Sustainable Technologies
EVALUATION PROGRAM

Wychwood Subdivision, City of Brampton

Low Impact Development Infrastructure Performance and Risk Assessment

Technical Report Monitoring Results (2016-2017)

Prepared by:
Credit Valley Conservation

May 2020

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The water component of STEP is a collaborative of:

Lake Simcoe Region conservation authority

Credit Valley Conservation inspired by nature

Toronto and Region Conservation Authority

Wychwood Subdivision, City of Brampton
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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The water component of the Sustainable Technologies Evaluation Program (STEP) is a partnership between Toronto and Region Conservation Authority, Credit Valley Conservation and Lake Simcoe Region Conservation Authority. STEP supports broader implementation of sustainable technologies and practices within a Canadian context by:

- Carrying out research, monitoring and evaluation of clean water and low carbon technologies;
- Assessing technology implementation barriers and opportunities;
- Developing supporting tools, guidelines and policies;
- Delivering education and training programs;
- Advocating for effective sustainable technologies; and
- Collaborating with academic and industry partners through our Living Labs and other initiatives.

Technologies evaluated under STEP are not limited to physical devices or products; they may also include preventative measures, implementation protocols, alternative urban site designs, and other innovative practices that help create more sustainable and livable communities.

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
BMP	best management practice
BMPDB	International Stormwater Best Management Practices Database
cm	centimetre
CCME	Canadian Council of Ministers of the Environment
Cu	copper
CVC	Credit Valley Conservation
EC	Environment and Climate Change Canada
EMC	event mean concentration
g	Gram
GTA	Greater Toronto Area
ha	hectare
hr	Hour
HSG	hydrologic soil group
kg	kilogram
IRPA	infrastructure performance and risk assessment
L	Litre
L/s	litres per second
LID	low impact development
m	Metre
m^2	square metre
m^3	cubic metre
MDL	method detection limit
MEDEI	Ministry of Economic Development, Employment and Infrastructure
mg	milligram
µg/L	micrograms per litre
min	Minute

mm	Millimetre
MTO	Ontario Ministry of Transportation
N	Nitrogen
NSQD	National Stormwater Quality Database
NO_2 and NO_3	nitrite and nitrate
MOE (to 2014), MOECC (to 2018) or MECP (present day)	Ontario Ministry of the Environment, Conservation and Parks
PO_4	orthophosphate
P	Phosphorus
PAH	polycyclic aromatic hydrocarbon
PDSB	Peel District School Board
PoC	parameters of concern
PSD	particle size distribution
PVC	polyvinyl chloride
PWQO	Provincial Water Quality Objective
RL	reporting limit
s	Second
SWMM	Stormwater Management Model (EPA SWMM)
TDS	total dissolved solids
TMIG	The Municipal Infrastructure Group
TKN	total Kjeldahl nitrogen
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
UNHSC	University of New Hampshire Stormwater Center
U.S. EPA	United States Environmental Protection Agency
WWE	Wright Water Engineers, Inc.
Yr	Year
Zn	Zinc

EXECUTIVE SUMMARY

Credit Valley Conservation's (CVC) Infrastructure Performance and Risk Assessment (IPRA) program is a multi-year stormwater monitoring program designed to evaluate the performance of stormwater management infrastructure across various land uses, climate conditions, and real-world scenarios. The program monitors and evaluates low impact development (LID) features that CVC and partner municipalities have implemented on both public and private land.

For more than 10 years, the IPRA program has monitored LID's ability to provide flood control, erosion protection, nutrient removal, cold weather performance, and maintenance of pre-development water balance. This information helps municipalities:

- Identify opportunities to reduce stormwater risks, and plan for and justify future infrastructure investments.
- Develop measures to improve water runoff quality, protect receiving stream habitats, and support stormwater management in tablelands upstream of flood zones.
- Inform climate change strategies: the program can supply metrics to help measure the mitigation of stormwater runoff impacts over time. The performance monitoring includes maintenance inspection and tracking to record the frequency and extent of maintenance activities during a stormwater feature's life cycle.
- Guide development of municipal asset management programs in adherence to Ontario Regulation 588/17 by 2024. While typical asset management programs focus on asset condition and operational needs such as inspections and maintenance, monitoring programs can also build an understanding of maintenance needs and conditions assessments of existing stormwater assets.

Municipalities are aiming to achieve the water resource enhancement objectives for providing effective water quality and quantity improvements proposed within their official plans. CVC is working together with the municipalities to address knowledge gaps and make further improvements in new developments, as well as the areas that do not already meet stormwater control standards.

Figure 1: Wychwood grass swale. Source: CVC

The Wychwood Subdivision Pilot

Located in the City of Brampton, the Wychwood Subdivision has a unique design addressing all stormwater criteria through distributed low impact development features within municipal right of ways and residential lots. As a result, land that would otherwise have been reserved for a pond can be used to build additional homes.

