CREDIT VALLEY CONSERVATION

Central Parkway

Low Impact Development Infrastructure Performance and Risk Assessment

May 2016

Technical Report

Road Right-of-Way Retrofit

CENTRAL PARKWAY, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK ASSESSMENT

TECHNICAL REPORT

MONITORING RESULTS (2015)

CREDIT VALLEY CONSERVATION

NOTICE

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

BMP	Best Management Practices
BMPDB	International Stormwater Best Management Practices Database
Cd	Cadmium
CCME	Canadian Council of Ministers of the Environment
cm	centimetre
Cl	Chloride
Cu	copper
CVC	Credit Valley Conservation
EC	Environment Canada
EMC	Event Mean Concentration
g	gram
GTA	Greater Toronto Area
hr	hour
IPRA	Infrastructure Performance and Risk Assessment
Fe	Iron
kg	kilogram
Pb	Lead
L	litre
L/s	litres per second
LID	Low Impact Development
LGRA	Low Volume Groundwater Recharge Areas
m	metre
m^2	square metre
m^3	cubic metre
MEDEI	Ministry of Economic Development, Employment and Infrastructure
mg	milligram
mg/L	milligrams per litre
µg/L	micrograms per litre
mm	millimetre
min	minute
Ni	Nickel
N	Nitrogen
NO_2 and NO_3	Nitrite and Nitrate
NSQD	National Stormwater Quality Database
MOE	Ontario Ministry of Environment

MOECC	Ontario Ministry of the Environment and Climate Change
MNR	Ontario Ministry of Natural Resources
MTO	Ontario Ministry of Transportation
O&M	Operation and Maintenance
PoC	Parameters of Concerns
P	Phosphorus
PAH	polycyclic aromatic hydrocarbon
PO_4	Orthophosphate
PWQO	Provincial Water Quality Objectives
s	second
SWM	Stormwater management
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
U.S. EPA	United States Environmental Protection Agency
yr	year
ZN	Zinc

EXECUTIVE SUMMARY

Stormwater management (SWM) has been headline news given the flooding in the Greater Toronto Area (GTA) in recent years. It is estimated that the replacement value of stormwater collection and management systems is $40.8 billion across Canada (CCA et al., 2012). This value does not account for land costs, which can be as high as three or four times that of infrastructure costs within Ontario's Greater Golden Horseshoe (Reinthaler, Partner, Schaeffers & Associates, Ltd., 2012). Moreover, it does not take into consideration the need for new infrastructure to service areas that have not yet receiving stormwater control to current standards. There is roughly 35 per cent of the GTA that had SWM controls as of 2013 (TRCA, 2013). An additional $56.6 billion is needed to address new stormwater infrastructure needs nationwide (FCM, 2007). Since the GTA had experienced more frequent localized high-intensity storms, such as the one on July 8, 2013, in the past decade, it is still uncertain whether the current standards will provide the level of protection that is needed to safeguard our communities.

In an attempt to mitigate risk, the Ministry of the Environment and Climate Change (MOECC), the City of Mississauga and Credit Valley Conservation (CVC) have partnered with over twenty-five (25) public and private-sector organizations to implement a number of innovative SWM retrofit sites spanning both public and private properties. Central Parkway is one of those sites. It hosts a low impact development (LID) bioretention with tree-lined landscape which will filter out nutrients and pollutants as the runoff moves through the soil profile beneath paved surfaces.

LID is an innovative stormwater management practice that consists of green infrastructure, and source and conveyance controls.

Streets, sidewalks and driveways contribute 65-75 per cent of total loadings of suspended solids, total phosphorus, and metals (Bannerman, et. al., 1992). Given that streets are the largest urban contributor and are municipally owned land, they provide a great opportunity to control runoff. LID retrofits implemented as part of road reconstruction projects have also been found to save on average 25 per cent in comparison to traditional practices when land costs are considered (USEPA, 2007). For more information on CVC's LID sites and Infrastructure Performance and Risk Assessment project, visit www.bealeader.ca

The LID practices at Central Parkway treat stormwater runoff, promote infiltration, and slow the release of stormwater runoff. The construction of the Central Parkway retrofit and the installation of the performance assessment equipment were completed in Spring 2015.

CVC is conducting comprehensive performance and risk management assessment at this site to evaluate the bioretention site's ability to remove stormwater pollutants and control runoff volume. The 2015 findings for the Central Parkway Project indicate very strong preliminary performance. For water quantity control, Central Parkway provides an average volume reduction of 97 per cent and an average peak flow reduction of 96 per cent. Furthermore, the LID practice at Central Parkway is able to replicate a more natural water balance in a highly urbanized setting, contributing to effective erosion control, improved water quality, and protection of aquatic habitat.

This performance evaluation would suggest that wide-spread adoption of LID would yield significant benefits to receiving streams as well as the Great Lakes. Results from the Central Parkway Project will provide municipalities with the tools to optimize costs of infrastructure upgrades and make improvements to address pressures due to growth, infill, redevelopment and at the same time protect and enhance the environment (in keeping with the MOECC's proposed Great Lakes Protection Act; the Ministry of Economic Development, Employment and Infrastructure's (MEDEI's) Building Together: Municipal

Infrastructure Strategy; and the Ministry of Municipal Affairs and Housing's Go Green: Ontario's Action Plan on Climate Change).

1. BACKGROUND

This section introduces the business case for LID performance assessments through field monitoring by demonstrating that performance assessment provides asset management accountability facilitates minimizing risk and liability and provides information required to optimize infrastructure selection and sizing in Ontario.

1.1. The State of Stormwater Infrastructure in Ontario

Some of the challenges facing the Great Lakes today include a fast-growing population that is causing stress on ecosystems. One such stress is insufficiently treated urban runoff from land management practices which contributes unwanted pollutants such as phosphorus and E. coli to enter the Great Lakes. High levels of nutrients in nearshore water can lead to excess algae growth and impairment of aquatic habitat. These ongoing changes in land use and climate have shown that conventional stormwater management systems in urban watersheds are no longer adequate to deal with increased runoff and flooding events (CMWC, 2014). Contaminants from impervious areas are washed off land surfaces and delivered to watercourses through surface runoff during rainfall events. While roadways make up a small component of urban areas, they have shown that they are the greatest contributor of urban pollutants (Bannerman and Dodd, 1992) accounting for 31 to 42 per cent of total suspended solid loadings and 11 to 17 per cent of total phosphorus loadings to our natural waterways and lakes (Aquafor Beech Limited, 1994). Once in rivers and streams, these contaminants can lead to poor stream health leading to fish and wildlife mortality, groundwater contamination, and unsafe drinking water.

Much of the country's infrastructure is in need of repair and replacement, and the extrapolated replacement value of all stormwater assets in Canada is approximately $134 billon (CIRC, 2016). Ontario holds an infrastructure deficit estimated at tens of billions of dollars (MEDEI, 2015). This estimate does not take into consideration the need for new infrastructure within existing urban areas that do not currently have flood control or water quality treatment. For example, it is estimated that only 35 per cent of the greater Toronto area has stormwater management (SWM) controls (TRCA, 2013). To bring older developments across that nation to today's standards, FCM estimates that it would cost an additional $56.6 billion (FCM, 2007). The estimated value assumes conventional practices are feasible and does not include land acquisition costs, which in growth areas around Toronto can be three or four times that of infrastructure costs (Reinthaler, Partner, Schaeffers & Associates Limited, 2012). Building cost-effective resiliency into stormwater infrastructure requires an alternate solution.

The estimated damage of the July 8, 2013 storm event is almost $1 billion, and is now the most expensive storm in Ontario's history (IBC, 2014). Both nationally and locally, water damage is the largest single component of insured loss with claims tallying $1.7 billion per year (IBC, 2012).

As indicated in Ontario's Climate Ready Adaptation Strategy and Action Plan, climate change is predicted to result in extreme drought and extreme flooding placing more strain on aging water, wastewater and stormwater infrastructure. Combined with increased urban runoff from urbanization, the Great Lakes could also experience strain on water quality and fish and wildlife habitat.

As a result, there is growing interest in innovative stormwater management including low impact development (LID) in Ontario to address the effects of urbanization and climate change. Innovative stormwater management uses holistic thinking to plan, design and incorporate a variety of practices or technologies in a treatment train approach. Source control or LID techniques manage precipitation close to where it falls and mimic the natural water cycle by intercepting, infiltrating, filtering, storing, evaporating, and detaining precipitation. This aids municipalities and communities in building resiliency to climate change, and improving nearshore water quality and aquatic habitat by implementing small scale, decentralized practices as close to the runoff source as possible.

1.2. The Need for Long-Term Performance Assessment of LID Techniques in Ontario

To address the province's infrastructure deficit, the Ministry of Economic Development, Employment and Infrastructure (MEDEI), through Sustainability Planning program, requires Ontario municipalities to develop asset management plans when requesting provincial infrastructure funding. Asset management is an integrated, life-cycle approach to effective stewardship of infrastructure assets to maximize benefits, manage risk, and provide satisfactory levels of service to the public in a sustainable and environmentally responsible manner.

One of the barriers to wide-scale adoption of source and conveyance controls (or LID) in Ontario is the limited local long-term performance data available to conduct the integrated life-cycle analysis required for asset management. The lack of data to support the adoption of individual and/or treatment train practices makes it difficult for designers to select and size stormwater infrastructure, for municipalities and landowners to budget for maintenance costs, and for approval agencies to permit these innovative techniques in varied land-use applications.

To build confidence in sizing stormwater infrastructure and long-term performance, CVC and its partners have implemented a series of demonstration sites within various land-use settings and are delivering an LID Infrastructure Performance and Risk Assessment (IPRA) program. The multi-year IPRA program will evaluate LID effectiveness in flood control, erosion protection, nutrient removal, and maintenance of pre-development water balance. This program will produce performance data that addresses the outstanding knowledge gaps and priority stakeholder objectives identified by multiple stakeholders within CVC's SWM Monitoring Strategy (2012). **Section 2** discusses the nineteen objectives identified for CVC's overall SWM monitoring program.

The guiding objectives for all CVC stormwater monitoring projects can be found within the *CVC SWM Monitoring Strategy.*

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Performance data inherently supports Ontario's *Water Opportunities Act*, the proposed Great Lakes Protection Act, and recommendations from MOECC's Policy Review of Municipal SWM in the Light of Climate Change by providing information on innovative water technologies. Building on the findings of existing research, CVC's program will also advance the understanding of maintenance requirements for optimal LID performance and life-cycle cost analysis for asset management planning to meet provincial requirements for sustainability planning.

The knowledge gained through performance evaluation will strengthen existing tools and be used to create new tools to support the promotion of voluntary efforts. This research directly supports the protection of the Great Lakes by providing elected officials, municipal engineering and operations personnel, developers, contractors, consultants and businesses and residential landowners with the tools they need to successfully implement LID in their communities.

1.3. Central Parkway Retrofit

Nearly 60 per cent of Canadians feel that municipalities are upgrading storm sewer systems to handle excess stormwater (RBC, 2013). However, the reality is that Canada is facing a substantial infrastructure deficit that is exacerbated by extreme events due to climate change. Within urban areas, limited opportunities exist to build stormwater capacity due to increasing urbanization and built-out land. Municipally owned land and public spaces provide great opportunities to incorporate stormwater features and educate the public on stormwater management.

Toronto alone has enough roads that if put end to end would extend from Vancouver to Halifax and back (City of Toronto, 2015).

To showcase innovative stormwater technologies, the City of Mississauga partnered with DeepRoot, TD Friends of the Environment Foundation and CVC to retrofit the existing streetscape with a Silva Cell bioretention system on Central Parkway East (**Section 3**). Through this partnership, CVC is assessing the performance of the bioretention system installed in the existing median with respect to water quality and quantity. Central Parkway East is a mixed-use street that drains runoff from the four-lane road surrounding the median. Residential homes, schools, a community centre, and a high-volume shopping area are located nearby. **Figure 1-1** shows the location of the Central Parkway site in the context of the Cooksville Creek sub-watershed.

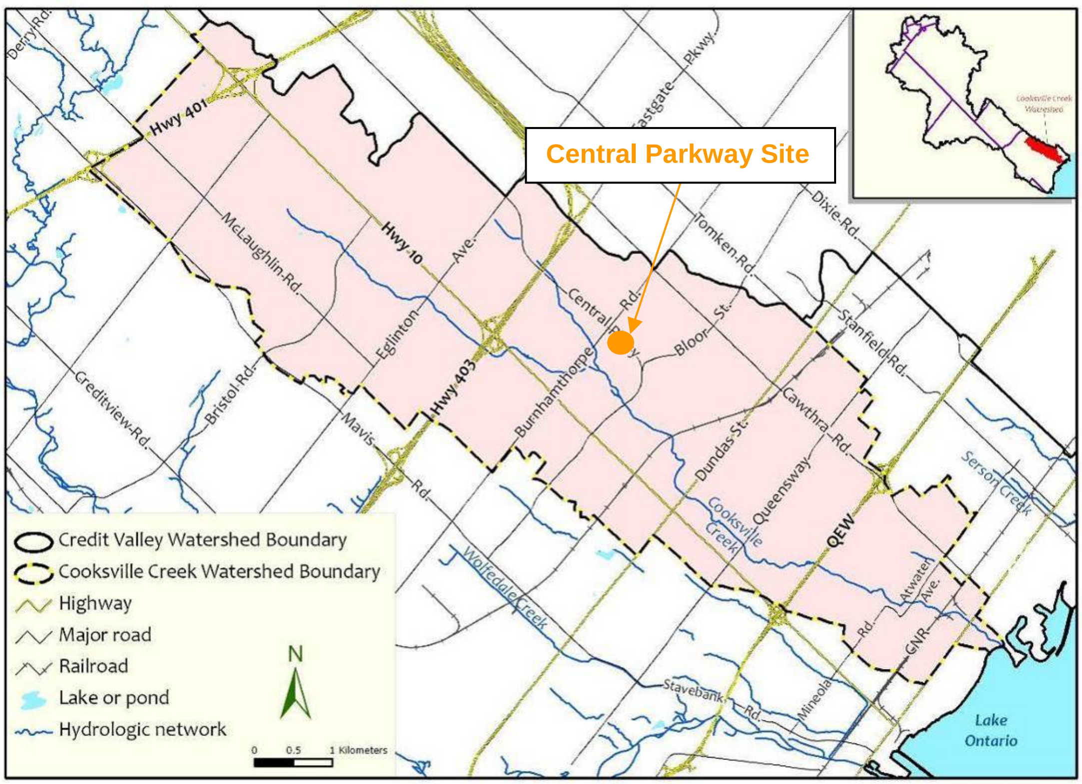

Figure 1-1: Central Parkway stormwater management site location in Cooksville Creek sub-watershed of the Credit Valley Watershed

2. LID MONITORING OBJECTIVES

Figure 2-1: Stakeholders at the monitoring objectives meeting.

Working with project partners and stakeholders, CVC has defined nineteen objectives for CVC's overall SWM monitoring program. CVC held several meetings to collect input from stakeholders including municipal decision makers, provincial and federal environmental agencies, engineering and planning professionals, conservation authorities, academia, and watershed advocate groups.

The stakeholder group identified these nineteen objectives for the program. The key objectives in bold print (2, 3, 8 and 9) were used to frame the basis of the monitoring program at Central Parkway. To assess objectives, CVC has developed comprehensive meteorological, hydrologic and water quality assessment protocols (**Appendix B**):

1. Evaluate how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity as a whole.
2. **Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance.**
3. **Determine the life-cycle costs for LID practices.**
4. Assess the water quality and quantity performance of LID designs in clay or low infiltration soils.
5. Evaluate whether LID SWM systems are providing flood control, erosion control, water quality, recharge, and natural heritage protection per the design standard.
6. Assess the potential for groundwater contamination in the short- and long-term.
7. Assess the performance of LID designs in reducing pollutants that are dissolved or not associated with suspended solids (i.e. nutrients, oils/grease, and bacteria).
8. **Demonstrate the degree to which LID mitigates urban thermal impacts on receiving waters.**
9. **Assess the water quality and quantity performance of LID technologies.**
10. Evaluate how SWM ponds perform with LID upstream. Can the wet pond component be reduced or eliminated by meeting the erosion and water quality objectives with LID?
11. Assess the potential for soil contamination for practices that infiltrate.
12. Evaluate effectiveness of soil amendments and increased topsoil depth for water balance and long-term reliability.
13. Evaluate and refine construction methods and practices for LID projects.
14. Develop and calibrate event mean concentrations (EMCs) for various land uses and pollutants.
15. Assess performance of measures to determine potential rebates on development charges, credits on municipal stormwater rates and/or reductions in flood insurance premiums (i.e. can LID reduce infrastructure demand?).
16. Assess the ancillary benefits, or non-SWM benefits.
17. Assess the potential for groundwater mounding in localized areas.
18. Improve and refine the designs for individual LID practices.
19. Assess the overall performance of LID technologies under winter conditions.

3. CENTRAL PARKWAY LID SITE DESIGN

The Central Parkway Project incorporates the DeepRoot Silva Cell green infrastructure technology with a tree-lined landscape within the existing median on Central Parkway East, south of Burnhamthorpe Road in the City of Mississauga, Ontario (**Figure 3-1**). In addition to providing aesthetic improvement, the tree-lined landscape feature provides stormwater filtration and retention of stormwater runoff from impervious surfaces before entering Cooksville Creek and Lake Ontario. Prior to construction, this site drained directly into Cooksville Creek with little opportunity for pre-treatment. **Figure 3-1** and **Figure 3-2** demonstrate the site pre-construction and post-construction, respectively.

