaded with the runoff in a sudden wave, while the shock loading of solid and hydrophobic pollutants occurs closer to the end when little snow is left.

Furthermore, the amount of pollutants created during winter is larger than the other seasons (Backstrom & Viklander, 2000). For instance, starting cold car engines creates two to eight times more emissions than its warm counterpart (Backstrom & Viklander, 2000). Additionally, suspended solid levels in snowmelt runoff are between 2 to 5 times greater than in rainfall runoff (Backstrom & Viklander, 2000), most likely due to the use of gravel or sand for reducing skidding (TRCA, 2009f). Deicing salts also contribute to pollutant concentrations as they promote corrosion of metals. It has been reported by Hallberg *et al.* (2007) that cars that have been on roads with deicing salts have between double and triple the corrosive damage than cars travelling on roads without salts. The additional pollutant loading generated from winter activities warrants the need to have adequate management of snowmelt and rain on snow runoff to improve or protect the quality of the receiving water body.

Due to the below freezing temperatures that are typical of winters in Ontario and similar cold climate countries, infiltration and filtration stormwater management practices have been viewed with hesitation (Roseen *et al.*, 2009). Performance concerns in winter include frozen filter media, dormant biological functions in wetlands or vegetation strips, reduced infiltration capacity due to ground frost (Roseen *et al.*, 2009) or to high groundwater tables during the end of winter, or clogging of pipes due to icing or sediment/debris accumulation during snowmelt (TRCA, 2009f).

From the above information, it can be seen that hydrological cycle during winter is much different than that of warmer seasons. Rain and/or snow events could occur, evaporation is low, as is transpiration due to the dormant vegetation, snow can be accumulated into snow packs (Backstrom & Viklander, 2000), and the low temperatures cause frost in the ground minimizing infiltration. Snowmelt has low intensity (Backstrom & Viklander, 2000) and long duration flow (Maksimovic *et al.*, 2000), but when accompanied by rain, runoff flows can significantly increase. As such, it is not correct to use rainfall hydrologic and hydraulic processes to manage snowmelt and rain on snow events (Maksimovic *et al.*, 2000). One researcher named Lars Bengtsson realized this and created a method for determining snowmelt intensities by using a lengthy data set of temperature and snowfall in various parts of Sweden (Maksimovic *et al.*, 2000).

Calculating snowmelt has proven difficult because many of the parameters required are estimated. Parameters include the snow pack area, depth, density and distribution (which is generally non-uniform), the temperature, radiation from buildings, and the rainfall characteristics if a rain on snow event is being modelled (MNR, 2002b). Models that have been created include the energy balance model which incorporates the heat balance of a snowpack, and the temperature index models (using the degree day method) which use air temperature to approximate the snowmelt process (MNR, 2002b).

Because the hydrologic cycle of winter and early spring is so complex, and is still little understood, stormwater management in this season is very poor and is the reason why most cold climate urban drainage problems are associated with snowmelt runoff (Maksimovic *et al.*, 2000). Instead of cold region countries incorporating cold climate hydrology and hydraulics which account for snowmelt and rain on snow events, many instead adopt the practices used in warm climates which only deal with rainfall (Maksimovic *et al.*, 2000).

4.1.4 Summary of Seasonal Characteristics

Ontario's four seasons have unique climatic characteristics that in turn affect each season's stormwater characteristics. Precipitation occurs in the form of rainfall during spring, summer and fall; however a mixture of snow, hail and rainfall can occur during winter. The different forms of precipitation are an important factor to consider in stormwater management because of their different runoff generation and pollutant transportation dynamics. This can be seen at the end of winter and early spring which represents the melting of the remaining snow combined with rain on snow events. These events have resulted in spring accounting for the largest portion of annual stream flow due to the high input of runoff from snowmelt and rain on snow events. In addition, these large runoff events are in conjunction with larger than normal seasonal pollutant loading due to winter activity pollution. Therefore, this shows the necessity to adequately manage stormwater from winter and spring.

Furthermore, although it seems that much research has been conducted on cold climate stormwater management, the topic is extremely complex and requires much more research. This can also be said for the other seasons, spring and fall (Maksimovic *et al.*, 2000).

4.2 Ontario's Stormwater Practices for the Seasons

As previously mentioned, many northern cold climate countries have been focused on stormwater management based on warm climates and Ontario (and Canada) are no exception. Both combined sewers and stormwater sewers have been designed according to warm climate hydrology and hydraulics (Maksimovic *et al.*, 2000). Stormwater infrastructure has been designed using IDF curves that are based on rainfall from summer and fall, highlighting the need for IDF curves to be developed for winter and spring (MNR, 2002b). Five sets of rain on snow frequencies (two of which are for Ontario) have been developed for Canadian climate by AES using the degree day method (MNR, 2002b). Despite this, the rain on snow frequencies have rarely been used, with the few times consisting of floodplain mapping of small/intermediate catchments, and predicting the probability of combined sewer overflows in order to design structures to hold the overflows (Watt *et al.*, 2003).

With this in mind and using the cumulative mean season stream flows from Figure 25, it can be said that the current stormwater infrastructure in Ontario has been designed to manage roughly 21-28% (summer and fall) of the annual runoff. This leaves a gap of 72-79% of annual runoff being inadequately managed as the stormwater systems have not been designed to account for the winter and spring stormwater characteristics.

Reviewing the 2003 SWM Manual (MOE, 2003) reveals that for the most part, seasons are mentioned in the context of maintenance and operations during winter and spring. The contamination of groundwater supplies by road salt is acknowledged, as well as ice build up, spring melt and the effects of high summer temperatures. Very little is mentioned about the storm characteristics associated with each season other than a statement on intensity, size and duration length. Additionally, the Manual's Table 1.1 'Distribution of May to November Rainfall for Forested and Urbanized Area' excludes the winter season and the beginning of spring, which happens to be the time when the most runoff is generated in the year (Table 14).

Table 14: Distribution of May to November rainfall for forested and urbanized areas (MOE, 2003).

Item	Forested Areas		Urban Areas with 40% Impervious Cover	
	Depth (mm)	% of Total Depth	Depth (mm)	% of Total Depth
May to November Rainfall	515	100.0	515	100
Interception Storage and Depression Storage on Impervious Areas	342	66.5	235	45
Infiltration	155	30.0	100	20
Runoff	18	3.5	180	35

The Manual also has subsections relating to adaptation for cold climate designs such as volume and inlet/outlet modifications in light of ice buildup and snowmelt runoff, as well as a subsection on design adaptation to mitigate temperature increases from end of pipe controls. A brief list has been compiled to show the type of references made regarding seasons in the Manual:

- Infiltration trenches inappropriate for water quality treatment during winter and spring due to limited infiltration capacity from freezing or soil saturation. Risk of contamination with road salt.
- Surface/subsurface filters and bioretention areas have similar problems as infiltration trenches in the winter. Subsurface filters can be adapted to operate throughout the year if desired.
- Hybrid wet pond/wetlands are recommended for water quality control during winter and spring, but not purely wetlands as the pool volume will freeze.
- Rooftop storage openings inspected for blockages more often during winter and fall
- SWMPs can be activated ahead of the average annual date of the first frost and deactivated in spring when snowmelt is complete. This is to minimize groundwater contamination.
- Removal efficiencies of SWMPs may decline in response to finer particles being loaded from low flow snowmelt.
- Increase storage volumes in ponds to compensate for ice build up and the runoff from multi-day spring melt.
- Ponds which have 3m or greater permanent pool depth may become stratified during the hot summer, leading to potential anoxic conditions and pollutant resuspension.
- Facility siting must include consideration of the 'depth to the seasonally high water table.' This is required for certain SWMPs such as infiltration trenches, pervious catchbasins, pervious pipe systems and roof leaders discharging to soakaway pits.

Other practices affected by the seasons, though not explicitly stated in the Manual, include plowing snow to the roadside where debris and pollutants accumulate (Oberts, 2000) hauling snow into designated man-made piles (Roseen *et al.*, 2009) and sweeping streets before spring rains. Additionally, the 2008 Design Guidelines for Sewage Works (MOE, 2008) which provides guidelines on stormwater sewer networks only acknowledges rain and water from roofs, streets and other areas as the sources of stormwater. There is no mention of snow or snowmelt.

In general, the stormwater infrastructure that has been designed in Ontario is based on rainfall IDF curves and a warm climate. There continues to be minimal to no consideration of snowmelt or rain on snow events in the design of traditional stormwater practices or BMPs. As such, stormwater infrastructure has been designed towards summer and fall rainfall-runoff characteristics.

4.2.1 Impacts on the Water Body

The use of a drainage system geared towards rainfall management of warm climates has left winter and early spring runoff not being accounted for in the design of stormwater infrastructure, and thus leaving two seasons lacking proper stormwater control.

Although there is limited data on the physical impacts on the receiving water body, research can be taken from other locations with a similar four season climate. Two watersheds in Western Oregon, U.S., show that rain on snow runoff events have resulted in erosion, such as landslides, as well as downstream flooding (Harr, 1981). Van Vliet & Hall (1991) also reported that snowmelt runoff represented up to 96% of the total annual runoff and 80% of the total annual soil loss from the studied Peace River region in British Columbia. It can be assumed that due to the inadequate design of stormwater infrastructure to account for all the seasonal characteristics, these similar erosion impacts from snow melt and rain on snow events also occur in Ontario watersheds.

In addition, the larger generation of pollutants from winter activities occurs in tandem with the largest annual runoff events, and therefore may result in increased loading of pollutants for winter and spring. In Minnesota, it was found that small mid winter melts and the last snow melt contributed less than 5% and 8-20% of the annual total phosphorous, respectively (Oberts, 2000). Similar nutrient loading may be present in Ontario waters.

The use of deicing and anti-skid agents during the winter has had a significant negative effect on the water body. Sand or gravel is used liberally and enters our water bodies or pond facilities, with Hallberg *et al.* (2007) reporting that the TSS concentration ranged from 13 to 4800 mg/L in winter, compared to only 14 to 520 mg/L in summer. Taking into consideration that pond removal efficiency is reduced during winter, high levels of suspended solids may be discharged into the streams, especially at the end of winter during rain on snow events. Salts (i.e. NaCl) are also used generously as deicing agents and chloride has been found at extremely high concentrations throughout urban streams and groundwater aquifers, such as Frenchman's Bay in Pickering, Ontario (Meriano *et al.*, 2009). Not only are these high chloride levels directly toxic to aquatic species (TRCA, 2009f), but salts also indirectly impact aquatic life through their influence on metals. It has been suggested that metal concentrations increase with the application of deicing salts in winter (Hallberg *et al.*, 2007). Dissolved Al, Cd, Co, Cr, Mn and Ni have been shown to be at higher concentrations in winter runoff than in summer, whereas particulates of Cd, Cr, Cu, Mn, Ni, Pb, and Zn were higher in summer (Hallberg *et al.*, 2007). This high concentration of dissolved metals during winter may be due to the effects that deicing salts have on metal speciation, transforming them from particulate form in snow packs or roadside soils to a dissolved mobile phase (TRCA, 2009f). This is achieved by the sodium ion taking the place of the metal on a soil particle's adsorption site, effectively putting the metal into dissolved form where it can be mobile in the runoff (TRCA, 2009f).

Additionally, the heavy use of ponds has led to not only hydraulic problems as discussed in 2.4.3 Stormwater Ponds, but also temperature concerns. During the summer months, the slow moving stormwater in ponds are quickly heated up and then eventually discharged into a stream (Aquafor Beech Ltd., 2006). This is confirmed by a study by CH2M Hill (2003) reported that there was about a 10°F temperature increase between the inflow and outflow of the tested ponds. Furthermore, this research also found that on average, Maryland's urban streams were warmer than those undisturbed and could be up to 8.6°F higher in temperature. This increase in urban stream temperatures could be reflective of a lack of vegetation to provide shading, as well as the input of heated runoff from either paved surfaces or from stormwater ponds. To compound the problem further, the use of detention ponds does not allow for infiltration of the stormwater and thus baseflow is reduced. This means that there is less cold baseflow supplying the streams, and instead more surface runoff that has been heated (CH2M Hill, 2003). The resulting temperature increase in the stream negatively affects aquatic species as they have adapted to a specific temperature range and can result in decreased reproductive health and/or mortality (CH2M Hill, 2003).

Overall, not accounting for all of the characteristics of Ontario's four seasons can result in negative impacts to the receiving water body. Seasonal characteristics include the form of precipitation and its resulting effect on runoff and pollutant dynamics, the use of deicing and anti-skid agents to manage ice formation during cold weather, and hot summer temperatures. Without accounting for these variable characteristics, snowmelt and rain on snow events will continue to be erosive, and stream quality will not improve from the high pollutant loading and high temperature in the runoff discharge.

4.3 Adaptations

Several adaptations or modifications to Ontario's stormwater management are needed to address the various conditions that each season presents. A few winter/spring and summer modifications will be discussed; however, there seems to be little to no information on modifications during the fall season.

The knowledge of highway metal pollutant loadings and how their concentrations/properties vary between seasons should be incorporated into the selection and design of BMPs (Hallberg *et al.*, 2007). For instance, BMPs used during the winter/spring should concentrate on removing soluble metal pollutants (Maksimovic *et al.*, 2000) since, as Hallberg *et al.* (2007) reported, most of the studied metals were found to be dissolved in the runoff during winter. This will ensure that both dissolved and particulate pollutants in runoff are treated throughout the year.

Another water quality factor to address is thermal stress. To mitigate the high surface water temperatures that occur during summer from stormwater ponds, adaptations must be made to their designs. Pond modifications to reduce the exposure to the sun's heat include: 1) narrow water surface and orientating the pond so that the sun's rays are not heating the runoff the entire day; 2) tree planting around the edge of the pond; 3) avoiding rock lining for the discharge channel; and 4) vegetation planting on discharge channel banks and if this is not possible, discharge should be piped underground to the stream (CH2M Hill, 2003). Additionally, other practices (i.e. infiltration) that do not expose runoff to heat for prolonged periods should be emphasized during summer. Stormwater will instead be cooled as it moves underground and eventually provide cool baseflow to streams which compensate for runoff from other surfaces which are heated. It is very important to note that special attention must be made when using infiltration practices and ponds within the same development. In regards to infiltration practices, although CH2M Hill (2003) states that reduced runoff also minimizes the volume of potentially heated stormwater in the pond, this smaller volume of runoff that is detained will be heated much faster and may reach even high temperatures, thereby negating the thermal benefits from infiltration. Thus, it is important that if the development has utilized many infiltration practices, the applicability and necessity of using a pond must be well analyzed.

In order to accommodate snowmelt and rain on snow events, the 2003 SWM Manual (MOE, 2003) states that volume requirements for quality ponds are based on continuous modelling using snow melt data. This is under the belief that a larger storage volume will be able to manage the long runoff duration and volume of snowmelt. However, this is a reactionary measure to spring runoff and focus should be put on developing practices which reduce the generation (or frequency) and duration of spring runoff from the beginning.

The most essential adaptation that Ontario needs to make in regards to stormwater management is for the design criteria to incorporate both the runoff and the pollutant characteristics that results from snowmelt and rain on snow events (Maksimovic *et al.*, 2000). With Ontario's current stormwater infrastructure design geared towards summer and fall stormwater, only a maximum of 28% of annual runoff is being sufficiently managed (Vink & Chin, 2004). If winter and spring runoff were also addressed in stormwater design, this would allow for 100% of the annual stormwater being managed. This shows the importance that these two seasons have in the success of stormwater management in

Ontario. However, in order to modify design criteria, much research is still needed to model urban snow, snowmelt and rain on snow events for quantity and quality build up and wash-off (Maksimovic *et al.*, 2000).

4.4 Summary

Ontario has four unique seasons, each with their unique characteristics. Winter and spring runoff have often been overlooked in the design of stormwater infrastructure and the majority of facilities do not account for the frequencies of snowmelt and snow on rain events. This has resulted in less annual runoff being adequately managed, and has led to the continued degradation of Ontario's water body.

Addressing all four seasons will allow a significantly larger percentage of annual runoff to be managed through design modifications. Winter snowmelt and spring runoff result in the highest annual stream flows and serious steps must be taken to understand the hydrology of these two seasons. Once accomplished, this knowledge can be applied to develop a more complete set of snowmelt and rain on snow event frequencies for cities across Ontario. Also, with a better understanding of the hydrology, snowmelt models can be improved to account for more parameters and make fewer assumptions. Ultimately, the desired goal is to be able to design stormwater infrastructure that is able to handle the runoff from extreme summer, winter and early spring events.

5.0 Stormwater Management Based on Regional Conditions

One of the goals of stormwater management is to alleviate and mitigate the impacts urban stormwater has on the environment. To truly achieve this, the design and selection of stormwater practices must be based on the region's climate, receiving water body characteristics, drainage area conditions. Design criteria and performance targets must be developed according to what the receiving water body requires to maintain/achieve a healthy ecosystem. In situations where a stream will be impacted for the first time by development, practices must be designed to maintain that aquatic ecosystem's integrity. However, in existing developments which have already negatively affected water bodies, the practices implemented must be designed to increase the ecosystem's health. As such, one cannot use the excuse that performance targets can be less stringent for water bodies that are already deteriorated.

According to the trilogy of the watershed documents (MOEE & MNR, 1993a, 1993b, 1993c), which is emphasized in the 2003 SWM Manual (MOE, 2003), stormwater management and any BMPs implemented are to be developed in tandem with municipal and site planning, taking into consideration the region's ecological attributes and functions. However, a critical review of Ontario's stormwater management highlights that this is not the case and that there are region specific conditions which are not accounted for. This includes the local climate, the receiving water body parameters and drainage area conditions. These factors all affect the design and success of the BMP's in alleviating the stormwater impacts on a water body.

5.1 Local Climate

Ontario is a large province and by simply looking at a map, one can see that the southwestern and central region is mainly surrounded by very large lakes, while the eastern border with Quebec is inland. The regional climate differs across the province, as dictated by its environment and proximity to large water bodies. With a non-uniform climate, that means that not only do storm characteristics (volume, peak flow, quality, duration, frequency) vary by region, but the length of seasons would also be influenced according to the region's latitude, amongst other factors. As such, stormwater management design criteria must be modified to reflect that region's climate. This is acknowledged by municipalities who use their own set of IDF curves to assist in the determination of storm sewer pipe sizes (MOE, 2008), indicating that regions can indeed have storms with different intensities, durations and frequencies. Alberta also states the importance of designing BMPs according to the specific climate, reporting that many of its regions are unique in climate with the south undergoing numerous freeze-thaw episodes due to Chinook winds (CH2M Gore & Storrie Limited, 1999). However, the 2003 SWM Manual states that 'an assessment of regional variations in climate indicated that the same volumetric guidelines could be used throughout the province.' These storage volume criteria are found in Table 3.2 of the 2003 SWM manual, as seen in Table 15. With these two contradicting approaches, it is unclear as to why unique IDF curves would be created for each region/municipality, while still using uniform water quality volume requirements for BMPs throughout the province.

Table 15: Water quality storage requirements based on receiving waters (MOE, 2003).

Protection Level	SWMP Type	Storage Volume (m^3/ha) for Impervious Level			
		35%	55%	70%	85%
Enhanced 80% long-term S.S. removal	Infiltration	25	30	35	40
	Wetlands	80	105	120	140
	Hybrid Wet Pond/Wetland	110	150	175	195
	Wet Pond	140	190	225	250
Normal 70% long-term S.S. removal	Infiltration	20	20	25	30
	Wetlands	60	70	80	90
	Hybrid Wet Pond/Wetland	75	90	105	120
	Wet Pond	90	110	130	150
Basic 60% long-term S.S. removal	Infiltration	20	20	20	20
	Wetlands	60	60	60	60
	Hybrid Wet Pond/Wetland	60	70	75	80
	Wet Pond	60	75	85	95
	Dry Pond (Continuous Flow)	90	150	200	240

This design criteria may lead to over- or under-sizing the water quality volume of BMP end of pipe practices, especially ponds. In the case of under-sizing, the influent runoff may not have undergone the required treatment time for solids settling and attenuation of the peak flow. While over-sizing a pond may lead to a reduced pool depth of runoff which is able to be heated faster by the sun. In both scenarios, the currently used water quality storage requirements design criteria may negate any beneficial effects it may have had otherwise.

Furthermore, Ontario's water quality storage requirements for treating stormwater is based on modelling where a fixed particle size distribution for suspended solids loading is assumed for *all* storms (Bradford & Gharabaghi, 2004). This does not acknowledge that amongst the varying storms, some events will have more erosive energy than others which will erode and transport a wide range of suspended solids particle sizes, as opposed to an event with much lower energy capable of mainly transporting fine particle sizes. Brodie and Dunn (2010) found through regression models that the concentration of suspended solid particles (less than 500 um) was negatively correlated with rainfall depth, and positively correlated to peak six minute rainfall intensity. Storm duration (amount of time which had 0.25 mm/hr rainfall intensity or greater) made a small contribution. This means that events with high and prolonged intensity will have higher suspended solid concentrations, and as such, it is important for regions to calculate the frequency and duration of such events in order to determine appropriate design criteria for BMPs.

When implementing stormwater practices, it is essential to account for the local climate and the type of storms generated in that area in order to better design for that region's storm intensities, frequencies and durations, as well as the associated erosive energies and suspended solids particle size distribution ratios.

5.2 Characteristics of the Receiving Water Body and Drainage Area

This section discusses how some aspects of stormwater management in Ontario, such as design criteria and performance targets, have not been based on the receiving water body. Catchment conditions in terms of soil type and geological formation will also be included as they also vary by location and have only been discussed in the 2003 SWM Manual in regards to infiltration practices for infiltration rates and volumes.

5.2.1 Design Criteria

The sizing of end of pipe controls are dictated by several factors, such as imperviousness percentage, type of practice, level of water quality protection and a twenty year climatic record assumed to be uniform for the entire province. The model that was used to determine water quality storage requirements for stormwater treatment also assumed that the particle size distribution for suspended solids loading was the *same* for storms throughout the *entire* province (Bradford & Gharabaghi, 2004). This is unreasonable to assume since the soil characteristics can change within small areas, let alone across a province. The types of soils are numerous, ranging from sand, silt and clay to all their possible mixtures. Additionally, although this model was for BMP application within Ontario, it used a particle size distribution which was suggested by the US EPA (Bradford & Gharabaghi, 2004). Overall, these assumptions make it likely that the water quality storage requirements are also incorrect, thereby meaning that there may not be optimal treatment capability and effluent quality.

Assuming that the volume requirements are correct, the size of the receiving water body must also be accounted for. Unfortunately this is not the case and detrimental impacts may arise during summer if a large stormwater pond discharges into a small stream because a smaller volume of heated runoff is needed to cause thermal stress (CH2M Hill, 2003).

5.2.2 Performance Targets

There is insufficient data and studies being conducted which analyze the true effectiveness of SWMPs in mitigating the impacts to receiving water bodies (Horner *et al.,* 2002; Strecker & Urbonas, 2002). Instead, it is common to see in literature the performance analysis of SWMPs according to their removal efficiencies of pollutants. As Bradford & Gharabaghi (2004) stated, there is a 'disconnection between effluent monitoring and the effects of stormwater practices to mitigate receiving water and aquatic organisms.'

Problems arise when the performance of SWMPs is evaluated according to 'performance targets' such as removal efficiencies of total suspended solids (TSS). In Ontario, end-of-pipe controls must have 60-80% removal efficiency of TSS, depending on the level of water protection required (MOE, 2003). However, percent removal efficiency targets do not take into account the influent concentration of the end-of-pipe control and thus does not guarantee that the effluent being discharged into the receiving water body is at an adequate TSS concentration conducive to the aquatic ecosystem's health (McNett *et al.*, 2010). Two separate studies have documented two possible extremes that show that the performance evaluation according to percent removal is an inaccurate assessment of any improvements in the water body's health. First, Lenhart and Hunt (2011) reported that a wetland was given poor performance evaluation because it did not remove the required percentage between influent and effluent concentrations. Yet, the influent total nitrogen level was so minimal that there was not much for the wetland to treat in that aspect. Second, Schaafsma *et al.* (1999) showed that although the studied wetland had decreased the influent pollutant loads greater than 90%, the pollutant concentrations within the effluent still exceeded regulations. Without proper performance evaluation methods of the BMPs, it will continue to be assumed that the receiving water body is greatly benefiting from the stormwater management so long as it reaches the current performance targets removal efficiencies.

While Ontario has set suspended solid removal efficiencies for end of pipe facilities, little consideration has been made as to what ratio of suspended solids the stream requires to maintain its geomorphology. Since the effluent discharge has a larger proportion of fine particles, what impact has this had on the stream's stability? Is the stream being fed the appropriate ratio of suspended solids to maintain its stability? Nonetheless, even if the suspended solids ratio was sufficient, pond flow control does not account for the stream's geomorphology either, as discussed in section 2.4.3 Stormwater Ponds, threatening stability even more.

Additionally, there are no phosphorous removal targets set in Ontario. As previously discussed, coarser sediment (sand and gravel) is readily deposited, such that an end of pipe control's effluent has a larger percentage of fine sediment (clay and silt) when compared to its influent (Bradford & Gharabaghi, 2004). This fine sediment that is escaping the end-of-pipe controls is associated with the majority of the phosphorous and other metal contaminants such as copper and zinc, and has contributed to eutrophication throughout Ontario (Bradford & Gharabaghi, 2004).