Given that streets are the largest urban contributor and are municipally owned land, they provide a great opportunity to control runoff. Implementing subsurface low impact development features as part of land development practices not only improves stormwater quality but can increase the number of available residential lots for sale. Additionally, property values typically increase with proximity to green space which can be incorporated into stormwater management designs. **(USEPA, 2012)**

The site manages stormwater runoff through a variety of low impact development features that provide enhanced water quality and quantity treatment. As part of the IPRA program, CVC is conducting comprehensive monitoring and site inspections at Wychwood to evaluate the combined performance of permeable paver driveways, rain gardens, infiltration trenches, oil and grit separators and a bioswale. From 2016 to 2020, monitoring is focused on the rate in which runoff volume and pollutant load reduction is achieved before discharging to the Credit River. This evaluation is achieved by:

- Collecting stormwater quantity and quality performance data from a range of precipitation event sizes.
- Conducting site inspections and maintenance activities to evaluate the condition of the feature throughout its life cycle, starting at construction.
- Tracking the frequency and cost of maintenance activities and the impact on feature performance; to inform asset management protocols and provide guidance to optimize assets in future development applications.

Figure 2: Wychwood bioswale. Source: CVC

Construction Inspection

The construction of the Wychwood subdivision was completed in June 2015. CVC's monitoring staff began inspecting the feature conditions while the site was still under construction. As construction is a critical time in a feature's life cycle, any issues will have performance impacts as soon as the feature is online. During the construction period, CVC monitoring staff observed poor erosion and sediment control and storage of concrete material within the feature. The developer was immediately informed of these concerns and remediated the area of major concern prior to placing the bioswale feature in service.

Figure 3: Rehabilitation of bioswale. Source: CVC

Low impact development features are relatively new to Ontario and many builders and sub-contractors have little to no background on how these features function and the importance of keeping them clean and clear of debris during construction. As an added level of protection, site inspection and post-construction performance monitoring should be included as part of the site assumption process to ensure the municipality is assuming a site performing to the approved design standard. To ensure features are constructed as designed, performance results to the satisfaction of municipal reviewers could be an added condition for the release of development securities.

Compliance and Performance Monitoring

Due to the site's unique stormwater management design, the Ontario Ministry of the Environment, Conservation and Parks (MECP) included specific monitoring, inspection, and reporting criteria through the site's Environmental Compliance Approval (ECA). This report summarizes the performance results of CVC's monitoring and inspections from January 2016 to December 2017. During this time, CVC:

- Analyzed 125 precipitation events,
- Collected 41 water quality composite samples,
- Collected 3 event grab samples within the event size and season criteria as required by the ECA.

Figure 4: Performance monitoring data collection. Source: CVC

Studies have shown that events up to 25 mm in magnitude make up 90 per cent of rainfall events in a given year **(STEP, 2018).** As these events occur most frequently, they are responsible for transporting a large proportion of the annual contaminant load delivered to receiving waters.

This report provides lab results for total suspended solids (TSS) for all grab and composite samples collected during the monitoring period.

Performance monitoring results from Wychwood found that:

- Low impact development features provide 77 per cent volume reductions for events up to 25 mm.
- There was 84 per cent load reduction of TSS, exceeding the site's specific stormwater management water quality criteria of 80 per cent TSS removal.
- For events greater than 30 mm, peak flows were reduced on average by 74 per cent, with a total volume reduction of 59 per cent.

These findings show low impact development systems can provide resilience under large and intense rainfall events, to support meeting flood control targets and erosion control criteria. Furthermore, limiting peak flow at the source will reduce pressure on downstream infrastructure which is often damaged during larger events with high intensities.

Performance monitoring determined that the low impact development features are not able to collectively meet the site's erosion control design criteria of managing, detaining or reusing all rainfall events up to 15 mm. The results indicate that for most events of approximately 15 mm in size, a portion of the precipitation is released as outflow. Review of the post-development observed dataset, site conditions, design assumptions and pre-development site conditions, provided several explanations for observed outflows for these events. CVC determined that the contributing factors to the erosion control criteria performance included:

1. Antecedent conditions impacting available storage within the feature;
2. Limited infiltration rates and available runoff storage within the infiltration trench feature due to a high groundwater table; and
3. Increases in lot-level impervious area.

Figure 5: Resident walkway constructed through grass swale. Source: CVC

It is essential for municipal authorities to properly regulate impervious landscaping within stormwater features on municipal property and enforce by-laws to protect the feature from being included in lot-level landscaping. Figure 5 represents a case from Wychwood where a resident has extended a private walkway through the enhanced swale, potentially impacting the underlining infrastructure and the feature's infiltration and storage capacity.

Legal precedent has identified risk to municipalities surrounding operation and maintenance of stormwater networks. The Risk Management Framework has shown that tracking and documenting compliance of stormwater systems has led to a reduction of overall risk and ability to demonstrate duty of care for meeting stormwater ECAs and permitting requirements. **(Peel Climate Change Partnership, 2018)**

Figure 6: Site Maintenance Inspections. Source: CVC

Maintenance Inspection

Once Wychwood's low impact development features were receiving storm flow, CVC staff performed site inspections of the conditions of the bioretention features, oil and grit separator units, and permeable pavement and began to collect data on completed maintenance activities. During these site inspections, CVC documented significant landscape changes across the subdivision from the approved plan that may impact overall stormwater performance. Spaces within the residential lots originally allocated in design plans as permeable area for runoff storage were converted to impervious walkways, driveway extensions, and storage structures.