Figure 3-1: Aerial view of Central Parkway LID site

Figure 3-2 Before retrofit

Figure 3-3 Completed site

The DeepRoot Silva Cell system is a modular suspended-pavement soil cell system which provides filtration of stormwater runoff for the contributing 1,046 m^2 impervious road and median drainage area; the total drainage area including the Silva Cell feature is 1,116 m^2 (**Table 3-1**). The trees, shrubs, and bioretention soils within this system filter out nutrients and pollutants as the water moves through the soil profile beneath the median surface. The project proposed to utilize infrastructure improvements to the extent possible such that removal/replacement was minimized, and disruption to traffic on Central Parkway was minimized. The existing street pavement, curb/gutter, and storm sewer system remain in place, routing stormwater runoff to the Silva Cell system (**Figure 3-4**).

The project is designed to achieve the maximum stormwater treatment benefit by taking full advantage of the available void space provided by the Silva Cells and bioretention soil media. The Silva Cells and planter area for the project provide a soil media volume of 105 m^3. The macropore void space volume for the project is approximately 21 m^3. This volume is then utilized for water storage/filter capacity.

Table 3-1 Central Parkway drainage area

Land use	Classification	Area (m^2)
Road (west sub-catchment)	Impervious	545
Road (east sub-catchment)	Impervious	501
Bioswale/planter	LID	70
		Total 1,116

Existing infrastructure (pavements and curb/gutter) direct stormwater from defined contributing drainage areas to existing catch basins adjacent to the street median. Stormwater is initially captured and pre-treated in the existing catch basins that are retrofit with internal pipe extensions to create a sump area and provide surface water screening. The sump area and surface water screening result in pre-treatment of larger sediments as well as floatable debris prior to conveyance to the system. Distribution pipes installed within the LID facility route water to the bioretention/filtration system. The water is then distributed through perforated pipes into bioretention soil media where it percolates through the soil column, providing water to the trees and filtering out excess nutrients. Once percolated through the soil column, water ultimately discharges at the base of the system through an underdrain installed with connection to an existing manhole connected to the City's storm sewer system.

The underdrain at the base of the Silva Cells ensures the trees are not inundated for extended periods. Any excess soil moisture in the bioretention system will be removed and transported to the storm sewer system via this underdrain. This design feature and its components also dictate that there is not permanent water storage within the soil volume, but rather the soil volume will act as a filter through which water flows.

Stormwater treatment and benefits are provided for smaller rainfall events as the capacity of the system allows. Larger rain events that exceed the capacity of the Silva Cells bypass the system through overflow pipes within the existing catch basins and discharge into the existing storm sewer system.

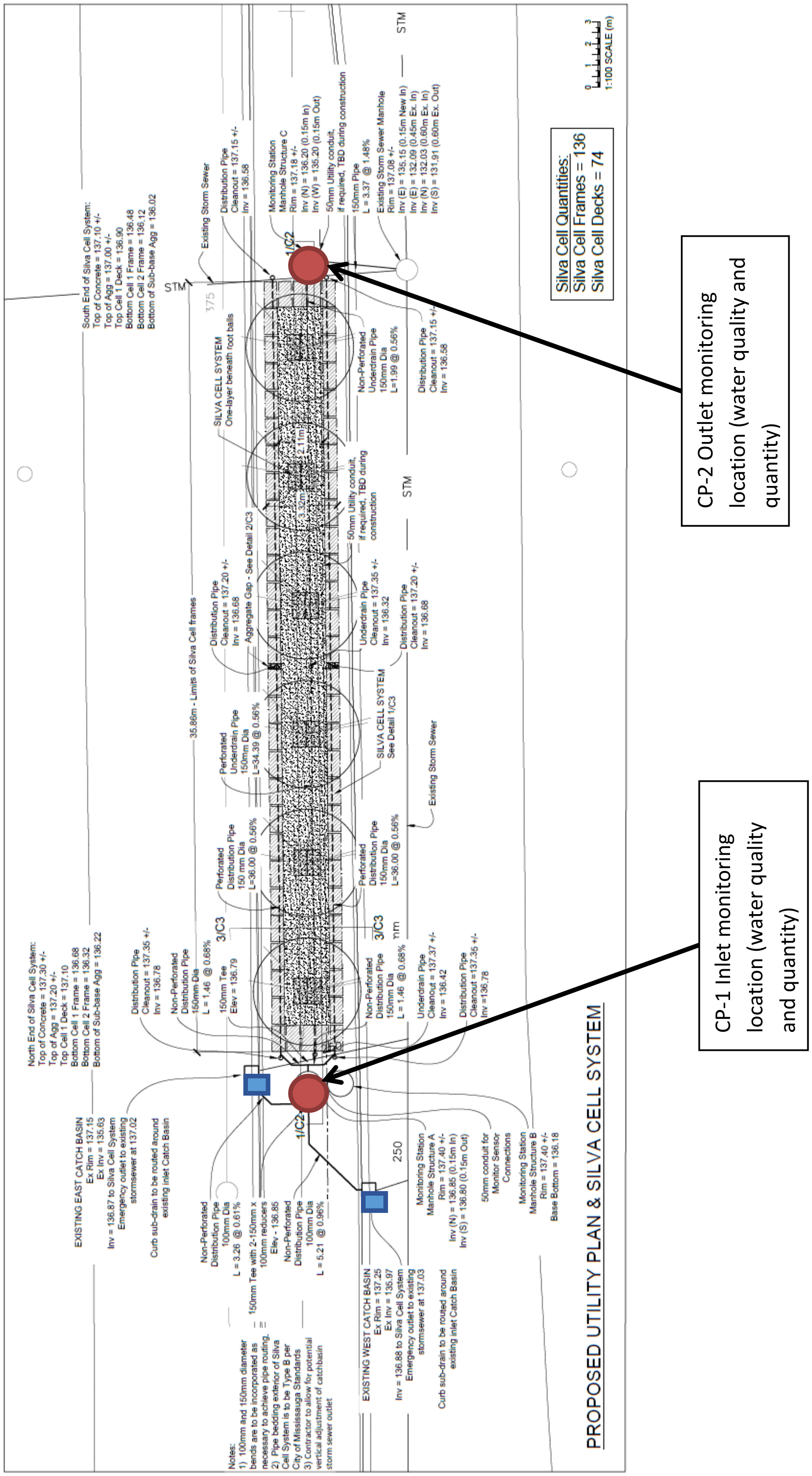

Figure 3-4 Central Parkway LID site design and monitoring locations

4. MONITORING RESULTS AND INTERPRETATIONS

This section presents results from the analysis of data from the monitoring program at Central Parkway from August 2015 to September 2015. The monitoring program at Central Parkway includes a variety of elements such as precipitation, flow, water quality and water temperature monitoring. **Table 4-1** summarizes these activities and their locations. A more detailed discussion is included in the following subsections. This report contains the analyses of a range of precipitation and flow events during the study period. The monitoring protocols, comprehensive data management and analysis for Central Parkway are discussed in **Appendices B**, **C** and **D** respectively.

Table 4-1: Summary of the measurement type, monitoring equipment and monitoring locations

Measurement Type	Monitoring Equipment	Location / Description
Level and Flow	ISCO 2150 area velocity flow meter; v-notch weir	Monitoring chamber upstream and downstream of the LID feature (inlet and outlet)
Stormwater Quality Sampling	ISCO 6712 automatic sampler	Monitoring chamber upstream and downstream of the LID feature (inlet and outlet)
Water temperature	HOBO UA-002-64K	Monitoring chamber upstream and downstream of the LID feature (inlet and outlet)

Figure 4-1: Monitoring equipment installed in inlet chamber (left) and outlet chamber (right

4.1. Precipitation

Precipitation at Central Parkway was collected from the Mississauga Valley precipitation gauge (STN-06) between August 10, 2015 and September 30, 2015 (**Table 4-2**). Additional gauges maintained by the City of Mississauga and CVC are used as a check on the site data and in the event of any gaps in the data from the primary gauge. For comparison, precipitation record from the Environment Canada (EC) weather station, *Toronto Pearson International Airport* (climate ID: 6158733), is used to provide support in characterizing the events to be expected at Central Parkway and the general distribution of rainfalls in the GTA. **Table 4-2** compares the monthly and total annual precipitation normals between *Toronto Pearson*

International Airport (1981 – 2010) weather station and the precipitation recorded at Mississauga Valley STN-06.

Table 4-2 Precipitation comparison between Toronto Pearson International Airport weather station and Mississauga Valley STN-06

Parameters	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Station: *Toronto Pearson International Airport* (1981-2010)													
Precipitation (mm)	51.8	47.7	49.8	68.5	74.3	71.5	75.7	78.1	74.5	61.1	75.1	57.9	785.9
Station: *Mississauga Valley STN-06*													
2015 Precipitation[a] (mm)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	47.8	74.8	n/a	n/a	n/a	n/a

Note: [a] Data starts on August 10, 2015 at 12:05 and ends on September 30, 2015 at 12:30

The average annual precipitation at *Toronto Pearson International Airport* weather station from 1981 - 2010 was 786 mm. From August to September 2015, the total recorded precipitation at Central Parkway was about 123 mm. An annual or complete precipitation record is not available, since monitoring initiated August 10, 2015 and concluded September 30, 2015 due to equipment removal for the season. From this preliminary analysis, the precipitation in August 2015 was 39 per cent lower than the precipitation normal. This is due to the dataset starting on August 10, 2015; if the first 10 days of August are included, the total precipitation for the month is 68.6 mm, which is only 12 per cent lower than the precipitation normal. The total recorded precipitation in September 2015 was close to the precipitation normal.

The frequency of events for a given size from EC *Toronto Pearson International Airport* station is presented in **Figure 4-2**. An event is considered to occur when 2 mm or greater precipitation is recorded, and a minimum of 6 hour dry is observed between precipitation and/or flow. In this chart, hourly weather records from 1950-2005 have been analyzed with WQ-COSM software. This software is designed for determining and maximizing the 'water quality capture volume' for a BMP based on local historical rainfall data. This volume is used to adequately design and size BMPs for improved water quality and quantity control based on historical rainfall, and to aid in determining performance. Since monitoring at Central Parkway has just started, the number of precipitation events captured to date (i.e. eight events) is insufficient to be compared with the *Toronto Pearson International Airport* weather station frequency distribution. This comparison will be made as more data is collected.

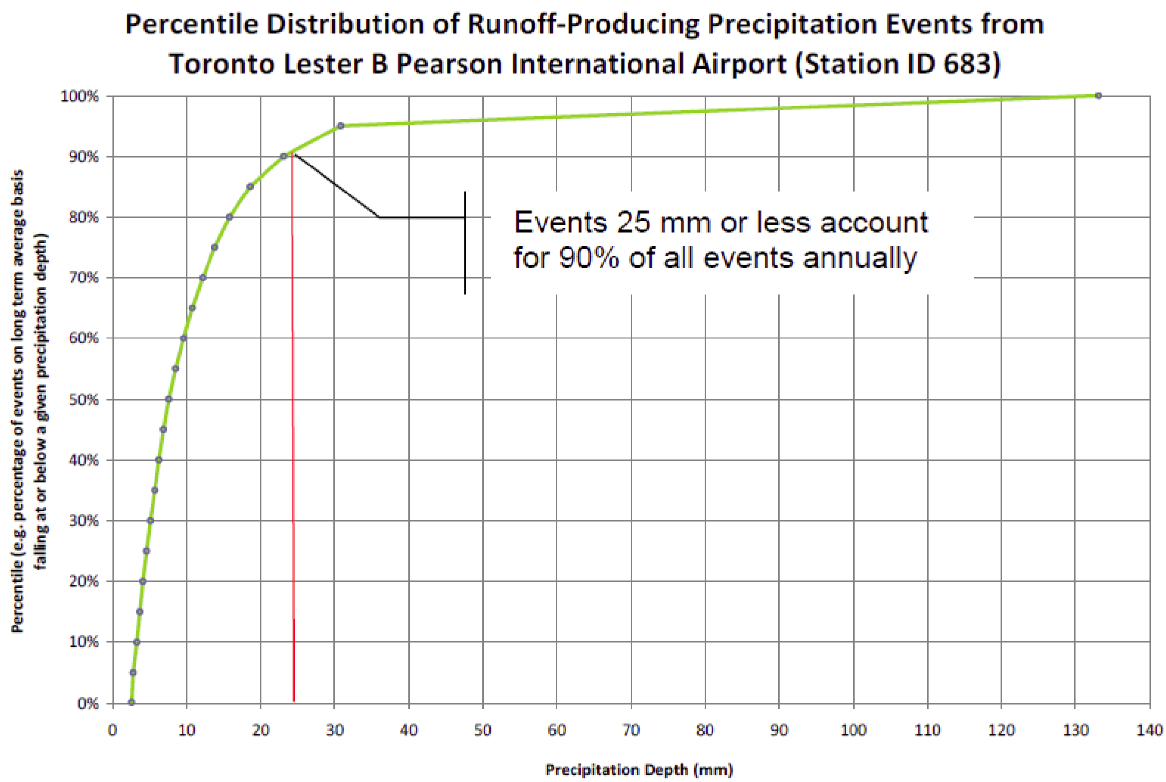

Figure 4-2 Percentage of events failing at or below a given precipitation depth at Toronto Pearson International Airport station using hourly precipitation records from 1950-2005

4.2. Hydrology

In natural and rural environments with natural land cover, surface runoff is generally low and represents a small fraction (10-20 per cent) of the total precipitation (Prince George's County, 1999). Water either percolates into the ground or is returned to the atmosphere by evaporation and transpiration. A considerable percentage of the precipitation infiltrates into the soil and contributes to the groundwater. The local water table is often connected to nearby streams, providing base flow to streams and wetlands during dry periods and helps maintain biological and habitat integrity of streams.

Land development converts permeable land into impermeable surfaces. During urbanization, natural stream and drainage channels are replaced by artificial drainage pipes and conveyance that decrease the amount of infiltration and storage within the soil column. This alters the hydrologic regime by allowing less infiltration and more channeled runoff through the urban infrastructure**.** The process is shown in **Figure 4-3**.

As a much larger percentage of rainwater hits impervious surfaces including roofs, sidewalks, parking lots, driveways, and streets, it must be controlled through stormwater management techniques. Traditional approaches have focused on collection and conveyance to quickly transport stormwater to the nearest watercourse to prevent property damage (National Academy of Sciences, 2008). Current stormwater management has taken an "end of pipe" approach, using piping systems to convey runoff to ponds or detention basins. This approach does not mitigate or alter the runoff volume component of the water cycle which is the driving force of erosion, pollution and lower dry weather stream flows due to changes in hydrology (National Academy of Sciences, 2008).

Cook and Dickinson (1986) examined the impacts of urbanization, including the installation of a stormwater conveyance system near Guelph, Ontario. Comparing the pre-development conditions of the area with ongoing development, the researchers noted several changes in the hydrologic response. Changes included an increase in annual runoff, a change in the time of peak flow, a reduction in hydrograph lag time, and an increase in

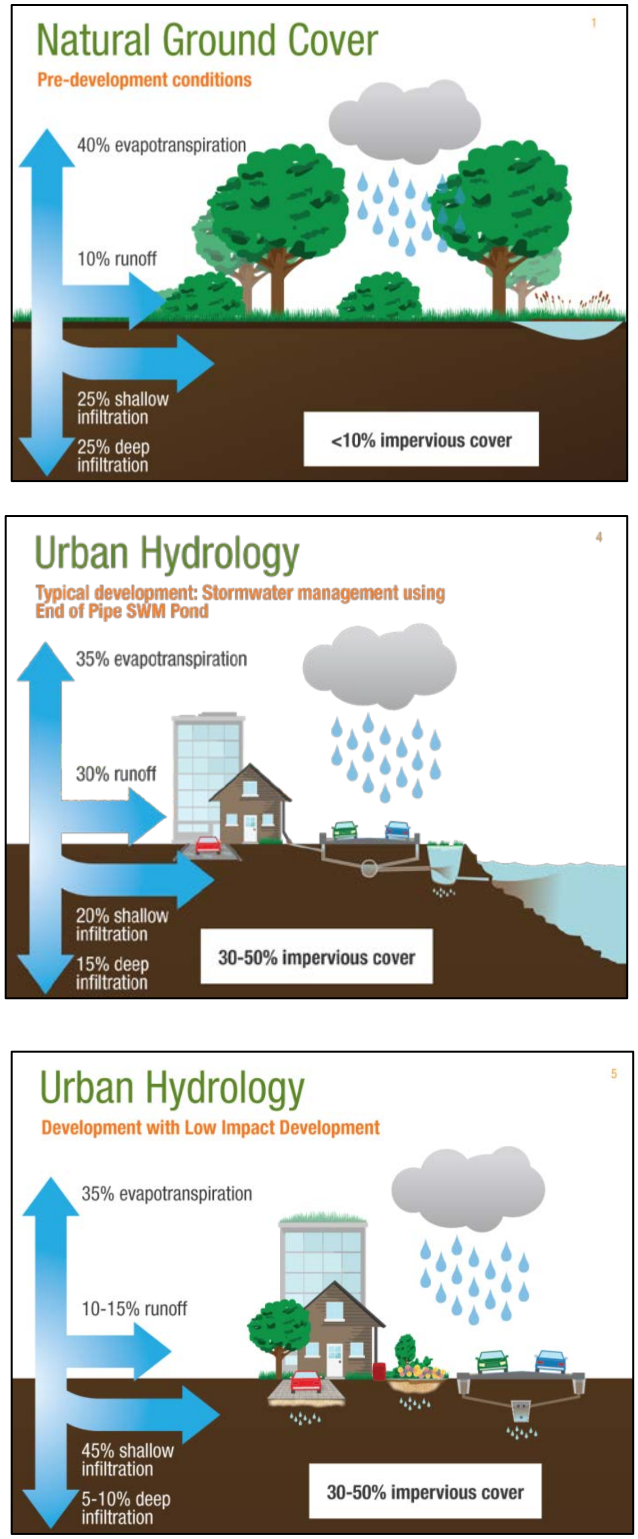

Figure 4-3 Development conditions; urban water cycle with stormwater management ponds and LID (adapted from FISRWG, 1998)

hydrograph peak discharge. Urban development produces runoff for events where pre-development conditions produced no runoff, such as during the summer months outside of the snowmelt or spring runoff period.