In terms of pollutant removal, there are other methods to determine if water quality and subsequently aquatic biodiversity is being protected. This includes basing performance on effluent chemical concentrations below regulation levels, and/or assessing aquatic macroinvertebrate diversity and abundance, as well as comparing the effluent's ratio of suspended solids to what is needed for the stream to maintain stability. In terms of thermal performance, one could measure the temperature of effluent discharges to ensure that it is within the thresholds of the resident aquatic species. Infiltration performance methods could also be developed such that minimal infiltration volume targets would be calculated based on maintaining stable flows to support perennial streams, especially during the summer. These are simply ideas, but emphasize the need to develop performance targets based on what the receiving water body needs to flourish, whether it is chemical and suspended solid concentrations, temperature, surface flows and baseflows.

5.2.3 Acidic Rain

Lastly, there is the issue of acidic rain in Canada. For decades, acid rain has occurred in Canada from the emissions of two main pollutants: sulphur dioxide (SO_2) and nitrous oxide (NO_x) (Environment Canada, 2012). Soil contact with acid rain can result in metal speciation whereby metals detach from soil particles and become mobile with runoff (US EPA, 2007). This is especially important to understand as it influences the effectiveness of stormwater quality ponds to reduce the influent metal concentrations by the time it is discharged. When runoff enters the facility, its acidic pH can influence the metals in the surficial sediment which have already settled from previous events to turn into soluble form. Once dissolved, it will be mobile and move with the runoff as it travels the course of the pond, and eventually discharge into a stream. Therefore it is important to know if acidic rain occurs within your catchment to properly select and design SWMPs to account for metal speciation that may result from the rain's acidity.

The Eastern Canada has been more affected by acidic rain because of the heavy regional production of SO_2 and NO_x and the presence of the Canadian Precambrian Shield geological formation which is unable to neutralize the acidity of the rain. As Figure 26 shows, the ability of the soils of Ontario to neutralize the acidity varies throughout the province. This difference in ability coincides with the Canadian Precambrian Shield that is dominated with non-carbonate rocks like granite, and the other regions which are associated with limestone and act as a base to neutralize the rain. The importance of knowing the local soil's vulnerability to acidic rain relates to how BMPs are implemented. Infiltration practices used within the Shield should be aware that the runoff's acidity may cause metals to detach from the soil's particles and dissolve into solution, potentially resulting in groundwater or baseflow that is high in metals.

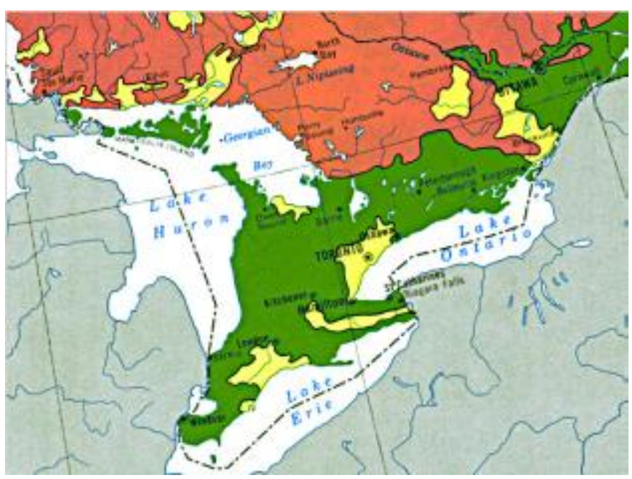


Figure 26: Map of Ontario's soils and its potential to reduce acidic rain (Natural Resources Canada, 1991). Red = poor; yellow = moderate; green = high.

5.3 Upstream and Downstream Development

End of pipe controls are designed in isolation (within a development) or by a "development by development basis", with no regard of stormwater management plans from neighbouring developments (Aquafor Beech Ltd., 2006). Consequently, the flow duration standard that was used for the discharge of the downstream pond can be exceeded by the upstream pond's hydrograph. While the runoff peak discharges of all the ponds are reduced, the hydrographs from neighbouring developments are cumulative and create a prolonged and highly erosive flow downstream that is also increased in volume as seen in Figure 27 (Aquafor Beech Ltd., 2006). Therefore, it is essential to account for the hydrographs of neighbouring developments when designing stormwater practices. This does not translate into treating overland stormwater draining from an adjacent development, but instead to keep in mind during stormwater designs that runoff discharging into a stream will be added unto the existing stream flow rate which has increased due to input of runoff discharge by upstream development. Since one of the objectives of stormwater is to prevent undesirable and costly geomorphic changes in the watercourse (MOE, 2003), the impact of cumulative discharge hydrographs on stream flow and consequently stream stability must be accounted for in the design and implementation of stormwater practices.

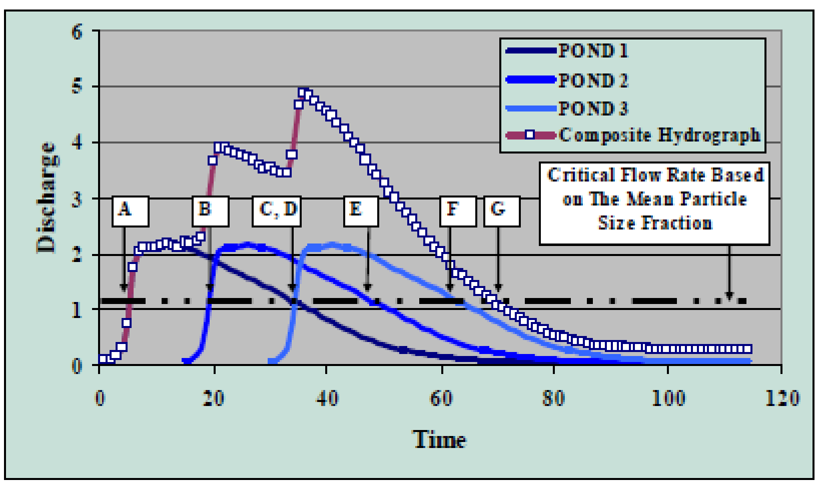


Figure 27: Cumulative nature of multiple hydrographs from neighbouring developments (Aquafor Beech Ltd., 2006).

5.4 Summary

In order for stormwater management to alleviate and mitigate the impacts urban stormwater has on the environment, the design and selection of stormwater practices must be based on the region's climate, receiving water body characteristics, drainage area conditions and neighbouring development. All these factors vary throughout the province as well as within watersheds. As such, standard province-wide design criteria values and performance targets should be used with extreme caution and instead should develop region specific design criteria in order for stormwater management to truly effective.

6.0 Proposed Stormwater Management Objectives

The currently used stormwater management objectives, which are found within the 2003 SWM Manual (MOE, 2003), are to:

- "Preserve groundwater and baseflow characteristics,
- Prevent undesirable and costly geomorphic changes in watercourses,
- Prevent any increase in flood potential,
- Protect water quality, and
- Maintain an appropriate diversity of aquatic life and opportunities for human use."

The objective to maintain an appropriate aquatic diversity is very vague and does not elaborate or specify which regions of a water body are of high importance in order to maintain biodiversity. Additionally, the objectives need to be updated to incorporate different types of human habitat which require protection by stormwater management.

With this in mind, Tran (2011b) has developed and proposed a new set of stormwater management objectives which have been organized into 'environmental' and 'human habitat' categories (Table 16). The objectives have been split into categories to address different and unique issues that each group faces. The 'environmental' group, like the name suggests, entails protection of the environment such as maintaining the water balance and preserving aquatic biodiversity through protection of the essential habitat conditions required for the early development phases and migratory routes of fish. Stormwater management objectives have never been developed solely towards human habitat. This group consists of objectives which are to protect humans and their habitat/infrastructure. Human habitats can comprise of a multitude of land use activities, such as residential or industrial sites, and various types of transportation roads (local roads, collectors, arterials). Protection of these habitats involves the use of stormwater control, through the implementation of various practices at new sites, and retrofitting existing sites or upgrading combined sewers for separated networks. Additionally, the protection of humans and their infrastructure includes maintaining the flood potential and preventing geomorphic changes to channel banks which could result in damage or destruction to adjacent property. Furthermore, protection of drinking water supplies also accomplishes the same goal of protecting humans.

Subsections 6.1 Support for Environmental Objectives and 6.2 Support for Human Habitat Objectives will discuss the basis and reasoning for the inclusion of the proposed objectives and any modifications.

Table 16: Proposed stormwater management objectives for environmental and human habitat (Tran, 2011b).

Environmental Objectives	Human Habitat Objectives
Preserve groundwater	*Prevent any increase in flood potential*
Preserve baseflow characteristics	*Prevent geomorphic changes*
Protect water quality	Protect drinking water supplies
Maintain terrestrial biodiversity	New residential sites
Protect spawning and rearing grounds	New industrial sites
Protect migratory corridors	Retrofit existing residential sites
Protect wetlands	Retrofit existing industrial sites
Minimize impacts of climate change	Combined Sewers
	Residential local roads
	Residential collectors
	Residential arterials
	Industrial roads

*Objectives in italics are currently established in the 2003 SWM Manual (MOE, 2003).

6.1 Support for Environmental Objectives

The first three environmental objectives, 'to preserve groundwater', 'to preserve baseflow characteristics', and 'to protect water quality' are current stormwater management objectives found in the 2003 SWM Manual. As such, the reasoning behind them will not be discussed. Discussion will be provided only for the new environmental objectives as the basis for their inclusion in stormwater management.

Furthermore, according to the Fisheries Act (1985), fish habitat consists of areas used for spawning and nursing/rearing, food supply, or migration. The proposed objectives directly or indirectly support the Fisheries Act and are an expansion of the currently used objective 'to maintain an appropriate diversity of aquatic life.'

6.1.1 Maintain Terrestrial Biodiversity

Biodiversity is important to humans as it supports ecological services such as climate regulation, desalination, hydrological services, soil management and pollination services which are all essential for human survival (Albers & Ferraro, 2006). Maintaining biodiversity is also important for the species of a particular ecosystem. This is because all species are interconnected in a food web and the removal of one species may negatively or positively affect other species which may then be in over-abundance and have an additional negative influence on the ecosystem. For example, the local extinction of a certain species of vegetation may directly reduce the population of specific species of insects which feed on them, thereby consequently indirectly negatively affecting any birds, amphibians or fish which feed on these particular insects. Therefore, maintaining terrestrial biodiversity will increase the resiliency of the ecosystem. That is, if one species of a functional group (a group of species which perform the same ecosystem function, or serve the same purpose) is removed, then there will be other species of that same functional group which will continue its function, and thus no loss of function will occur (Walker, 1995).

A well-known example of the ripple effect that the removal of a species can have on an ecosystem is the reintroduction of grey wolves in the Yellowstone National Park in the U.S. The over-hunting and local extinction of grey wolves in the park led to an explosion in elk populations which travelled less and browsed intensely on riparian vegetation such as young willow, aspen and cottonwood during the winter. This negatively affected the ecosystem's beavers that depend on willow for food. The reintroduction of wolves has reshaped the park's ecosystem through its widespread impacts on terrestrial and aquatic animals, vegetation and even the water cycle. The increase in predator pressure on the elk led to more travelling such that they did not stay within the same area for extended periods of time which consequently reduced the intensity of the riparian vegetation. Vegetation recovered and not only allowed beaver populations to increase, but also became habitat for local birds. Additionally, the carcasses left from wolf kills became a food source for scavengers such as eagles, coyotes and bears (YNP, 2011). Furthermore, beaver dams reduce stream velocities and increase floodplains thereby playing an essential role in groundwater recharge, attenuating stream peak flows, increasing water quality, and creating conditions for wetland habitat. The groundwater recharge also allows for sustained downstream flows during summer that may otherwise dry up, provides cool water suitable for fish habitat, and maintains an adequate water table level necessary for nearby terrestrial vegetation (Pollock *et al.*, 2003).

In general, maintaining the balance within a food web will allow the species within an ecosystem to not only coexist but thrive. It is important to note that primary producers, such as vegetation, are the basis of any food chain, thereby making it an essential factor to preserve.

The establishment of an array of terrestrial vegetation results in both a habitat and a food source for numerous species of herbivorous mammals, as well as terrestrial insects (Naiman and Decamps, 1997) which are consumed by amphibians and birds. The diversity of vegetation also supports a variety of aquatic species such as macroinvertebrates which in turn are eaten by fish (Bertrand *et al.*, 2012) and consequently by higher order predators such as birds and bears, which again supports terrestrial diversity. This allochthonous source (originates outside of the stream) can comprise of leaf litter, woody debris and other organic matter which is deposited into the stream via surface runoff, wind and direct litter fall (McClain and Richey, 1996). Lastly, vegetation establishment, especially trees can promote soil aeration through their sprawling root network, as well as infiltration and recharging of the groundwater table (Bartens *et al.*, 2008), proving them to be useful for maintaining pre-development hydrologic cycles and supplying cool baseflow to streams.

One way of maintaining terrestrial vegetation and thus terrestrial biodiversity is through proper stormwater management to restore the pre-development hydrologic cycle. This is because water is the backbone of life. As long as a water source is accessible, vegetation and the associated wildlife will be quick to follow, thereby increasing biodiversity of an ecosystem. Therefore it is important that there is an adequate water supply (surface or groundwater) to establish and support vegetation.

Groundwater is a resource for both streams and the riparian vegetation found within the floodplain, as well as for inland vegetation. Shallow groundwater can feed streams, springs and wetlands during the dry season and can also act as a water supply for the riparian vegetation surrounding it. This can be seen by a study in the dried lower reaches of China's Tarim River where water was fed intermittently to evaluate the response on the groundwater level and vegetation. Chen *et al.* (2008) found that not only did the water table rise significantly, but it also extended its reaches outwards away from the river bank. Prior to the supply of water, vegetation diversity and abundance decreased with increased shallow groundwater depth. However, with an elevated groundwater table, diversity and abundance of riparian vegetation increased and flourished, as well as the restoration of drought tolerant shrubs and trees. Additionally, while stream flows can be used a water supply for small riparian vegetation, it has been reported that the majority of mature riparian trees use groundwater as a source instead (Dawson & Ehleringer, 1991). Inland vegetation also relies on groundwater, and Bijoor *et al.* (2011) reported that urban trees in Los Angeles utilized soil moisture from irrigation but also from groundwater.

Regardless of location, a certain groundwater level is required for optimal vegetation growth, and maintenance near that level is essential for survival during droughts or dry seasons. Therefore, attaining the infiltration rates associated with the predevelopment hydrologic cycle will recharge groundwater tables and ultimately lead to a stable food web through the maintenance of terrestrial biodiversity.

6.1.2 Protect Spawning and Rearing Grounds

Under the federal Fisheries Act (1985), fish are deemed as a vital resource to be protected, thereby also requiring protection of fish habitat, such as the spawning and rearing grounds. As such, this makes the protection of the spawning and rearing grounds of fish an essential objective for stormwater management in protecting Ontario's fisheries. In addition to requiring relatively unpolluted water, most fish species have specific conditions which are required for successful spawning, such as temperature, water depth and velocity, oxygen content and streambed substrate composition (Armstrong *et al.*, 2003).

Fish species like the salmonids (i.e. trout and salmon) are triggered by temperature to spawn, as seen by Chinook salmon (*Oncorhynchus tshawytscha*) where spawning has been observed to be held back if temperatures are above 12.8°C in the fall (McCullough, 1999). Salmonids also require their redds (spawning nests) to be oxygenated which is associated with the substrate composition and the water velocity (Armstrong *et al.*, 2003). As such, salmonids generally choose redds in the tail transition zone between pools and riffles (Bagliniere *et al.*, 1990; Fleming, 1996) where sufficient downwelling currents supply adequate oxygen to embryos (Keeley & Slaney, 1996), and some choose hyporheic zones where a constant cold flow within the redd is established by the stream's downwelling current and the groundwater's upwelling baseflow (Macisaac, 2010). Each type of fish species have spawning substrate preferences, with Atlantic salmon (*Salmo salar*) preferring reds comprised more of coarse gravel (Beschta and Platts, 1986), while Brook trout (*Salvelinus fontinalis*) prefer a higher ratio of fine gravel (O'Connor & Andrew, 1998). Infiltration of sediments finer than 2 mm can have adverse effects of egg survival and development as concluded by a literature review by Louhi *et al.* (2008). Fine sediment deposition can reduce the permeability of oxygen to the developing embryo, or it can create a physical barrier and trap fry from hatching (Louhi *et al.*, 2008). A laboratory experiment by O'Connor and Andrew (1998) showed that when redds contained more than 10% of fine sediments through deposition, Atlantic salmon egg survival decreased. Spawning habitat is also influenced by water depth and velocity, with Atlantic salmon spawning in deeper and higher flowing regions than the Brown trout (*Salmo trutta*) which prefer shallower and slower locations (Louhi *et al.*, 2008).

Similar to spawning conditions, the rearing grounds for juvenile fish also contain specific requirements essential for survival and growth. This includes riparian vegetation as shade and a source of insects for food, in-stream logs or large woody debris for protection, and low flowing riffles and pools which have flows that the juveniles can withstand (Beschta and Platts, 1986). A study by Curry *et al.* (1997) of lake Brook trout (coldwater species) found that 81% of the hatchlings being studied travelled to small streams which were connected to the lake, with some overwintering and even spending a second summer. The researchers concluded that the small streams were supplied by groundwater resulting in a stable and cold environment that was conducive to rearing coldwater fish. Pools near stable stream banks are also favoured by juveniles of Coho salmon (*Salvelinus fontinalis*) as they can provide shade and protection from the undercut bank and riparian vegetation (Beschta and Platts, 1986).

Overall, the specific habitat requirements for spawning and rearing grounds make it vital that proper stormwater management is implemented to mitigate any disturbances to these sites which are essential to the survival of aquatic species. Use of infiltration practices should be emphasized in these areas to ensure that cool baseflow is being provided to the streams. Fine sediment deposition and erosion of stream banks can be controlled through the attenuation of peak flow, duration and frequency to pre-development rates, as well as with riparian vegetation establishment. This would ensure that spawning sites are not smothered with silt and clay, and that juveniles will continue to shelter in pools or near stream banks. Retaining riparian vegetation will not only help control stormwater and bank stability, but will also be a source of food and shade, and provide large woody debris to serve as protection for juveniles. Additionally, toxic and nutrient concentrations of discharged runoff must be at reduced levels which the embryos and juveniles can withstand. Another important factor for stormwater management to consider when protecting spawning and rearing grounds is the timing of these events and how it coincides with seasonal runoff events (Section 8.1.5 Protect Spawning and Rearing Grounds).

6.1.3 Protect Migratory Corridors

The protection of the spawning and rearing grounds for migrating aquatic species will be rendered null if migratory corridors are not protected. This includes both the aquatic and riparian habitat within the migratory corridor. Migratory native and non-native fish species in Ontario include Chinook, coho and pink salmon, and rainbow, brook and brown trout. While efforts are made to remove physical barriers to fish migration, there are other non-physical barriers that need to be acknowledged. This includes stormwater quality issues such as increases in temperature, suspended solids, nutrients and toxins detrimental to fish survival and reproductive health, described in Chapter 2.

A current example for the need to protect migratory fish corridors is seen with the Longfellow Creek restoration project in Seattle, Washington that was completed in the 1990's (NOAA, n.d.). Stream habitat restoration was carried out for the region's coho salmon by removing fish barriers, channel reconstruction, and the addition of riparian vegetation, in-stream large woody debris and spawning gravel (Booth, 2005). Despite the physical habitat restoration, surveys documented very high pre-spawn mortality rates (range of 20 % to 90%) of mature coho salmon females that were returning (NOAA, n.d.). This trend was found in nearby urban streams, but not in non-urban catchments. Although the specific cause is undetermined, preliminary results suggest that the poor quality of the urban stormwater discharge into the small streams is the reason. The evidence to support this is that the pre-spawn mortality occurs during and after storm events and that the salmon show no signs of health issues prior to entering the freshwater system (NOAA, n.d.).

This shows that their exposure to toxins from runoff during the migration has significantly negatively impacted the efforts taken to restore the spawning ground's physical conditions. Similarly, this can be applied in the opposite direction where juvenile salmon migrate towards the estuaries to smolt prior to living in the ocean.

An additional factor to consider is stream peak flows. The migration of salmonids swimming upstream against the stream current is energy exhausting. If the stream flow is increased significantly during and after a storm, the migrating fish may be unable to make travelling progress and could eventually result in death (Cooke *et al.*, 2004). In the Fraser River of British Columbia, high stream flows areas were causing sockeye salmon mortality due to exhaustion. High stream flows also increased sediment transport and resulted in injury and even death to the migrating salmon (Cooke *et al.*, 2004). Therefore, an increase in stream flows also makes it essential to have suitable fish habitat for resting within the migratory route. If a stream does not have many quiet pools dispersed throughout its entire length (i.e. concrete channels), the energy reserves of the migrating fish will be depleted much faster and could result in mortality.

The protection of migratory corridors is not limited to removing physical barriers (i.e. dams), but also restoring water quality and stream flows to levels which the migrating fish has been evolved to withstand. The positive impacts that proper stormwater management can have to alleviate these concerns are similar to those outlined for the protection of spawning and rearing.

6.1.4 Protect Wetlands

Wetlands provide several ecological functions and also act as habitat for both aquatic and terrestrial species. These functions consist of flood control, groundwater replenishment, shoreline stabilisation and storm protection, sediment and nutrient retention and export, water purification, reservoirs of biodiversity, wetland products and climate change mitigation and adaptation (MNR, 2002a). Some of these functions will be briefly discussed.

There are different types of freshwater wetlands, with some relying solely on precipitation or seepage of groundwater like springs, or others which move between phases of receiving and recharging groundwater (Ramsar Convention on Wetlands, 2010). Thus, wetlands can play an important role in replenishing the groundwater table, and can equally be dependent on groundwater as a source (MNR, 2002a). Additionally, surface flows from rivers or overland flows which enters a wetland will slow down in velocity and any pollutants (i.e. nutrients, suspended solids, heavy metals) that have been mobilized by the water will begin to settle to the bottom where they will become part of the sediment layer or they will be taken up by the wetland's vegetation (Hui *et al.*, 2009). Any water that infiltrates and percolates into the groundwater table will also be filtered, thereby increase water quality. Wetlands are also ecosystems highly rich in biodiversity, and can be higher than that of surrounding environments as they can be a home to a multitude of birds, fish, insects, amphibians, mammals and plants (Hui *et al.*, 2009).

The role that wetlands play in flood control has led to the practice of engineered wetlands being used for urban stormwater management. Natural wetlands are avoided because the 2003 SWM Manual (MOE, 2003) specifically states that natural wetlands are not permitted to be used for this purpose as it will have negative impacts on the wetland ecosystem. This position is also supported by the U.S. EPA (US EPA, 1996).

Impacts are associated with changes in hydrology and water quality resulting from the receiving urban stormwater, which ultimately impacts the resident biota. These impacts include drying of wetlands from lack of baseflow recharge in urban areas, flooding of urban runoff during large storms, and pollutant loading beyond the wetland's treatment capacity and resident biota's threshold, thereby resulting in decreased biodiversity (Hui *et al.*, 2009). Protection of wetlands would involve not only limiting the discharge of polluted urban stormwater into its water body, but also promoting infiltration practices which would supply a constant baseflow to support wetlands, especially during droughts or dry seasons.

Overall, wetlands provide invaluable functions to the environment, and this has been acknowledged by the Ramsar Convention on Wetlands treaty, which aims for signatories to 'maintain the ecological character' of wetlands deemed of international importance and 'to plan for the sustainable use of all wetlands within their jurisdiction (Ramsar Convention on Wetlands, n.d.).' Canada is a signatory of this treaty and Ontario has implemented legislation regarding the protection of wetlands as seen in the Provincial Policy Statement (MMAH, 2005) and the Conservation Authorities Act (Conservation Ontario, 2009a). As such, it is necessary that the objective to protect wetlands should also be included in stormwater management.

6.1.5 Minimize Impacts of Climate Changes

Climate change has been acknowledged worldwide as a real and current threat to our ways of living (IPCC, 2007). One of the projections in the the 2009 'Adapting to Climate Change in Ontario' report forsees that annual average temperatures in Ontario by 2050 will rise from 2.5 to 3.7°C, relative to 1960-1990 (EPCCA, 2009). It is also projected by that date that there will be significant increases in winter and spring precipitation with rainfall to be the dominant form during winter, while summer precipitation remains constant. The higher volumes of winter and spring precipitation may lead to even larger spring runoff events. Additionally, although the increase in precipitation is higher during winter and spring, the total annual precipitation is projected to remain relatively unchanged in Southern Ontario. It is likely that extreme events will occur with more frequency and magnitude, with increased flooding and longer dry spells.

The possible consequences on the environment include low surface water levels of rivers or lakes, drying of small tributaries or wetlands, surface water temperatures rising above threshold levels of aquatic species, and sporadic flooding events on regions that are not accustomed to that volume of water. Ecosystems and the species themselves (aquatic and terrestrial), such as Ontario lake trout (*Salvelinus namaycush*), may not be able to adapt quickly enough to the wide extremes that they may have to face between floods, prolonged droughts, reduced surface and groundwater levels, higher temperatures and thermal stratification in lakes (Minns *et al.*, 2009). Additionally, extreme storm events may increase the frequency of combined sewer overflows, thereby contaminating water bodies with more raw sewage and stormwater (EPCCA, 2009).