As more of the subdivision becomes impervious, runoff volumes will increase, leading to greater runoff directed to site low impact development features. Despite these lot-level changes, the enhanced swales and bioswale located on municipal property remain in great condition. There is no evidence of residual runoff ponding 24 hours after events, but as mentioned, these cumulative alterations offer a partial explanation for the site's under performance in meeting the 15 mm event erosion control criteria. Additionally, private site alterations described above are not unique to Wychwood; residential developments over time tend to increase in impervious cover (Credit Valley Conservation and Zizzo Strategies, 2018).

An annual site inspection is an ECA requirement at Wychwood; tracking site conditions over time provides guidance on required frequency of inspection appropriate for each low impact development feature. During the study period, CVC performed seasonal inspections (10 in total) to track maintenance trends and the impacts on feature performance. The main findings included:

- CVC documented the frequency and type of maintenance completed by either the residents or maintenance contractors.
- Residents maintained the lawns within the bioswale and trimmed vegetation within the rain gardens. Municipal sub-contractors completed all other maintenance activities within the bioswale and oil and grit separator units.
- Low impact development features were used for landscape material storage and as a throughway for construction equipment traffic during property maintenance and initial construction.
- The curb cut inlet to the rain gardens is a 90° inlet perpendicular to the curb gutter with a narrow opening. The inlet's poor design allows untreated stormwater in the road to bypass the rain garden and enter directly into the nearest catch basin
- The majority of permeable driveways are in good shape and are maintained by residents. Site inspections documented three occurrences of pavers clogged by sediment and 11 cases of structural damage allocated to minor chips on the edges of the pavers.

Nearly half of the 70 lots at Wychwood have either added impervious landscape features to their property or have modified lot-level drainage, increasing runoff volumes directed towards the LID features. **(CVC, 2020)**

Figure 7: Residential yard with added impervious cover. Source: CVC

Observed and modelled results from the Wychwood features indicate low impact development can be successful in managing stormwater across a subdivision. The low impact development features are achieving the site's design criteria of maintaining pre-development infiltration rates and controlling the 2 to 50-year design storm peak flows. These results, in addition to 84 per cent TSS removal, show that distributed and maintained low impact development features can meet regulatory approvals for stormwater management in newly built developments and reduce the footprint of traditional end-of-pipe management techniques.

Conclusion and Next Steps

For future low impact development residential subdivision application, here are some key lessons from Wychwood:

- Site inspection during the construction phase is critical for ensuring the features are built according to design, and appropriate sediment barriers are in place to protect the features from contamination.
- The presence of high groundwater will limit a stormwater feature's ability to store runoff and increase the volume of outflow released during runoff events.
- If landscaping enhancements include impervious materials, there will be an increase in impervious cover within the subdivision. Development of stormwater management designs and performance standards should anticipate a loss in pervious cover and storage volume within residential lots.
- Selecting the appropriate low impact development inlet design and ideal location within the site is critical to ensure the desired volume of runoff is directed towards and into each feature. This

consideration will improve overall performance and contribute to attaining approved design standards.

Tracking changes in site conditions over time will allow the City of Brampton to develop feature-specific inspection and maintenance schedules and inform compliance monitoring requirements for future low impact development projects required through the Province of Ontario's asset management legislation (Ontario Regulation 588/17). CVC in collaboration with STEP partners have developed an extensive training program on a range of stormwater management topics including how to complete routine maintenance inspections for municipally owned and operated low impact development features. Training services may also include the development of site-specific standard operating procedures. At the request of the City of Brampton, site specific training can be providing to municipal staff.

To further investigate the impact that high groundwater levels have on runoff infiltration rates and storage within the features, CVC recommends a focused groundwater monitoring program be implemented in 2020. This program will inform the extent to which high groundwater levels impact low impact development performance. Groundwater monitoring will also fill in knowledge gaps in site water balance currently estimated with only surface flow monitoring data.

In 2020, the City of Brampton will begin collecting a stormwater charge to provide dedicated funding for operation, maintenance, renewal, and rehabilitation of the City's stormwater infrastructure valued at $1.12 billion (City of Brampton, 2019). With newly obtained funding for stormwater infrastructure, implementing low impact development generates a valuable return for taxpayers given the peak flow reduction performance, erosion protection, and runoff water quality improvements that these features can provide.

1.0 BACKGROUND

1.1 State of Stormwater Infrastructure in Ontario

Canada's aging infrastructure is receiving a great deal of attention due, in part, to the increasing frequency of flood events such as the 2013 floods in southern Alberta and Greater Toronto Area (GTA). The 2016 Canadian Infrastructure Report Card documented 671 storm events that resulted in flood damages since 2009. More than 66,000 private properties were affected, with more than $500 million in damages (Canadian Infrastructure Report Card, 2016). Within the last 5 years, Ontario has experienced some severe flood events. The 2013 Toronto flood is the fourth most costly natural disaster in Canadian history ($943 million in insured damage) (Mertz, 2016). Burlington's flood in August 2014 caused more than $90 million in insured damages (IBC, 2014b). More than 1,700 homes were flooded in Windsor and Tecumseh in September 2016 (Canadian Press, 2016).