A robust stormwater management system that meets all environmental and economic goals must include both conventional stormwater management facilities and source-based LID practices (National Academy of Sciences, 2008). Conventional facilities typically lack the ability to provide water balance benefits or reduce the volume of runoff from heavily urbanized areas. As a result they offer fewer benefits with respect to infiltration, water quality and erosion mitigation. LID practices excel where conventional systems fail by allowing for natural hydrologic processes including infiltration and evapotranspiration as close to the source as possible (U.S.EPA, 2007). A greater discussion of the urban water cycle can be found in **Appendix F**.

Figure 4-4 shows a hydrograph comparing stream discharge before, during, and after a storm under pre- and post-development conditions (Schueler, 1987). As indicated, streams with developed watersheds have substantially higher peak flows which occur more quickly than under pre-development conditions. Impervious surface coverage as low as 10% can destabilize a stream channel, raise water temperatures, and reduce water quality and biodiversity (Schueler, 1995).

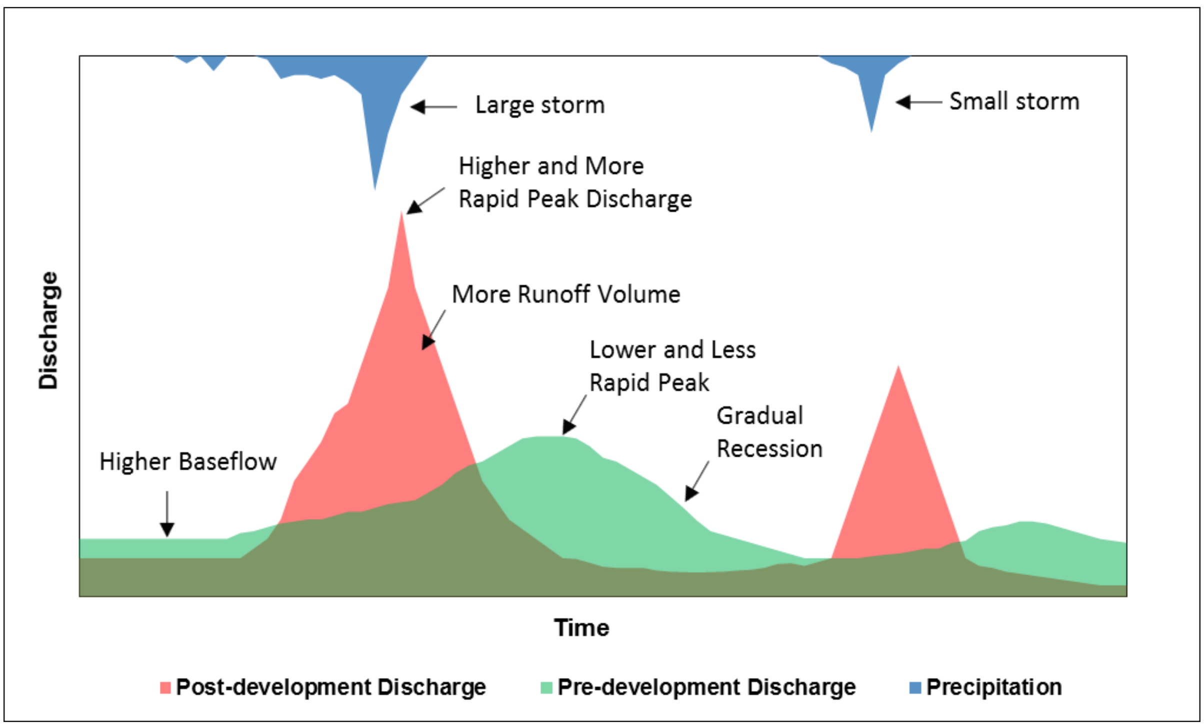

Figure 4-4 Changes in stream flow hydrograph as a result of urbanization (Schueler, 1987)

LID practices are designed to mitigate the rapidly changing runoff hydrographs by mimicking the predevelopment hydrology within the urban environment. LID strategies strive to allow natural or pre-development infiltration to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, the landscape can retain more of its natural hydrological function. Although most effective when implemented on a community-wide basis, using LID practices on a smaller scale can also have a positive impact.

4.2.1. Central Parkway Hydrology

Central Parkway hosts a Silva Cell bioretention design, demonstrating how the effects of urbanization on the local hydrology and watershed can be mitigated on a smaller scale. The project team assessed the preliminary monitoring performance of the reduction in runoff volume, the reduction in peak flow, and the lag between peak influent and effluent flow. The site receives inflows curb and gutter flow, by entering the existing storm sewer catch basins. Inflow is measured through level measurements in an inlet chamber before entering the feature. Effluent flow is measured in the same manner in a chamber at the outlet of the LID feature (**Figure 3-4**). **Appendix C** contains a discussion of the data management and analytical methodology.

4.2.2. Hydrologic Observations

An important component in ensuring the feature at Central Parkway is functioning and performing as intended involved going on-site and conducting visual inspections, photo logs and videos during rain events. Staff videotaped the site during precipitation events with various intensities shortly after the site was constructed. Prior to these observations, monitoring equipment had been installed and indicated that monitored flows at the inlet were low compared to expected flows calculated based on the Simple Method, which calculates flow according to drainage area, amount of precipitation, and a runoff coefficient based on level of imperviousness. Further discussion of the Simple Method is in **Appendix C**.

A SWMM model was generated to compare the expected runoff to the monitored flows at the inlet. The model and monitored flows are also compared with the Simple Method. The estimated flows generated by the model further support the observations that some form of bypass was taking place. Estimated flows from the model and the Simple Method were similar, while monitored inflow was much lower than the modelled inflow. This suggested that the system was not receiving the amount of runoff it was designed for based on the drainage analysis and design catchment. The model will be further evaluated in the future; a description can be found in **Appendix C**.

By videotaping the site during a particular event, staff observed runoff bypassing the system by entering the overflow pipe in the west catch basin prior to entering the inlet pipe, which had been inadvertently installed at a higher elevation than the overflow pipe.

Based on this observation, a water test was conducted in July, 2015 by pouring water directly into the two catch basins that receive runoff before entering the LID feature. The water test confirmed that the invert of the overflow pipe was at a lower elevation than the invert of the inlet pipe in the west catch basin. Water did not enter the inlet pipe at any point during the test, indicating that the drainage area of the west sub-catchment was bypassing the feature entirely (**Figure 4-5**).

Figure 4-5 Water test in east catch basin

In addition, an obvious drawdown of water was observed in the west catch basin, indicating that a significant leak was also occurring. Observations indicated that surface flows from the east sub-catchment area directly entered the open overflow pipe as a result of its location close to the curb-side of the catch basin. A slight drawdown was observed in the east catch basin.

As a result of these observations several repairs were performed in August, 2015. The overflow pipe in the west catch basin was raised several inches and fitted with an elbow to prevent bypass, and the overflow pipe in the east catch basin was fitted with an elbow to prevent direct surface flows. The sumps for both catch basins were filled, with the new bottoms raised to approximately the obvert of the existing overflow pipes.

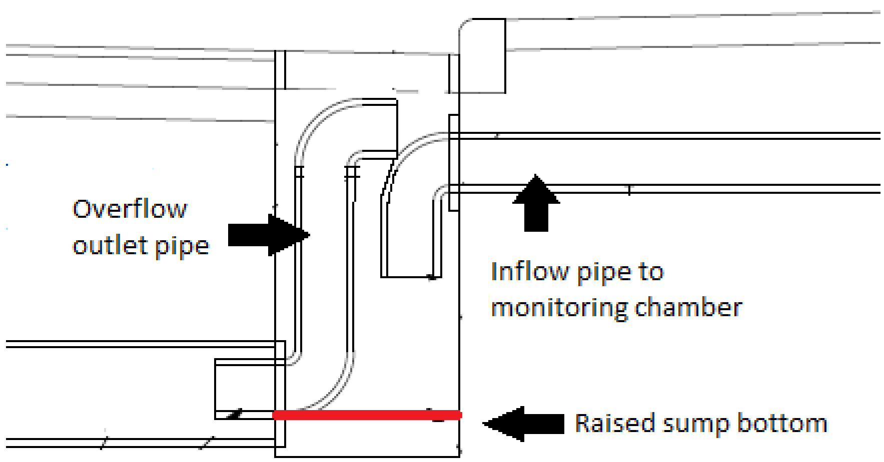

Figure 4-6 Catch basin side view, with overflow and inlet pipes

With continued monitoring and additional observations during precipitation events, some runoff was still bypassing the system and entering the overflow pipe in the west catch basin, despite the fact that the overflow pipe was raised. Upon measuring the invert of the overflow and inlet pipes, the inlet pipe was still at a lower elevation than the overflow pipe.

In November, 2015 the west overflow pipe was raised to the bottom of the catch basin grate, ensuring that the inlet pipe is at a lower elevation and that the system receives runoff from the entire catchment area. Since this modification occurred after the end of the monitoring season, the water quantity analysis is based on the monitored runoff that actually entered the LID feature and not the runoff from the entire catchment. As a result, comparisons to the site design cannot be made without additional monitoring data.

4.2.3.Water Quantity Analysis

Table 4-3 presents the hydrologic summary for all eight events over the monitoring period to date (August-September 2015). This analysis includes precipitation events greater than 2 mm during the monitoring period. Each precipitation event was analyzed for total depth and peak intensity. Inflow volume and outflow volume were measured on site, and inflow peak, outflow peak, and lag time were determined from the monitoring data. A detailed hydrologic summary for all eight precipitation events is presented in **Appendix D**.

Increasing the amount of water that infiltrates and does not become runoff (i.e. volume reduction) is necessary to reduce impacts on local stormwater infrastructures and receiving water bodies. The average estimated event runoff volume reduction for all events is 97 per cent and the average estimated peak flow reduction is 96 per cent. Large runoff volume reductions reflect higher filtration of stormwater runoff, smaller flows to the stormwater network, and the potential for a reduction in contaminant loading.

Figure 4-7 and **Figure 4-8** show runoff volume reduction and peak flow rate reduction, respectively, for events of different magnitude. Events are binned into six categories: 2-5 mm, 5-10 mm, 10-15 mm, 15-20 mm, 20-25 mm, and greater than or equal to 25 mm. It should be noted that due to the limited dataset, no rainfall events were observed in the 15-20 mm or 20-25 mm categories during the August-September 2015 monitoring period. Based on the amount of runoff actually entering the system and not the runoff from the entre catchment, both runoff volume and peak flow rate is reduced for events of all sizes. The feature at Central Parkway retains on average 98 per cent of runoff for all events smaller than 25 mm. The site also provides on average 85 per cent peak flow rate reduction for all events less than 25 mm. Due to the low number of events recorded during the monitoring period, these analyses are preliminary.

Hydrologic lag times from peak influent to peak effluent flow were also computed for the storm events presented in **Table 4-3**. Larger lag periods mimic pre-development conditions and give greater opportunity for surface runoff to infiltrate, filtrate, and delays runoff entry into the receiving water body. The lag time for events with discharge ranges between 20 and 55 minutes.

Table 4-3 Statistical analysis of all precipitation events during the 2015 monitoring period

Statistic	Event precipitation (mm)	Event duration (hr)	Peak precipitation intensity (mm/hr)	Antecedent dry period (days)	Peak effluent flow rate (L/s)	Measured influent volume (L)	Measured effluent volume (L)	Estimated peak flow reduction (%)	Estimated event runoff volume reduction (%)
Count	8	8	8	8	8	8	8	9	8
Mean	14.82	13.66	27.60	6.43	0.21	7000	462	96%	97%
Standard Deviation	11.92	20.59	16.33	6.07	0.48	5997	1025	9%	6%
Minimum	2.00	2.50	2.40	0.35	0.00	100	0	75%	83%
25% Percentile	5.90	2.71	19.80	2.69	0.00	2500	0	98%	97%
Median	9.70	4.92	30.00	5.35	0.00	5234	52	100%	99%
75% Percentile	27.15	11.10	37.20	6.71	0.10	10809	278	100%	100%
Maximum	31.00	62.00	50.40	19.74	1.36	17739	2975	100%	100%

Note: Monitoring period is August 10-September 30, 2015

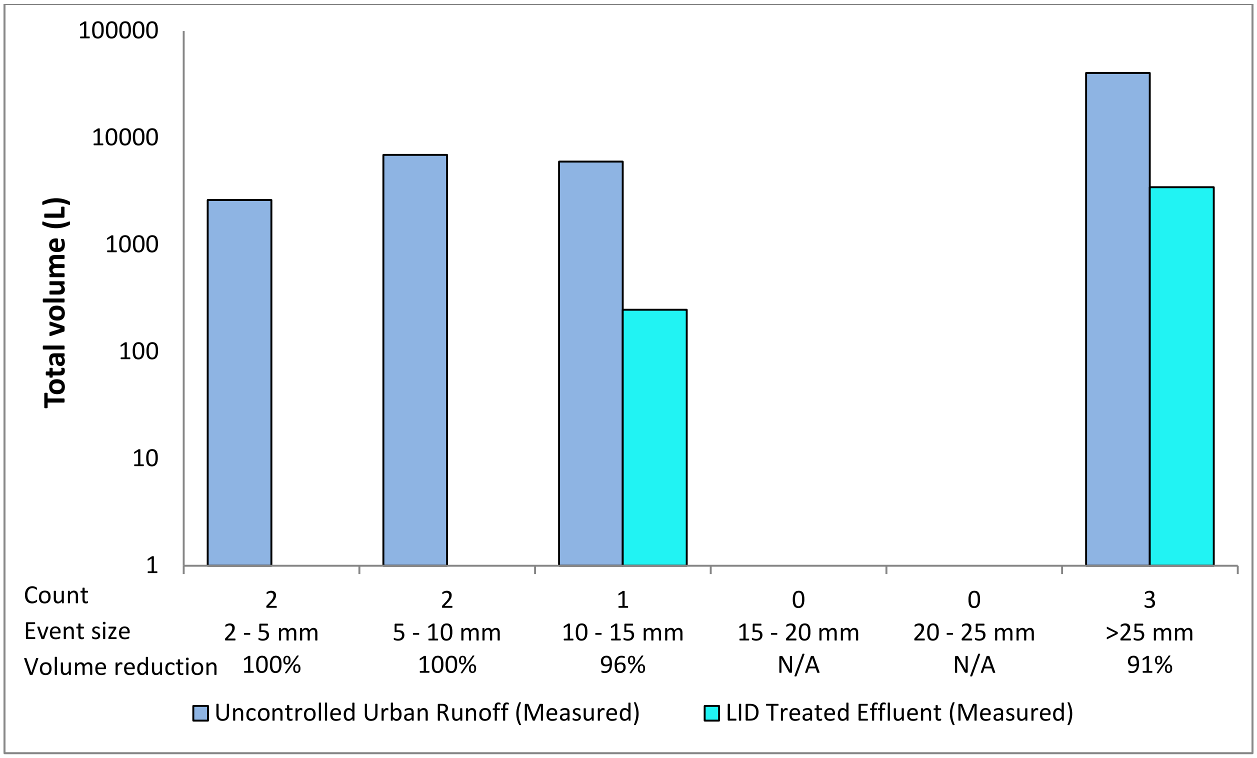

Figure 4-7 Runoff volume reduction during monitoring period

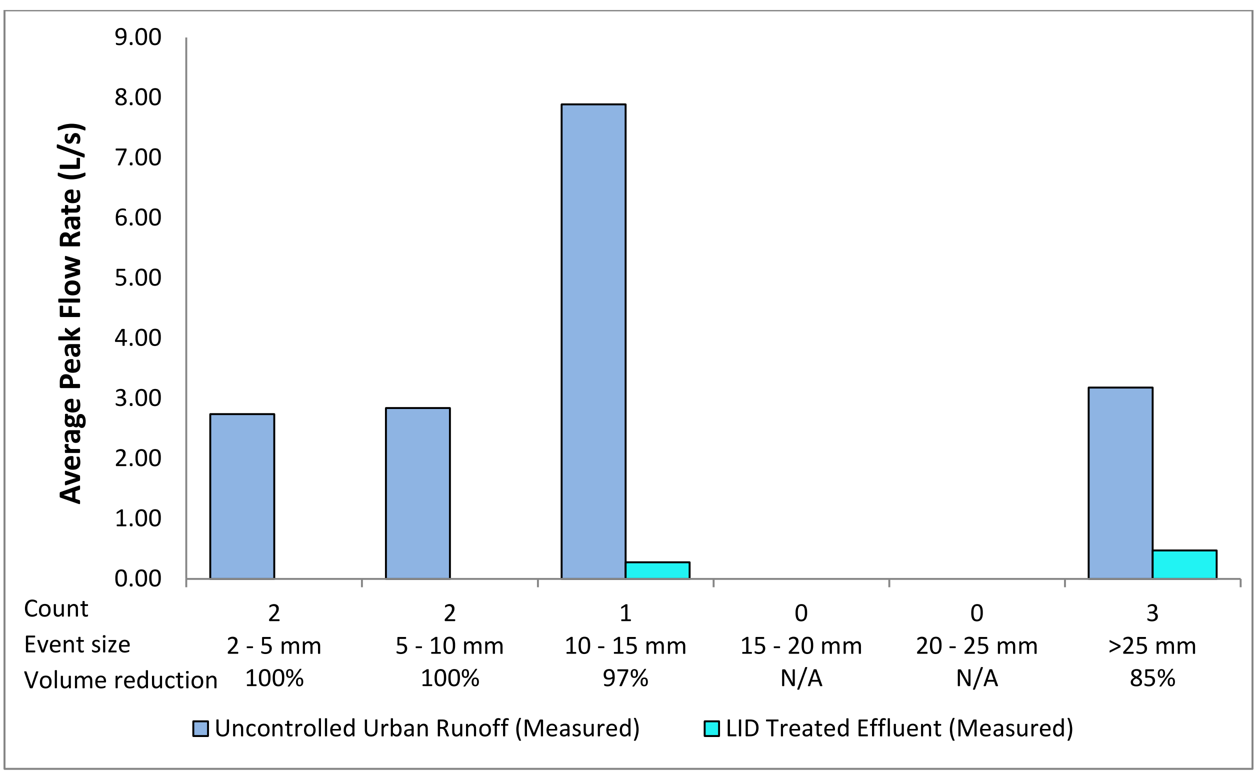

Figure 4-8 Peak flow rate reduction during monitoring period

Figure 4-9 is an example of a hydrologic event summary for a monitored event, illustrating hydrograph response with reduced peak and outflow lag. This storm event had a 22 hour duration and a precipitation depth of 28.8 mm, with a peak rainfall intensity of 40.8 mm/hr. Volume reduction for this event was estimated to be about 83 per cent and peak flow reduction was estimated to be about 75 per cent. A lag time of approximately 35 minutes was observed between the inflow runoff peak and the outflow peak for this large event.