In addition to environmental concerns, Ontario's infrastructure has already seen the impacts of not addressing climate change in stormwater management. Peterborough experienced severe flooding in 2004 from an extreme storm (Binstock, 2011). While in August 19, 2005, an event greater than a 100-year storm destroyed a road on Finch Avenue in Toronto, with the City of Toronto alone incurring a $50 million insurance claim for damaged infrastructure (MOE, 2010). This is not surprising since the average age of Ontario's stormwater infrastructure is 16.3 years, meaning that they were built without climate change design considerations (EPCCA, 2009). Furthermore, municipal stormwater systems have been designed using IDF curves which are based on the analysis of historical storms and assume that the probability and distribution of these design storms is stationary (Rosenberg *et al.*, 2010). However, taking into account climate change, a study by Rosenberg *et al.* (2010) suggests that stormwater infrastructure which was designed using rainfall statistics around the 1950s may be faced with different rainfall probabilities and distributions in the future for which they were not designed. For example, the 24 hour rainfall depth of a 50-year design storm in New Zealand is 195 mm and could increase up to 244 mm by the 2080s – a depth which is higher than the country's currently used 100-year design storm of 221 mm (Shaw *et al.*, 2005). These severe storm events and the inability of the City of Toronto's stormwater infrastructure to manage the runoff eventually led to a review of Ontario's municipal stormwater management systems in regards to climate change (MOE, 2010). It was acknowledged that there was a lack of a framework to support stormwater management in adapting to climate change and consequently the 2003 SWM Manual did not include best practices and design consideration regarding climate change (MOE, 2010). With this knowledge, the MOE stormwater management policy review emphasized that Ontario can no longer prolong implementing measures to adapt to climate change. Therefore, the inclusion of the stormwater management objective 'to minimize climate change impacts' is not only based on sound reasoning, but also comes at the right time when calls are being made to modify stormwater management to incorporate climate change.

Furthermore, the objective to minimize climate change impacts should be revised to be for both environmental and human habitat categories. This is because both groups, as seen with the above information, can be negatively impacted. To minimize the impacts of climate change, stormwater management measures could consist of infiltration practices which maintain groundwater supplies during droughts, or practices capable of controlling and attenuating runoff volumes, peak flows, frequencies and durations of extreme storm events. Furthermore, with a rise in temperatures projected in the future, promoting infiltration practices will provide cool baseflows for aquatic ecosystems instead of allowing surface runoff to be heated to even higher temperatures. This is supported by the MOE stormwater management policy review which encouraged the use of source control practices and identifying stormwater practices which would be resilient to climate change (MOE, 2010). To achieve the greatest climate change mitigation from stormwater management, designs must be based on updated rainfall IDF curves and consider snowmelt and rain on snow events, as well as projected temperatures (Watt *et al.*, 2003).

6.2 Support for Human Habitat Objectives

The human habitat objectives to prevent any increases in flood potential and geomorphic changes are already part of the current stormwater management objectives. Only the reasoning behind the proposed human habitat objectives will be discussed.

The protection of human infrastructure is briefly mentioned within the 2003 SWM Manual (MOE, 2003), which describes that some of the drainage design objectives are to protect property from surficial or basement flooding. However, protection of property is not included in the main list of stormwater management objectives that is repeatedly found throughout the manual. It is unclear as to why this is the case considering that the safety of humans and their property is amongst the top priorities of any development, hence the numerous safety regulations found for buildings, transportation roads and vehicles. British Columbia also acknowledges the importance of human safety by stating that stormwater management is necessary in the protection of the quality of life and property (Stephens *et al.*, 2002).

After the extreme destruction and loss of life in Southern Ontario caused by Hurricane Hazel in 1954, the Conservation Authorities Act was amended to allow authorities to implement land safety regulations for a community. As a result, Metropolitan Toronto Regional Conservation Authority (and other authorities which followed suit), created the Plan for Flood Control and Water Conservation whereby floodplain lands were acquired, numerous flood control structures (i.e. dams and reservoirs) developed, and eventually provincial floodplain regulations were created and implemented (TRCA, n.d.). This became the start of mapping flood vulnerable areas to control any future development in these designated areas. Additionally, one of the objectives of the Conservation Authorities of Ontario's mandate is to 'develop and maintain programs that will protect life and property from natural hazards such as flooding and erosion (Conservation Ontario, 2009c).' This would include programs related to flooding and urban stormwater management (Conservation Ontario, 2009d).

By 1978, Ontario joined the federal Flood Damage Reduction Program which further identified and mapped any remaining designated flood risk areas to implement flood regulation policies on new developments (Environment Canada, 2010a). Within Ontario, 270 communities have been designated as flood risk areas, including major urban cities such as Toronto and portions of Ottawa and Hamilton. Ontario's flood risk areas are determined by the flooding hazard limit which varies throughout the province and can be the 100-year peak flow, a regional storm or the highest observed flood (Environment Canada, 2010a). With these events, the floodway and the flood fringe can be used in outlining the areas (Fig. 28). There are two exceptions to allow new development in flood risk areas, provided that there is adequate flood control (relative to the flooding hazard limit). These consist of new developments within the flood fringe, and areas within a designated community which are labelled as a Special Policy Area (SPA). SPAs are areas which have historically existed in floodplains, and as such, barring new developments within these communities is not socially or economically viable (Environment Canada, 2010b).

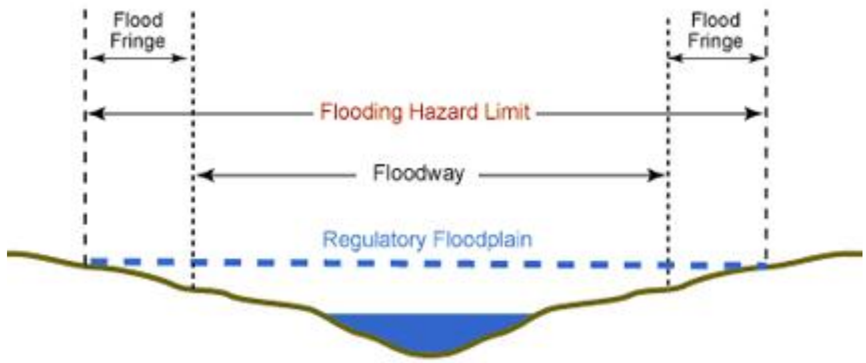


Figure 28: Delineation of floodway and flood fringe (CVC, 2010).

From the above information, one can see that human infrastructure and life is at risk, in particular the existing or new infrastructure that is built in flood risk areas, which is a significant portion of Southern Ontario's infrastructure. Therefore, it is important to specifically include and highlight that the protection of human property and life is an essential part of stormwater management which will help manage the flood potential risks.

Of the new human habitat objectives proposed, nine out of ten deal with protecting the varying degrees of human urban infrastructure. These range from the protection of new or existing developments, residential or industrial land use, and different transportation roads based on usage. Since the reasoning behind the inclusion of developing human habitat objectives has been discussed, the following sections consist of the different stormwater management issues to consider relative to the type of infrastructure. These have been categorized into stormwater management required for residential vs. industrial sites, the various types of roads, and new developments vs. retrofitting existing sites. The objective of protecting drinking water will also be discussed.

6.2.1 Protect Water Quality for Drinking Purposes

Although this does not deal with the protection of human property, a healthy and safe supply of drinking water will protect human life from any water-related diseases or toxins. Water quality protection for the environment has been listed as an objective within the 2003 SWM Manual (MOE, 2003), but does not highlight its need for human consumption.

This is alarming considering that the importance of protecting drinking water at the source was already highlighted by the Walkerton tragedy in 2000 where a drinking water well was contaminated by *Escherichia coli* O157:H7 laden farm runoff resulting in seven deaths and 2,300 ill (O'Connor, 2002). Although this occurred in a rural town area, it shows how polluted runoff can easily contaminate our drinking water supplies if care is not taken. In an urban setting, drinking water supplies could be contaminated through a multitude of ways. Polluted overland flow, storm sewer outlets and CSO's all discharge into a river or lake, which, like Lake Ontario, may be used as a drinking water supply. Drinking water can also be threatened from stormwater infiltration practices near groundwater aquifers that are used for drinking water abstractions. Therefore, although infiltration practices are encouraged, it is important to analyse a site's surroundings to ensure that the selected stormwater practice is suitable for that area. Throughout the next sections, protection of water quality will be a common factor that must be accounted for when deciding which stormwater practices to use.

In addition, protection of water quality should not be limited to drinking purposes, but also include areas with recreational activities that involve body contact with water. This was part of the original 2003 SWM Manual objectives, with activities consisting of swimming, water sports, etc. When *Escherichia coli* concentrations exceed 100 CFU per 100 ml, as set by the provincial water quality guidelines, beaches will be closed until the health risk no longer exists (TRCA, 2009e). Therefore, it is recommended that the objective to protect water quality should be in association with drinking water as well as water used for recreational purposes.

6.2.2 Land Use Type: Residential vs. Industrial

As discussed, stormwater management is necessary for the protection of human habitat. However, the practices undertaken need to account for the differences in pollutants according to the land use type. The various land use types and their pollutants vary between residential, commercial and industrial sites (US EPA, 1996).

Urban runoff from residential sites has been reported to have lower loadings of polycyclic aromatic hydrocarbons (PAHs) (Walker *et al.*, 1999), hydrocarbons (Fam *et al.*, 1987), and metals such as zinc, copper and lead (Davis *et al.*, 2001), relative to commercial and industrial sites. The predominant use of copper sheeting for commercial roofs has been identified as an explanation for the significantly high copper concentrations in roof runoff from these areas (Davis *et al.*, 2001). Other toxins such as arsenic, mercury and PCBs have been identified as emissions from industrial activities such as smelting, paint manufacturing and battery production (Walker *et al.*, 1999).

Consequently, to minimize any risks to water quality, it would be logical to implement stormwater management practices according to the variety and distribution of pollutants found within a particular land use type. Infiltration practices within commercial or industrial areas should be used with caution and avoided as the type of commercial or industrial activity can vary between locations, thereby emitting different toxic pollutants. Mixed land uses with both residential and commercial developments are frequent in Ontario. When deciding which practices are suitable for these mixed areas, the percentage of commercial land use and the type of activity should be considered.

To summarize, stormwater management should protect not only residential and industrial sites, but also commercial developments, and account for varying pollutants and risk of groundwater contamination.

6.2.3 Land Use Type: Transportation Roads

The protection of roads from stormwater is essential in delivering safe and efficient transportation for a city's inhabitants. The reduction of surface flooding on roads and any associated damage will not only prevent health hazards, but will also allow for all lanes of a road to be utilized and avoid traffic congestion which is a major concern within large cities.

There is a wide array of pollutants associated with roads: heavy metals such as zinc from corrosion, tires and vehicle exhaust, lead from gasoline combustion, copper from vehicle brake linings and wearing out of asphalt (Walker *et al.*, 1999), and iron from vehicle rust and steel guard rails; hydrocarbons and PAHs from vehicle engine oil spills and leaks; sediment and debris; and components used in de-icing agents such as sodium, calcium, chloride, sulfate and cyanide (TRCA, 2009f). Therefore, stormwater management for roads must account for road pollutants to protect water quality.

The type of transportation roads influences the pollutant concentration in the runoff and thus the water quality downstream of the drainage area. The variety of roads can be organized into residential local roads, collectors, arterials and expressways, and industrial roads. In terms of residential transportation roads, a lower traffic density/usage of the road results in less pollutant loading in the road runoff (Davis *et al.*, 2001). Therefore, the ranking of residential roads from least to greatest in terms of usage is local roads < collectors < arterials < expressways. Local roads and collectors have low to moderate traffic within residential areas, while arterials (i.e.: Dundas Street and Yonge Street) and expressways accommodate very large volumes of traffic. A study in Australia also found that the toxicity of urban runoff from residential roads was less toxic than arterial roads (Kumar *et al.*, 2002). As such, the types of stormwater management practices implemented to treat road runoff should account for the accommodated traffic volume and the associated loading/type of runoff pollutants.

Furthermore, pollutants from commercial or industrial have uncertainty in terms of type of pollutants not only released from the industrial or commercial site, but also from any potential spills or leaks of industrial compounds/materials that are being transported to and from the site. Additionally, atmospheric deposition from the industrial activity can also occur around the source location. Research by Dannecker and Stechmann (1990) reported that the industrial street which they studied had similar pollutant loadings as an arterial road which had roughly seven times higher traffic usage but much less truck transportation. This shows that pollutant loadings in industrial road runoff should also be acknowledged as a serious concern for water quality.

Commercials sites have also been found to have higher pollutant loadings than residential areas. However, designation of 'commercial' roads proves difficult as the majority of the roads that service commercial sites also service a neighbouring residential area. Transportation areas with solely commercial development would consist of the roads and parking lot areas surrounding a plaza and mall. Areas with mixed residential and commercial development could use residential local roads, collectors or arterials, depending on their location with a city. Caution should be taken when selecting and designing stormwater practices used in commercial parking lots and arterial roads in mixed zones such as Dundas Street or Yonge Street which is surrounded by a high density of commercial zones scattered with residential zones.

Overall, stormwater practices must consider not only the land use type and activity, but also the volume of vehicle traffic in determining the potential of groundwater contamination. It is also suggested that expressways and commercial parking lots be included as part of the human habitat road infrastructure that requires protection from stormwater. When determining which stormwater practices to implement, infiltration practices should not be recommended for arterials, expressways, industrial roads and commercial parking lots.

Besides the issue of contaminants, the selection of a stormwater practice should also include how practical it is for the site of concern. Does it take into account the variety of human uses of roads? For example, installing grassed ditches alongside a road which has a bus route would be highly impractical as bus passengers would be forced to step off into a ditch which may be full of runoff after a storm.

6.2.4 New Developments vs. Retrofitting

Both new (proposed) and existing (constructed) human habitat and the humans that use the infrastructure must be protected from the physical hazards posed by stormwater, especially infrastructure within flood risk areas.

In terms of new development, stormwater management practices can be developed in tandem with site planning to ensure the integrity of the infrastructure doing storm events. However, many developments have been built prior to the era when stormwater management was required, resulting in numerous infrastructures which only have combined sewers or separated storm sewers which are not equipped to adequately deal with the runoff produced in their catchment. For example, 75% and 80% of the urban development of the Humber River in 2008 (TRCA, 2008b) and the Don watershed in 2009 (TRCA, 2006a), respectively, did not have any stormwater management. When this is combined with the fact that much of this historic development was built on floodplains, (i.e. Toronto) (Environment Canada, 2010a), high peak flows and flooding continue to be a major concern (TRCA, 2008b). Retrofitting these existing developments with stormwater practices is essential to provide flood control in areas where it is lacking and to increase the protection of the infrastructure and the people's safety. Retrofit practices can consist of LID practices such as disconnecting downspouts, rain gardens, rain barrels, vegetated swales and green roofs.

Combined sewer separation can also be viewed as a retrofitting practice. Every year, large storm events cause combined sewer overflows (Banting *et al.*, 2005) which, in addition to the environment impacts from the raw sewage discharging into water bodies, can also cause sewage backup and flooding in basements, as well as discharge onto streets through manholes (US EPA, 1999a). Therefore, separating combined sewers into sanitary and stormwater sewers would positively benefit property and water quality for drinking and recreational purposes.

6.3 Summary

Of the proposed objectives made by Tran (2011b), a few modifications are suggested. Firstly, climate change is an issue that will have negative impacts on both the environment and humans. Secondly, water quality protection for human habitat should be for drinking water and recreation purposes. Thirdly, selection of stormwater practices according to human land use and transportation road types should also include commercial developments and their parking lots, as well as expressways.

The holistic approach taken to connect stormwater management to the proposed objectives has shown the broad influence that stormwater has on both the environment and humans. Expanding the original stormwater objective to 'maintain an appropriate diversity of aquatic life' provides stormwater management with a clearer direction of the areas it must protect in order to maintain aquatic diversity. The inclusion of maintaining terrestrial diversity shows the important link that stormwater has to terrestrial life, which can also be applied to the protection of wetlands and its biota. The incorporation of climate change in stormwater management is also essential in addressing and minimizing the impacts on both the environment and human habitat.

Furthermore, the development of human habitat objectives provides another step into the right direction for stormwater management. Acknowledgement of the different types of human habitat that require stormwater protection allows practices to be properly selected and effectively designed according to its targeted area. The resulting benefit from this knowledge will increase the protection of human infrastructure and life, as well as increased protection of the environment from contaminating groundwater supplies.

The purpose of developing these new stormwater management objectives is to show how stormwater has numerous direct and indirect connections to the environment and to ultimately provide a clearer direction for stormwater management that is based on holistic reasoning.

7.0 Modeling Results

Two scenarios of model calibration were conducted with one scenario using MIDUS's fixed C factor of 0.63, while the other scenario adjusted the trench parameters such that the EES functioned as if it were using a C factor of 1. Once calibration parameters were determined for each model scenario (C factor = 0.63, C factor = 1), the model was then run for the 2-, 5-, 10-, 25-, 50-, and 100-yr Chicago storms under each scenario. Table 17 displays the rainfall and runoff characteristics associated with each synthetic storm. Tables 18 and 19 show the pipe and trench hydraulics under the scenario of C factor = 0.63 and C factor = 1, respectively. Figures 29 and 30 display the trench hydrographs for the 5- and 50-yr design storms, under the scenarios of C factor = 0.63 and C factor = 1; however all of the modelled design storm trench hydraulics are compiled in Appendix A. The results of this EES modelling provide additional support to the benefits of accounting for seasonal and regional characteristics.

7.1 Rainfall and Runoff Characteristics

The rainfall depths and maximum intensities for the synthetic storms ranged from 24 mm to 102 mm, and 121 mm/hr to 280 mm/hr, respectively. As mentioned in Chapter 3, the use of a 2 min time step led to higher rainfall peak intensities. It is also important to note when analyzing performance that the rainfall depths and maximum intensities were significantly higher than the 15 mm depth and 50 mm/hr intensity that the EES was designed for. Runoff volumes ranged between 38 m^3 and 503 m^3, while runoff peak intensities varied from 0.035 m^3/s to 0.205 m^3/s (Table 17).

7.2 Trench Hydraulics

The performance of the trench hydraulics in terms of peak flow and volume reduction is compared between the two modelled scenarios, one under a C factor of 0.63, and one under a C factor of 1. This was to show the influence that the C factor has in performance. Also, since the scenario modelled under a C factor of 1 is the true EES design, the outflow hydrographs under this scenario were compared to that of pre-development catchment hydrographs for each design storm modelled. This was to examine how close the EES was in maintaining the pre-development hydrologic cycle.

7.2.1 Comparison of C Factors

In terms of trench hydraulics, it was found for both C factor scenarios that the amount of overflow volume and peak intensity increased as the storm's return period decreased. This was also true for the upstream trench head level. The 2-yr storm did not generate any overflows and the upstream head level was 0.018m (Table 18) and 0.0196m (Table 19) below the upstream trench invert under a C factor of 0.63 and 1, respectively. However, overflows began to occur from the 5-yr storm and up when the C factor was 0.63. These overflow volumes ranged from 33 $m^3$to 323 m^3, but these must be compared in relation to the inflow volume of that specific storm after flow diversion (if affected). The percentage of the reduced overflow volume ranged from 100% (2-yr storm) to 33% (100-yr storm). Peak flows (C factor = 0.63) were also found to be reduced for all synthetic storms, with a reduction percentage between 100% (2-yr storm) to 17% (100-yr storm). In comparison, the scenario under a C factor of 1 produced significantly different results in terms of overflows and peak flows (Table 19). The 5- and 10-yr design storms produced negligible overflows and as such volume reduction was 100% and 97%, respectively. The 25- to 100-yr design storms resulted in overflows, with a range of 55% to 78% volume reduction. Similarly, peak flows of the 5- and 10-yr design storms were reduced by a minimum of 96%, whilst the 25-, 50- and 100-yr peak flows were reduced by 81%, 68% and 41%, respectively.

The results of the modelling under different C factor values show the significance that the C factor has in the EES's performance. This is because a lower C factor decreases the flow rate of runoff that the perforated pipes can accommodate. As a consequence, the runoff entering the EES backs up such that the head in the manhole will rise quicker and produce an overflow more frequently. Modelling under a C factor of 1 has shown that less overflows occur, and that the overflow volumes and peak flows between the 2- to 100-yr storms were significantly less (Table 20).

Table 17: Time and storm parameters and resulting rainfall and runoff characteristics for 2- to 100-yr Chicago storms in Mississauga.

Design storm	Time Parameters			Chicago Storm Parameters					Rainfall		Runoff	
	Time Step (min)	Duration (min)	Max Storm Hydrograph (min)	A	B (min)	C	r	Duration (min)	Total depth (mm)	Max. Intensity (mm/hr)	Total Vol. (m^3)	Max. Intensity (m^3/s)
2-yr	2	60	500	610	4.6	0.78	0.4	60	23.624	121.27	37.89	0.035
5-yr	2	240	1000	820	4.6	0.78	0.4	240	44.965	163.019	150.09	0.064
10-yr	2	240	1500	1010	4.6	0.78	0.4	240	55.384	200.792	230.65	0.093
25-yr	2	240	1500	1160	4.6	0.78	0.4	240	63.61	230.612	296.14	0.12
50-yr	2	240	1500	1300	4.7	0.78	0.4	240	71.264	255.932	357.84	0.147
100-yr	2	720	1500	1450	4.9	0.78	0.4	720	102.219	280.039	502.92	0.205

Table 18: Pipe and trench results for modelled 2- to 100-yr Chicago storms under the scenario of C factor = 0.63.

Design storm	MH1 to MH2 Pipe	Diversion		Trench Results								
	Max. Outflow (m^3/s)	New Peak Flow (m^3/s)	New Volume (m^3)	Peak Exfiltration (m^3/s)	Infiltrated Vol. (m^3)	Max. Level (m)	Max. Storage (m^3)	Max. Outflow (m^3/s)	Total Outflow Vol. (m^3)	Trench upstream head (m)	Runoff Vol. Reduction [a] (%)	Runoff Peak Flow Reduction [a] (%)
2-yr	0.034	0.034	37.89	0.0021	36.219	154.86	31.6	0	0	-0.018[b]	100	100
5-yr	0.063	0.063	150.09	0.0034	114.072	155.673	100.155	0.009	33.25	0.755	77.9	85.7
10-yr	0.092	0.092	230.65	0.0035	121.392	155.781	107.961	0.04	109.12	0.903	52.7	56.5
25-yr	0.12	0.12	296.14	0.0036	123.749	155.85	112.788	0.065	172.51	0.972	41.7	45.8
50-yr	0.146	0.146	357.84	0.0037	125.565	155.93	118.151	0.087	232.59	1.052	35	40.4
100-yr	0.148[c]	0.148	476.8	0.0039	153.374	156.133	128.656	0.128	323.32	1.255	32.9	17.3

[a] Reduction is relative to the new peak flow and volume after diversion (if affected)

[b] 0.018 m below the upstream trench invert

[c] Reduction due to pipe capacity of 0.15 m^3/s

Table 19: Pipe and trench results for modelled 2- to 100-yr Chicago storms under the scenario of C factor = 1.