The replacement value for stormwater infrastructure in very poor, poor, or fair condition was estimated at $31 billion (Canadian Infrastructure Report Card, 2016). This estimate does not take into consideration the need for infrastructure within existing urban areas that do not currently have systems for flood control or stormwater treatment. For example, it is estimated that only 35 percent of the GTA has stormwater management controls (TRCA, 2013). To bring older developments across the nation to today's standards, Federation of Canadian Municipalities (FCM) estimated it would cost an additional $56.6 billion (FCM, 2007). This figure assumes that 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, 2014a)** If no stormwater adaptation measures are implemented a major (one-in-25 year) event occurring in the City of Mississauga could cost an estimated 195 million dollars, excluding expected impact of changing climate patterns **(IBC, 2017)**

In the United States, Europe and Australia there has been a growing movement towards green infrastructure for stormwater management. Green infrastructure for stormwater management, also referred to as low impact development (LID), is an integrated approach to stormwater management that uses site planning and small engineered controls to capture runoff as close as possible to where it is generated. LID controls can be incorporated within urban environments where space is a constraint. They can be implemented in infill, redevelopment and greenfield sites to meet stormwater management objectives. For most development design projects and retrofits, flood control is not the primary use of low impact development. Still, there are smaller scale developments within Ontario, where LIDs have been designed and constructed to provide site flood control (STEP, 2017). Performance monitoring of LID designs have observed reductions in runoff volumes and delays in measured outflow rates, thereby reducing pressures on downstream stormwater infrastructure and receiving waters (STEP, 2018).

1.1.1 Monetary Benefits of LID

A recent report generated estimates of the monetary value of flood loss avoidance that could be achieved by green infrastructure implemented watershed-wide, in new development and redevelopment, in the United States (Atkins, 2015). The present value of flood losses avoided between 2020 and 2040 for the conterminous United States, assuming no damages within the ten year floodplain and a 3 per cent discount rate, was estimated at $0.8 billion dollars (Atkins, 2015). If green infrastructure was also used to retrofit existing imperviousness, the flood loss avoidance benefits would be even higher. Eliminating the stormwater management (SWM) pond footprint from a development property would provide an additional 5-7 per cent of land for development depending on the size of the development and provide an opportunity to make more efficient and effective housing decisions to make housing more affordable with a more water sensitive design (CMHC, 2013).

1.1.2 Water Quantity Benefits

There is clear evidence that urban development in Southern Ontario has significantly increased the number of and potential for surface runoff events to occur within the growing season from May to October. Within the same growing season, natural and agricultural landscapes in Southern Ontario experience very few runoff events, limited runoff volume and little to no local or downstream flooding. Conversely, urbanization has contributed to an increase in runoff events, runoff volume and the occurrences of local and downstream flooding. (Dickenson et al, 2017) (Rudra et al, 2017)

1.1.3 Water Quality Benefits

One of the primary benefits of green infrastructure is water quality and stream protection. Practices such as permeable pavements and bioretention systems can retain the water from the smaller to mid-sized events that occur at a greater frequency. This helps to mimic pre-development hydrological conditions and reduce stream erosion. Stream erosion is a common response to high flows that occur more often and for longer durations after urbanization. Most of the pollutants that accumulate in urban areas are carried to streams and other receiving waters by the moderate sized events that occur more frequently. Therefore, capturing and treating the runoff from these events can play a large role in protecting water quality.

Bannerman et al. (1992) found that streets, sidewalks and driveways can contribute a large amount of urban runoff and pollutants; with streets contributing up to 65-75 per cent of the total suspended solids (TSS), total phosphorus (TP), copper (Cu) and zinc (Zn). Given that streets are the largest urban contributor of TSS and are municipally owned land, they provide the greatest opportunity to mitigate stormwater runoff. Determining the extent to which low impact development features can mitigate the contribution of pollutants from lot level, street and sidewalk runoff to receiving stream water is one of the IPRA program's monitoring objectives.

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

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. Municipalities will need to demonstrate they have an asset management planning program in place to be able to access provincial funding for infrastructure (MMAH, 2019).

One of the barriers to widespread adoption of 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 for practices, individually and in combination, 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 support further use of LID technologies, CVC continues to contribute performance data pertaining to the extent in which LIDs can reduce the number of runoff events, volume of runoff and reduce peak flows.

STEP along with municipal partners have development 3 tools to support municipalities meet provincial and federal requrements for asset management and managing risk. 1.Risk and Return on Investment Tool (RROIT) 2. Green Infrastructure Asset Management Tool (GIAT) 3. LID Treatment Train Tool (LIDTTT) Monitoring data from CVCs Infrastructure Performance Risk Assessment program was used to calibrate the tool.