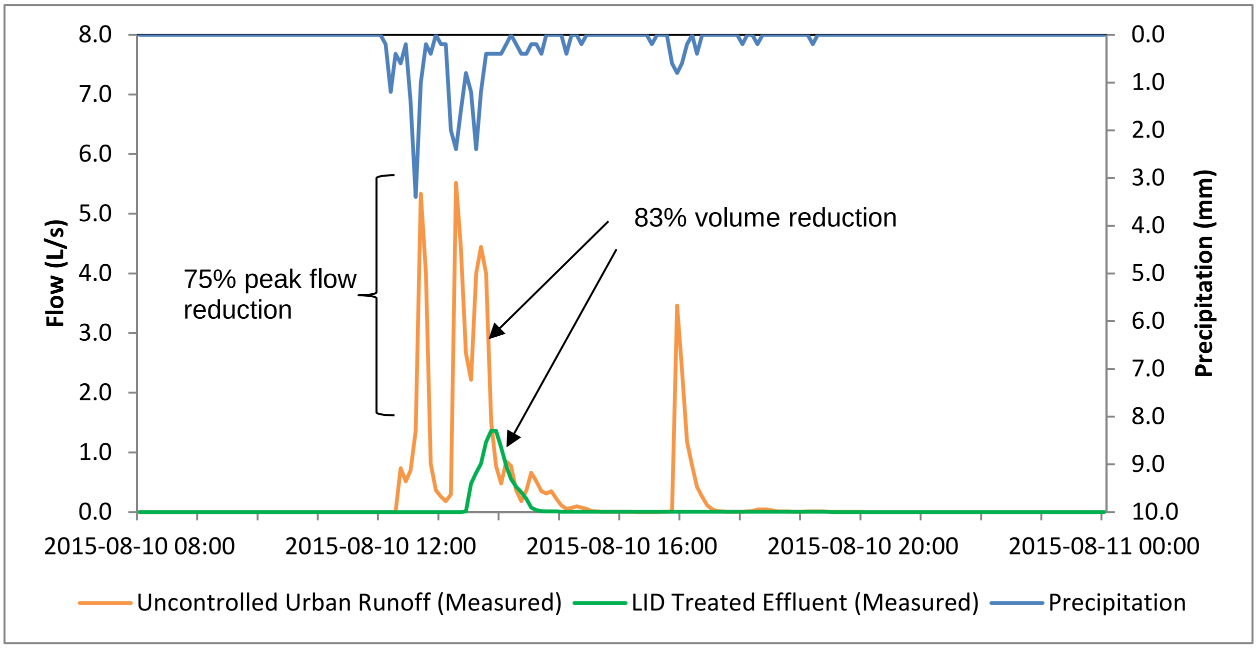

Figure 4-9 Hydrologic summary for a large event

Preliminary results indicate that Central Parkway is providing water quantity control for the runoff entering the system. The site has demonstrated its ability to retain a variety of event sizes and provide peak flow reduction. Additional monitoring is needed to strengthen the dataset and account for runoff from the entire catchment.

5. DISCUSSION – MONITORING OBJECTIVE ASSESSMENT

To advance the use of LID designs and practices, CVC has worked with partners and stakeholders to address their questions about performance, operations, implementation and maintenance. Stakeholders identified top priorities to help maximize the benefits of investments in LID, and provide the data that is needed to develop long-term solutions for SWM plans. CVC has consulted the expert advisory committee to develop and implement a robust monitoring program to better understand LID performance and address information gaps. The Central Parkway monitoring program directly assesses several of the stakeholder objectives. This list assesses each objective received in the feedback.

1. Evaluate how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity as a whole.
    - This objective is not studied at Central Parkway, but information can be found in the Elm Drive Technical Report where CVC monitors permeable pavement and bioretention cells. The report can be found at **www.bealeader.ca.**
2. **Evaluate long-term maintenance needs and maintenance programs and the impact of maintenance on performance.**
    - Since May 2015, CVC monitoring staff have been collecting data on maintenance activities performed and inspecting conditions of the Central Parkway LID practices on a bi-weekly basis. A site inspection checklist is used by staff during each site visit (**Appendix E**).
    - Based on site inspections to date, the shrubs and trees within the planter are becoming well established.
    - Pending further funding, CVC plans on continuing to monitor Central Parkway to access long-term performance and maintenance requirements. It is expected that several years of observations will be needed to address maintenance and asset management related questions.
3. **Determine the life-cycle costs of LID practices.**
    - Maintenance is an important part of ensuring the proper function of LID practices, particularly during the initial establishment phase. It is necessary to follow up with the contractor post-construction to ensure that activities specified within the maintenance agreement are taking place. These activities may include, but are not limited to, maintaining soil moisture until grass and plant establishment, weed removal.
    - Additional costs could include supplemental plantings to replace plants that do not establish, the replacement of filter media, and debris removal. It is recommended that assumption protocols are carried out before assuming the LID or SWM feature to ensure that site is performing as designed. See CVC Certification Protocols at **www.bealeader.ca.**
    - CVC is currently developing a database to quantify maintenance activities and on-going life-cycle costs based on inspections and interviews with maintenance staff.
    - Pending funding, CVC will continue to conduct site inspections and ongoing communication with maintenance staff to assess ongoing costs.
4. Assess the water quality and quantity performance of LID designs in clay or low infiltration soils.
    - This objective is not studied at Central Parkway, but information can be found in the Elm Drive Technical Report at **www.bealeader.ca.**

5 Evaluate whether the LID SWM systems are providing flood control, erosion control, water quality, recharge and natural heritage protection per the design standard.

- This objective will be assessed at Central Parkway with the collection of additional monitoring data.

6 Assess the potential for groundwater contamination in the short- and long-term.

- This objective is not assessed at Central Parkway but will be assessed at the Meadows in the Glen LID site.

7 Assess the performance of LID designs in reducing pollutants that are dissolved or not associated with suspended solids.

- Water quality monitoring has not commenced at Central Parkway. This objective may be evaluated in the future.

8 Demonstrate the degree to which LID mitigates urban thermal impacts on receiving waters.

- The current monitoring program at Central Parkway includes thermal monitoring however due to the limited dataset, analysis of thermal data has not yet been completed. Please see the Elm Drive Technical Report at **www.bealeader.ca** for a discussion on thermal analysis.

9 Assess the water quality and quantity performance of LID technologies, which currently do not receive credits or are only given limited credit in the 2003 MOE SWM Planning and Design Manual.

- Bioretention filters are eligible for credit towards the water quality criteria as shown in Table 3.2 of the 2003 MOE SWM Planning and Design Manual. Based on the findings during the monitoring period (**Table 4-3**), Central Parkway is expected to provide 96 per cent peak flow reduction and 97 per cent volume reduction in average. However, LID benefits for peak flow reductions are often overlooked. The sizing of SWM features downstream will need to take this into account, as these reductions minimize pressure on stormwater infrastructure.

10 Evaluate how SWM ponds perform with LID upstream. Can the wet pond component be reduced or eliminated by meeting erosion and water quality objectives with LID?

- This objective is not assessed at Central Parkway but will be assessed at the Meadows in the Glen LID site.

11 Assess the potential for soil contamination for practices that infiltrate.

- While this objective is not assessed at Central Parkway, it is being assessed at the Elm Drive and Lakeview LID sites. Information on both sites can be found at **www.bealeader.ca.**

12 Evaluate effectiveness of soil amendments and increased topsoil depth for water balance and long-term reliability.

- This objective is related to the practice of accounting for the stormwater benefits of increasing the topsoil depth in landscaped areas. As this was not done at this site this objective is not relevant to Elm Drive. This practice will be examined in part at the Wychwood LID study site.

13 Evaluate and refine construction methods and practices for LID projects.

- Lessons learned with respect to LID designing are being documented over the course of the monitoring program and will be used to update the CVC/TRCA Design Guide and CVC Construction Guide. Refer to **www.bealeader.ca** for further information on workshops and case studies.

14 Develop and calibrate EMCs for various land uses and pollutants.

- Influent runoff sampling must be collected from numerous sites to develop robust land-use EMCs. Both influent and effluent monitored in planned at Central Parkway and will commence in the next monitoring period.

15 Assess performance of measures to determine potential rebates on development charges, credits on municipal stormwater rates and/or reductions in flood insurance premiums.

- Understanding the long-term performance potential for LID is important when developing rebate plans and offering credits. This objective will be assessed at CVC's Head Office monitoring location.

16 Assess the ancillary benefits, or non-SWM benefits.

- Refer to CVC's Grey to Green Road Retrofits: Road Right-of-Way and **www.bealeader.ca** for indirect benefits, such as reduced erosion, street greening and improved fish health in receiving waters.

17 Assess the potential for groundwater mounding in localized areas.

- While this objective is not assessed at Central Parkway, CVC has monitored the response at several Public Lands sites. Information can be found at **www.bealeader.ca.**

18 Improve and refine the designs for individual LID practices.

- LID landscapes should conform to typical urban landscaping principles, unlike stormwater ponds or stream restorations which follow natural landscaping approaches. Consistency of plant placement and spacing and the use of various textures and colours should be considered.
- There are many options for design depending on the LID practice. It is important to determine the right design for the right location. One perceived barrier is maintenance. If maintenance requirements and responsibilities of the property owner can be incorporated into the agreement and design. Many residential rain gardens have been enhanced with residents adding their own plants. Refer to **CVC's Grey to Green Road Retrofits: Road Right-of-Way**, as well as the **Landscape Design Guide for Low Impact Development** for a complete discussion of landscaping principles for successful LID design.

19 Assess the overall performance of LID technologies under winter conditions.

- Monitoring equipment is not installed at Central Parkway during winter months due to site constraints. LID performance during winter conditions is assessed at several other LID sites including Elm Drive, IMAX and Wychwood. Details can be found at **www.bealeader.ca.**

6. SUMMARY OF OBSERVATIONS

These findings focus on the short-term performance assessment of the Silva Cell practice at Central Parkway. The ultimate goal is to continue monitoring long-term performance and life-cycle cost objectives. Discussed below is a summary of findings from the assessment conducted during the monitoring period.

6.1. Water Quantity

Monitoring has shown that Central Parkway is performing well based on preliminary data:

- The average runoff reduction for all eight hydrologic events observed during the monitoring period was 97 per cent (**Table 4-3**).
- Storm events with depths <25 mm, which make up 63 per cent of the total number of events at Central Parkway, were almost completely attenuated with a 98 per cent volume reduction. This reduces the resulting stress on stormwater infrastructure downstream of the feature.
- During the monitoring period, peak flow was reduced by 96 per cent in average (**Table 4-3**).
- The average lag time for events that produced outflow is 35 minutes. The LID feature at Central Parkway retains effluent flow and slows its release to the system, which reduces stress on the existing stormwater infrastructure and receiving water bodies.

6.2. Water Quality

Due to the short monitoring period in 2015, water quality sampling and analysis will commence in 2016.

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CENTRAL PARKWAY, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix A

Monitoring Plan

Table of Contents

Introduction

Low Impact Development Features and Site Design

The project proposes to retrofit an existing street with a tree-lined landscape and low impact development (LID) feature within the existing median on Central Parkway East, south of Burnhamthorpe Road, in the City of Mississauga, ON.

The tree-lined landscape feature will serve dual functions as bioretention/filtration of stormwater and beautification/aesthetic improvement. The bioretention system created within the median will utilize the DeepRoot Silva Cell system, a modular suspended-pavement soil cell system which will provide filtration of stormwater runoff for the contributing 1,046 m^2 drainage area. The trees, shrubs, and bioretention soils within this system will filter out nutrients and pollutants as the water moves through the soil profile beneath paved surfaces.

The project proposes to utilize infrastructure improvements to the extent possible such that removal/replacement is minimized, and disruption to traffic on the road is minimized. The existing street pavement, curb/gutter, and storm sewer system are to remain in place.

The majority of the project involves removal of the concrete median pavement and replacement of it with Silva Cells and bioretention material. Stormwater from select areas will be collected into existing storm sewer catchbasins with a portion of the stormwater routed to the biofiltration/filtration system that will ultimately discharge to existing storm sewer facilities.

The project is designed to achieve the maximum stormwater treatment benefit by taking full advantage of the available void space volume provided by the Silva Cells and bioretention soil media. The Silva Cells and planter area for the project provide a soil media volume of 105 m^3. An industry standard conservative value of 20% void space is assumed to be provided within the soil media macropores. The resulting void space volume for the project is then 21 m^3. This volume is then utilized for water storage/filter capacity.

The existing infrastructure (pavements and curb/gutter) direct stormwater from defined contributing drainage areas to existing catchbasins adjacent to the street median. Stormwater will initially be captured and pre-treated in the existing catchbasins that are retrofit with internal pipe extensions to create a sump area and provide surface water screening. The sump area and surface water screening result in pre-treatment of larger sediments as well as floatable debris prior to conveyance to the LID feature. Distribution pipes installed within the LID facility will route water to the bioretention/filtration system. The water will then be distributed through perforated pipes into bioretention soil media where it will percolate through the soil column, providing water to the trees and filtering out excess nutrients. Once percolated through the soil column, water will ultimately discharge at the base of the system through an underdrain installed with connection to an existing manhole connected to the City's storm sewer system.

The underdrain at the base of the Silva Cells ensures the trees are not inundated for extended periods. Any excess soil moisture in the bioretention system will be removed and transported to the storm sewer system via this underdrain. This design feature and its components also dictate that there is not permanent water storage within the soil volume, but rather the soil volume will act as a temporary "filter" through which water flows.

The system is designed as "offline" of the City's standard storm sewer system. Stormwater treatment and benefits are provided for smaller rainfall events as the capacity of the system allows, and larger rain events that exceed the capacity of the Silva Cells bypass the system.

Water exceeding the capacity of the system will overflow within the retrofit existing catchbasins through the internal pipe extensions and will discharge through existing storm sewer pipes.

Monitoring Purpose and Objectives

Purpose

The purpose of this study is to evaluate the functionality of the Silva Cell and low impact development bioretention feature at Central Parkway East. The evaluation of functionality will focus on water quality, water quantity and maintenance aspects during the spring-fall seasons from 2015-2018. The monitoring program aims to address the outstanding knowledge gaps and stakeholder objectives identified in CVC's Stormwater Management Monitoring Strategy (2012).