Design storm	MH1 to MH2 Pipe	Diversion		Trench Results								
	Max. Outflow (m^3/s)	New Peak Flow (m^3/s)	New Volume (m^3)	Peak Exfiltration (m^3/s)	Infiltrated Vol. (m^3)	Max. Level (m)	Max. Storage (m^3)	Max. Outflow (m^3/s)	Total Outflow Vol. (m^3)	Trench upstream head (m)	Runoff Vol. Reduction [a] (%)	Runoff Peak Flow Reduction [a] (%)
2-yr	0.034	0.034	37.89	0.002	35.642	153.773	31.779	0	0	-0.0196[b]	100	100
5-yr	0.063	0.063	150.09	0.0036	139.109	154.776	122.311	0	0.01	0.983	100	100
10-yr	0.092	0.092	230.65	0.0047	222.281	155.569	187.697	0.004	6.8	1.776	97.1	95.7
25-yr	0.12	0.12	296.14	0.0049	227.909	155.702	198.769	0.023	66.51	1.909	77.5	80.8
50-yr	0.146	0.146	357.84	0.005	229.793	155.809	205.754	0.046	126.12	2.016	64.8	68.5
100-yr	0.148[c]	0.148	476.83	0.0051	247.388	155.895	212.02	0.087	214.17	2.102	55.1	41.2

[a] Reduction is relative to the new peak flow and volume after diversion (if affected)

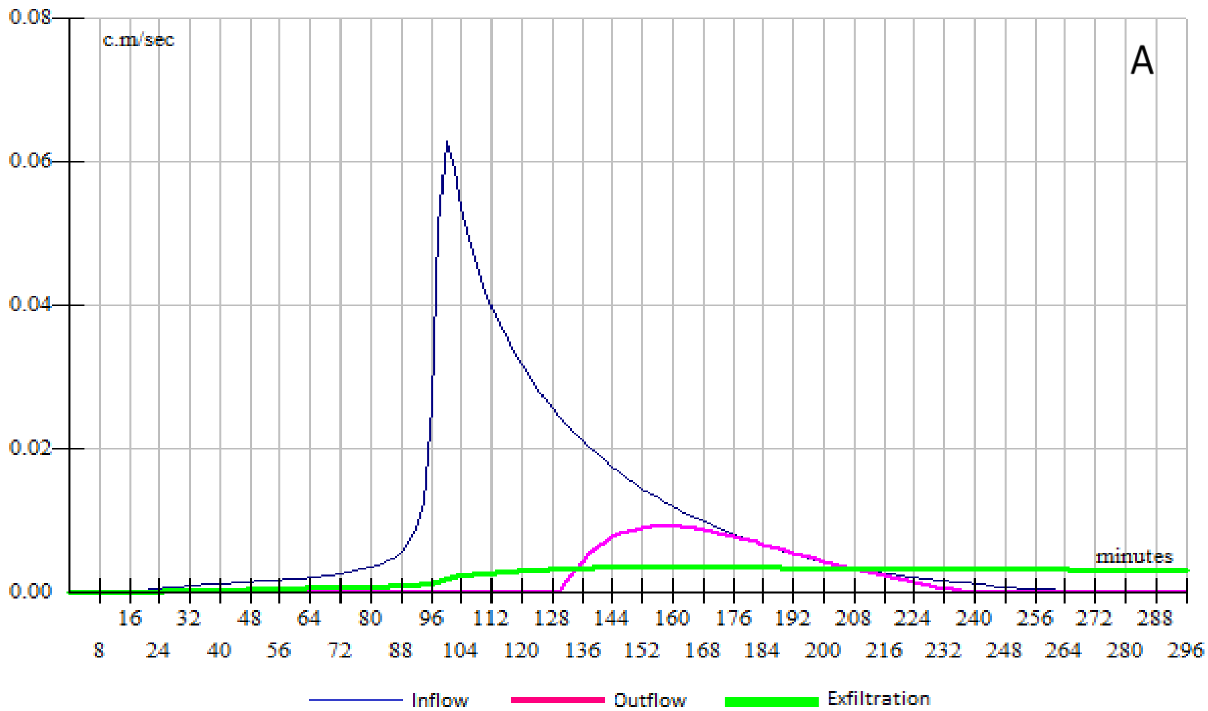
[b] 0.0196 m below the upstream trench invert

[c] Reduction due to pipe capacity of 0.15 m^3/s

Table 20: Comparison of EES performance under a C factor of 0.63 and 1.

Design Storm	Peak Flow (m^3/s)		Volume (m^3)		Trench Upstream Head [a] (m)		Runoff Vol. Reduction [b] (%)		Peak Flow Reduction [b] (%)	
	C=0.63[c]	C=1[d]	C=0.63	C=1	C=0.63	C=1	C=0.63	C=1	C=0.63	C=1
2-yr	0	0	0	0	-0.018[e]	-0.020[e]	100	100	100	100
5-yr	0.009	0	33.25	0.01	0.795	0.983	77.9	100	85.7	100
10-yr	0.040	0.004	109.12	6.8	0.903	1.776	52.7	97.1	56.5	95.7
25-yr	0.065	0.023	172.51	66.51	0.972	1.909	41.7	77.5	45.8	80.8
50-yr	0.087	0.046	232.59	126.12	1.052	2.016	35	64.8	40.4	68.5
100-yr	0.128	0.087	323.32	214.17	1.255	2.102	32.9	55.1	17.3	41.2

[a] Head level required for overflow: 0.713 m (C=0.63), 1.796 m (C=1)
[b] Relative to the new volume of peak flow after diversion (if affected)
[c] C factor value of 0.63 fixed in MIDUSS
[d] MIDUSS calibrated for EES to simulate a C factor of 1
[e] Below upstream trench invert level



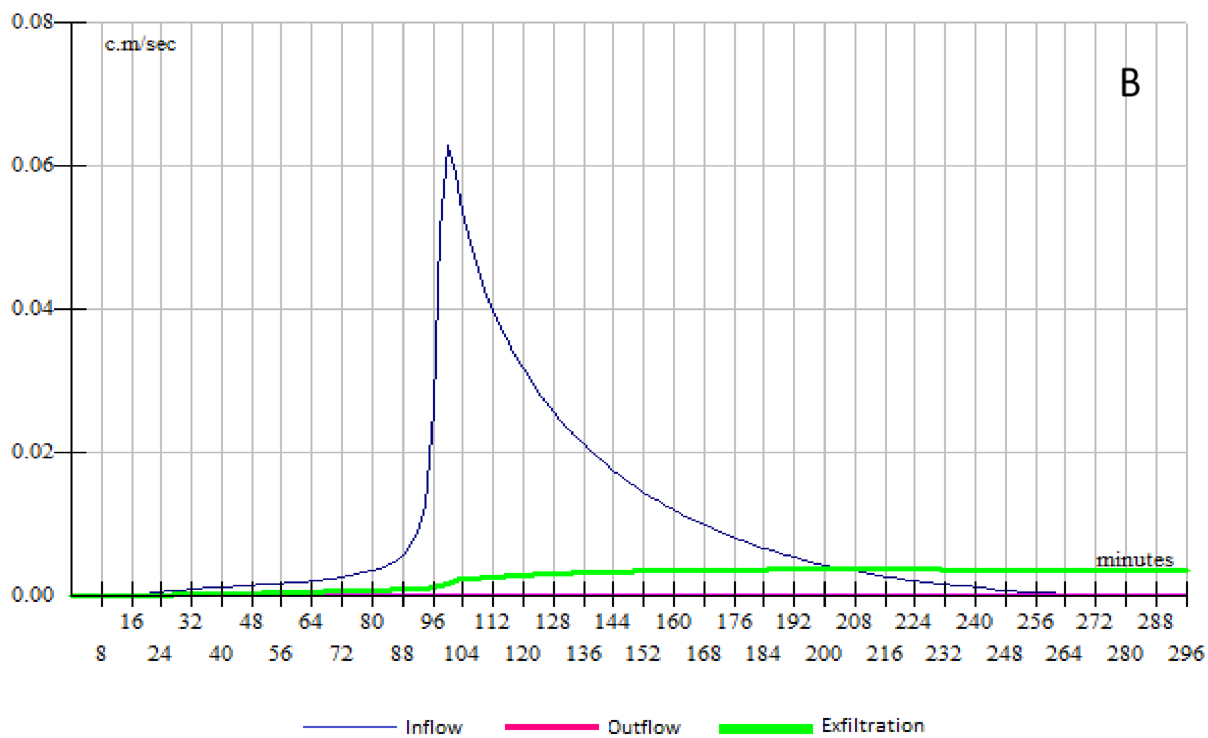


Figure 29: EES trench hydraulics for Mississauga's 5-yr Chicago storm, under scenario A of C factor = 0.63 and scenario B of C factor = 1.

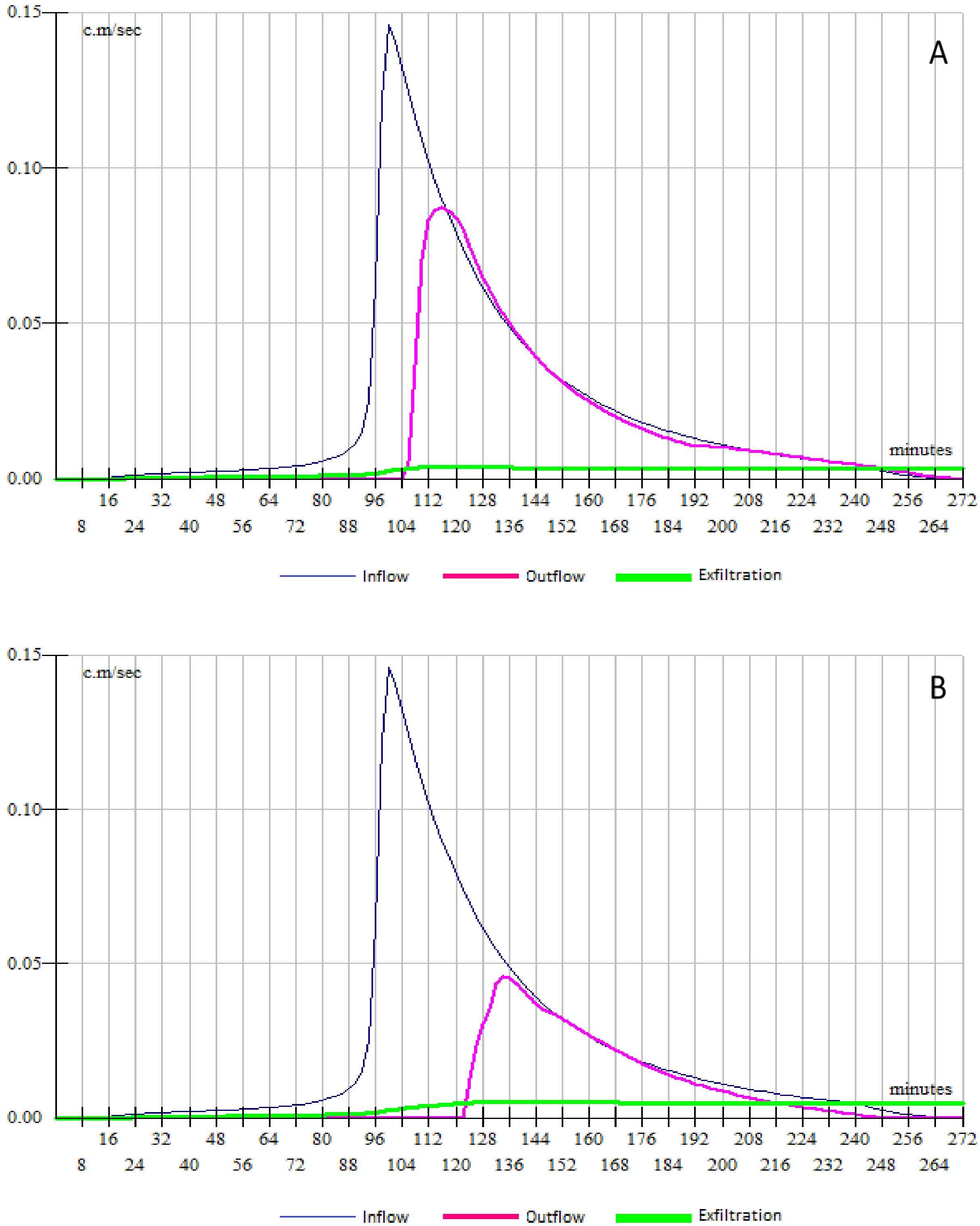


Figure 30: EES trench hydraulics for Mississauga's 50-yr Chicago storm, under scenario A of C factor = 0.63 and scenario B of C factor = 1.

7.2.2 Comparison to Pre-development

A summary of the results comparing the pre-development hydrographs to the post-development EES outflow hydrographs of the modelled 2- to 100-yr Chicago storms is shown in Table 21. The post-development hydrographs are based on a simulated C factor of 1. Also to consider in interpreting the data in Table 21, is that the 2- and 5-yr design storms produced no overflows and the 10-yr design storm produced an extremely small overflow (Table 19).

In addition, it is important to note that the catchment parameters used for modelling the pre-development scenario of 0% imperviousness are assumed to be those which were calibrated for the existing 15% residential scenario except for modifying the impervious percentage. This is because it is not possible to determine pre-development catchment values as only existing conditions are present. Values of parameters such as depression storage, maximum and minimum infiltration, and lag time will be different under a pre-development scenario where no land grading or soil compaction has occurred due to construction. As such, the modelling of the pre-development scenario is not a true reflection of zero development, but instead a model of the existing runoff conditions under 0% imperviousness.

The time to peak for the post-development hydrographs of all the design storms was delayed much longer than that under a pre-development scenario. In the case for the 2- and 5-yr design storms, no overflow occurred and therefore a time to peak was not applicable. The peak flow rate for the post-development hydrographs was reduced in comparison to pre-development rates between 100% (2- and 5-yr storms) and 47% (100-yr storm). Similarly, the EES outflow volume was much smaller than the runoff volume produced under pre-development conditions such that the EES outflow was 100% (2- and 5-yr storms) to 50% (100-yr storm) less in volume. Duration of post-development EES outflow was also less than that of pre-development runoff by 100% (2- and 5-yr storm) to 36% (100-yr storm).

Overall, it can be seen that the post-development EES outflow hydrograph has reduced volume, peak flow, and duration far beyond the levels under a pre-development scenario of 0% imperviousness. This can be mainly attributed to the large storage volume of the EES as well as partially to the EES's trench exfiltration rate. Under a simulated C factor of 1, the EES has a trench storage volume of 230 m^3 and thus was more than capable of storing all of the runoff generated from the modelled 2- and 5- yr storms under post-development 15% imperviousness, as well as nearly all of the runoff from the 10-yr design storm. In addition to this large storage volume, the EES exfiltration rate also allowed additional runoff to be stored in the trench as it exfiltrated runoff out of the trench and thus opened up space within the trench to be re-filled. The maximum stored volume and infiltrated volume of runoff (exfiltrated) of the modelled design storms is shown in Table 19. Therefore, the attenuation of the overflow volume and peak flow during a single event design storm was heavy influenced by the large EES storage volume, with the exfiltration rate also aiding. Furthermore, the reduction of runoff volume beyond that of pre-development rates has led to the runoff duration of the post-development hydrograph to also decrease as there is less volume overflowing. An example of the difference between the pre-development and post-development hydrographs is shown in Figure 31, with Appendix A containing a comparison of the hydrographs of all the modelled design storms.

The effect of decreased runoff volume entering the stream and instead infiltrating into the ground requires further research to quantify its impact on baseflow, evapotranspiration and sediment loading.

Table 21: Comparison of pre-development and EES post-development hydrographs for Mississauga's 2- to 100-yr Chicago storms.

Design Storm Event	Pre-development[a]				Post-development[b]			
	Time to Peak (min)	Peak Flow (m^3/s)	Volume (m^3)	Duration (min)	Time to Peak (min)	Peak Flow (m^3/s)	Volume (m^3)	Duration (min)
2-yr	32	0.005	8.71	54	0	0	0	0
5-yr	106	0.035	107.57	149	0	0	0.01	0
10-yr	106	0.063	186.19	164	190	0.004	6.8	48
25-yr	105	0.088	250.46	171	149	0.023	66.51	104
50-yr	104	0.113	311.17	177	134	0.046	126.12	126
100-yr	294	0.17	433.78	239	314	0.09	218.92	152

[a] 0% imperviousness

[b] 15% imperviousness

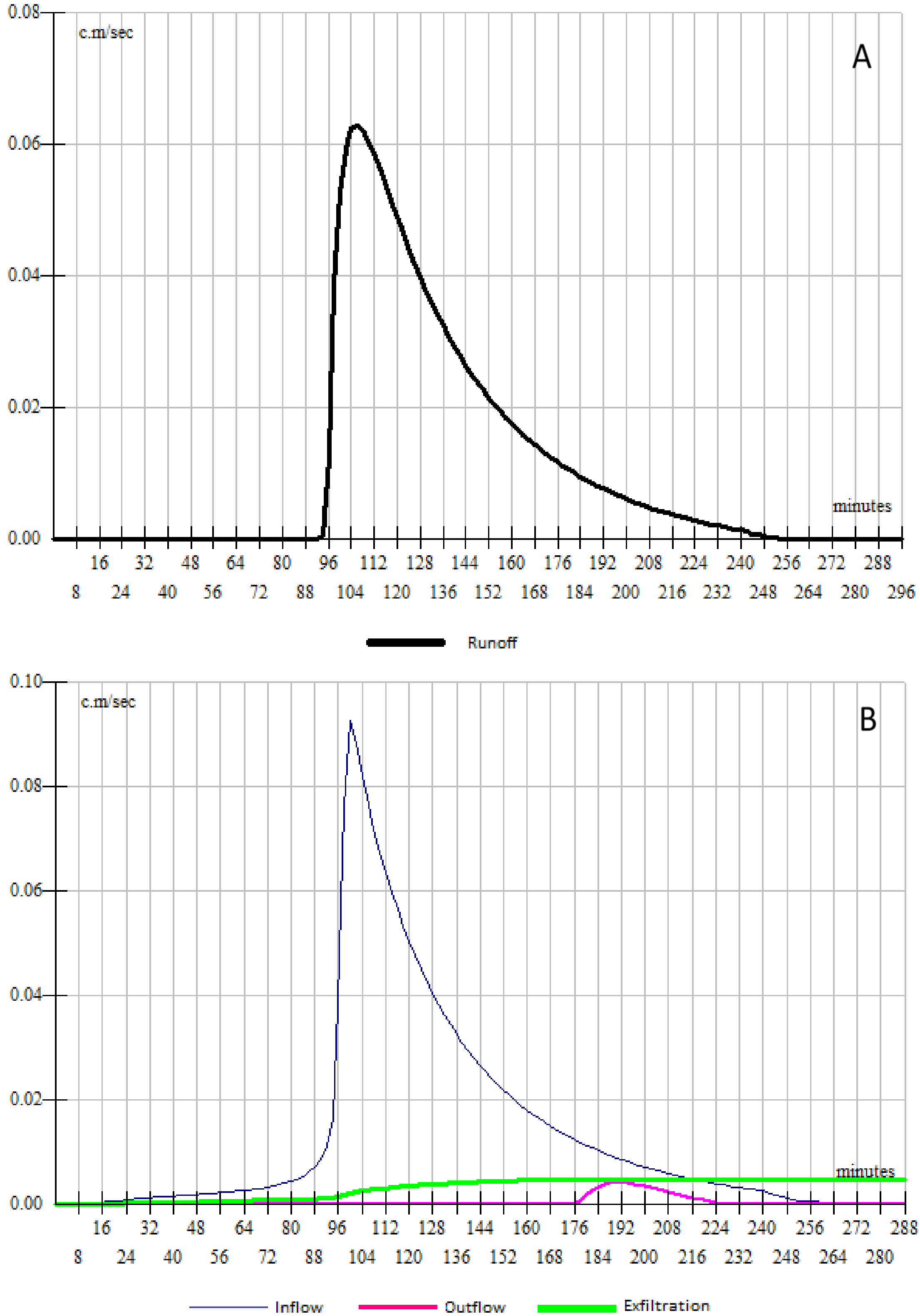


Figure 31: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 10-yr Chicago storm.

7.2.3 Discussion

The results of the modeling have shown that the EES can easily treat a 2-year storm with 25 mm rainfall depth and 121 mm/hr rainfall peak intensity, with sufficient trench storage and upstream trench head to spare. Also, simulating a C factor of 1 resulted in a minimum of 96% and 97% of the peak flow and volume, respectively, to be reduced for the 2- to 10-yr design storms. In addition, after some of the runoff of the 100-yr Chicago storm was diverted before entering the EES, 55% of the volume and 41% of its peak flow was reduced, which is equivalent to 262 $m^3$and 0.061 m^3/s, respectively. This shows that although the EES was originally designed to treat 15 mm of rainfall depth and 50 mm of rainfall peak intensity, it has significantly exceeded that design criteria and is capable of even lessening the impacts of a 100-yr storm.

In analyzing the system's ability to treat the 100-yr storms, two factors must be considered. First, the grate inlet's capacity (0.1548 m^3/s) limited the runoff flow rate and thus the runoff volume that could be captured by the four catchbasins between MH1 to MH2. Once captured, the transportation of this runoff between MH1 to MH2 to enter the EES was further limited by the storm sewer pipe's capacity of 0.15 m^3/s. Due to these thresholds, the peak flow and volume of the inflow into the EES were 28% and 5% lower, respectively, than that of the catchment runoff. It is important to consider this when examining the percent reduction of peak flow and volume of the 100-yr storm because this reduction is relative to the modified peak flow and volume that was able to enter the EES.

The pipe size between MH1 and MH2 was the greatest limiting factor for the amount of runoff that could enter the EES as its flow capacity (0.15 m^3/s) was slightly smaller than the grate inlet's capacity (0.1548 m^3/s). However, downstream between MH2 and MH3, the pipe size is 0.45 m and thus has a flow capacity of 0.244 m^3/s, which is capable of transporting the 100-yr peak flow of 0.205 m^3/s. Therefore, in this section, the greatest limiting factor is the grate inlet's capacity. This could be remediated by choosing grates with a higher inlet capacity or increasing the number of grates. However, this would not make a significant improvement in the amount of runoff being treated by the EES because roughly only 5% (26 m^3) of the catchment runoff is reduced by the four grates between MH2 and MH3.

It is important to understand that these modelling performance results for the EES are for the specific pilot study area of Princess Margaret Blvd. The reference to the study area is of importance because, as mentioned in Chapter 5, the storm characteristics of a different city may not produce the same rainfall depths or intensities. Similarly, the catchment conditions of a different region may vary such as slope, percentage of imperviousness, soil infiltration rates and hydraulic conductivities. The use of existing stormwater management practices can also impact the hydrology and therefore the hydraulics of a system. For example, the original imperviousness given by the City of Etobicoke for the pilot study area was 28% (Candaras, 1997). However, during calibration of MIDUSS, the imperviousness was modified to 15% as this percentage resulted in the best fit for the catchment runoff hydrograph. The difference can be attributed to the disconnected downspouts in the study area allowing roof runoff to be spread overland, infiltrate into the ground where possible, and result in an increased lag by the time the runoff enters the catchbasin and storm sewer network. This is in contrast to buildings with connected downspouts where 100% of the roof runoff is directed into the storm sewer without any lag. The calibration has shown that by disconnecting the downspouts, this practice has decreased the effective imperviousness of the drainage area. Overall, when applying the EES to different regions and sites, the exact same performance under the synthetic storms may not occur due to the varying storm characteristics and catchment conditions. For instance, the runoff volume of a 10-yr Chicago storm may be reduced by 97% in Etobicoke, but that reduction percentage may increase or decrease for a 10-yr Chicago storm in Ottawa using locally derived parameters.

Furthermore, a question may arise as to why an overflow did not occur during the Oct 5-6, 1995 storm but instead for the two synthetic storms (5- and 25-yr) which had similar rainfall and/or runoff characteristics. To recap, the historic event produced 63 mm rainfall depth with a rainfall peak intensity of 13.3 mm/hr and resulted in 130 m^3 runoff volume with a runoff peak intensity of 0.01 m^3/s. This historic storm was four times larger than the design rainfall depth (15 mm), but four times smaller than the design rainfall peak intensity (50 mm/hr). The 5-yr storm generated a slightly higher runoff volume of 150 m^3, while the 25-yr storm produced 64 mm of rainfall depth. Overflows were produced from these two synthetic storms for a number of reasons. First, the rainfall maximum intensities were significantly higher than that of the historic event (and EES design criteria), and this is attributed to the 2 min time step parameter and also from the Chicago A, B and C parameters that dictate the distribution pattern of the rainfall. Second, although the runoff volume of the 5–yr storm was slightly higher than the historic event, it exceeded the storage capacity of the trench of 135 m^3. Of the synthetic storms modeled, only the 2-yr storm runoff volume was below the trench storage capacity. Third, the runoff peak intensities were significantly higher than the historic storm, such that the 5-yr storm's and 25-yr storm's peak intensities were six and twelve times greater, respectively.

In addition to the above reasons, storm duration also had a significant impact on the hydrology and hydraulics. The historic event produced 63 mm of rainfall depth over 18 hours, thereby the rainfall volume had more time to be distributed and as such its peak intensity was relatively small for a storm of that volume. On the other hand, the 25-yr storm had 64 mm of rainfall depth in only four hours. As such, the distribution of the rainfall could not be spread out as much and the rainfall peak intensity increased to accommodate for the short storm duration. This in turn affected the catchment's response to the storm where the rainfall intensity was substantially greater than the soil infiltration rate and so generated larger volumes and faster flows of runoff. A system will find it more challenging to treat the resulting runoff from a short duration storm as oppose to a long duration storm with equivalent rainfall depth.

If the same rainfall depth of these synthetic storms was fixed but the duration was extended, this would most likely ease the burden on the EES. The rainfall peak intensity would decrease as the rainfall will have longer time to be distributed. The reduced intensity would be at a level which the catchment's soil infiltration rate could handle and so more rainfall would be infiltrated, thus there would be less runoff volume and intensity. These parameters may not drastically change to the point where overflows would not occur, but the amount of overflow and its peak flow will most likely be reduced. This shows the importance that storm duration has on the influence of rainfall and runoff characteristics, and ultimately performance of stormwater practices.

Also of importance is how these modelling results indirectly showed the effect the EES has on runoff frequency and duration. Modelling of the Mississauga 1-hour 2-yr Chicago storm between MH2 and MH3 showed that no overflow occurs and it is assumed that this will hold true for the entire system except for the last sewer length where some catchbasin runoff will not be directed into the perforated pipes but straight into the main sewer pipe and discharge though the outlet. With this basis, the near 100% capture of runoff entering the EES leads to very minimal runoff volume discharging from the stormwater system outlet and entering the stream. This equates to the runoff frequency to be reduced by 100% for this size of storm because there are no overflows. When overflows do occur, as seen with the modelled 10-yr synthetic storm, the overflow volume and peak flow are significantly reduced in comparison to the inflow. This results in runoff entering the stream, but for a shorter duration because there is less volume being discharged.