To build confidence in sizing and long-term performance of stormwater infrastructure, 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 mimicking the pre-development water balance. This program produces performance data addressing the outstanding knowledge gaps and priority objectives identified by multiple stakeholders within CVC's Stormwater Management Monitoring Strategy (2012). **Section 2** of this report discusses the 19 objectives identified for CVC's overall stormwater management monitoring program.

LID performance data inherently supports Ontario's Water Opportunities Act, the Great Lakes Protection Act, and recommendations from MOECC's Policy Review of Municipal Stormwater Management in the Light of Climate Change by providing information on innovative water technologies (MOECC, 2016). Building on the findings of existing research, CVC's program also advances the understanding of maintenance requirements for optimal LID performance and life-cycle cost analysis for asset management to meet provincial requirements for sustainability planning.

The guiding objectives for all CVC stormwater monitoring projects can be found within the *CVC Stormwater Management Monitoring Strategy*. **https://www.creditvalleyca.ca/low-impact-development/**

The knowledge gained through performance evaluation strengthens existing tools and can be used to create new tools to support the promotion of voluntary efforts. These include the LID Treatment Train Design Tool and the update of LID design guidelines. Additionally, evaluating the performance of LIDs will advance design and implementation techniques and help to develop standard design features that can be easily reproduced by designers for similar land uses. Operation and maintenance frequency tracking and the impact maintenance has on performance is needed to inform how routine maintenance of LIDs can fit within a municipal operator's maintenance program and determine if additional training is required. 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.

1.3 Proposed Stormwater Management Standards

In February 2015, the Ministry of Environment and Climate Change (MOECC, now MECP) released an Interpretation Bulletin regarding stormwater management expectations. The bulletin clarifies that the *"Ministry's existing policies and guidance emphasize an approach to stormwater management that mimics a site's natural hydrology as the landscape is developed. The main tenet of this approach is to control precipitation as close as possible to where it falls by employing lot level and conveyance controls otherwise known as Low Impact Development (LID), often as part of a treatment train approach".* LIDs and other source control practices that mimic the predevelopment hydrologic cycle and provide a range of benefits on a watershed scale will be reflected in the Ministry's Environmental Compliance Approval (ECA) process (MOECC, 2015).

The MECP is expected to provide further guidance on Low Impact Development Stormwater Management in a method that will accompany the 2003 Stormwater Management Planning and Design Manual to guide the approval process. The new guidance is expected to utilize many of the concepts already in practice throughout the United States where the 90th percentile event determined through historical rain zone data, geographically, is managed through natural hydrologic pathways such as infiltration and evapotranspiration. The purpose of this stormwater management design is to maintain predevelopment water balance in urban areas.

1.4 Financial Capital Costs to Municipalities from Stormwater Management Ponds

As of 2018, there were 180 ponds within the City of Brampton stormwater infrastructure inventory (City of Brampton, 2019) and estimates suggest that approximately 400 ponds will exist at build out when Brampton has reached its municipal development boundaries (Region of Peel, 2010). As Brampton continues to grow and develop, the capital costs of maintaining its stormwater ponds will increase. Preventative and corrective maintenance costs for stormwater ponds can vary depending on the work required. Ongoing pond inspection is the most common maintenance cost accrued and can cost anywhere between $713 and $1425 per inspection depending on staff salary. Once a stormwater pond reaches its full sediment load, the settled material must be removed and disposed of to maintain the pond's sediment removal design storage. Sediment removal and disposal costs range from $53 to $513 per cubic metre of sediment removed. These costs are dependent on a variety of factors including site accessibility, extent of site clearing and preparation, level of in-situ sediment accumulations, and dewatering method and time (TRCA and CH2M, 2016).

As of 2018, there are 180 stormwater ponds within the City of Brampton's stormwater infrastructure inventory. Inspecting every pond would cost the city over $128 thousand dollars in staff salary at a rate of $713 dollars per inspection **(TRCA and CH2M, 2011)** Implementing a stormwater charge in the City of Brampton will close a funding gap of $16 million needed to maintain stormwater infrastructure moving forward **(City of Brampton, 2019)**

A study was done in 2011 by the Lake Simcoe Region Conservation Authority (LSRCA) to assess the level of TSS removal efficiency of stormwater ponds within its watershed boundaries; they determined that removing the sediment from 98 ponds to recover the ponds' design storage efficiency would cost $18 million (LSRCA, 2011). Although pond maintenance costs would be spread over a number of years, as pond performance thresholds tend to be a factor of age, size and loading rate, planning for maintaining stormwater ponds has become a significant cost burden on the municipal budget year over year.

In addition to budget implications, there is evidence that stormwater ponds are not completely alleviating peak flows from urban areas at the watershed scale (Goff and Gentry, 2006). Furthermore, stormwater ponds do not control the volume of water discharged to receiving streams; rather, ponds delay the discharge of stormwater flows. Streamflow data from Brampton indicates that while stormwater ponds do reduce peak flow from individual ponds to receiving streams, the cumulative impact can still result in peak flows that are up to two orders of magnitude higher than pre-development peak flow conditions, despite the use of ponds (CVC, 2018). The addition of sustaining funding in Brampton's municipal budget will help maintain stormwater assets in the near term, however based on studies from LSRCA and CVC, funding gaps will remain if stormwater ponds continue to be the preferred method of managing stormwater.