Goals and Objectives

The ***monitoring objectives*** are as follows:

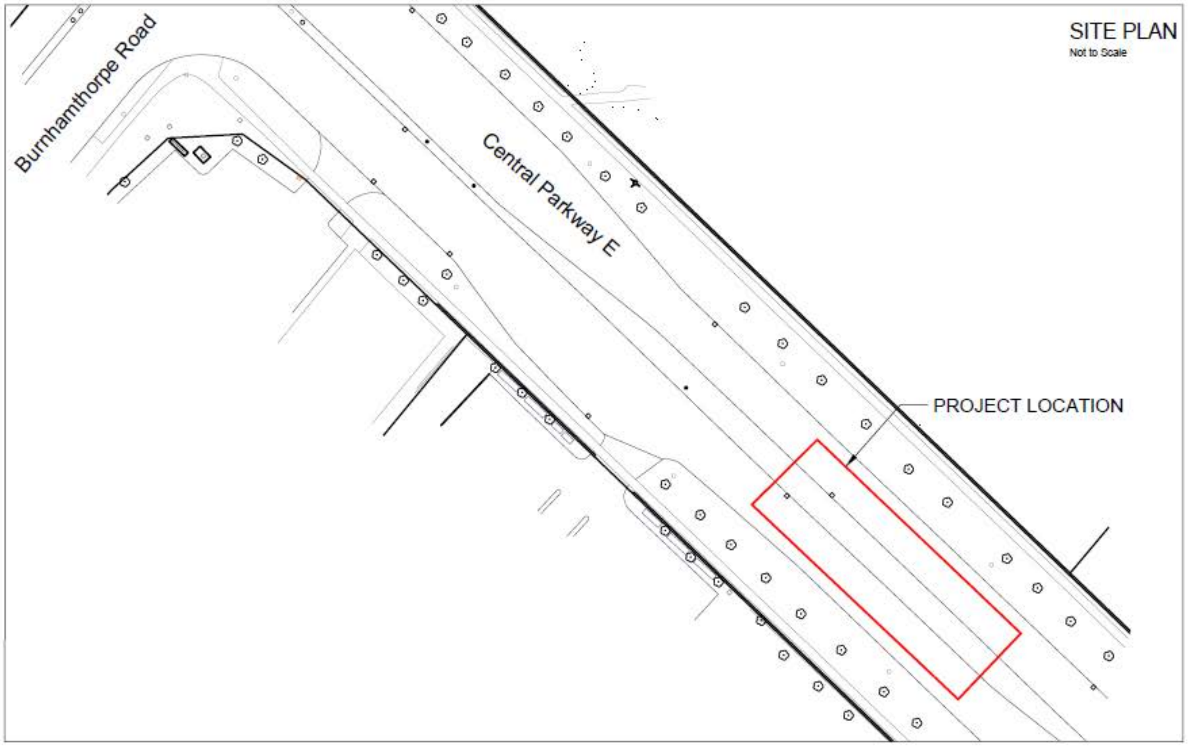
1. Assess the water quality and quantity performance of LID technologies
2. Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance
3. Determine the life cycle costs for the LID practices
4. Demonstrate the degree to which LID mitigates urban thermal impacts on receiving waters

Project Schedule

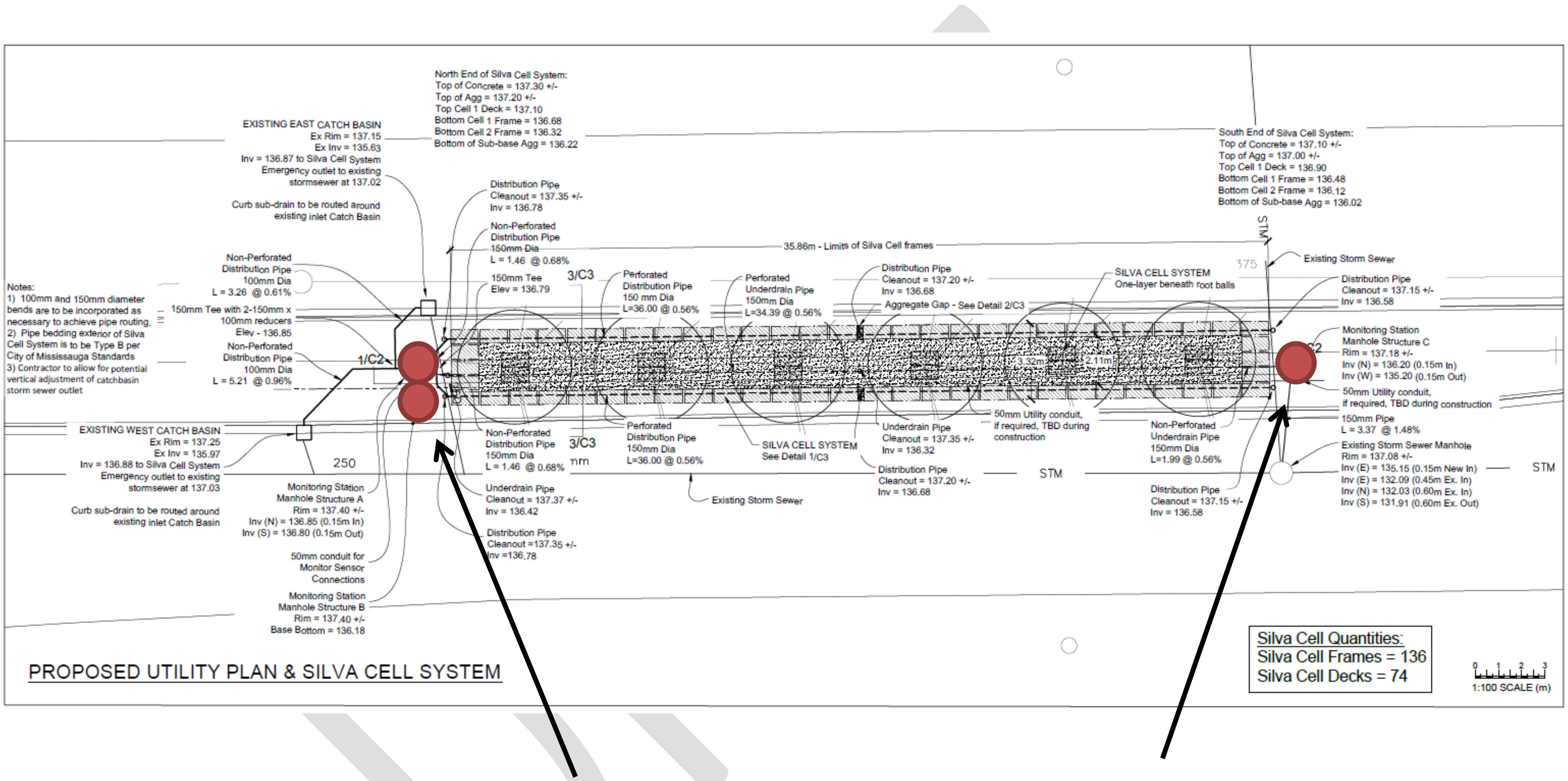
1. Construction of the LID feature and infrastructure – Fall 2014
2. Installation of monitoring infrastructure – Winter 2015
3. Installation of monitoring equipment – Spring 2015
4. Initiation of water quantity monitoring – Spring 2015
5. Initiation of water quality sampling – Spring 2016
6. Final data analysis and reporting – Spring 2019

Study Area

Site Location



Monitoring Locations



CP-1 Inlet monitoring location with water quality and quantity (one chamber houses the monitoring equipment)

CP-2 Outlet monitoring location with water quality and quantity

Work Plan

Location(s)	Objective(s)	What will be monitored	Frequency	Equipment (How)

Stormwater Quantity Monitoring
1. CP-1 Inlet
2. CP-2 Outlet
	#1	• Flow and level
		  o Flow reduction/control
		  o Peak flow reduction
			• Continuous logging at 5 minute intervals
			• Site visits bi-weekly for calibration
				• ISCO 2150 Area/Velocity logger and pressure transducer in conjunction with v-notch weirs
				• Water meter to calibrate levels

Monitoring Wells 1. Within bioswale	#1	Continuous soil infiltration and ponding	• Continuous logging at 5 minute intervals (spring-fall) • Data downloaded once per month (spring-fall)	• Hobo level loggers installed in shallow and deep wells at two locations along the bioswale (1 deep and 1 shallow well) • One barometric pressure logger for compensation

Catch Basin Level Monitoring
1. East catch basin
2. West catch basin
	#1	• Water level in catch basins relative to:
		  o LID inlet pipes
		  o Municipal overflow pipes
			• Continuous logging at 5 minute intervals (spring-fall)
			• Data downloaded once per month (spring-fall)
				• Hobo level loggers

Stormwater Quality Monitoring
1. CP-1 Inlet
2. CP-2 Outlet
	#1	• Chloride
		• Conductivity
		• pH
		• Total Suspended Solids (TSS)
		• Nutrients:
		  o Total Phosphorus
		  o Total Ammonia
		  o Nitrate and Nitrite
		• Metals
		• PAH (only in the first year of sampling)
			• 15 flow-weighted samples per year for each station starting in year 2 of monitoring
			• Sampled events will be = or > 5mm
				• ISCO 6712 autosamplers and associated parts and equipment (batteries, tubing etc.)
				• Samples to be submitted to an accredited lab for analysis
				• Lab sample containers and associated equipment

Meteorological Monitoring 1. Mississauga Valley (STN 06) rain gauge from the City of Mississauga Precipitation Network 2. CVC's Elm Drive meteorological station (located at 100 Elm Drive)	#1	• Precipitation (Mississauga Valley gauge) • Air temperature (Elm Drive meteorological station)	Continuous precipitation and air temperature data recorded at 5 min interval	Heated rain gauge with 12v battery charged by a solar panel
Soil Quality Sampling 1. Composite samples (2) within bioswale	#2	Pollutant removal quantities	Once every other year in the fall	Lab sample containers
Thermal Reduction Monitoring 1. CP-1 Inlet 2. CP-2 Outlet	#4	Stormwater temperature	Continuous temperature loggers recording at 5 minute intervals	• Hobo pendant temperature loggers • Spare batteries
Maintenance Inspection 1. Drainage area, inlets, outlets, facility	#2	• Site conditions • Maintenance needs, tasks and costs	• Each site visit or when maintenance is completed • Fill out inspection checklist monthly • Annual reviews with municipal staff	Inspection checklists and legend, camera

Location(s)	Objective(s)	What will be monitored	Frequency	Equipment (How)
2. Double ring infiltrometer tests (2 in bioswale)		Soil infiltration	Annually	• Double ring infiltrometer • Stop watch • Source of water • Buckets • Graduated cylinder
Overall Project	#3	Track costs throughout lifecycle: • Design • Pre-construction • Construction • Maintenance • Rehabilitation • Disposal	As needed during the duration of monitoring. Expected costs outside of the monitoring timeframe will be estimated using the TRCA life cycle assessment tool.	Staff time

Overview of Monitoring Components

Hydrology

V-notch weirs will be installed in the monitoring manhole structures to ensure accurate (+/- 3mm) level and flow measurements. An area velocity level and flow meter will be installed and set to record water level and flow at 5-minute intervals. A rain gauge installed nearby will supply precipitation data.

Level probes will be calibrated weekly using measured datum points and water level tapes to measure water level behind the weir. A lab-generated rating curve will be used to calculate flows from collected level data.

The Simple Method in conjunction with measured flows at the inlet location will be utilised to evaluate data and determine the water balance of the site, as well as evaluate the overall retention capability of the LID feature.

Qualitative Observations

Throughout the monitoring program, photos will be taken at consistent locations at regular intervals to track seasonal and long-term variations. In addition, CVC staff will visit the site throughout the monitoring program during a variety of precipitation events in order to record videos of flows into and out of the LID median. This type of information will provide insight into the functioning of the system during various sizes of rain events.

Water Quality

A minimum of 15 precipitation events will be sampled per year from the monitoring manhole structures with the Isco autosampler. A wet event will be defined as any rainfall event greater than 2 mm or snowfall event greater than 5 cm. Events greater than 5 mm will be considered for sample collection.

Samples will be analysed for:

- Chloride
- Conductivity
- pH
- Total Suspended Solids (TSS)
- Nutrients:
  - Total Phosphorus
  - Total Ammonia
  - Nitrate & Nitrite
- Metals
- PAH (only in the first year of sampling)

The autosampler holds twenty-four (24) one (1) litre bottles. Event sampling will be conducted as follows:

- One (1) sample will be submitted per monitoring station per event.
- The 24 bottles will be filled 500 mL every 10 minutes. Therefore, 1 bottle will be filled every 20 minutes and the program will last for 8 hours. The 24 bottles will then be mixed into 1 flow weighted composite sample and submitted for analysis.

- Samples will be brought to an accredited Canadian Laboratory such as the MOECC Laboratory Services Branch in Etobicoke or Maxxam Analytics in Mississauga for laboratory analysis.

Figure 3: Example of the monitoring equipment that is used in the catchbasin

Meteorological Monitoring

A City of Mississauga rain gauge, located approximately 200 m from the site, will be used for precipitation data. Data will be recorded downloaded in 5 minute intervals. Data from this gauge will be compared to other nearby gauges for QA/QC purposes, and any significant differences will be evaluated using measured flow data and information from the Toronto-Pearson Environment Canada meteorological station. An air temperature logger at the Elm Drive demonstration site, approximately 1.5 km from the site will be used for air temperature data.

Water Temperature Monitoring

Water temperature information will be collected using Hobo pendant temperature loggers, tied to strings and deployed in the inlet and outlet monitoring locations. Loggers will record continuously, but data will be post-processed to focus on water temperature during precipitation events. Water temperature monitoring will be isolated to the spring-fall seasons in order to capture temperatures during the warmest times of the year.

Information regarding contributing surface temperatures will be collected through occasional use of a thermal imaging camera.

Continuous Soil Infiltration and Ponding

In order to measure infiltration/detention rates in bioretention media, piezometers and pressure transducers will be used to monitor depth of water within the bioretention practice as well as on the surface.

The depth of water and infiltration rate through the bioretention practice will be measured using deeper wells that are perforated throughout and installed to the bottom of the bioretention cells.

Ponding depth will be monitored with the installation of shallow wells that are perforated above the surface, but solid below the surface. This allows for the quantification of surface water ponding as well as the duration of ponding. The image below shows a cross section of a bioretention cell with a deep well on the left and a shallow well on the right. Hobo pressure transducers will be deployed in the wells to record continuous levels at 5 minute intervals.

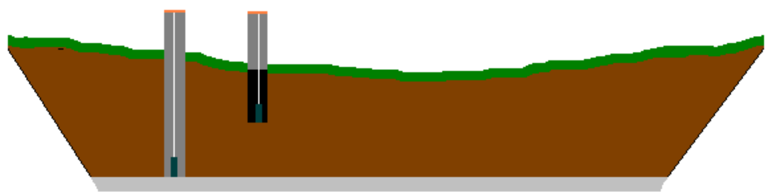


Figure 4: Bioretention cell cross section with monitoring wells

Maintenance Inspections and Records

Long-term infrastructure performance assessment is needed (both water quality and quantity performance) to capture when a decline in performance occurs and how performance is restored once maintenance work has been completed. Therefore maintenance documentation in concert with long-term performance assessment is required in order to link maintenance activities to changes in performance over time. Some maintenance requirements may only be detectable through long-term performance (i.e. filter media reaching saturation). This information in addition to cost tracking will support effective asset management.

A checklist inspection format will be used to record site conditions and maintenance needs throughout the monitoring program. The same information will be collected each time in the same format, ensuring proper documentation so that it is easier to track changes over time.

In order to document maintenance and the associated costs, CVC staff will evaluate and note maintenance needs during site visits and coordinate with those responsible for performing maintenance. CVC staff will then follow up with those responsible to gather associated records and costs. Once a year CVC staff will interview municipal staff to collect maintenance records, costs and information on recurring maintenance issues.

The table below outlines the type of information that will be collected and the frequency:

Activity	When to be Completed

Take photos from reference locations at the site.	When an inspection checklist is completed (biweekly in the spring, summer, and fall, monthly in winter) and before and after maintenance.
Keep logs of site visits, inspections and maintenance dates, activities performed, observations and associated costs.	Each visit or when maintenance is performed.
Look for common issues and maintenance tasks associated with LID such as trash accumulation, sediment deposition, erosion, and vegetation health to watch for changes over time.	Each visit
Inspect different areas of the LID feature such as the drainage area, inlets, outlets, and vegetation, to ensure nothing is overlooked and that the site can perform optimally.	When an inspection list is completed.
Outline any maintenance issues that need to be addressed and whether they are urgent or routine so that the appropriate actions can take place.	When an inspection list is completed.

Infiltration Testing

The infiltration rate of the bioswale soil media will be measured using a double ring infiltrometer outlined under the ASTM standard designation D3385-09. The double-ring infiltrometer method consists of driving two open cylinders, one inside the other, into the ground, partially filling the rings with water or other liquid, and then maintaining the liquid at a constant level. The test is used to find the maximum steady state or average infiltration rate. These tests will be conducted right after construction to set a baseline infiltration rate.

Tests will be conducted once per year during growing season months to monitor infiltration in dry conditions and twice during winter months to evaluate infiltration rates during the winter.

Figure 5: Double ring infiltrometer used to measure infiltration rate in a bioswale

Soil Sampling

Soil sampling will be conducted for the analysis of soil quality for contaminant tracking. Sampling will be conducted every other year in the fall after summer precipitation events but prior to the ground freezing. Soil (filter media) sampling will be conducted at two depths.

Two composite soil samples will be collected from the planter, at shallow and deep depths. The shallow and deep samples will be collected at approximately 10 cm and 30 cm below the filter media surface. In the planter, three subsamples from each depth will be combined to produce one composite sample. Samples will be submitted to an accredited lab for analysis of metals, nutrients and PAHs.

Comparison between two sampling depths provides information regarding the depth at which pollutant removal occurs for different parameters. In addition, sampling at two depths helps determine whether or not pollutants are migrating through the soil column over time.

Data Management and Analysis

Data from all locations and loggers will be downloaded at minimum once every 2 weeks and more frequently during rainy periods. Any issues encountered will be dealt with in a timely manner in order to avoid any loss of data records. Initial reviews of the data will be conducted using logger software in the field, while more detailed reviews and QA/QC will be conducted in the office at a minimum of once per month. A discussion outlining CVC's QA/QC process can be found in "Lessons Learned: CVC Stormwater Management and Low Impact Development Monitoring and Performance Assessment Guide" at **bealeader.ca**.

Calibrations will be conducted once per week for level/flow stations, with all remaining calibrations conducted once every 2 weeks.

Microsoft Excel (MS Excel) is the primary tool used for data analysis for this project. Due to the large dataset being generated, data is split into a number of different spreadsheet files to perform the statistical analysis and calculations. A master spreadsheet is used to compile data and ensure that data is not lost when transferring it between users and spreadsheets.

Reporting and Communication

Results will be analysed and reported on at the end of the project period with fact-sheets/bulletins produced annually. Annual fact-sheets/bulletins will include interesting monitoring information/observations with more detailed analyses conducted for the final report. Fact sheets and case studies will provide more regular information to stakeholders and interested parties. Results will also be reported on during conferences and workshops.

The final report will include analysis methodology, results, discussion and recommendations.

Content of discussion will be focused on giving context to the results including:

- The extent of volume and load reductions including the percent of storms not producing runoff and the implications on load reduction.
- Results related to project specific monitoring objectives.
- Water quality result comparison to International BMP DB, NSQD and other jurisdictions.
- Comparison to a site serviced by traditional SWM pond (i.e., no LID).
- How results translate to alleviating pressure on local stormwater infrastructure.
- How results/performance benefit local environment (thermal benefits, water quality improvements etc.).
- Causes of elevated water quality results.
- Rainfall/event volume and or intensity related to performance.
- Water quality discussion focused on load reductions (inlet and outlet comparisons) rather than EMC.
- Overall LID performance compared to design standards

CENTRAL PARKWAY, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix B

Infrastructure Performance and Risk Assessment Protocol

INFRASTRUCTURE PERFORMANCE AND RISK ASSESSMENT PROTOCOL

This section of the document presents the monitoring protocol prepared by CVC. The section also includes information relevant to potential monitoring refinements on the site. This section of the report will evolve as monitoring methods are refined.