In conclusion, the results of the EES modeling show that it is indeed possible to capture 100% of a 1-hour 2-yr storm with 25 mm rainfall depth and 121 mm/hr rainfall peak intensity, as well as to reduce runoff frequency and duration.   With proof of the system's capability, the achievement of capturing 25 mm should become a benchmark for other practices to compare to and strive towards. Practices should not be designed to capture and treat 5 or 10mm storms, when it is now known that it is possible to capture and treat a 25mm storm. In order to move forward in stormwater management, practices must be designed to achieve the best performances that are known to be capable.

8.0 EES and Fulfilment of Objectives

The purpose of this chapter is to determine which objectives the EES is able to fulfill. This in turn will provide support for stormwater management to be based on the five stormwater characteristics, and seasonal and regional conditions, which the EES addresses. The stormwater management objectives to be considered consist of those proposed in Chapter 6. Judgement of the EES's applicability to fulfill an objective was based on the quantitative data from previous reports and modelling from Chapter 7, where applicable. The EES modelling results that were used consist of those under a C factor of 1 as this is the accurate representation of the orifice flow into the perforated pipes. Due to the limited data available, a holistic approach using both quantitative and qualitative reasoning was used.

8.1 Environmental Objectives

8.1.1 Preserve Groundwater

One way of preserving the groundwater table is by providing constant recharge to the water table through infiltration of storm events. This is achieved by the EES. The modelling results from Tables 17 and 19 in Chapter 7, show that substantial amounts of the inflow into the EES system were infiltrated. This also translates into the amount of overflow volume that is reduced. The percentage of infiltrated runoff ranges from more than 50% under a 12 hour 100-yr Chicago storm to 100% under a 1 hour 2-yr Chicago storm. Furthermore, Appendix E from the SWAMP report shows that 177 rainfall events were measured between 1996 to 1998, yet only three overflows were produced. This means that 98.3% of the total rainfall events for a three year period were captured and infiltrated. This value also translates into a reduction of runoff frequency at the EES outlet by 98.3%. Furthermore, the three overflows occurred within the same year which had 69 total rainfall events. This means that within the three year monitoring period, the EES had a minimum of 95.6% of annual events infiltrated. Although there are no qualitative data on how the EES affects the groundwater table, it is reasonable to conclude that groundwater within the pilot study areas is being preserved due to the high percentage (minimum of 95.6%) of events being completely infiltrated per year.

8.1.2 Preserve Baseflow Characteristics

By preserving groundwater, baseflow characteristics can also be maintained. Therefore, it can be assumed that groundwater recharged by the EES will allow a constant baseflow to be fed to nearby water bodies and most importantly be able to support small head water streams. Although no rivers or streams have been quantitatively analyzed for the effects the EES has had on baseflow or stream water level during any time of the year, observations of the environment can be used as support. At the location of the EES outlet at the intersection between Queen Mary Drive and Kingsway Crescent, a small stream can be found which eventually drains into the Humber River. This small stream resembles that of a head water stream with large healthy mature trees and thick vegetation surrounding its banks (Fig. 32). It can be assumed with reason that an adequate groundwater level has allowed for healthy vegetation to grow in this area and has preserved the baseflow needed to maintain this small stream.

Figure 32: Field observations of the Queen Mary Drive site showing healthy riparian vegetation supported by a small stream.

8.1.3 Protect Water Quality

Pollutant removal from the runoff can be seen in the Princess Margaret Boulevard sediment analysis by Candaras (1997) and the Queen Mary's Drive relief pipe water quality analysis by SWAMP (2004). The sediment analysis reveals that extremely high concentration of metals such as copper, lead, manganese and zinc are retained within the sediment. This shows that the concentration of runoff pollutants is being reduced before the runoff even enters the trench bedding.

In terms of monitoring the relief pipe, it provides the closest measurements available to give an idea about the quality of runoff entering the groundwater. This is because the relief pipe drains the water just below the trench, and thus is the runoff that has just been exfiltrated. The results of the relief pipe grab samples show that the trench effluent is of much better quality than that of stormwater ponds (Tran *et al.*, 2012). Metal concentrations were found to be much lower in the EES trench effluent than of pond effluent, as well as suspended solids, chloride, and nitrite (Tran *et al.*, 2012). In addition, pollutant reduction of chloride was found to be up to 95% (Tran *et al.*, 2012). This is a significant achievement because it is the first practice to be able to significantly reduce chloride concentrations. However, the EES mechanisms involved in reducing chloride in the runoff are unknown and require future research.

8.1.4 Maintain Terrestrial Biodiversity

As stated in Chapter 6, terrestrial biodiversity can be maintained through a constant supply of water, whether it is surface or groundwater. When an adequate supply of groundwater is available, the diversity of vegetation will increase, thereby providing food and shelter for a variety of herbivorous terrestrial animals, which in turn provides food for predator terrestrial animals. Therefore the act of maintaining groundwater levels prior to development will indirectly maintain terrestrial biodiversity. With this in mind, it is assumed that since the EES has been able to infiltrate runoff and recharge the groundwater table, it is also able to maintain terrestrial biodiversity. Although no species survey has been conduct, a healthy variety of terrestrial vegetation are present at the pilot (Fig. 32), which in turn has provided a home to several species of insects, reptiles, amphibians, birds and mammals.

8.1.5 Protect Spawning and Rearing Grounds

Spawning and rearing grounds for aquatic species have specific requirements. Coldwater fish such as the salmonids require a constant baseflow to not only maintain the spawning and rearing grounds, but also to provide the cold temperature it needs to trigger spawning and to ensure egg and juvenile survival. Maintaining the riparian vegetation will also provide shade, shelter and food for aquatic species. Additionally, stream quality needs to be high, with minimal runoff contamination of metals, nutrients and fine sediment which can be lethal to egg survival of aquatic species.

The EES is able to protect spawning and rearing grounds through a variety of ways. Firstly, by recharging the groundwater, it also provides cold baseflow to the stream which may be used for spawning and/or rearing. Secondly, the maintained groundwater table enables riparian vegetation to establish and thrive around streams, thereby providing shade and a food source. Thirdly, the significant reduction of runoff pollutant concentrations improves the water quality of the stream. Lastly, the decreased runoff peak flows of storms means that stream flows are at adequate levels that allow spawning pools and riffles to be maintained such that the eggs remain in place within the redds and the juveniles can withstand the stream flow. Peak flows leaving the EES outlet has not been monitored; however, the results of the modelling from Chapter 7 show that in cases where overflows are present, the peak outflow is substantially lower than the inflow into the system. For example, the 4 hour 10-yr Chicago storm with an inflow of 0.092 m^3/s produces a peak outflow (overflow) of 0.004 m^3/s (96% reduction) between MH2 and MH3 of the EES. Thus, it can be assumed that there would be an overall significantly decreased peak flow at the outlet of the system. Furthermore, not only are runoff peak flows decreased, but the frequency of runoff entering the stream via the EES outlet is reduced as well as the duration of runoff.

The EES has also benefited spawning grounds by minimizing the number of overflows during spawning seasons for fish species such as the brook trout which spawn during fall in Ontario (MNR, 2007) and yellow perch which spawning in spring (DFO, 2009). The three overflows that occurred were on June 13, June 30, and September 6 of 1998 at Princess Margaret Boulevard. The two overflows in June would have had no impact on these species, whilst the overflow in September would have very minimal impact on the brook trout because it was only ten minutes in duration (SWAMP, 2004). Overall, the result is a stream habitat more conducive for fish habitat including spawning and rearing grounds.

8.1.6 Protect Migratory Corridors

Other than bed stream substrate for fish spawning, the same requirements needed for spawning and rearing grounds are also applicable to protecting migratory corridors. The Humber River is a migratory corridor for several aquatic fish species such as yellow perch, brook trout and walleye (TRCA, 2008a). Without adequate stream temperature, quality and habitat provided throughout the migratory route, the survival of the migrating aquatic species can be negatively affected. As mentioned in the above objective, the ability of the EES to recharge groundwater, to reduce runoff pollutant concentrations, and to decrease runoff volume, peak flow, duration and frequency results in the protection of aquatic migratory corridors.

8.1.7 Protect Wetlands

The protection of wetlands involves providing a constant baseflow and reducing contaminant loadings and peak flows/volumes which exceed the threshold of the wetland species. As mentioned previously, the EES is capable of providing all these functions which are conducive for a wetland.

Although no wetlands are present nearby these pilot sites, the EES is assumed to be capable of protecting wetlands because of the functions it is able to provide which support wetlands.

8.1.8 Minimize Impacts of Climate Change

Climate change impacts to the environment associated with stormwater include higher temperatures and a higher frequency of extreme events such as larger storms and prolonged droughts. The EES is able to prevent stormwater from being heated because its system is underground, thereby cooling the runoff as it enters the systems. Runoff which is infiltrated into the ground will become cool baseflow and any outflows from the system's outlet will have spent time underground and thus will be much cooler than runoff stored and treated in above ground stormwater management practices such as ponds. Additionally, modelling the EES has shown that it is able to attenuate the peak flows of extreme storms, including those as large as Mississauga's 12 hour 100-yr Chicago storms whose runoff inflow into the system was reduced by 41% within one section (MH2 to MH3) of the EES. Runoff duration of these extreme storms is also lowered at the EES outlet as some of the runoff is being infiltrated throughout the system. This runoff infiltration would also be beneficial during prolonged dry periods. The absence of storms during droughts to recharge the underground aquifers would result in water table levels decreasing very quickly, which would negatively affect terrestrial vegetation and stream level/temperature maintenance. Therefore it is essential to take advantage of the occurrence of storms and recharge the groundwater table when possible. Overall, the ability of the EES to prevent the temperature increase in runoff, mitigate extreme storm peak flows, and recharge the groundwater enables the system to minimize some of the impacts of climate change on the environment.

8.2 Human Habitat Objectives

8.2.1 Protect New Residential Sites

New residential sites require protection from flooding that may occur during storms. The EES is able to attenuate the post-development flows of the 2-, 5-, 10-, 25-, 50- and 100-yr storms, as well as the runoff volume, frequency and duration. Although the EES pilot sites were not constructed in a new development, the EES's capability of attenuating post-development flows would result in flood protection within any new development with the EES, as well as new developments downstream by having less increase of stream flow and depth during a storm. In addition, EES could prove to be a substitute to stormwater quality ponds which are often used in new development sites because the EES's storage ratio may in fact be much better than that of current quality pond designs. The drainage area and sewer length of the Princess Margaret site is 30.5 ha and 1.3 km (Candaras, 1997) respectively, which translates into 2.34 ha of drainage area serviced by 100m of sewer. Knowing that the trench storage volume per 100 m is 134.8 m^3, the storage ratio is calculated to be 57.6 m^3/ha. A wet pond with enhanced long term TSS removal in a 35% impervious catchment requires 140 m^3/ha, which is nearly triple the storage ratio of the EES (MOE, 2003). In all, the EES would not only provide protection and more space for new development sites, but also remove any safety concerns of falling into the stormwater ponds as the EES is completely underground.

8.2.2 Retrofitting Existing Residential Sites and Combined Sewers

Existing residential sites can be protected using retrofitting practices to provide stormwater control in areas which may be of concern. The EES is an ideal retrofit practice when new transportation or public works are scheduled such as projects to repair/renew sanitary or water mains and roads. Instead of removing the road in question twice and incurring higher costs, two projects could be completed simultaneously. This also applies for when combined sewers are scheduled for sewer separation. The EES has the same installation as storm sewers, but with the addition of two perforated pipes within the original trench framework. When using the EES as a retrofit practice, goss traps must be fitted in the catchbasins which drain into the EES. This is because old residential areas use oil furnaces for heating in winter (as opposed to forced air liquid gas furnaces in new developments) and have become a major cause for spills when the oil needs to be refilled (Tran, 2011b).

8.2.3 Protect Residential Local Roads/Collectors

As with protecting new residential sites, reduction of runoff peak flow, volume, duration and frequency also applies to protecting local roads and collectors in residential areas. The EES minimizes the flooding risk, allowing safe and efficient road access to vehicles and pedestrians. Also, since the pilot studies were located within residential areas with low levels of vehicle traffic on local roads, pollutant loading was relatively low to other transportation roads. This reduced the risk of possible groundwater contamination when the road runoff was infiltrated by the EES.

The design of the EES to include cut-off walls below each manhole and to wrap the trench in geotextile fabric also positively impacted the road integrity. The cut-off walls stopped the downstream migration of both the infiltrated runoff and trench bedding between trenches. Similarly, wrapping the trench prevented the surrounding soil to migrate into the trench which in turn prevented the formation of large air pockets within the ground. By restricting the migration of the trench bedding and surrounding soil, the EES preserved the stability of the ground underneath the road and consequently the road's integrity.

8.2.4 Prevent any Increase in Flood Potential

As mentioned previously, the EES is able to attenuate both the runoff peak flows and volumes for a range of storms up to a 12 hour 100-yr Chicago storm, as well as their runoff duration and frequency. This is supported by the results of the modelling in Chapter 7 and in the SWAMP (2004) report where 98.3% of total rainfall events over three years were captured and treated. In doing so, the EES has reduced post-development runoff flow, volume, duration and frequency to be lower than that of pre-development levels, and consequently reduced the risk of flooding. Therefore, an additional function of the system is to prevent the flood potential of an area from increasing after development.

8.2.5 Prevent Geomorphic Changes

Reducing runoff peak flow, volume, duration and frequency also results in minimizing the increase in stream flow and level during a storm. By reducing the increase in stream flow, the erosive energy is also lowered. This in turn reduces the frequency of erosion of channel banks downstream of the EES outlet and overall minimizes geomorphic changes from occurring greater than that of a natural pre-development rate.

Additionally, the EES's reduction of runoff volume and concentration of suspended solids entering the stream may impact the morphology of the downstream channels such that there may be too little suspended solids being transported and deposited on channel banks, or the ratio of suspended solids required to maintain bank stability may not be correct. However, field observations of the small stream in Figure 32 resemble that of a headwater stream with minimal erosion and stable banks. Further research is required to quantitatively determine if the suspended solid loading into the stream from the EES outlet is of sufficient concentration and ratio required to maintain the stability of the receiving streams.

8.2.6 Other Objectives

This last section includes the objectives to protect drinking water, protect new industrial sites, retrofit existing industrial sites, protect residential arterial roads and expressways and industrial roads. These objectives have been grouped together because of one common factor - potential groundwater contamination. The EES is able to infiltrate a significant portion of a rainfall event up to 100% (i.e. 100% of the historic 63 mm Oct 5-6, 1995 event) which then percolates downwards to recharge the groundwater table. Although it is known that a large concentration of pollutants have been trapped within the sediment in the perforated pipes, there is still much research to be conducted for pollutant pathways and mechanisms thereafter. Areas that need to be studied include the quality of the groundwater below, the soil's ability to provide additional runoff remediation and the chemical interactions between the trench's stone bedding and the runoff's pollutants. Without this information, it is best to be conservative in the implementation of the EES to reduce the risk of groundwater contamination in areas which require special protection (i.e. drinking water aquifers) and in areas which are known to have high pollutant loadings (i.e. industrial sites and roads, busy residential arterials and expressways). Therefore, in terms of these objectives, the EES is not an adequate choice for stormwater management and is not recommended for the protection of these human habitat areas.

8.3 Summary

Through its ability to capture and infiltrate over 95% of annual rainfall events, the EES has been able to: 1) recharge groundwater; 2) reduce runoff peaks flow, volume, duration and frequency to more comparable levels of pre-development eras and even beyond; and 3) reduce pollutant loadings into the water body. This enables the system to accomplish a broad range of objectives, including all of the environmental objectives, as well as the human habitat objectives not associated with concerns of potential groundwater contamination.

The wide range of functions the EES can provide supports for the importance of stormwater management practices to go beyond treating stormwater for water quality, peak flow and volume, but to also account for frequency and duration. Once a system is able to cover all five aspects of stormwater, its performance will increase and the range of objectives that it can fulfill will expand. Furthermore, the range of objectives fulfilled by the EES also shows the benefits of accounting for seasonal and regional conditions in stormwater management.

Although much research is still needed to quantify many of the achievements of the EES, the system has set a new level of standard for stormwater management and shows what can be achieved using technology from twenty years ago. When new standards for design criteria are created, it must at minimum be able to achieve what the EES has, for example capture and treating 100% of Mississauga's 1 hour 2-yr Chicago storm. This is to ensure that stormwater management moves forward and progresses instead of remaining stagnant.

9.0 Conclusion and Recommendations

Despite the improvements made in stormwater management, Ontario's water bodies continue to be degraded. Three areas of concern have been highlighted which warrant modification.

The current design of stormwater infrastructure is based on warm climate conditions. Consequently, this equates to practices being designed to manage summer and fall runoff which only accounts for roughly 21% to 28%, while 72% to 79% of annual runoff is inadequately managed. This is especially a concern during snow melt and snow on melt events which produce the largest percentage of annual runoff in Ontario. Stormwater management in Ontario could be substantially improved and be more effective if all four seasons were incorporated into the design to adequately treat the varying types of runoff volumes, peak flows, durations, frequencies and quality associated with each season. In all, stormwater management should be addressing 100% of the annual runoff generated, and not that just from summer and fall.

Stormwater practices are not truly accounting for regional conditions. This includes inaccurate use of performance targets using percent removal efficiencies as a basis of improving water body health and inaccurate assumptions that local climate and soil characteristics are uniform throughout the province. Additionally, other regional factors that influence the design and performance of a practice are acidic rain and neighbouring hydrograph developments. Therefore, another substantial improvement to stormwater management would to ensure that designs have been developed with consideration of any regional influencing factors. This will ensure that practices will be designed accordingly to optimize its performance and to ensure that effluent parameters are in agreement with what the receiving water body requires to maintain or achieve a healthy aquatic ecosystem. Ultimately, the more region-specific the designs are based on, the better the protection of water bodies.

Stormwater management objectives must be revised as some are too simple and do not provide enough direction as to what requires protection. This is evident in the vague and broad objective to maintain aquatic diversity which must be split into several objectives to accomplish that goal. Objectives should be split into environmental and human habitat categories as each group requires different types of protection from stormwater. However, it should be noted that if the environmental objectives have been successfully fulfilled, then consequently, so will the human habitat objectives. This is because properly addressing the environmental objectives through the management and mitigation of the five characteristics of runoff (peak intensity, volume, frequency, duration, and quality), will effectively eliminate the same problems that affect human habitat. Furthermore, the proposed objectives provide increased insight as to the areas that urban stormwater negatively impacts and gives further direction on how the environment and humans and their infrastructure can be protected. Therefore, the current stormwater management objectives should be updated to include those proposed in Chapter 6.

In addition to highlighting the areas of stormwater management that must be modified, the case study of the EES has shown its effectiveness in addressing the five stormwater characteristics. Modelling has also shown that it is captures and infiltrates 100% of the Mississauga's 1 hour, 2-yr Chicago storm of 25 mm and 121 mm/hr rainfall depth and peak intensity, respectively. This shows that the EES is capable of treating storms beyond its design criteria of a 1hr AES storm of 15 mm rainfall depth and 50 mm/hr and peak intensity. It is also able to attenuate the large volumes and high peak flows of extreme events such as the 50- and 100-yr Chicago storms. The importance of these results is that it shows that current practices of designing for 5 to 10mm rainfall depth is extremely below what the EES is capable of. The treatment of 25 mm rainfall depth should become a standard design criterion for practices. In addition to this, some regions may have storms where 90% of the annual rainfall events have greater than 25 mm rainfall depth. Therefore, it would be best to choose the highest rainfall depth between either the 25 mm or the value determined by 90% of the annual rainfall events of the city.

The EES has also proven that it is capable of addressing a very wide range of stormwater management objectives. Those which it was not recommended for were due to issues of groundwater contamination. The success of the EES to fulfill these objectives is a result of addressing the five stormwater characteristics year round. It also shows that the new proposed objectives can indeed be achieved. Lastly, the determination that the EES is not suitable in all urban areas (ie industrial and arterial roads) shows the usefulness of the proposed objectives because it allows practioners to select practices based on their suitability of the targeted area.

Overall, if the recommended three modifications to stormwater management are accepted, Ontario's watershed, as well as humans, will benefit greatly.

9.1 Future Research

In regards to the EES, much research is still required. As described in Chapter 2, pollutant removal mechanisms and the groundwater quality must be studied. Of special interest is to understand the chemistry behind the significant reduction of chloride concentrations. Once the mechanisms are known, it can be applied to other practices and hopefully mitigate the increasing contamination of chloride in groundwater supplies. In addition, the concentration and ratio of suspended solids entering the stream from the EES outlet should be researched to quantitatively determine if it is at the required level to maintain the morphology of the receiving streams.

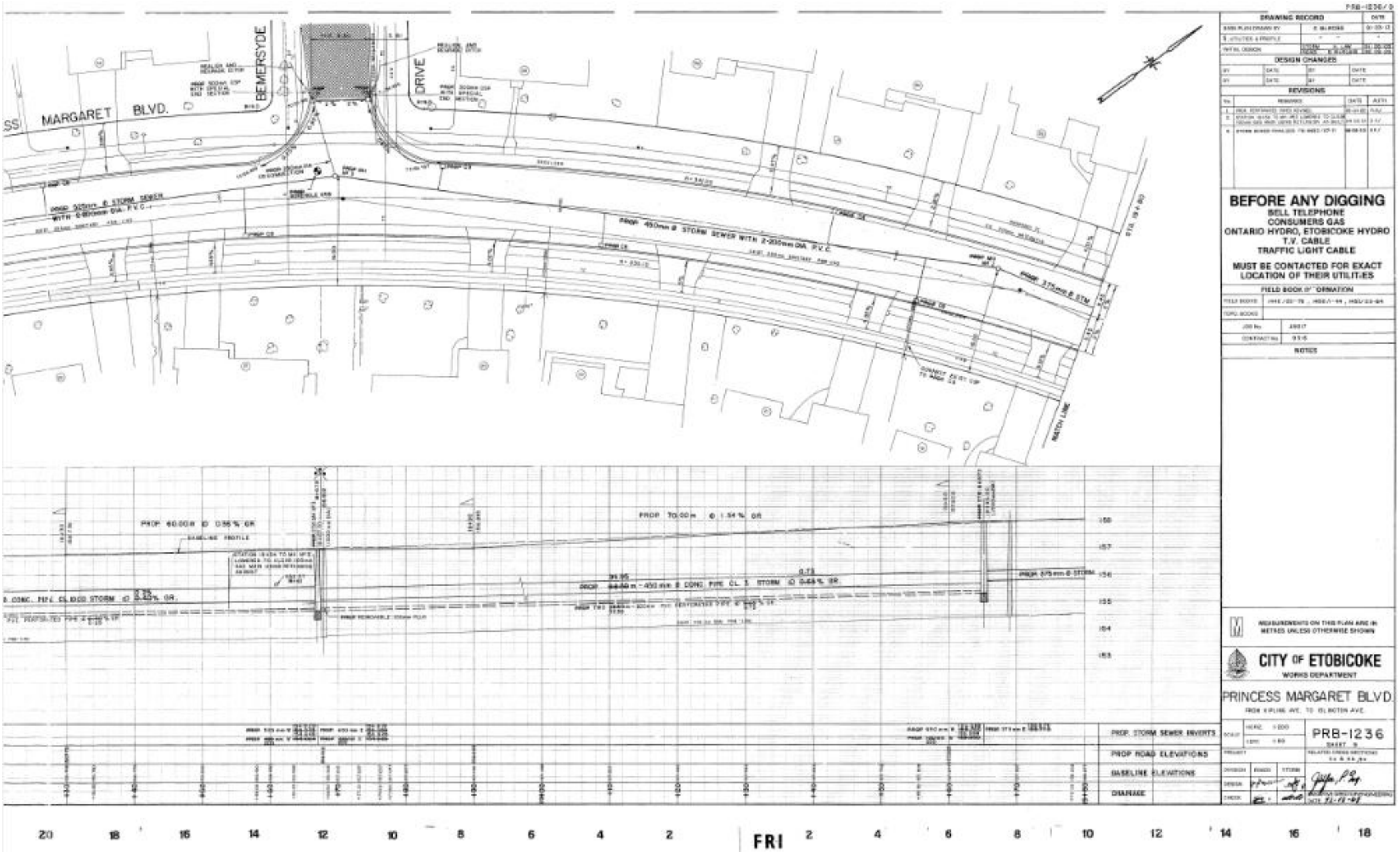
Also, since we know that the EES can exfiltrate 90% of the annual rainfall events, the next step is to quantify how much volume of rainfall is actually captured and exfiltrated by the EES in a year. This does not translate into 90% of the volume of the annual rainfall and requires understanding of the differences between volume, peak flow, frequency and duration. 90% of the rainfall events within the City have 15 mm depth or less, thus 10% of the events are of greater volume. This could mean that less than 90% of actual rainfall volume is captured annually.

Additionally, continuous modelling in the form of back to back rainfall events has not been conducted. This is an important aspect to investigate because overflows can result when two events have occurred in a shorter span than the inter-event period. We need to understand the dynamics of the EES during an event, but also between two events, of various size combinations. This will allow us to predict when an overflow may occur. Now that the EES's catchment and trench parameters have been calibrated, these values can be inputted into a model such as SWMM for continuous modelling.

Lastly, with the recent interest in the EES, modelling should be conducted to analyze its performance under different soil types and rainfall characteristics. This will give an idea as to how well the system can function in locations outside of Etobicoke, which is important considering the recent interest of implementing this system throughout Ontario.