In an effort to reduce maintenance costs and provide municipalities with additional tools to manage stormwater runoff within a pond block, it is recommended that LIDs are considered and monitored at the full subdivision scale. Monitoring data would provide observed volume and contaminant load reduction data to calibrate design models and potentially increase the cost efficiency of end-of-pipe stormwater facilities. However, LIDs should always be implemented strategically, and a full review of catchment hydrology and performance of existing features should be understood prior to catchment scale implementation.

2.0 LID MONITORING OBJECTIVES

As the first subdivision in the Credit River Watershed that uses an LID only stormwater management system in place of a stormwater pond, Wychwood presents the opportunity to address many of the priority monitoring objectives identified in the *CVC Stormwater Management Monitoring Strategy* (CVC, 2012). Specifically, for monitoring the Wychwood Subdivision a list of 13 monitoring objectives was identified (bolded in the list below) from the core 19 LID monitoring program objectives.

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.**

In addition to the monitoring objectives from CVCs Stormwater Management Monitoring Strategy, data collected from the project will be used to evaluate the stormwater models used to design the LID features within the Wychwood site.

2.1 How Monitoring Can Reduce Risk

2.1.1 Overview

By demonstrating duty of care, monitoring plays a critical role in reducing municipal risk and liability. It demonstrates stormwater facility performance, indicates when maintenance is needed, and informs asset management plans. This feeds into the design process by providing information that can be used to inform infrastructure sizing and configurations and improve future design practices. Additonally, litigation trends associated with flooding is increasing. The primary focus of litigation is the failure to maintain, monitor, inspect stormwater management features and document their findings.

Monitoring can help answer:

- Are these systems working properly or as designed?
- Does the contractor need to make corrections before the stormwater management feature is accepted by the owner?
- What is the water quality and quantity performance of the feature?
- What happens as the system ages?
- What size is appropriate (for a treatment train approach versus stand-alone technologies)?
- Are our design standards sufficient to protect the environment?

The City of Mississauga and Region of Peel were litigated in a class action lawsuit in 2012. Residence claimed persistent flooding in their neighbourhood and basements were due to negligence in duty-of-care by the municipality to maintain stormwater infrastructure **(National Post, 2012).**

2.1.2 Monitoring Categories

Monitoring can fall into four management categories, and monitoring activities can be simple to complex within each of these. Typically, simpler monitoring programs are included under assumption or compliance monitoring, and more complex programs are often included under performance and adaptive monitoring (Credit Valley Conservation, 2017).

Assumption Monitoring: Monitoring for the purpose of verifying design specifications prior to site assumption. Monitoring typically consists of one-off tests such as site inspections, infiltration tests, soil specifications, and as-built surveys. These tests can confirm feature design including inlet and overflow elevation, drainage area, or media installation.

Compliance Monitoring: Monitoring designed to evaluate whether a management measure or facility is functioning as intended and meeting minimum acceptable requirements and design standards. Monitoring may include relatively simple assessments such as inspections, photos or as-built surveys, but may also include more rigorous activities including infiltration testing, continuous water level measurements, or high intensity monitoring (e.g. inlet and outlet flows and quality).

Performance Monitoring: Monitoring designed to evaluate how a stormwater management facility or practice performs when compared to a range of performance indicators or targets. Performance monitoring also allows comparison with other facilities, designs, technologies, and/or development contexts. Information from this type of monitoring feeds into future designs based on the performance of existing sites. Performance monitoring activities are typically more complex, requiring a comprehensive assessment of the water balance (inflow and outflow) including volume and peak flow reduction and water quality sampling.

Adaptive Monitoring: Monitoring designed to evaluate how stormwater management practices can be adjusted to improve performance. For example, practices could be adjusted to improve water quality, meet hydrologic goals, last longer, require less maintenance, or meet new challenges of climate change. This type of monitoring is very helpful in informing best design practices and improvements to overall feature designs. Adaptive monitoring can occur with a variety of monitoring activities and tests ranging from simple to complex, based on the site design, feature and adaptation.

The Wychwood monitoring plan published by CVC in May of 2016 was developed to comply with the *compliance* monitoring requirements enforced by the Ministry of Environment, Conservation and Park's ECA #9879-8P6Q2S and stormwater *performance* design criteria presented in section 3.3.3. CVC will also be using the monitoring results to address the 13 bolded LID monitoring objectives listed in section 2.