1.1 Hydrology

ISCO 2150 area velocity level and flow modules were installed in two monitoring locations: an upstream chamber at the inlet to the Silva Cell system, as well as the outlet downstream of the feature. The level probes are secured to the bottom of each chamber, and measured datum have been added to ensure accurate water level measurements. Each flow meter records water level at 5-minute intervals. In addition, a v-notch weir is installed in each chamber to determine velocity. While water quality monitoring has not yet commenced, both monitoring stations are equipped with ISCO 6712 automatic samplers for collection of water quality samples.

A rain gauge maintained by the City of Mississauga is installed on the roof of the Mississauga Valley Community Centre to provide precipitation data. An additional rain gauge maintained by CVC is located less than 1 km from the monitoring site, at the Adult Education Centre on Elm Drive. This gauge is used as a comparison to ensure data accuracy. A precipitation event is considered to occur when 2 mm or more precipitation is recorded. If more than 6 hours elapse between precipitation and/or flow events, they are considered to be separate events.

1.2 Site Visits

CVC staff visits the site at least once every other week to check battery power, inspect equipment, and make sure the site is operating properly. Data is downloaded in person from each piece of equipment bi-weekly or more frequently using ISCO Flowlink 5 software or equivalent. The software automatically summarizes and plots the data graphically, which is easily exported to a program like Microsoft Excel. During site visits, CVC staff also note any changes that have occurred on the site and any equipment adjustments/maintenance.

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LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix C
Data Management and Analytical Methodology

NOTICE

DATA MANAGEMENT AND ANALYTICAL METHODOLOGY

CVC compiled monitoring data consisting of water level and flow at Central Parkway. The processes for the collection of water level, flow and precipitation data is laid out in **Appendix B**. Provided here is a description on the data management and analysis activities for this site.

1.1 Data Management

The collected site data include time series of precipitation and flow data. Data management includes initial processing and organizing, including identifying the site and reference input data to be analyzed and organization of the site data for event-based analysis.

1.1.1 Input Data Processing and Organization

The data analyses were completed with the Central Parkway monitoring data set collected by CVC. Hydrologic and water quality data dates from August 2015 - September 2015.

The flow and precipitation data were divided into hydrologic events for event-based analyses. Hydrologic events were defined using the time series of both flow and precipitation as defined in **Table 1-1**.

Table 1-1: Hydrologic Event Definition for CVC Data Analyses

Event Type	Beginning	End
Hydrologic Event	Precipitation > 2 mm	Flow *and* Precipitation = 0 for 6 consecutive hours

1.2 Data Analysis

Data analysis involved identifying appropriate evaluation and presentation (graphical) methods, and the data analysis tools and work flow as described in the following sections.

1.2.1 Data Analysis Evaluation Methods

The Central Parkway site was evaluated using event-based analysis, with the event defined as previously indicated in **Table 1-1.** Based on the limited dataset, the site was evaluated for water quantity performance only. Water quality performance will be evaluated moving forward. Unlike most sites, this site was monitored for both inflow and outflow, allowing for a direct comparison between measured runoff and effluent.

While inflows are measured, a comparison to estimated flows can aid in determining if the site is functioning as intended. Because of this, the Simple Method[1] was selected to estimate influent volume as a product of a calculated runoff coefficient, the drainage area, and the event precipitation. Estimated influent volume was compared to actual influent volume and actual effluent volume to evaluate BMP estimated volume reduction. In addition to the Simple Method, a SWMM model[2] was used to compare expected flows with estimations from the Simple Method and monitored inflow.

1 Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments. Washington, DC

2 EPA. (2010). "Storm Water Management Model (SWMM)." Water Supply and Water Resources Division, National Risk Management Research Laboratory, CDM.

Simple Method

The standard method for evaluating stormwater BMPs is to compare untreated inflows to treated outflows. This method is used in comparing both water quality and quantity parameters such as volume reduction, peak flow or contaminate loading. Using water quality and quantity monitoring equipment can be useful for monitoring inflows however; it can be impractical due to possible disruption in the intended design of the practice in diverting runoff into the LID. Additionally, many BMPs have multiple inflow points into the practice making inflow monitoring expensive and complex and may still require some form of flow estimation. In this case, inflow is measured and the Simple Method is used as a basis of comparison with monitored results as well as modelled estimations.

The Simple Method is a spreadsheet based runoff estimation procedure that is used for determining stormwater runoff and pollutant loading for urban areas. The Simple Method determines estimated inflow based on drainage area, amount of precipitation, and a runoff coefficient. This information is used to determine a runoff coefficient[1]. While the Simple Method is typically used to calculate annual runoff, CVC has modified the formula to determine runoff on an event-by-event basis. CVC has also added a BMP component to account for LID areas. Note that the BMP area is not considered in the runoff coefficient calculation since complete infiltration into the practice is assumed for BMP areas.

The drainage area for Central Parkway was obtained from the Drainage Analysis[3]. The catchment area was divided into impervious, pervious and BMP surfaces, which are used in the equation below to determine the runoff coefficient. Precipitation data was obtained from the local rain gauge located at the Mississauga Valley Community Centre, maintained by the City of Mississauga. This data is used with the drainage area to determine event inflow runoff volume. **Table 1-2** present the drainage area and use of the Simple Method at Central Parkway.

The runoff coefficient is defined as:

$$Rv = 0.05 + 0.9 * Ia$$

Where:

Rv is the runoff coefficient

0.9 is the fraction of rainfall events that produce runoff

Ia is the impervious fraction (Impervious Area/Drainage Area to the BMP)

The modified Simple Method formula used is:

Event inflow volume (L): Drainage Area to the BMP (m^2) * Rv + BMP area (m^2) * Event Precipitation (mm)

Note: the BMP area is added since precipitation on the BMP area is considered to fully infiltrate into the practice.

3 Civil Engineering Site Design. 2014. Silva Cell System Improvement Project at Central Parkway East, Mississauga, ON. Drainage Analysis. Revised June 24, 2014.

Table 1-2: Inlet drainage area and application of the Simple Method at Central Parkway

Land Use	**Area (m^2)**
Road (west sub-catchment)	**545**
Road (east sub-catchment)	**501**
Total impervious area	**1,046**
Total drainage area to the BMP (impervious area + pervious area)	**1,046**
Total BMP area	**0**
Ia= impervious fraction (total impervious area/total drainage area to the BMP)	1.00
Rv= 0.05 + 0.9 * Ia	0.95
Total drainage area to the BMP * Rv + total BMP area: Multiply this number by event precipitation (mm) to get event inflow volume (L)	**994**

Note: The BMP area is not added to this estimation of inflow, since this comparison is for inlet only. The inlet does not receive water that falls directly on the surface area of the BMP; water infiltrates through the system laterally from the inlet pipes, rather than top down through the column. The surface area of the BMP would be added if the calculation was estimating the total inflow and direct precipitation on the BMP to the outlet.

Best results are produced when the method is used for smaller catchments at a development site scale. Additionally, the Simple Method only provides estimates for the storm event itself and does not consider pollutant contribution from baseflow generated within the catchment[4]. Lastly, the Simple Method can overestimate inflow volume for smaller events where rainfall depths would be used up by catchment wetting and surface depression storage. This occurs because the Simple Method applies the same runoff coefficient to storms of all magnitudes.

SWMM Model

A hydrologic model was developed for Central Parkway and was used to estimate inflow for events from August-September 2015. The model was developed using US EPA SWMM 5, a widely used and publicly available model. The model setup divided the Central Parkway site into two sub-catchments, which included the road from the west side of the median, and the road from the east side of the median.

The purpose of setting up a model for this site was to estimate how much runoff is being generated by either sub-catchment, and to compare this to total measured inflow at the site and runoff estimated by the Simple Method. The bioretention system was not modelled as our only concern was inflow into the LID feature, and not what is flowing out of it. Outflow from the east and west sub-catchments was routed to their respective catchbasins. 100 mm pipes convey the runoff from the catchbasins to a manhole which outlets to the bioretention system.

The model was run utilizing available precipitation data from June 2015 to September 2015 at a 5-minute time step. Evaporation was assumed to be a constant 0.6 mm/day. No calibration was done as

4 Centre for Watershed Protection, (2010). Stormwater Management Design Manual. New York State Department of Environmental Conservation. Albany New York

measured inflow had to be verified due to bypass issues on site, as described in the main text of the report.

1.2.2 Data Analysis Presentation Methods

The summary tables include both parametric and non-parametric statistics. Parametric statistics operate under the assumption that data arise from a single theoretical statistical distribution that can be described mathematically using coefficients, or parameters, of that distribution. The mean and standard deviation are example parameters of the normal, or Gaussian, distribution. Non-parametric statistics, including the median, are fundamentally based on the ranks[5] of the data with no need to assume an underlying distribution. Non-parametric statistics do not depend on the magnitude of the data and are therefore resistant to the occurrence of a few extreme values (i.e., high or low values relative to other data points do not significantly alter the statistic).[6]

1.2.3 Data Analysis

Most of the data analysis was done using Microsoft Excel. Total influent volumes due to rainfall were measured on site, as well as estimated from a storm event's total precipitation by using the Simple Method as discussed in **Section 1.2.1 Data Analysis Evaluation Methods**. Volume reductions were then computed as the difference between the measured influent volumes and measured effluent volumes. Hydrologic lag times were then computed using the peak of precipitation hyetograph to the peak of effluent event hydrograph. Influent loads are calculated using the estimated influent EMC multiplied by the influent volume.

1.3 Table and Figure Definitions

Definitions for information found in the tables and figures presented in this report are included below for guidance.

Tables include a combination of the following results, listed in alphabetical order:

- *Antecedent Dry Period* - The amount of time with no rain or flow preceding the event.
- *Effluent EMC* - The event mean concentration of the effluent for the event.
- *Estimated Pollutant Load Reduction* - The estimated mass of a pollutant passing through the BMP; what has been removed from the system.
- *Estimated Total Influent Load* - The estimated total pollutant load carried by influent for the event, as calculated by multiplying the Estimated Total Influent Volume by the NSQD Residential EMC.
- *Estimated Total Influent Volume* - The estimated total volume of influent for the event based on an application of the Simple Method with the measured rainfall depth.
- *Estimated Volume Reduction* - The estimated amount of volume removed as calculated by the difference between the Estimated Total Influent Volume and the Total Effluent Volume.
- *Event Duration* - The total length of time for the event.
- *Lag Time* - The time as calculated from the peak of precipitation event hyetograph to the peak of effluent event hydrograph.

5 In this context, ranks refer to the positions of the data after being sorted by magnitude.

6 Helsel, D.R. and R. M. Hirsch, 2002. Statistical Methods in Water Resources Techniques of Water Resources Investigations, Book 4, chapter A3. U.S. Geological Survey. 522 pages.

- *Peak Effluent Flow* - The maximum effluent flow rate for the event based on measured effluent.
- *Peak Precipitation Intensity* - The maximum rate of precipitation for the event.
- *Sample Date* - The date the water quality sample was collected.
- *Storm Date* - The start date of the hydrologic event.
- *Total Effluent Load* - The total pollutant load carried by the effluent out of the BMP for the event, as calculated by multiplying the Total Effluent Volume by the Effluent EMC.
- *Total Effluent Volume* - The total measured volume effluent for the event.
- *Total Precipitation* - The total depth of rainfall for the event.
- *WQ Guideline* - The applicable PWQO or CCME water quality guideline for the pollutant.

Hydrologic Summary Figures presented in this report include the following results:

- *Flow* - The rate of flow for the estimated influent hydrograph and measured effluent hydrograph with corresponding flow rates increasing upwards along the left chart axis.
- *10-min Precipitation Depth* - The depth of precipitation per 10-minute intervals with corresponding depths increasing downward along the right chart axis.

Tables and Comparative BMP Box Plots include the following BMPs represented in the BMPDB:

- *Bioretention* - Vegetated, shallow depressions used to temporarily store stormwater prior to infiltration, evapotranspiration, or discharge via an underdrain or surface outlet structure. Treatment is achieved through filtration, sedimentation, sorption, infiltration, biochemical processes and plant uptake.
- *Detention Basin* (a.k.a. Dry Pond) - Grass-lined basins that, while fully drainable between storm events, temporarily detain water through outlet controls to reduce peak stormwater runoff release rates and provide sedimentation treatment. Volume losses and load reductions through infiltration may also be significant.
- *Green Roof* - Vegetated roofs that provide stormwater treatment via filtration, sorption, biochemical processes and plant uptake.
- *Biofilter* - Vegetated swales or strips that provide treatment via filtration, sedimentation, infiltration, biochemical processes and plant uptake.
- *LID* - low-impact development (LID) monitored at a site-scale basis; green infrastructure.
- *Manufactured Device* - Devices that are designed to provide various treatment processes such as sedimentation, skimming, filtration, sorption, and disinfection. Treatment process subcategories within the BMPDP include biological filtration, filtration, inlet insert, multi-process, physical (with volume control), physical (manufactured device), and oil/grit separators. The last two treatment process subcategories, which are of primary interest to CVC, are further described below:
    - Physical (manufactured device) are hydrodynamic devices that provide treatment via settling and includes proprietary devices like Stormceptors®. A performance summary[7] found statistically significant reductions for Zn and TP for physical (manufactured device) treatment processes. It was hypothesized that TSS results, showing no significant reductions, were affected by unusually low influent TSS concentrations.

7 Leisenring, M., Clary, J., Hobson, P. 2012. International Stormwater Best Management Practices (BMP) Database, Manufactured Devices Performance Summary. Prepared by Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. July.

  - Oil/grit separators are designed for removing floatables and coarse solids. The performance summary found statistically significant reductions for only TSS for oil/grit separators treatment processes.

- *Media Filter* - A constructed bed of filtration media that receives water at the surface and allows it to pond on the surface if inflows exceed the rate of percolation through the bed. Outflow from the media bed can be through underdrains or infiltration. Depending on the media used, treatment is provided via filtration, sorption, precipitation, ion exchange and biochemical processes.
- *Porous Pavement* - Pavement that allows for infiltration through surface void spaces into underlying material. Subcategories of porous pavement include modular block, pervious concrete, porous aggregate, porous asphalt, and porous turf. Treatment is provided via infiltration, filtration, sorption, and biodegradation.
- *Retention Pond* (a.k.a. Wet Pond) - Basins that feature a permanent pool of water (dead storage) below flood control (live storage) that is outlet controlled. Treatment is provided primarily through sedimentation; other treatment processes may include sorption and biochemical processes.
- *Wetland Basin* - Shallow basins typically designed with inflow energy dissipation and variable depths and vegetation types to promote interactions between runoff, aquatic vegetation, and wetland soils. Treatment is provided via sedimentation, sorption, biochemical processes, coagulation, flocculation, plant uptake and microbial transformations.
- *Wetland Channel* - Densely vegetated waterways used to treat and convey runoff. Treatment is provided via filtration, sedimentation, microbial transformations and plant uptake.

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LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix D

Data Analysis Summaries

1 RAINFALL EVENTS ANALYSIS

Table D-1: Summary of Rainfall Events

Starting Date and Time	Ending Date and Time	Event Duration (hrs)	Precipitation Depth (mm)
2015/08/10 12:05	2015/08/11 10:15	22	28.8
2015/08/14 05:30	2015/08/14 10:40	5	2.0
2015/08/19 22:05	2015/08/20 00:40	3	4.4
2015/08/20 09:05	2015/08/20 13:45	5	10.8
2015/09/09 07:25	2015/09/09 10:10	3	6.4
2015/09/11 18:50	2015/09/14 8:50	62	31.0
2015/09/19 14:05	2015/09/19 16:35	3	8.6
2015/09/29 12:25	2015/09/29 19:50	7	26.6

2 HYDROLOGIC ANALYSIS

Table D-2: Hydrologic Summary of Rainfall Events

Starting Date and Time	Antecedent Dry Period (Days)	Total Inflow Volume (L)	Peak Inflow (L/s)	Total Outflow Volume (L)	Peak Outflow (L/s)	Peak Reduction (%)	Estimated Volume Reduction	
							(L)	(%)
2015/08/10 12:05	5.67	17739.2	5.52	2975.0	1.36	75%	14764.2	83%
2015/08/14 05:30	2.8	100.03	0.05	0.00	0.00	100%	100.0	100%
2015/08/19 22:05	5.5	2518.9	5.43	0.00	0.00	100%	2518.9	100%
2015/08/20 09:05	0.4	5981.1	7.88	246.7	0.28	97%	5734.4	96%
2015/09/09 07:25	19.7	2442.8	1.59	0.00	0.00	100%	2442.8	100%
2015/09/11 18:50	2.4	12481.7	1.18	372.2	0.01	100%	12109.5	97%
2015/09/19 14:05	5.2	4487.2	4.09	0.00	0.00	100%	4487.2	100%
2015/09/29 12:25	9.8	10251.6	2.84	104.4	0.05	98%	10147.3	99%

CENTRAL PARKWAY, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix D
Site Maintenance and Inspection Logs

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1 BIORETENTION MAINTENANCE

A brief description of maintenance activities for Central Parkway is provided along with the inspection log used by CVC monitoring staff for site inspections.

The primary maintenance objective for bioretention practices is to keep vegetation healthy, remove sediments and trash, and ensure that the facility is draining properly. The growing medium may need to be replaced eventually to maintain performance. Typical recommended maintenance activities for bioretention cells include the following[1]:

- Inspect the infiltrating surface at least twice annually following precipitation events to determine if the bioretention area is providing acceptable infiltration. If standing water persists for more than 24 hours after runoff has ceased, clogging should be further investigated and remedied. Additionally, check for erosion and repair as necessary.
- Remove debris and litter from the infiltrating surface to minimize clogging of the media. Remove debris and litter from the overflow structure.
- Maintain healthy, weed-free vegetation. Weeds should be removed before they flower. The frequency of weeding will depend on the planting scheme and cover. When the growing media is covered with mulch or densely vegetated, less frequent weeding will be required.
- Replace mulch (wood recommended) only when needed to maintain a mulch depth of up to approximately 75 mm.
- If ponded water is observed in a bioretention cell more than 24 hours after the end of a runoff event, check underdrain outfall locations and clean-outs for blockages. Maintenance activities to restore infiltration capacity of bioretention facilities will vary with the degree and nature of the clogging.
    - If clogging is primarily related to sediment accumulation on the filter surface, infiltration may be improved by removing excess accumulated sediment and scarifying the surface of the filter with a rake.