Appendix A

A.1: Storm sewer system and EES under Princess Margaret Boulevard between MH2 and MH3 (City of Etobicoke, 1992)



A.2: Calibrated trench parameters, C factor 0.63

Trench Data:	
Ground elevation (m)	158
Downstream trench invert (m)	154.17
Trench height (m)	1.5258
Water table elevation (m)	10
Trench top width (m)	2.2758
Trench bottom width (m)	2.2758
Voids ratio (%)	40
K (mm/hr)	27.4
Trench gradient (%)	0.73
Trench length (m)	96.95
Trench volume (m^3)	134.8
Access riser diameter (m)	1.2

Outflow Data (Storm sewer):	
Upstream invert level (m)	155.589
Downstream invert level (m)	154.879
Pipe length (m)	96.95
Pipe diameter (m)	0.45
Manning's 'n'	0.013
Entry loss Ke	0.5

Trench pipes:	Pipe 1	Pipe 2	Pipe 3
Downstream Invert (m)	154.879	154.47	154.47
Pipe Length (m)	96.95	96.95	96.95
Pipe Diameter (m)	0.45	0.2	0.2
Pipe Grade (%)	0.73	0.73	0.73
Perforated?	No	Yes	Yes

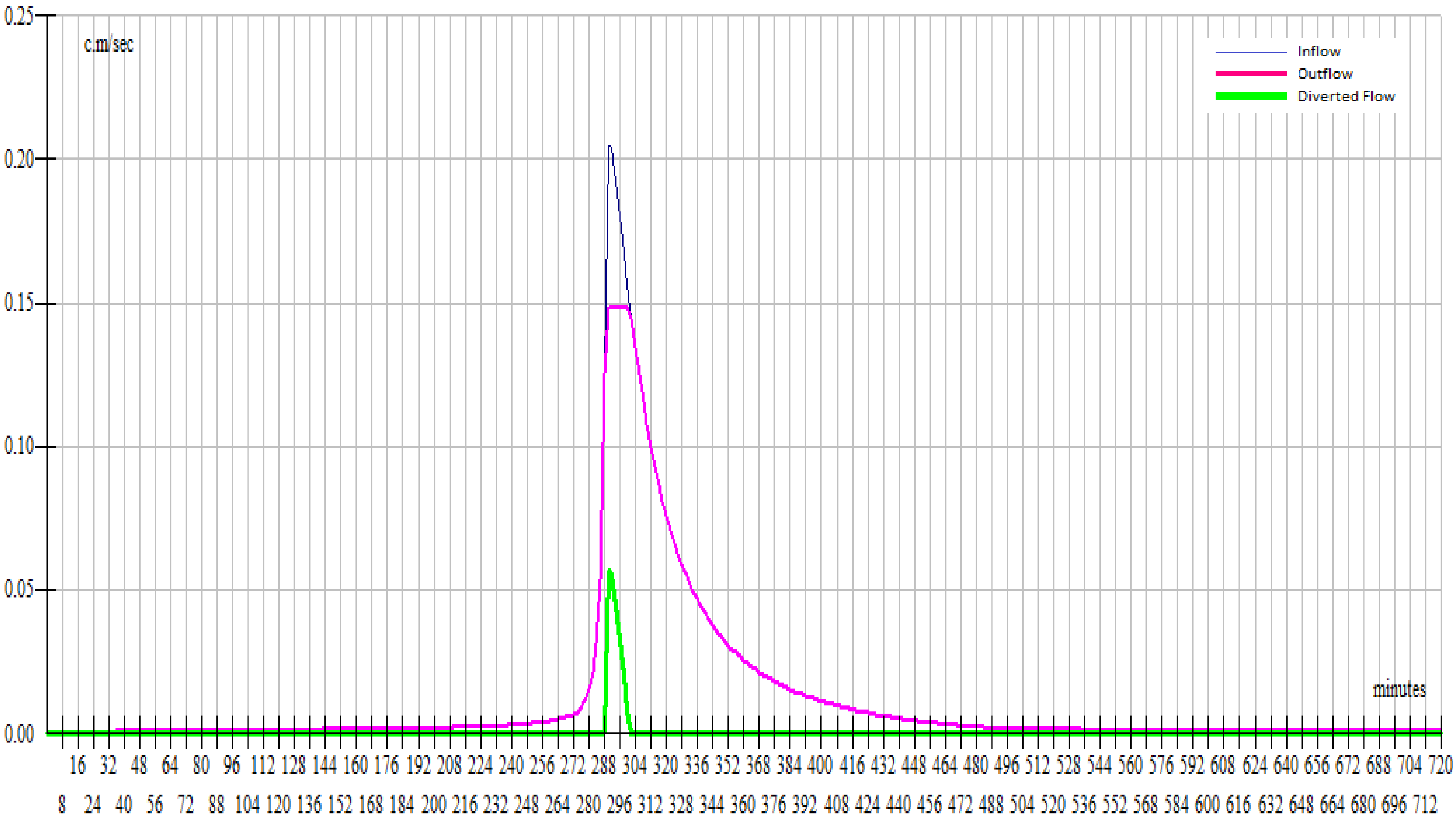
A.3: Calibrated trench parameters, C factor 1

Trench Data:	
Ground elevation (m)	158
Downstream trench invert (m)	153.0826
Trench height (m)	2.6093
Water table elevation (m)	10
Trench top width (m)	2.2758
Trench bottom width (m)	2.2758
Voids ratio (%)	40
K (mm/hr)	26.5
Trench gradient (%)	0.73
Trench length (m)	96.95
Trench volume (m^3)	230.4
Access riser diameter (m)	1.2

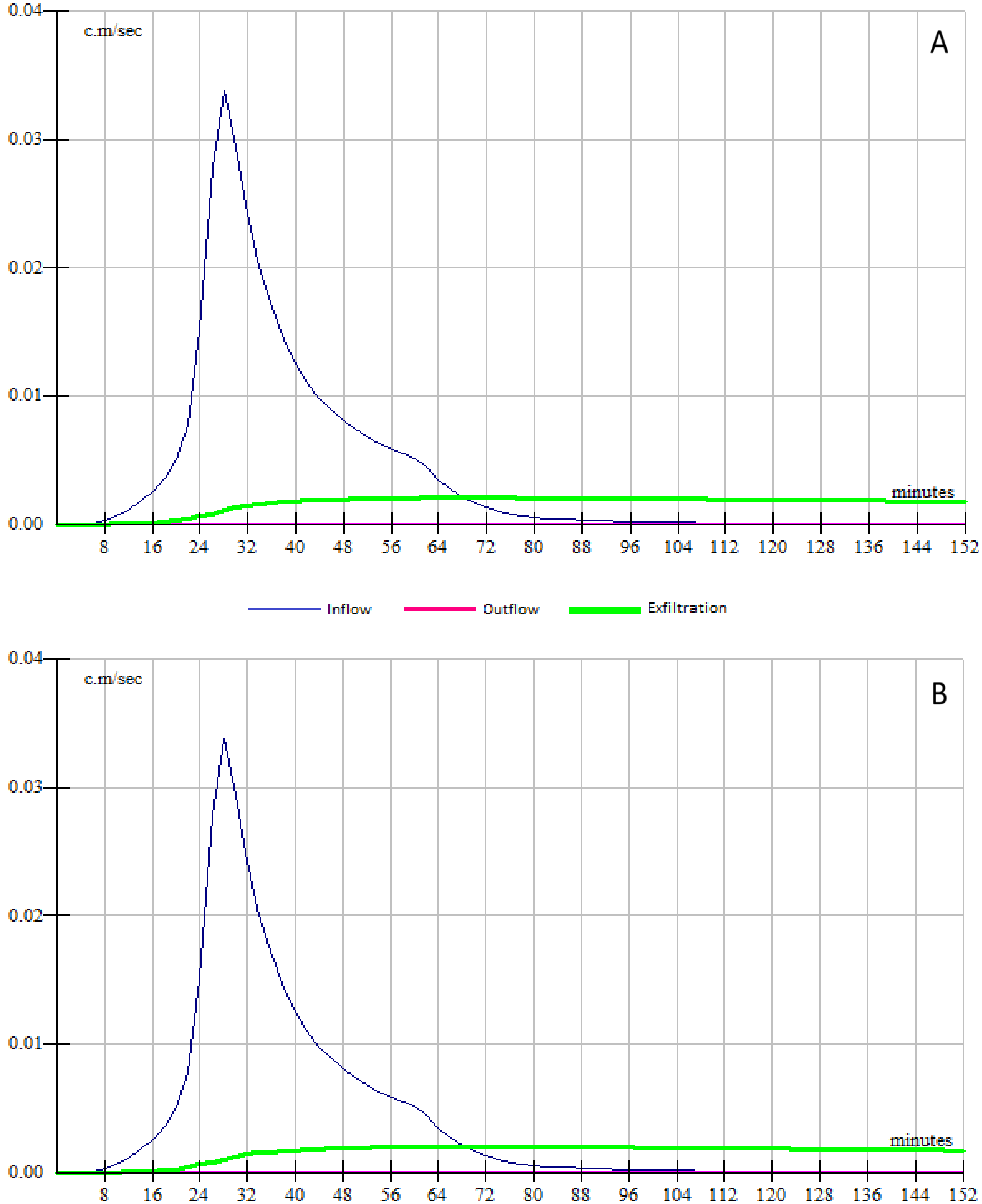
Outflow Data (Storm sewer):	
Upstream invert level (m)	155.589
Downstream invert level (m)	154.879
Pipe length (m)	96.95
Pipe diameter (m)	0.45
Manning's 'n'	0.013
Entry loss Ke	0.5

Trench pipes:	Pipe 1	Pipe 2	Pipe 3
Downstream Invert (m)	154.879	153.3826	153.3826
Pipe Length (m)	96.95	96.95	96.95
Pipe Diameter (m)	0.45	0.2	0.2
Pipe Grade (%)	0.73	0.73	0.73
Perforated?	No	Yes	Yes

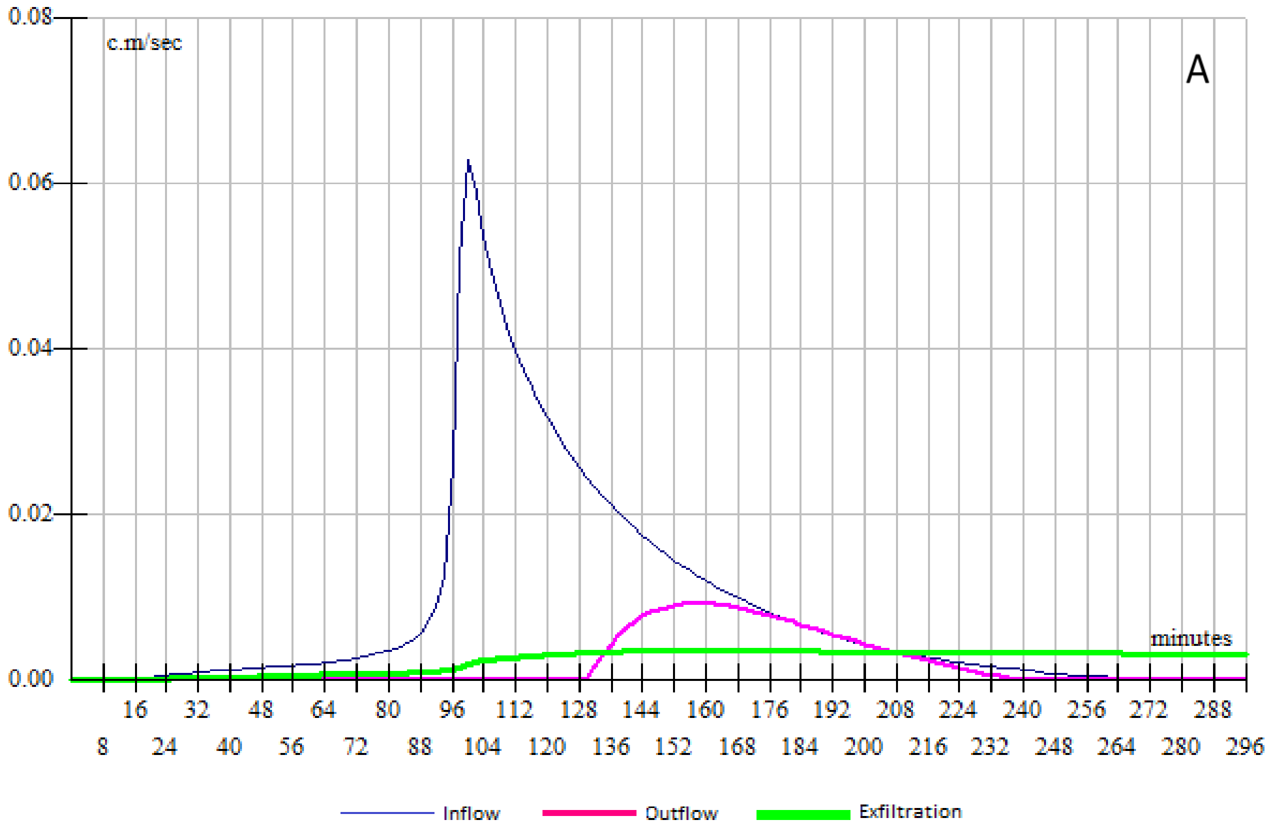
A.4: Pipe diversion of inflow hydrograph of Mississauga's 100-yr Chicago storm

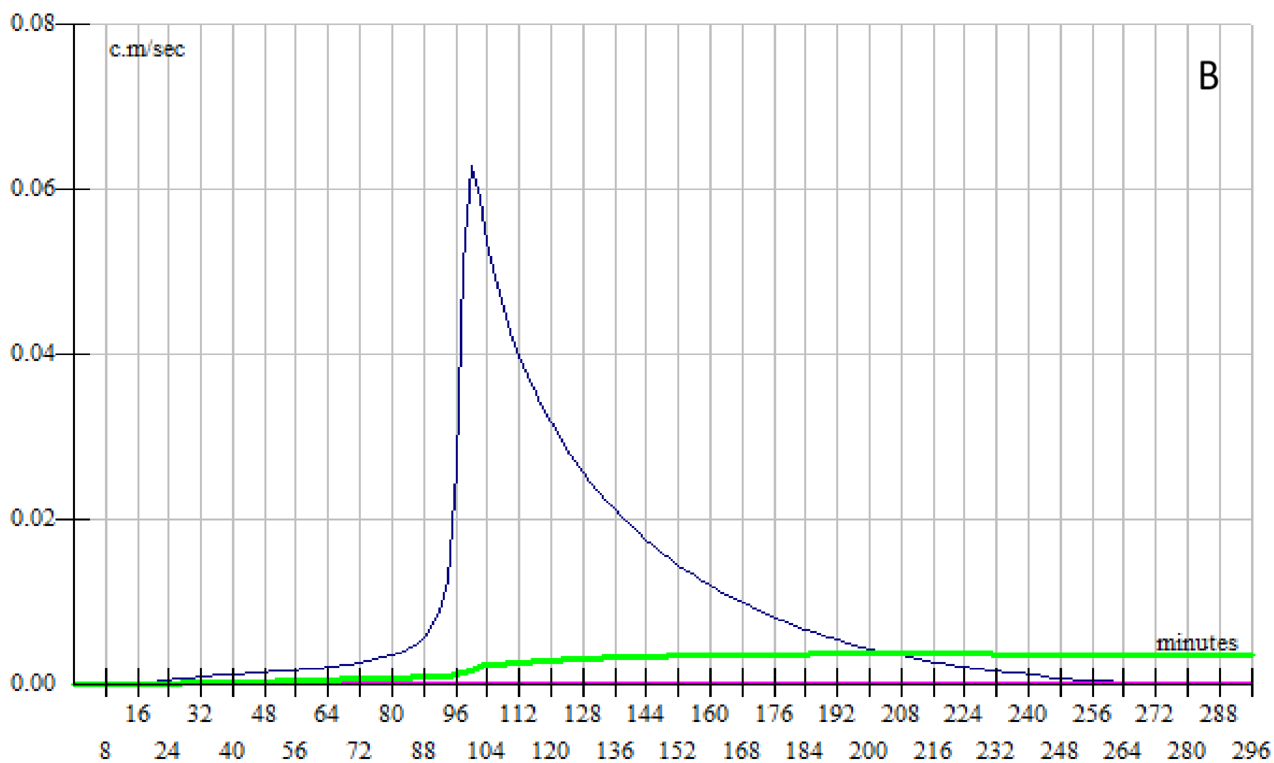


A.5: EES trench hydraulics - Mississauga's 2-yr Chicago storm
(A: C factor = 0.63: B: C factor = 1)

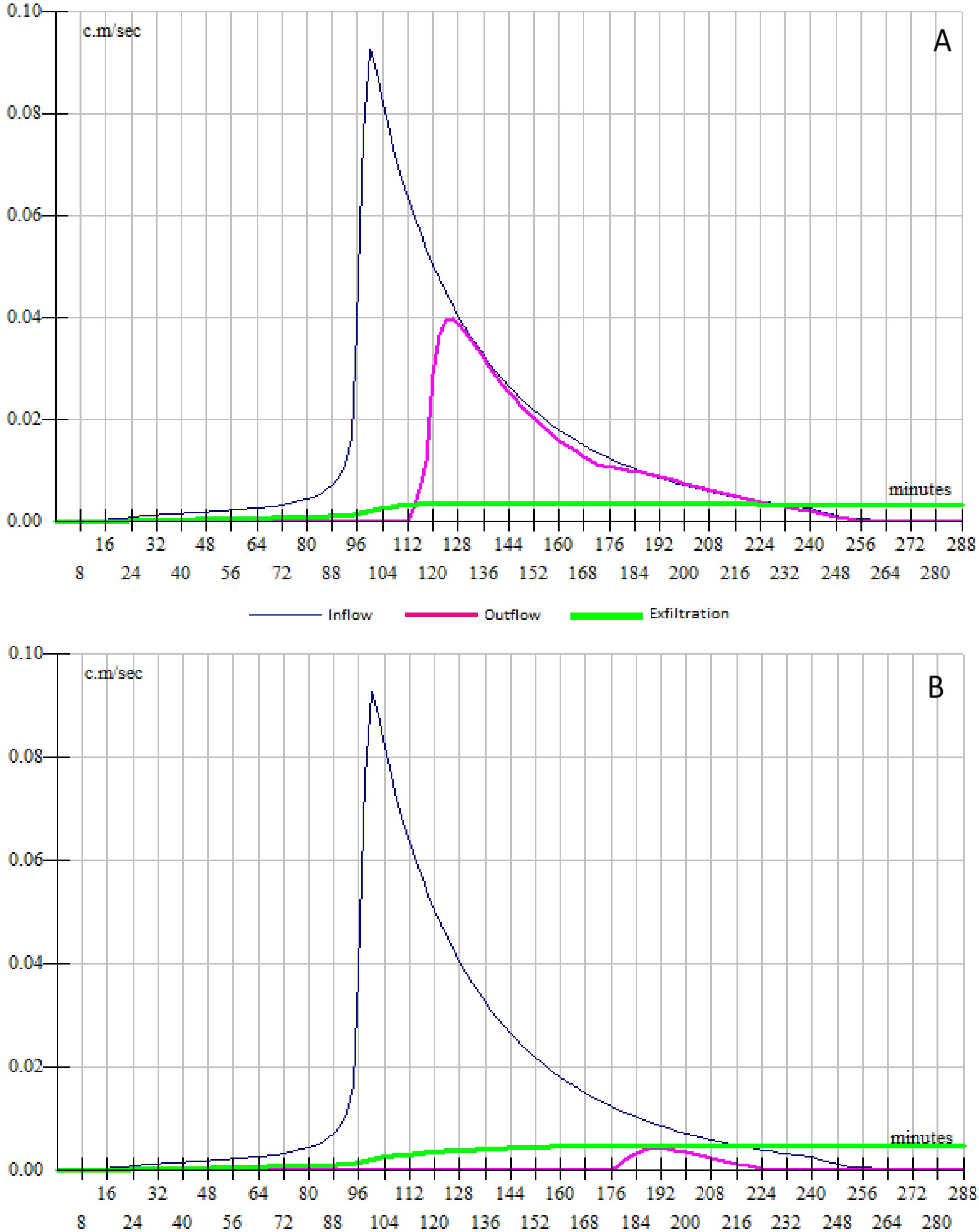


A.6: EES trench hydraulics - Mississauga's 5-yr Chicago storm
(A: C factor = 0.63; B: C factor = 1)

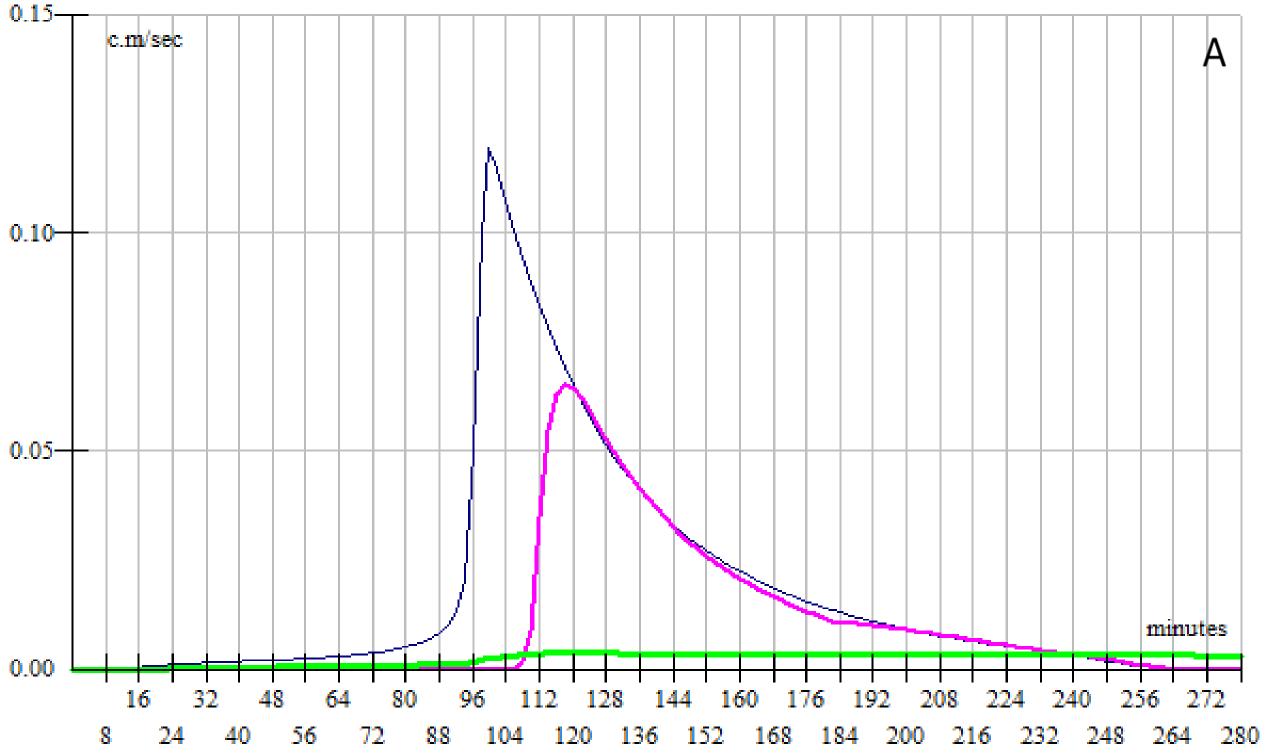


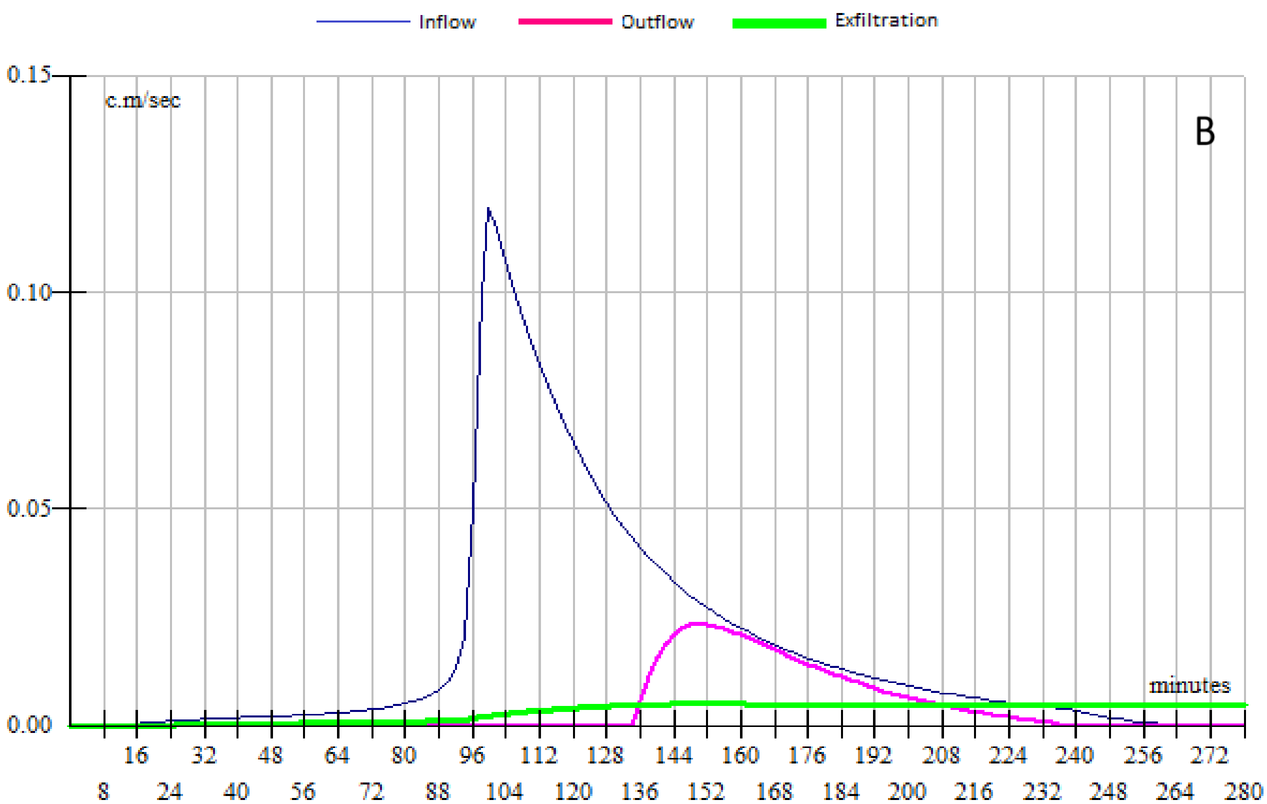


A.7: EES trench hydraulics - Mississauga's 10-yr Chicago storm
(A: C factor = 0.63; B: C factor = 1)