2.1.3 Compliance Requirements

The MECP prepared Environmental Compliance Approval #9879-8P6Q2S which dictates specific monitoring and reporting requirements for the LID stormwater management works within Wychwood. Requirements include:

The Owner shall inspect the Works at least **once a year** and, if necessary, clean and maintain the Works to prevent the excessive build-up of sediments, oil/grit, and/or vegetation. In addition to visual inspection, water quality samples need to be collected from the stormwater effluent discharging from the site to determine performance of the stormwater management works. Samples are to be collected from events generating a minimum of 15 mm of precipitation in the previous 24-hour period. One of these events must occur within the May to September time period. These samples must be sampled and analysed for total suspended solids in accordance with the Ministry's standards, and results must be available to Ministry staff every year. A performance assessment report will be produced every five years by the site owner and made available to the Ministry. The ECA document link for the Wychwood Development is provided in **Appendix A.**

3.0 SITE DESIGN

3.1 Site Location

The Wychwood residential development is located in the City of Brampton within the middle portion of the Credit Valley River Watershed (Figure 3-1 and 3-2). The property was formerly rural residential homes with a small agricultural operation.

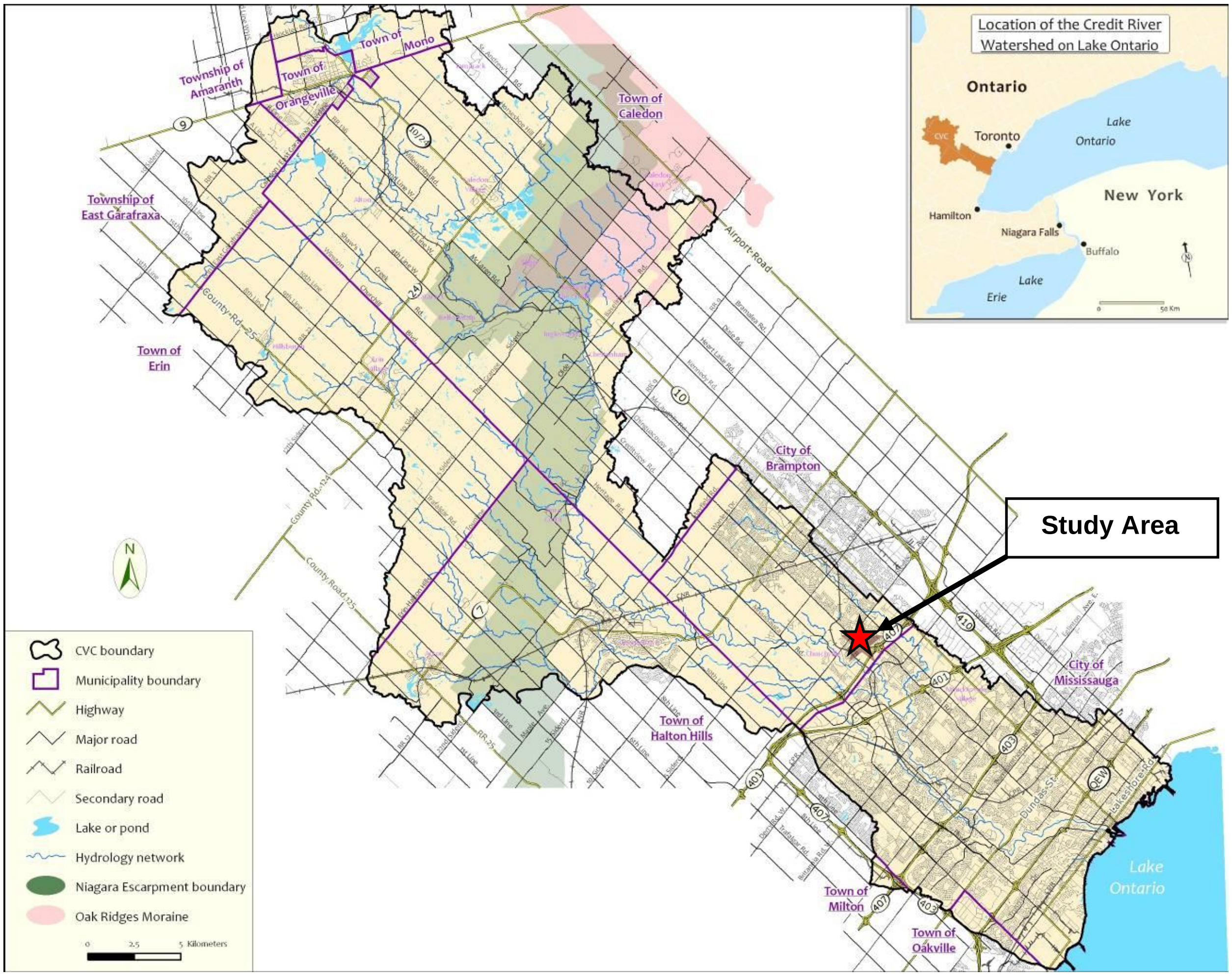

Figure 3-1: Study Area location within the Credit Valley Watershed

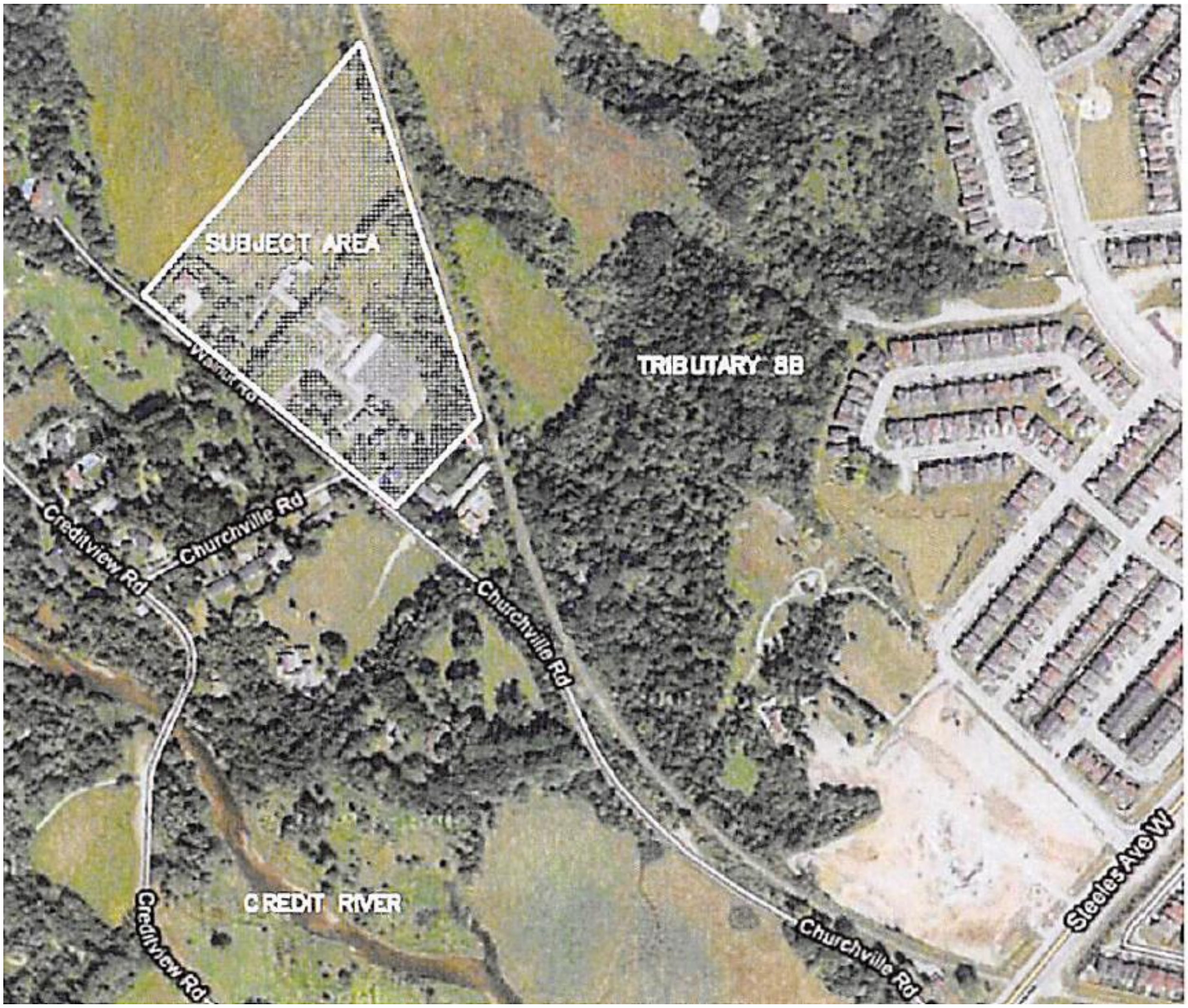

Figure 3-2: Study area and location of Wychwood Residential Development (source: TMIG, 2012)