If the clogging is due to migration of sediments deeper into the pore spaces of the media, removal, safe disposal and replacement of all or a portion of the media may be required. The frequency of media replacement will depend on site-specific pollutant loading characteristics. Since bioretention technologies have only recently seen more widespread application, the frequency of media replacement has not yet been well established. Although surface clogging of the media is expected over time, established root systems promote infiltration. This means that mature vegetation that covers the filter surface should increase the life span of the growing media, serving to promote infiltration even as the media surface clogs.

2 DOCUMENTATION OF MAINTENANCE ACTIVITIES AND COSTS

Because of the significance of maintenance over the life of a facility, in terms of performance, appearance and cost, and the fact that documentation of actual maintenance costs for bioretention facilities is lacking in the region (and across most of North America), documentation of maintenance is a critical component of the stormwater monitoring that is being conducted at Central Parkway. To document maintenance, CVC will evaluate and note maintenance needs during site visits and will coordinate with those

1 Urban Drainage and Flood Control District (UDFCD). 2010. Urban Storm Drainage Criteria Manual, Volume 3.

responsible for performing maintenance and repair to maintain a record of maintenance activities and costs. The following data collection efforts will aid in characterizing maintenance requirements and costs:

- Take photos from reference locations at the site every time an inspection checklist is completed (biweekly in the spring, summer, and fall, monthly in winter) and before and after maintenance.
- Keep logs of site visits, inspections and maintenance dates, activities performed, observations and associated costs.
- Look for common issues and maintenance tasks associated with LID such as trash accumulation, sediment deposition, erosion, and vegetation health to watch for changes over time.
- Inspect different areas of the LID feature such as the drainage area, inlets, outlets, and vegetation, to ensure nothing is overlooked and that the site can perform optimally.
- Outline any maintenance issues that need to be addressed and whether they are urgent or routine so that the appropriate actions can take place.
- Monitor the duration of standing water in the bioswales periodically. As the duration of standing water grows longer, it will be a sign that infiltration capacity is reduced and maintenance may be needed.

3 SITE INSPECTION LOG

Below is the checklist template used by monitoring staff to note maintenance needs during routine site visits. A photo log is also kept to supplement this information.

LID Inspection Checklist

Site: Central Parkway

Inspector: ______________________________

Date: __________________________________

Site Characteristics:

Central Parkway Silva Cells	
Drainage Area	Road
Soil Media	Engineered bioretention mix
Pre-treatment	None
Hydraulic Configuration	Online
Inlet Type	Catch basins

		Category:	Notes:
Contributing Drainage Area:			
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
Inlets:			
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		

% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +		
Structural damage?	Yes or No		
Is inlet clear and able to accept incoming flow?	Yes or No		
Facility:			
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
Evidence of Ponding	Yes or No		
% of Area Ponding	0% --- 5% --- 10% --- 15% --- 20% +		
Approximate Depth of Ponding	________________________		
% of Bare/Exposed Soil	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +		
Permeable Pavement:			
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
Structural damage?	Yes or No		
Area of broken/cracked/ heaving pavers or curbs?	0% --- 5% --- 10% --- 15% --- 20% +		
Evidence of Clogging	Yes or No		
Outlet:			
% of Trash/Debris Present	0% --- 5% --- 10% --- 15% --- 20% +		
% of Erosion	0% --- 5% --- 10% --- 15% --- 20% +		
% of Sediment Accumulation	0% --- 5% --- 10% --- 15% --- 20% +		
Structural damage?	Yes or No		
Is outlet clear and able to accept overflow?	Yes or No		
Non-LID Feature:			
Sign on Site	Yes or No		
Damage to Sign	Yes or No		
Vegetation (changes seasonally):			

% Vegetation Cover	0% --- 5% --- 10% --- 15% --- 20% +		
% Dead Vegetation	0% --- 5% --- 10% --- 15% --- 20% +		
% of Invasives/Weeds	0% --- 5% --- 10% --- 15% --- 20% +		
Winter Conditions:			
% Snow Cover	0% --- 5% --- 10% --- 15% --- 20% +		
Approximate Depth of Snow	______________________		
Maintenance:			
Is maintenance required?	Yes or No		
What needs to be done?	______________________		
How much time was spent on maintenance?	______________________		
Regular maintenance, long-term maintenance or emergency maintenance?	______________________		
Who is responsible?	______________________		
How often is regular maintenance done?	______________________		

Photos:

Number of Photo	Description/Notes

Site Comments:

CENTRAL PARKWAY, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK MANAGEMENT ASSESSMENT

Appendix E

Intensification of Urban Water Cycle

NOTICE

1 INTENSIFICATION OF URBAN WATER CYCLE

It is expected that the population of the Greater Toronto Area (GTA) will grow from 6.4 million in 2012 to 8.9 million by 2036[1]. This ongoing urbanization of our environment by increasing imperviousness results in a phenomenon commonly known as the "urban stream syndrome"[2], where hydrographs become flashier (i.e., increased flow variability), baseflow decline, water quality is degraded, stream channels are eroded, water temperatures rise, and biological richness declines. **Figure 1** shows a hydrograph comparing stream flow rates before, during, and after a storm under pre- and post-development conditions[3]. As indicated, streams with developed watersheds have substantially higher peak flows, and these peak flows occur more quickly than under predevelopment conditions. This is reflective of typical urban conditions, where runoff moves quickly over impervious surfaces and drains into a channel.

Impervious surfaces such as streets, sidewalks and driveways contribute 65-75% of total loadings of suspended solids, total phosphorus, and metals to our receiving streams and lakes (Bannerman et al., 1992). Furthermore, beach closures and reductions in recreational fishing due to pollutant loading from urban stormwater and have resulted in up to $87 million a year in lost revenue to local economies (Marbek, 2010).

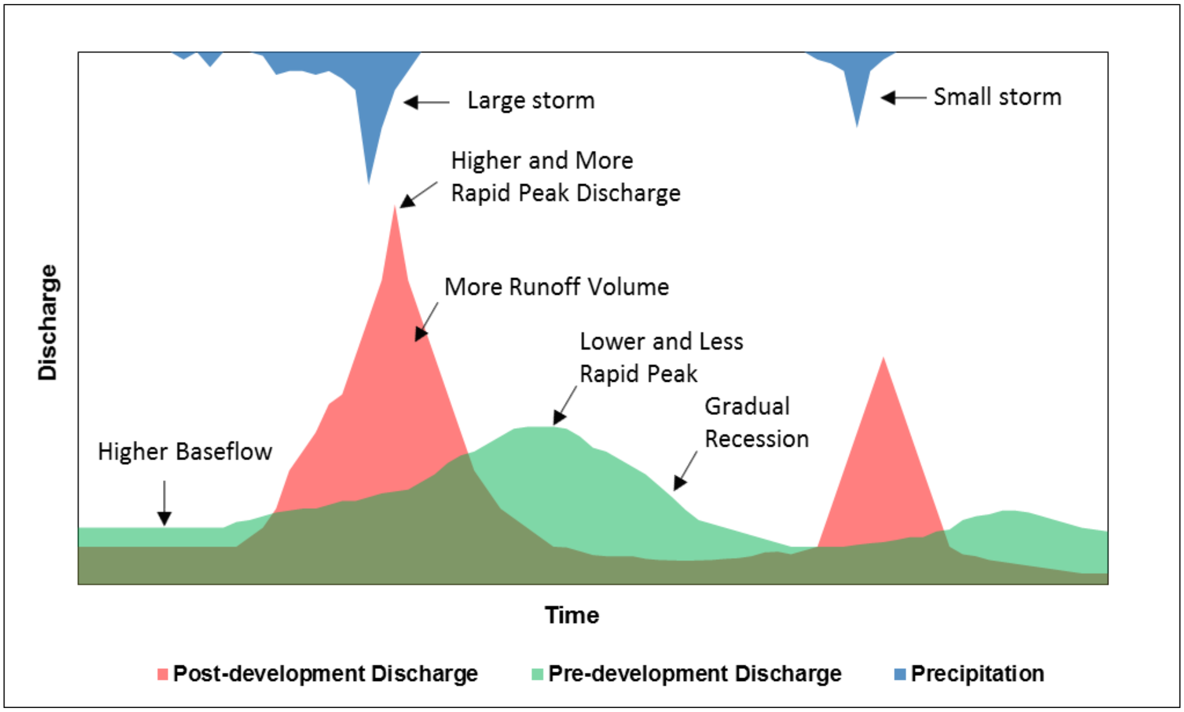

Figure 1: Changes in stream flow hydrograph as a result of urbanization (adapted from Schueler, 1987)

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[1] Ministry of Finance (MOF). 2013. Ontario Population Projections Update. http://www.fin.gov.on.ca/en/economy/demographics/projections/projections2012-2036.pdf

[2] Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP II. 2005. The urban stream syndrome: Current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3):706-723

[3] Schueler, T. 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices. Metropolitan Washington Council of Governments, Washington, DC.

This ongoing urbanization of our environment by increasing imperviousness also corresponds to a significant alteration to the water cycle. Continued development with structured conveyance and impervious pathways redistributes the water budget to favour runoff over evaporation, infiltration, and recharge for streams and groundwater. The figures below illustrate how four important components in the water cycle are affected by increasing levels of imperviousness[4].

In natural and rural environments with vegetated soils, surface runoff is generally low and represents a low fraction (10 to 20%) of the total fallen precipitation[5]. Water either percolates into the ground or is returned to the atmosphere by evaporation and transpiration. A considerable percentage of the rainfall infiltrates into the soil and contributes to the groundwater. The local water table is often connected to nearby streams, providing seepage to streams and wetlands during dry periods and maintaining base flow essential to the biological and habitat integrity of streams. Water that is evaporated into the atmosphere behaves like an air conditioner for the urban atmosphere, thereby more water in the atmosphere reduces the urban heat island effect, mitigating high air temperatures (**Figure 2a).**

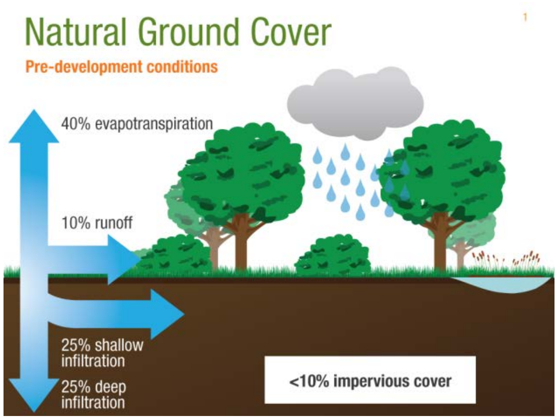

Figure 2a: Hydrologic Cycle: Natural ground cover Predevelopment Conditions*

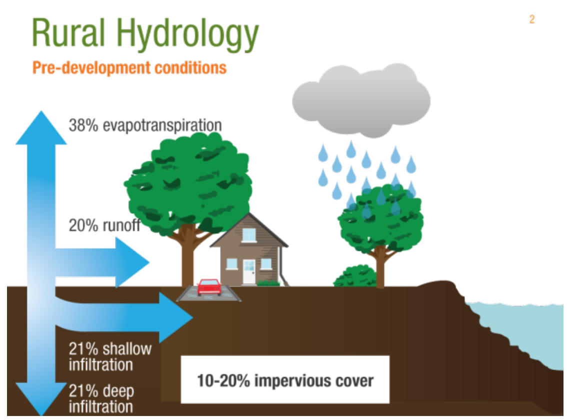

Figure 2b: Hydrologic Cycle: 10-20% Impervious - cover - Predevelopment Conditions

(Adapted from FIRSWG, 1998)

Land development converts permeable land into increasing impermeable surfaces. During urbanization, natural channels are replaced by artificial drainage pipes and channels that decrease the amount of water infiltration and storage within the soil column. This alters the hydrologic regime by allowing less rainfall infiltration into the ground, and more channeled runoff through the urban infrastructure**.** Alterations to site runoff characteristics can cause an increase in the volume and frequency of runoff flows (discharge), velocities that cause flooding, and accelerated erosion **(Figure 3a)**. This also decreases the amount of water available for evapotranspiration and infiltration. Evaporation decreases because there is less time for it to occur when runoff moves quickly off impervious surfaces. Transpiration decreases because vegetation has been removed. In addition, urban infrastructure removes water from shallow ponds and wetlands that could have otherwise been used to replenish the water table and maintain low flow conditions in local watercourses. Headwater streams, with small contributing drainage areas, are especially sensitive to localized changes in groundwater recharge and base flow.

[4] Adapted from Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream CorridorRestoration: Principles, Processes, and Practices. PB98-158348LUW.

[5] Prince George's County, Maryland Department of Environmental Resources Programs and Planning Division. 1999. Low-Impact Development Hydrologic Analysis

As a much larger percentage of rainwater hits impervious surfaces including roofs, sidewalks, parking lots, driveways, and streets, it must be controlled through storm water management techniques. Traditional approaches have focused on collection and conveyance to quickly transport stormwater to the nearest watercourse to prevent property damage (**Figure 3a**). Current stormwater management has taken an "end of pipe" approach, using gutters and piping systems to carry rainwater into ponds or detention basins **(Figure 3b)**. This approach does not mitigate or alter the runoff volume component of the water cycle which is the driving force over flood risk and drought due to decreases in subsurface flows.

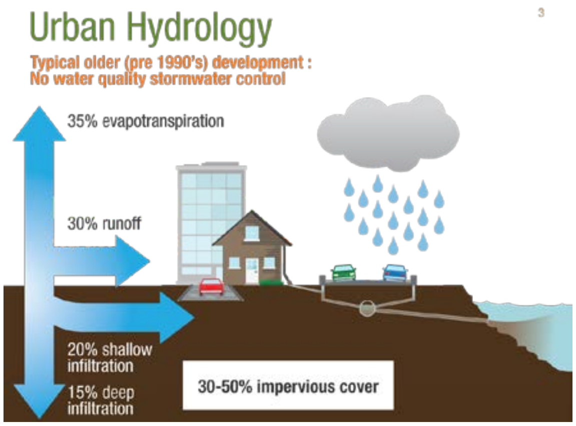

Figure 3a: Stormwater Management with no water quality control

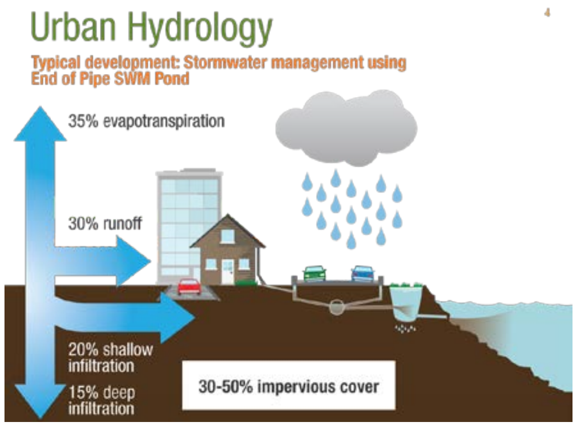

Figure 3b: Stormwater management using SWM ponds.

(Adapted from FIRSWG, 1998)

Urban areas are particularly susceptible to flooding due to a high concentration of impervious surfaces that channel precipitation runoff into the city's underground infrastructure. During rainfall events of high intensity, duration and/or frequency, the runoff component of the water balance will be overwhelmed and not mitigated by infiltration, creating flood-prone areas in urbanized zones (**Figure 4**).

Figure 4: Flood prone area in Cooksville Creek watershed

As part of adaptive management, stormwater management has evolved over time in Ontario, from flood control requirements in the 1970s, to water quality and erosion requirements in the 1980s, to water balance requirements in 2012. The cost and complexity of these engineered systems has increased. In light of the current spot light on climate change and aging infrastructure there is growing awareness that stormwater management has become more than just treating a storm event it's also about maintaining stream flows during dry weather periods for wastewater assimilation, fisheries, and water takings. Through the Great Lakes Protection Act, Water Opportunities Act and Redside Dace legislation, stormwater is being recognized as a resource to be treated at source, conveyance and prior to entering waterways.

A robust stormwater management system that meets all environmental and economic goals must include both conventional stormwater management facilities and source based Low Impact Development (LID) practices. Conventional facilities are typically effective at achieving flood control by providing large volumes of stormwater detention. Conventional facilities however lack the ability to provide water balance benefits or reduce the volume of runoff from heavily urbanized areas. As a result they offer little benefits with respect to infiltration and erosion mitigation. LID practices excel where conventional systems fail by allowing for natural hydrologic processes including infiltration and evapotranspiration as close to the source as possible.

LID practices are designed to mitigate the rapidly changing water cycle by mimicking nature within the urban environment. LID strategies strive to allow natural infiltration to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, the landscape can retain more of its natural hydrological function (**Figure 5**). Although most effective when implemented on a community-wide basis, using LID practices on a smaller scale can also have a positive impact.