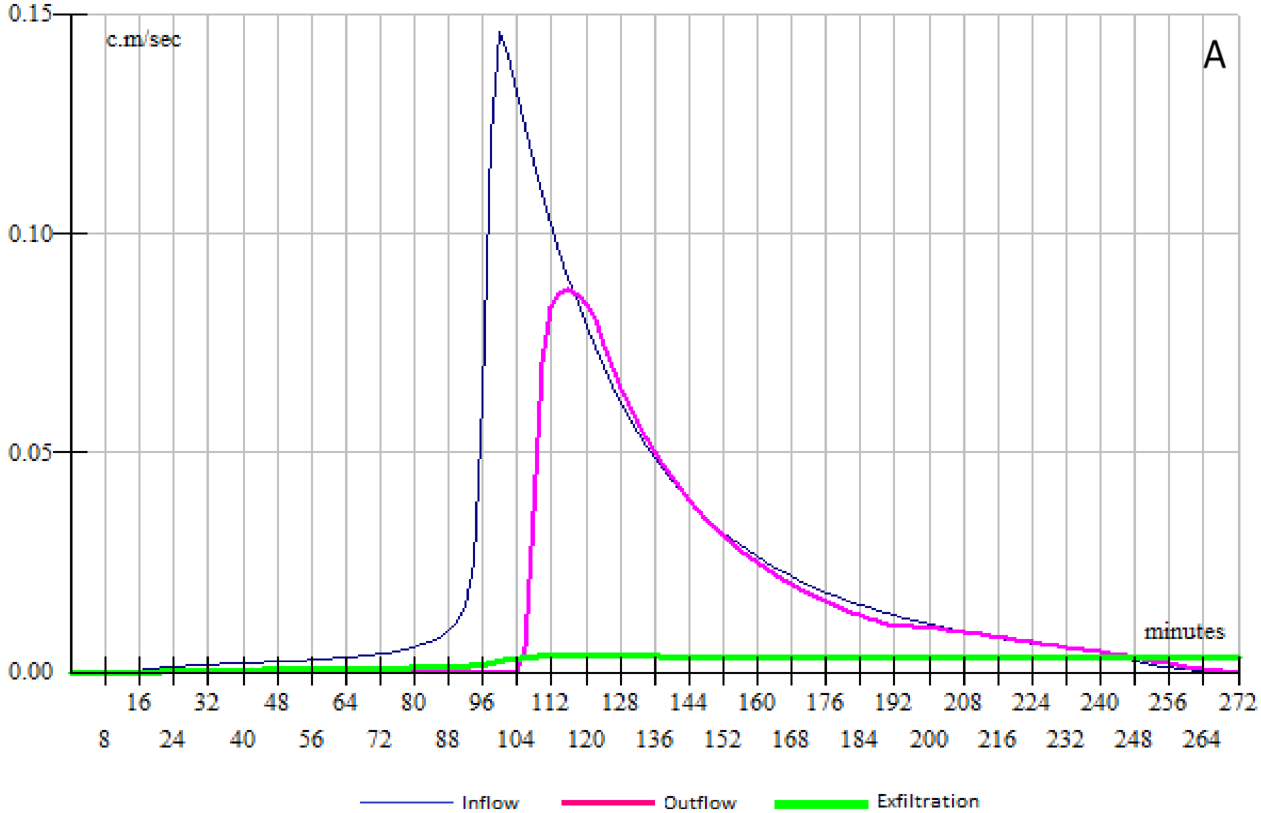


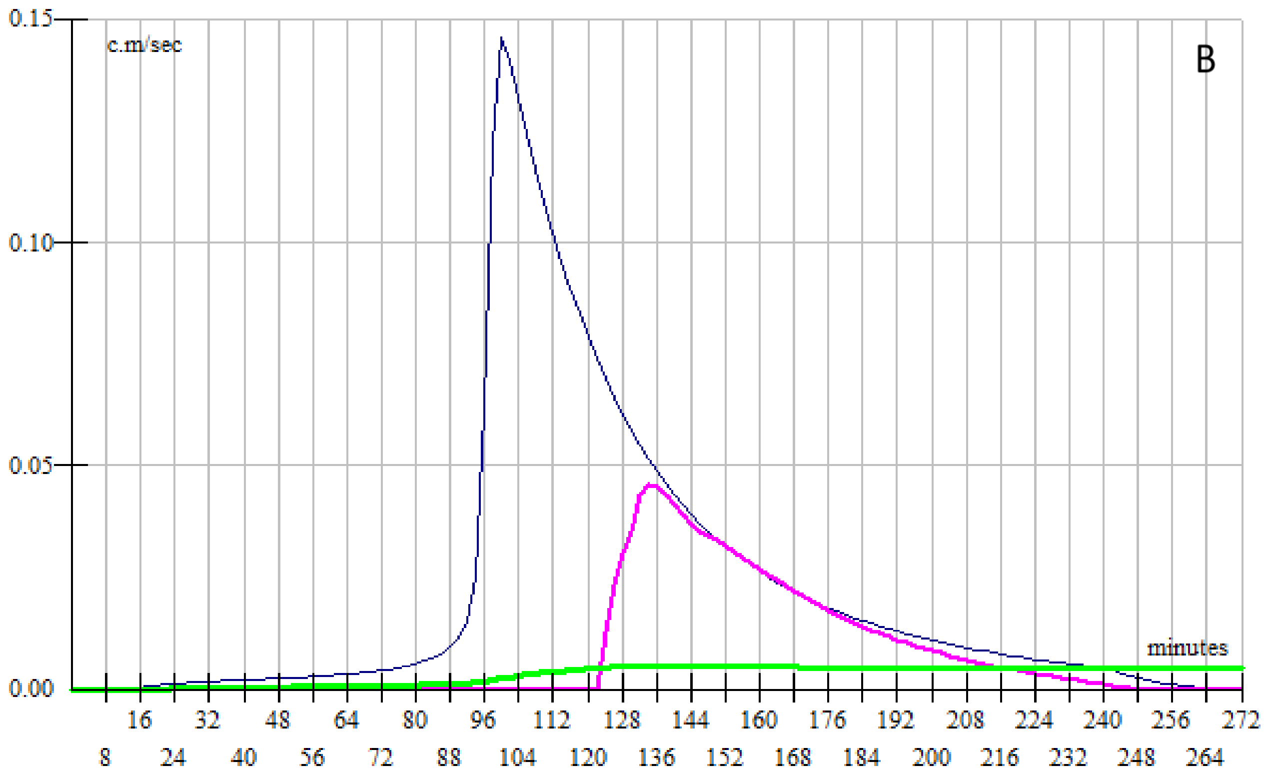
A.8: EES trench hydraulics - Mississauga's 25-yr Chicago storm
(A: C factor = 0.63; B: C factor = 1)



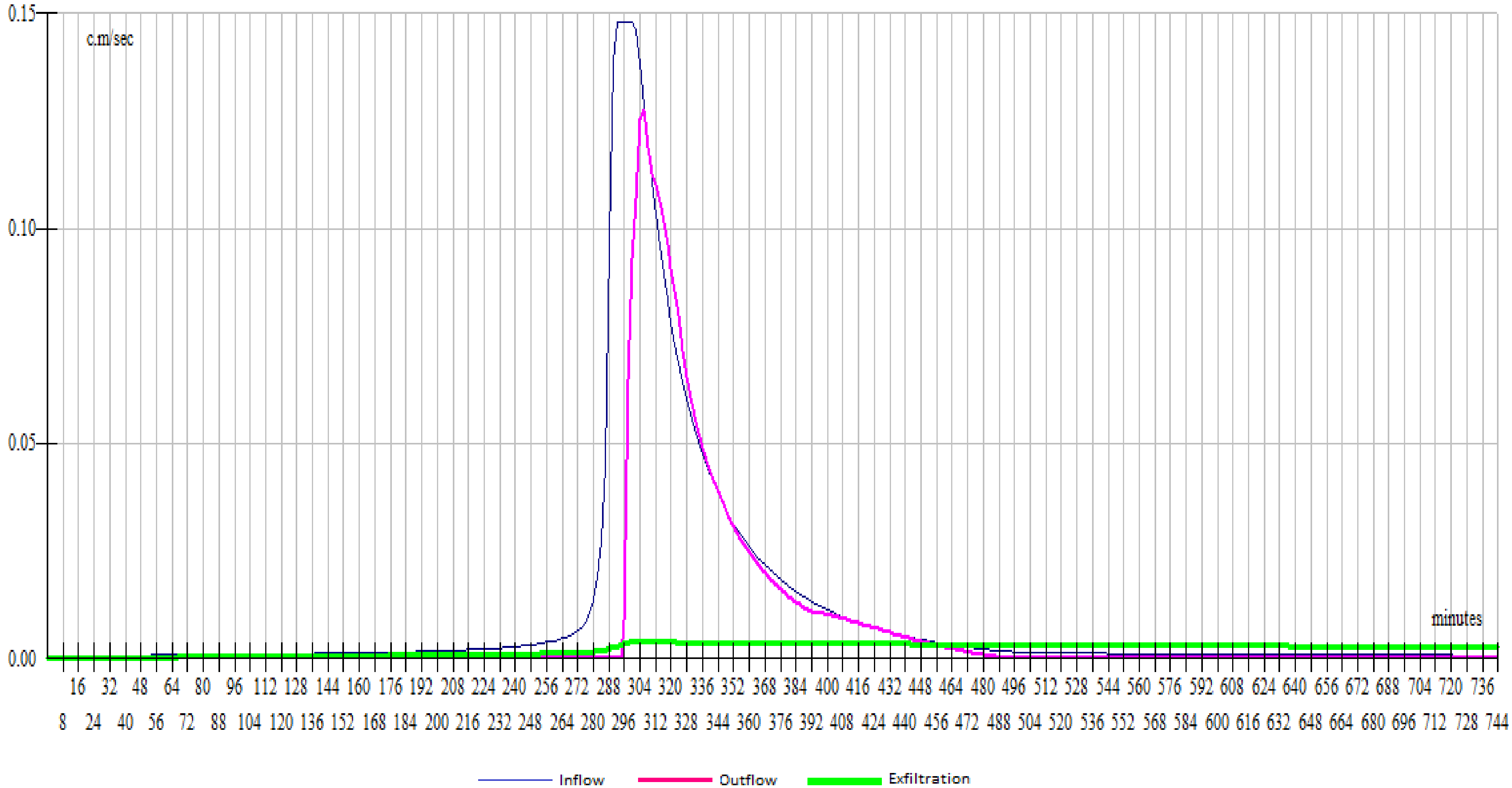


A.9: EES trench hydraulics - Mississauga's 50-yr Chicago storm
(A: C factor = 0.63; B: C factor = 1)

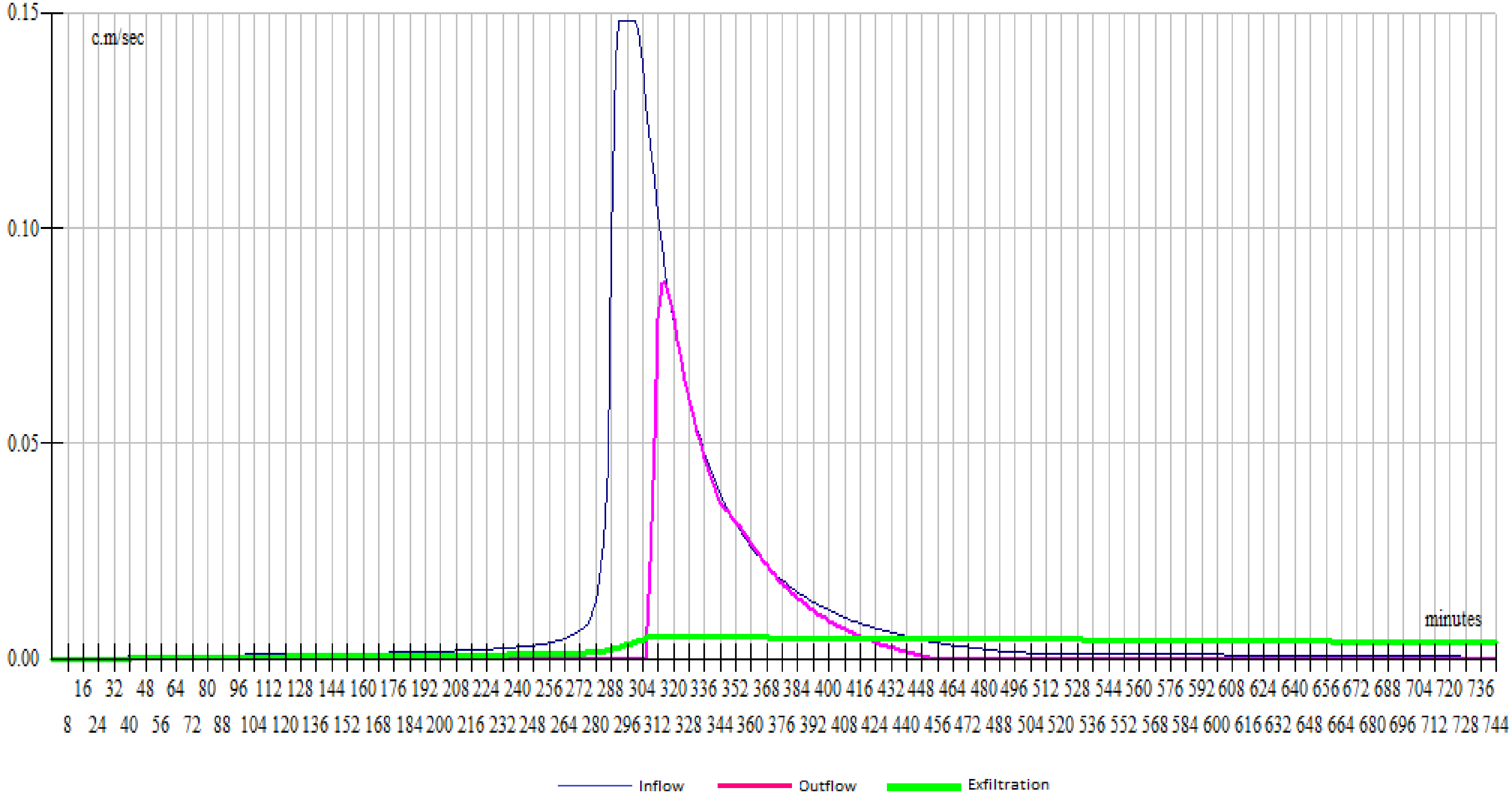




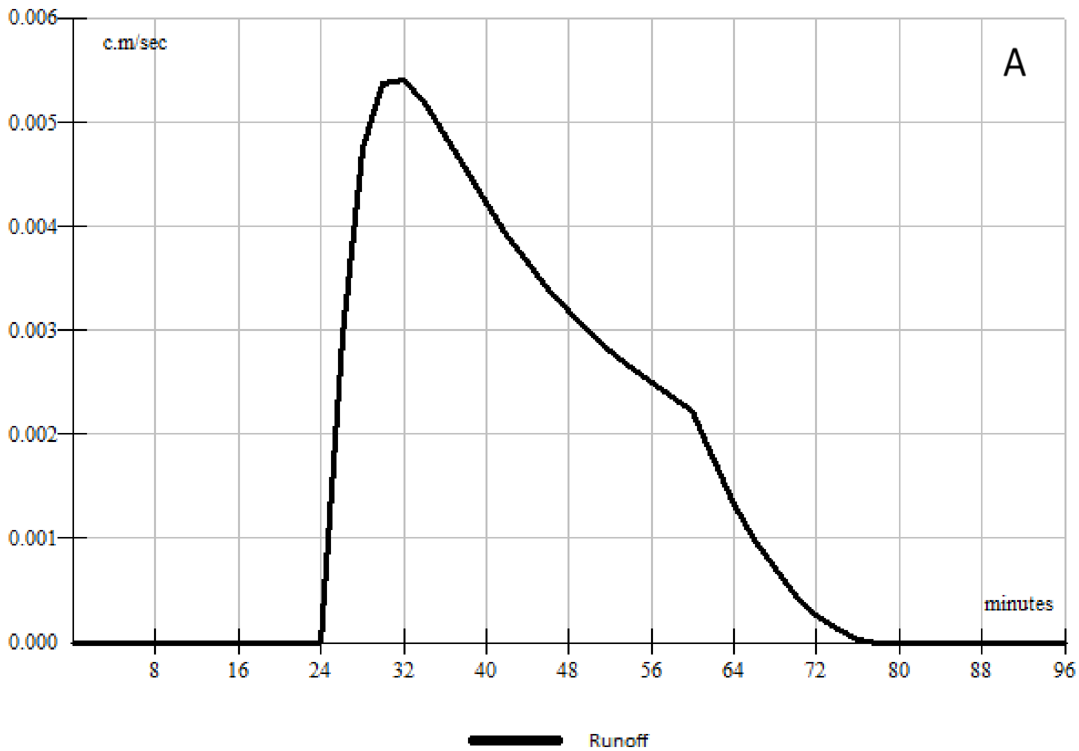
A.10: EES trench hydraulics - Mississauga's 100-yr Chicago storm (C factor = 0.63)

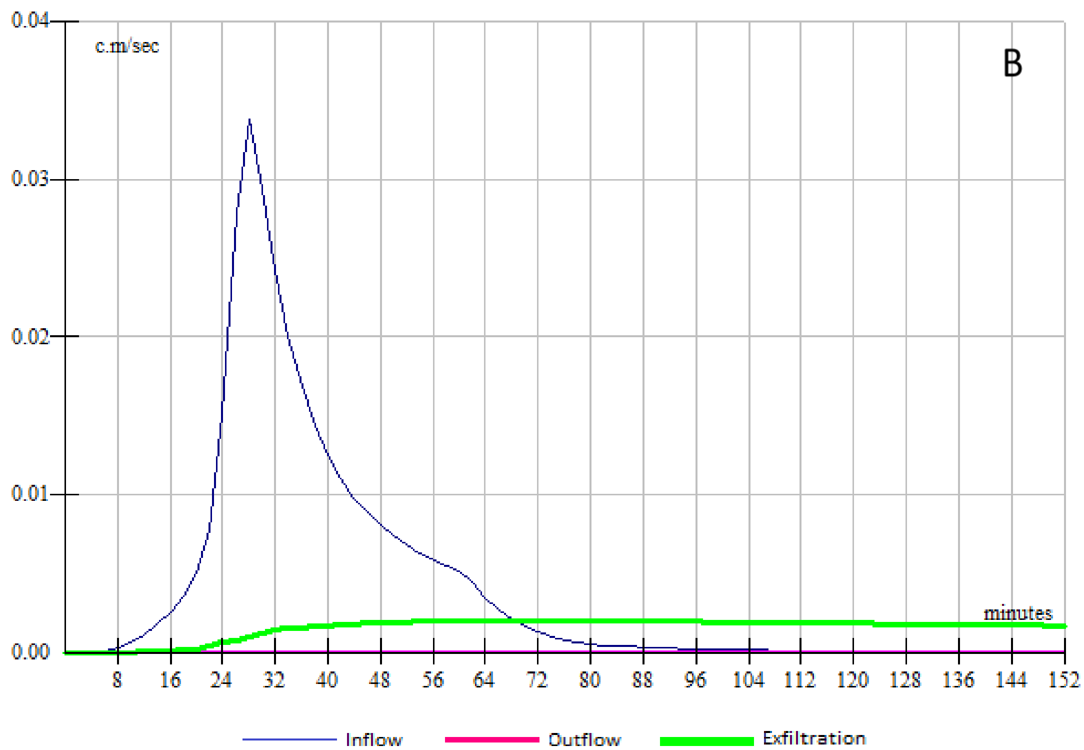


A.11: EES trench hydraulics - Mississauga's 100-yr Chicago storm (C factor = 1)

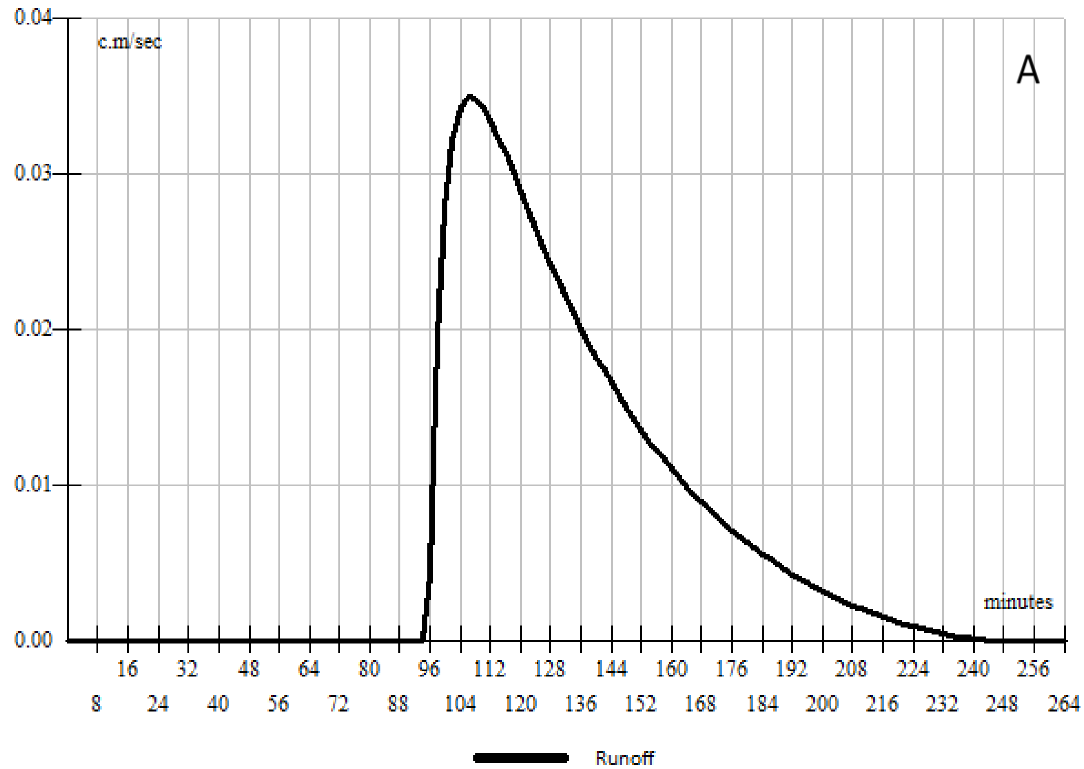


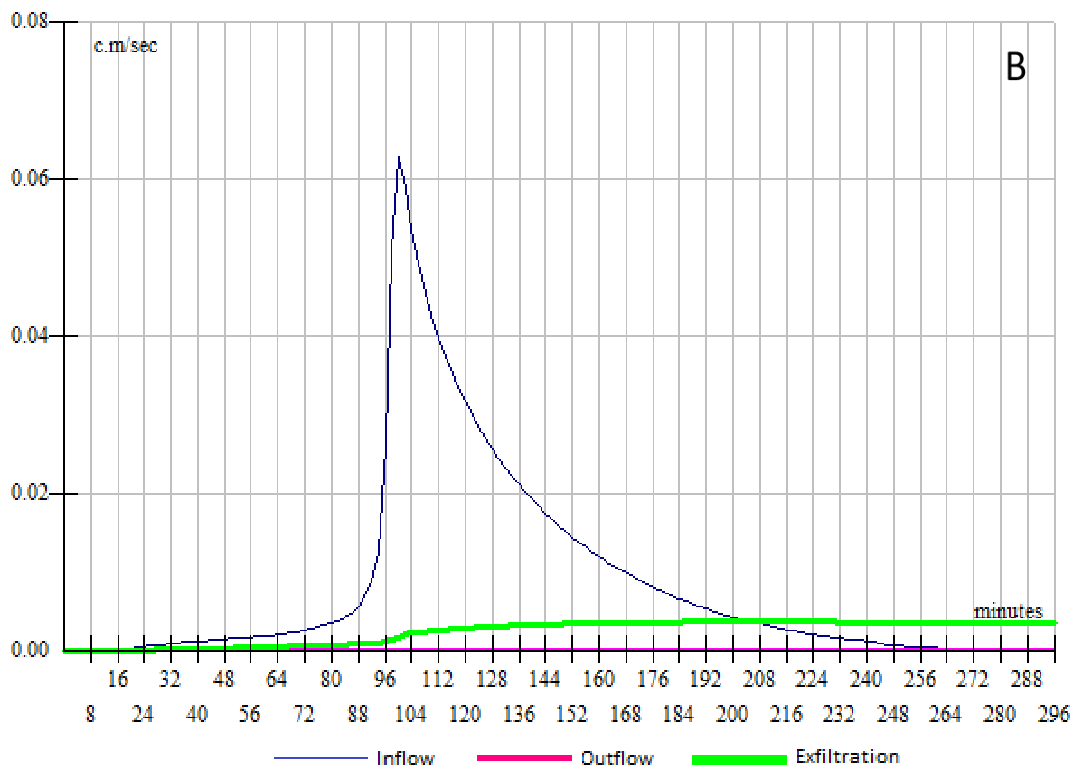
Appendix A.12: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 2-yr Chicago storm



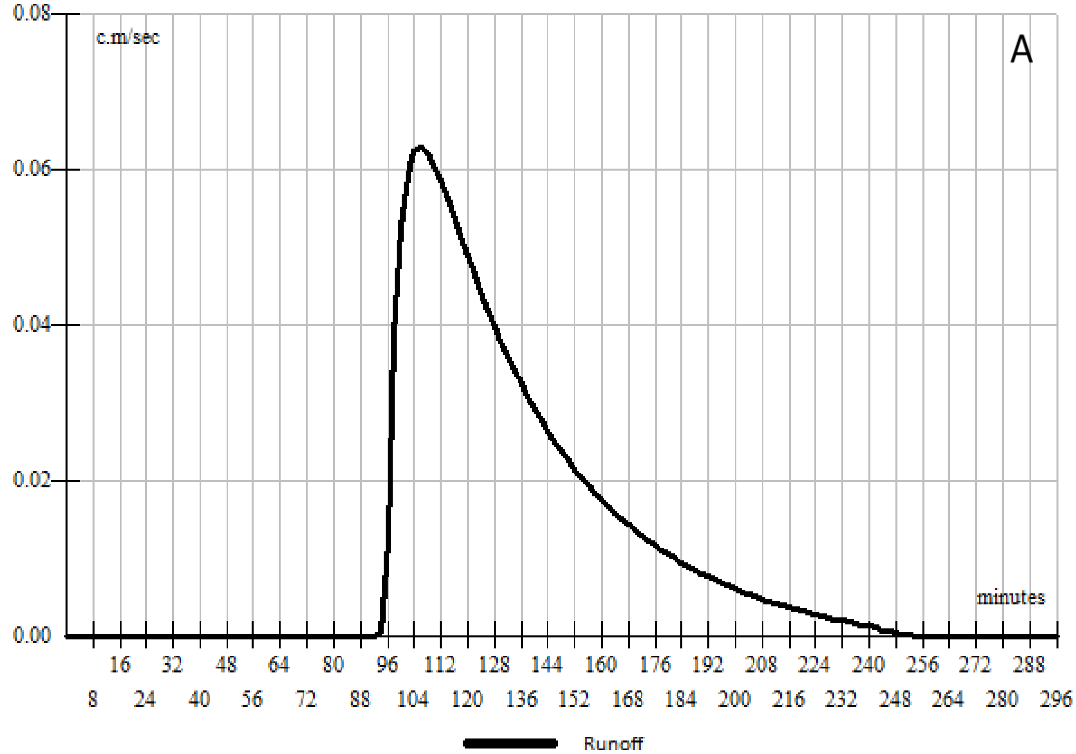


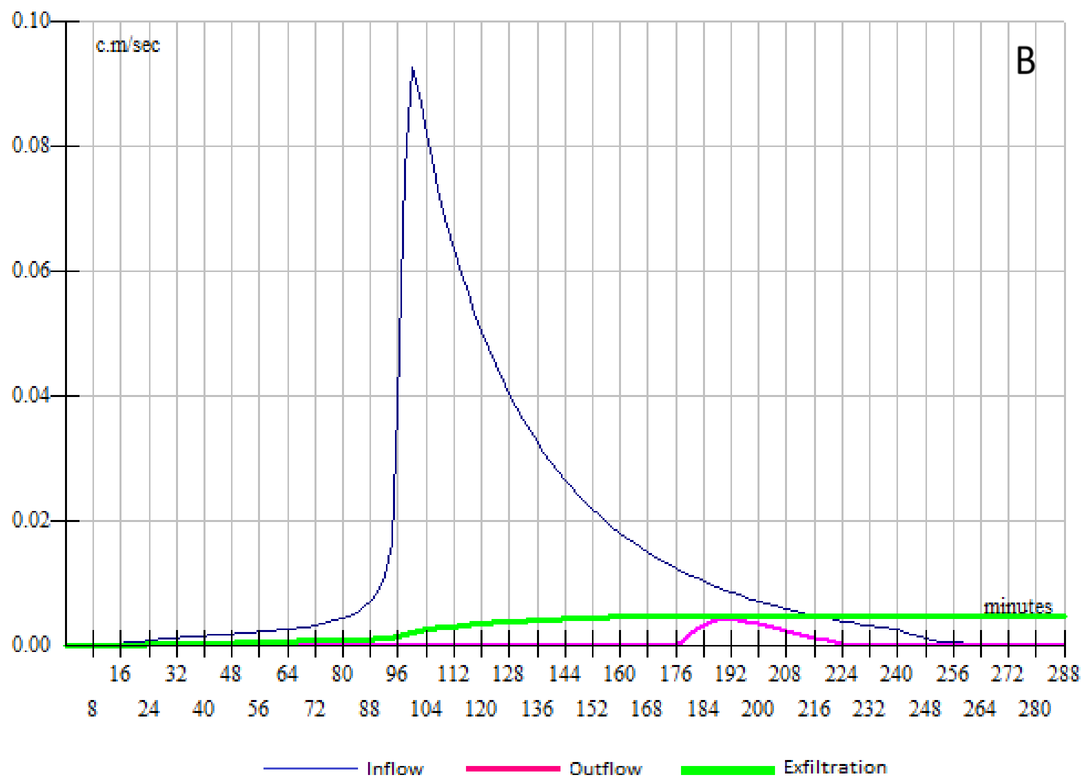
Appendix A.13: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 5-yr Chicago storm.



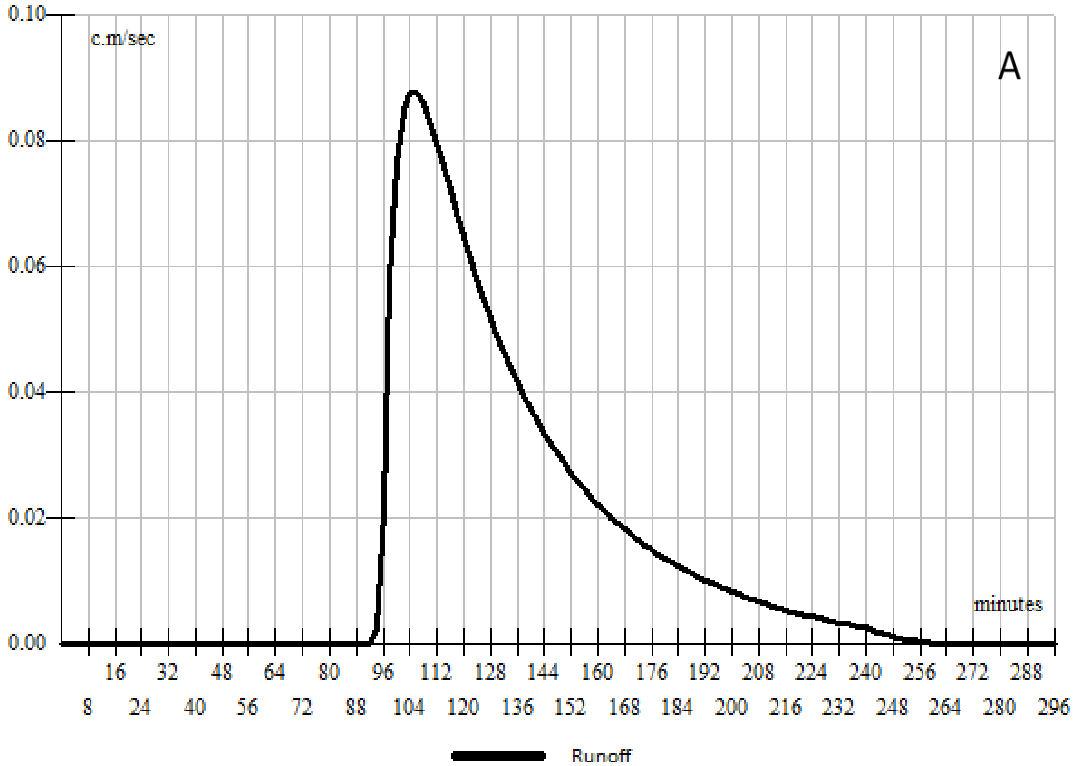


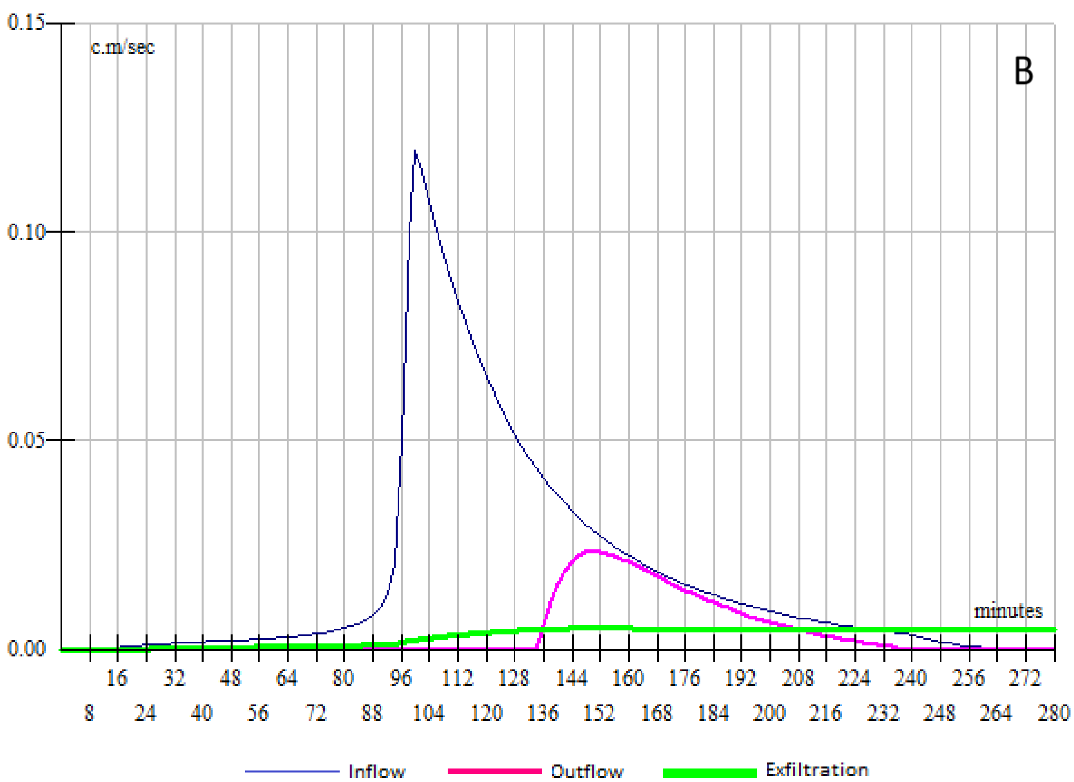
Appendix A.14: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 10-yr Chicago storm.



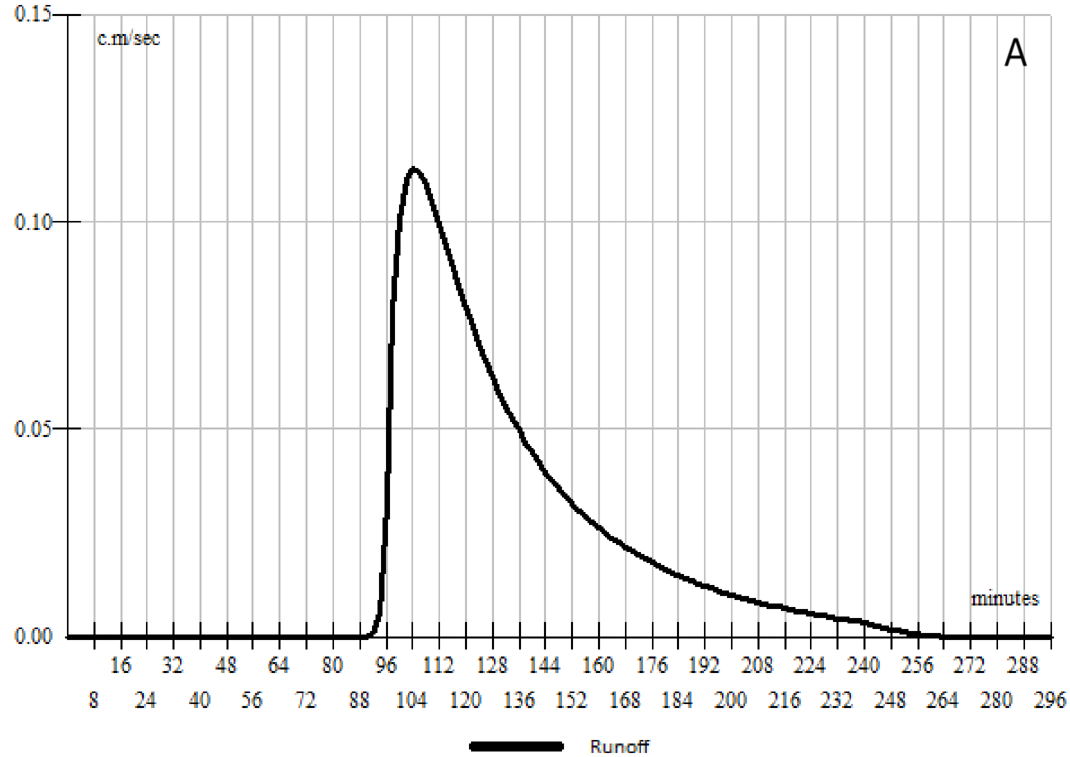


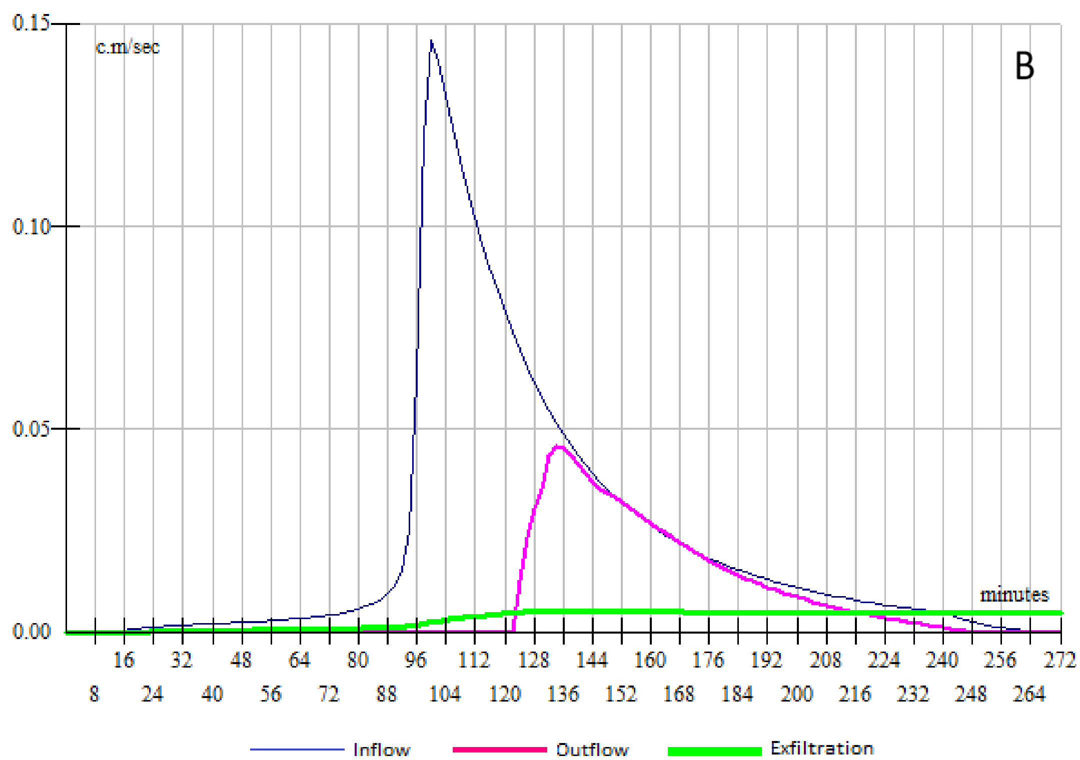
Appendix A.15: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 25-yr Chicago storm.



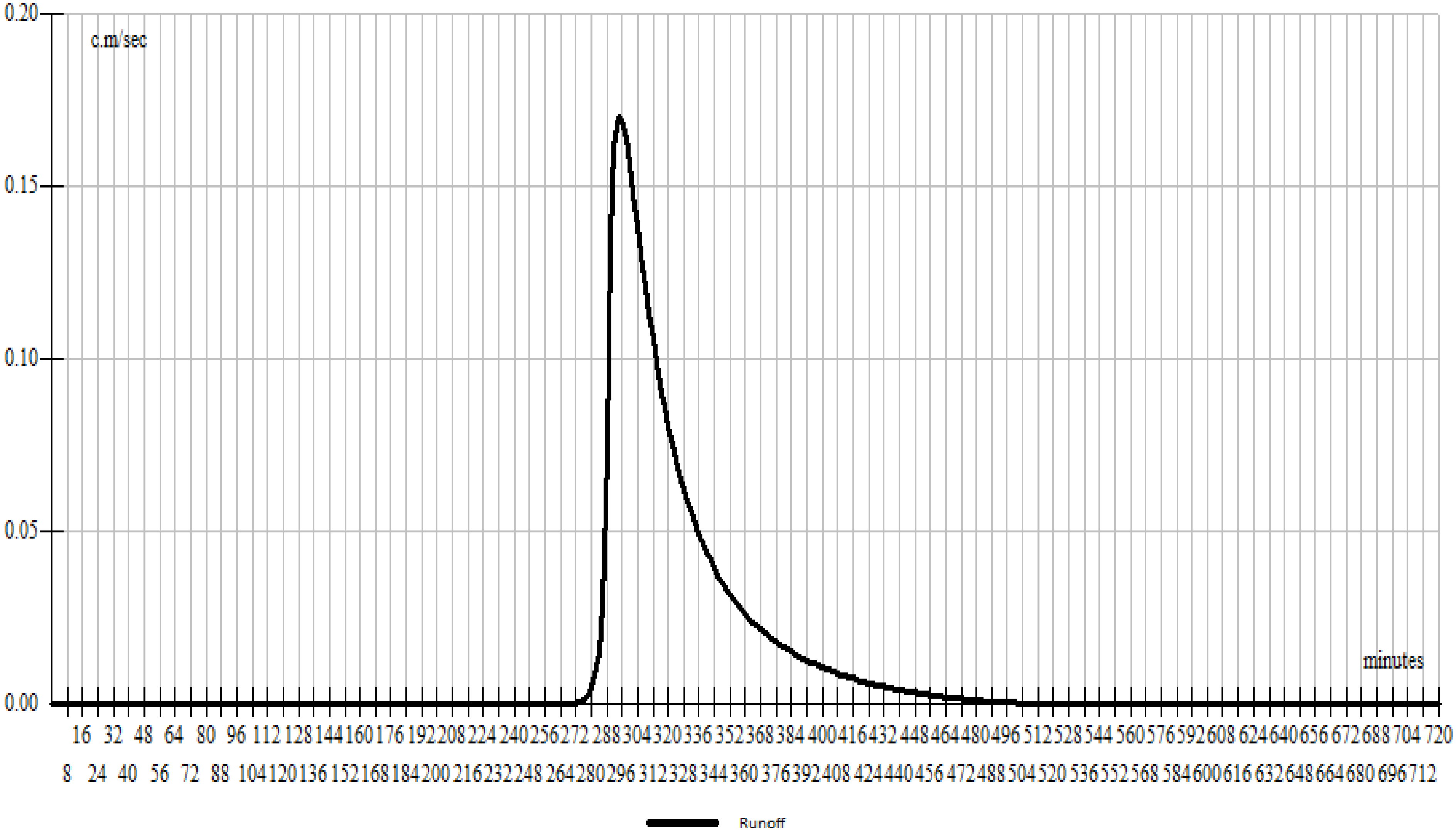


Appendix A.16: Pre-development (A) and post-development EES (B) runoff hydrographs for Mississauga's 50-yr Chicago storm.

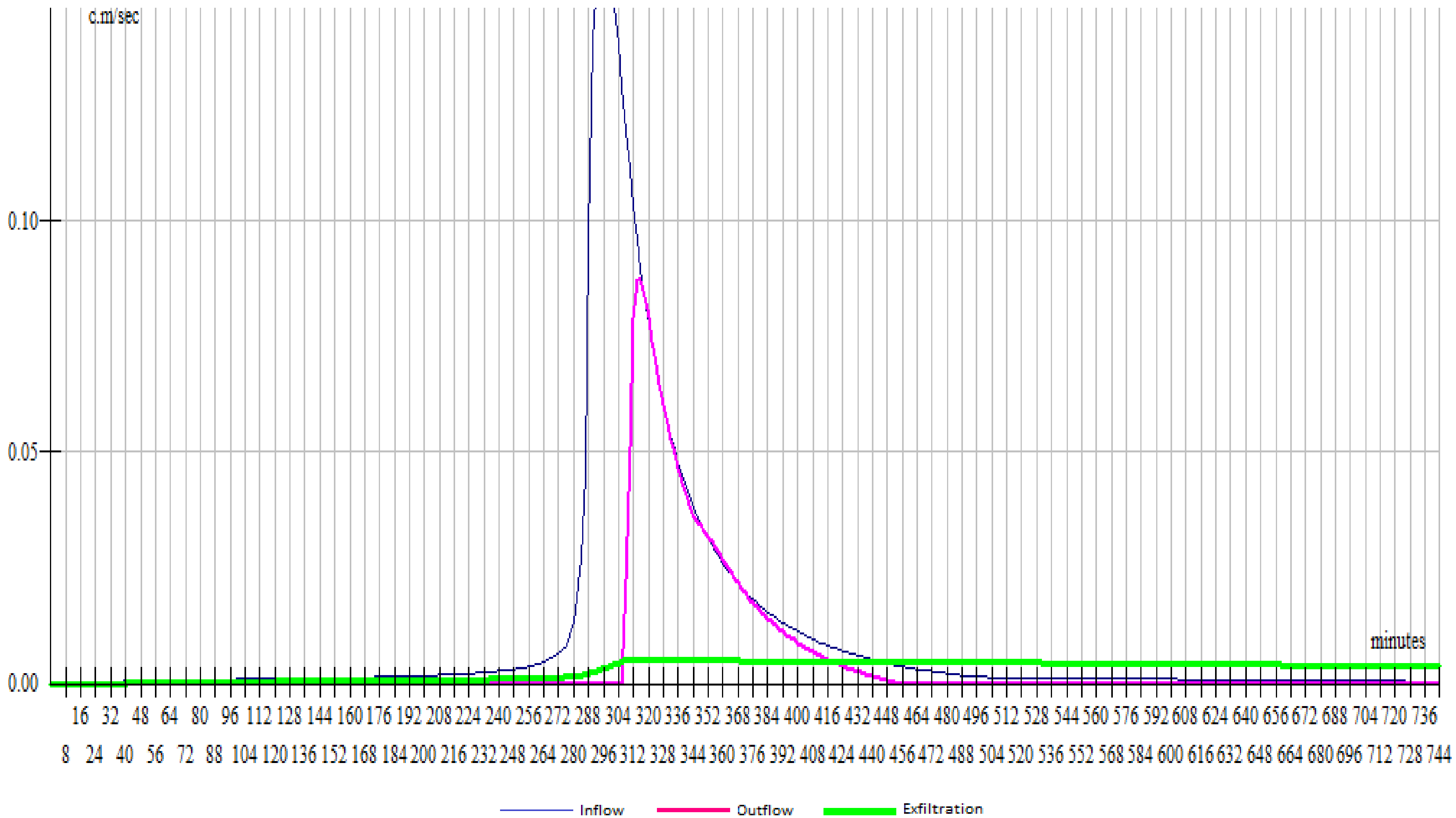




Appendix A.17: Pre-development runoff hydrograph for Mississauga's 100-yr Chicago storm.



Appendix A.18: Post-development EES hydrograph for Mississauga's 100-yr Chicago storm.



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