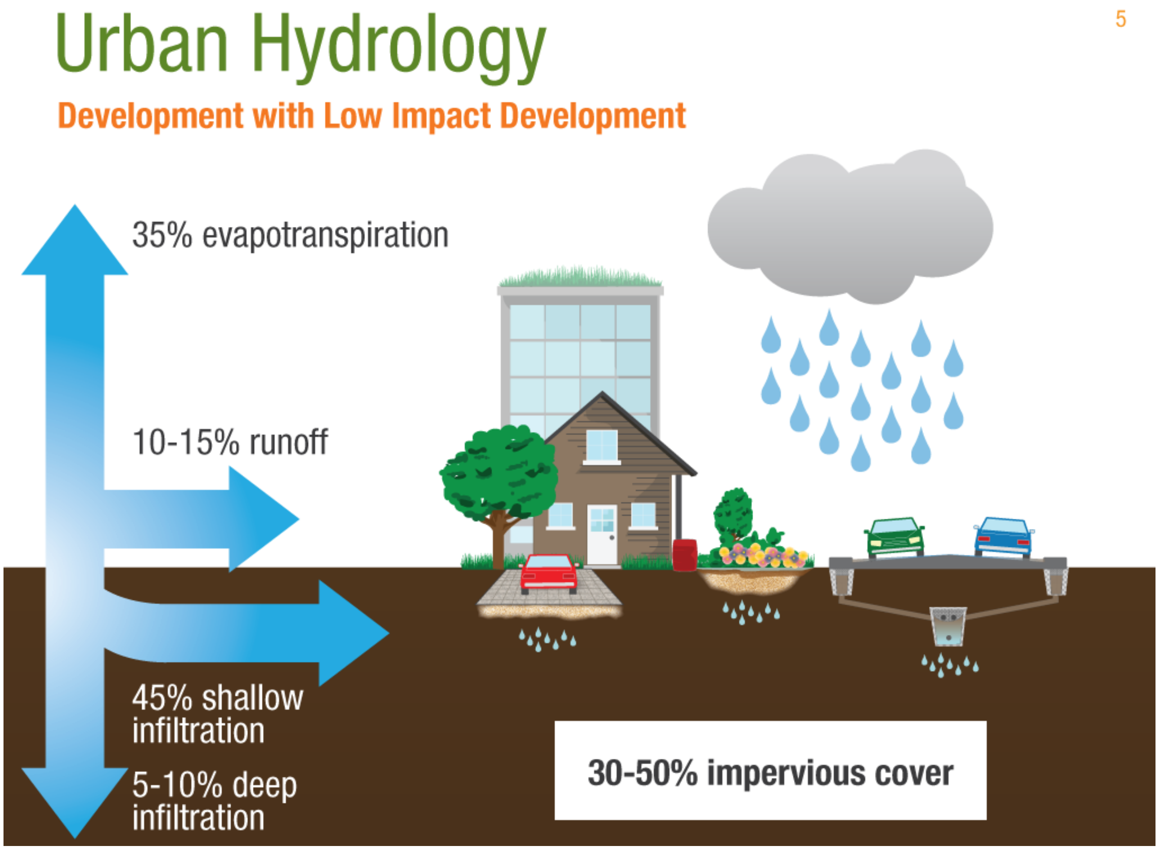

Figure 5: Urban water cycle with Low Impact Development stormwater Management - (Adapted from FIRSWG, 1998)

2 UNEXPECTED CONSEQUENCES OF URBAN DEVELOPMENT

As might be expected, there is a linear relationship between the amount of impervious surfaces in a given area and the amount of runoff generated. What is unexpected is what this means in terms of both the volume of water generated and the rate at which it exits the surface. Depending on the degree of impervious cover, the annual volume of storm water runoff can increase to anywhere from 2 to 16 times the predevelopment amount[6]. Impervious surface coverage as low as 10% can destabilize a stream channel, raise water temperatures, and reduce water quality and biodiversity[7].

This is consistent with monitoring data from the urbanizing subwatershed of Fletchers' Creek which shows increasing trends in peak flows downstream from developed catchments despite post to pre-development control with conventional SWM facilities such as wet ponds. In fact, the flow of the creek has on average increased by roughly two orders of magnitude despite the adoption of conventional stormwater management (**Figure 6**).

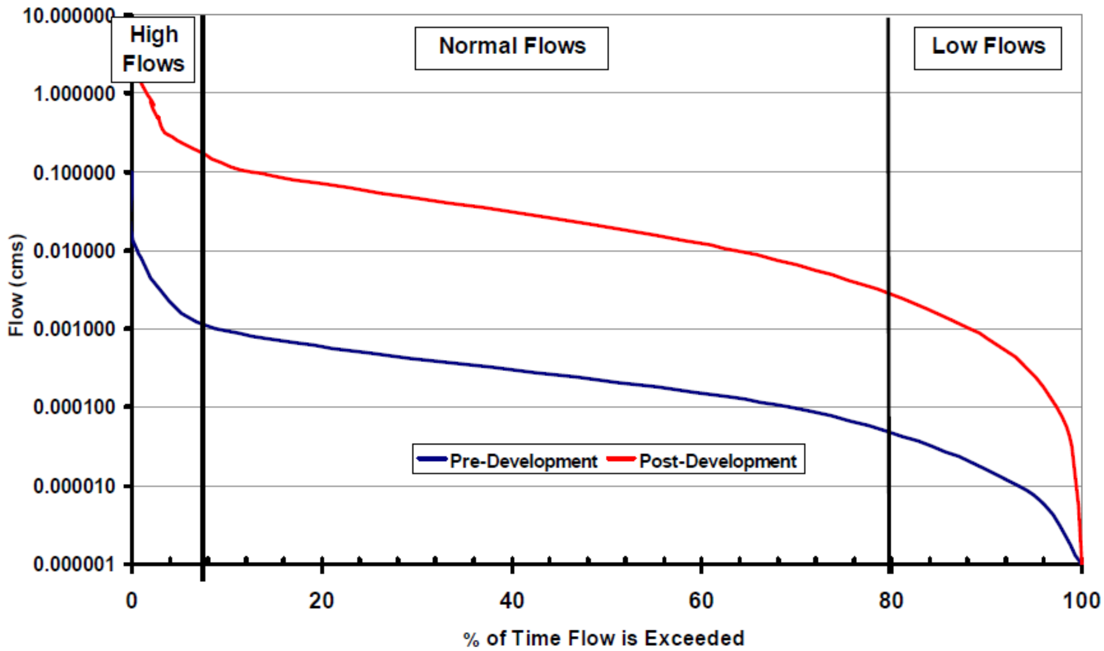

Figure 6: Increasing trends in stream flow pre- and post-construction in Fletchers' Creek

The longer duration of higher flows due to increased volume combines with that from downstream tributaries to increase the downstream peaks. As a result, the portions of Fletchers Creek is experiencing extensive bank slumping and erosion (**Figure 7**).

In a natural setting, typically 6-9 events per year produce runoff that enters the stream. With LID stormwater management, very little to no runoff is produced during precipitation events less than 25 mm in depth, that is 90% of all precipitation events. What this means is that 69% of all the rain to fall will not produce runoff.

Figure 7: High stream flow in Fletcher's Creek

[6] Schueler, T. 1994. The Importance of Imperviousness. Watershed Protection Techniques 1(3):1'00-111.

[7] Schueler, T. 1995. Site Planning for Urban Stream Protection. Metropolitan WashingtonCouncil of Governments, Washington, DC.

In fact, LID sites can prevent runoff for events up to 25 mm in depth (**Figure 8**). For rainfall events with a depth greater than 25 mm, in which runoff is produced, it was previously thought that LID would have little effect in mitigating flows. However, monitoring data has shown that there is runoff volume reductions and peak flow reductions even for large storm events.

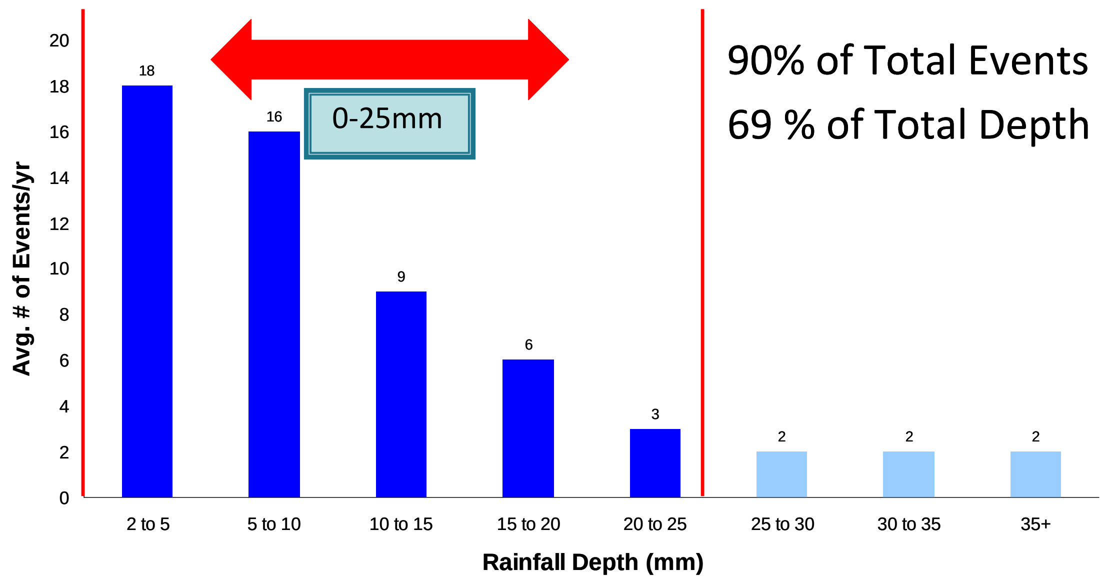

Figure 8: Typical Annual Rainfall Frequency Distribution for Toronto Lester B. Pearson 1960-2012

3 CHANGES IN WATER QUALITY

Pollution from storm water runoff can also be a major concern in urban areas. Rainwater washing across streets and sidewalks can pick up spilled oil, detergents, solvents, de-icing salt, pesticides, fertilizer, and bacteria from pet waste. Carried untreated into streams and waterways, these materials become "non-point source pollutants" which can increase water temperature, algae content, impact aquatic habitats, cause beach closures and require additional costly treatment to make the water potable for drinking water systems. Beach closures and reductions in recreational fishing due to pollutant loading from urban stormwater

Figure 9: Sediment Plume from Credit River to Lake Ontario (Photo Credit: Aquafor Beech, 1990)

and have resulted in up to $87 million a year in lost revenue to local economies[8].

During last three decades, Ontario developers and municipalities have constructed end-of-pipe wet facilities (i.e. wet ponds, wetlands and hybrid ponds) as standalone stormwater management facilities to provide water quality control through the removal of total suspended solids. Conventional end-of-pipe wet stormwater management ponds, in which the main treatment mechanism is capture of particulates through settling, are not effective in removing the fine particles that carry most of the nutrients as well as most of the dissolved pollutants and hydrocarbons. The increase in water temperature as result of the increase in impervious surfaces is also a major water quality concern in urban streams. Retention of stormwater in conventional wet ponds allows stormwater to warm up, causing thermal impacts on receiving water bodies. Because temperature plays a central role in the rate and timing of instream biotic and abiotic reactions, such increases have an adverse impact on streams. In some regions, summer stream warming can irreversibly shift a cold-water stream to a cool-water or even warm-water stream, resulting in deleterious effects on salmonids and other temperature-sensitive organisms.

In the Credit River Watershed, the difference in the concentration of total suspended solids (TSS) in an urban stream that was receiving stormwater from upland developments with conventional end-of-pipe wet facilities and a rural stream with only 10 - 20% impervious cover during dry ambient condition is shown in **Figure 10**. The comparison demonstrated that there are higher levels of TSS in the stream draining the developed area with conventional stormwater management wet facilities than in the rural area. This is due to the lack of runoff volume control in the stormwater management ponds.

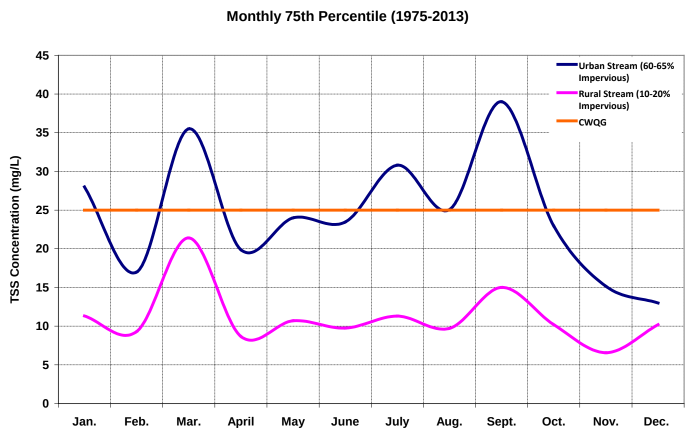

Figure 10: Monthly 75th Percentile Total Suspended Solids concentration compared at an urban vs. rural catchment

Note: Different urban/rural stream have unique responses to development. The example graphs how scenarios observed for one rural and one urban watercourse in CVC's jurisdiction.

There is also significant concern about phosphorus loading from urban areas. Phosphorus is one of main pollutants of concern in urban drainage. Phosphorus and other nutrients are transported by runoff in a particulate-bound and dissolved phosphorus form.

The Total Phosphorus (TP) concentration in two monitored streams within CVC's watershed showed similar results to those observed for TSS. Higher phosphorous concentrations were observed in the urban stream that was receiving stormwater from upland developments into a conventional end-of-pipe SWM facility than in the rural stream that had only 10 - 20% impervious cover during the summer months. Peak concentrations were seen in the rural stream during the spring season whereas peak concentrations were seen in the urban stream during the summer season (**Figure 11**). This is due to the greater level of impervious surfaces and lack of stormwater volume control in the urban stream. Elevated concentrations

[8] Marbek (submitted to Ontario Ministry of Environment). 2010. Assessing the Economic Value of Protecting the Great Lakes: Rouge River Case Study for Nutrient Reduction and Nearshore Health Protection. http://www.greeninfrastructureontario.org/sites/greeninfrastructureontario.org/files/Final%20Rouge%20Report%20Nov%2030.pdf

of nutrients in the summer season is the major factor contributing to excess algae growth and depressed dissolved oxygen in receiving streams[9].

Currently there is a significant concern about phosphorus loading from urban areas. Phosphorus is considered as one of main pollutants of concern in urban drainage. Phosphorus and other nutrients are transported by runoff in a particulate-bound and dissolved phosphorus form.

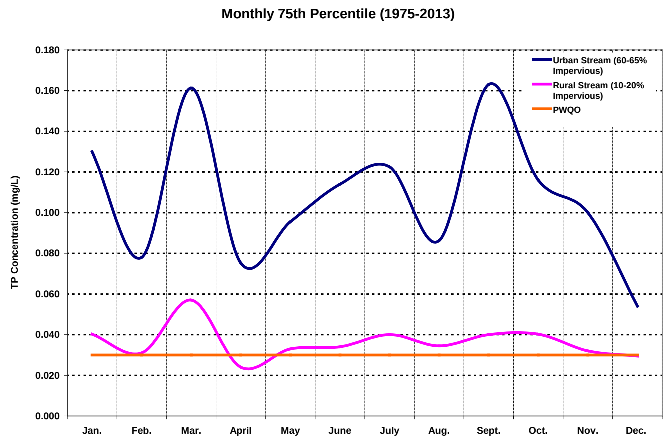

Figure 11: Monthly 75th Percentile Total Phosphorus concentration compared at an urban vs. rural catchment

New York State SWM Design Manual also states that "Based on the best available data, it has been observed that particles less than 10 μm tend to have substantially higher associated phosphorus concentrations than larger particle sizes". This raises concerns with respect to the ability of wet ponds to remove particulate phosphorus as they are not efficient in removing particles less than 10 μm[10]. Moreover, treatment mechanisms focused on capture of particulates does not address dissolved phosphorus removal. This is consistent with the *2003 MOE Stormwater Design Guidelines*, which state that while end-of-pipe facilities are typically designed to remove 60-80% suspended solids, the typical removal efficiency for total phosphorus is 40-50%.

Section 4.4 of the *2003 MOE Stormwater Design Guidelines* also recognize that the use of stormwater ponds for water quantity and quality control can impair receiving stream habitat because of the heating of the discharge water. Because a municipality may have hundreds of wet stormwater management facilities within a single watershed, the cumulative impacts on aquatic systems can be significant.

In streams containing Redside Dace, Ministry of Natural Resources requires that there be no storm runoff from rainfall events in the range of 5 to 15 mm, considering the recommendations of the subwatershed plans and soil permeability[11]. In such circumstances, low impact development strategies to promote infiltration and stormwater reuse should be utilized to match post development water balance with the pre-development condition.

Figure 12: High TSS from urban runoff in Springbrook Creek habitat of Redside Dace

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[9] Aquafor Beech (for Conservation Halton). 2005. LOSAAAC Water Quality Study. Aquafor Beech reference 64353. https://halton.ca/living_in_halton/water_wastewater/water_quality_protection/lake_ontario/LOSAAAC/

[10] Greb, S. and Bannerman, R. 1997. Influence of particle size on wet pond effectiveness. Water Environment Research, 69 (6): 1134-1138.

Ministry of Natural Resources (MNR). 2011. DRAFT Guidance for Development Activities in Redside Dace Protected Habitat. Ontario Ministry of Natural Resources, Peterborough, Ontario. ii+42 pp [11]

4 RESOURCE INFORMATION

Literature reviews show that LID practices mitigate the impacts of urbanization by mimicking pre-development hydrology. CVC/TRCA's *Low Impact Development Stormwater Management Planning and Design Guide* provides planning and design guidance on a wide range of stormwater management practices such as bioretention, disconnection of downspouts, rain harvesting, swales, permeable pavement, and green roofs.

Prevention of urban runoff is an effective means to achieve a broad range of stormwater management objectives such as maintaining pre-development runoff volume, frequency and duration for frequent storm events, reducing runoff temperature, reducing the concentration of TSS and reducing the loading of phosphorus into surface waters. Reducing imperviousness and disconnection of impervious areas can be achieved through alternative design standards for road widths, road right of ways, minimum numbers of parking lot, varied front and rear lots, the use of pervious materials and the use of source controls as discussed in the above document.

For detailed information on preventative and mitigation measures to address thermal impacts of urban developments, refer to *CVC's Study Report: Thermal Impacts of Urbanization including Preventative and Mitigation Techniques* and *CVC/TRCA Low Impact Development Stormwater Management Planning and Design Guide*.