3.2 Wychwood Subdivision

The Wychwood is the first development in the Credit River Watershed where all site stormwater is managed solely by LIDs. Additionally, the site provides an opportunity to educate urban municipalities on how to balance growth, stormwater infrastructure, and the environment in light of climate change. The approximately 5 ha subdivision utilizes LID features to manage and treat all stormwater runoff generated within the subdivision. The seventy-lot residential development manages all onsite stormwater runoff through LID practices which include permeable pavers, an infiltration trench, rain gardens and a bioswale. The site is designed to convey stormwater runoff in two separate drainage areas. All runoff from the east portion of the development is conveyed to a bioswale spanning the full length of the development, and all runoff from the west portion of the development is conveyed to four enhanced grass swales and two rain gardens (Figure 3-3). The Bioswale is a linear stormwater management feature located along the eastern perimeter of the subdivision. Situated adjacent to railway, the bioswale provides an additional buffer for homeowners and enhances a perceived aesthetic flaw of the home locations (Personal Communication, Giulio Bianchi, 2017). Additionally, seven Stormceptor® 300 Oil Grit Separator (OGS) units are installed within catch basins throughout the site for pre-treatment of runoff prior to entering perforated conveyance pipes installed within the infiltration trench and bioswale. The intent of the Stormceptors® is to remove a minimum 80 per cent of oil and grit and particulates from runoff to reduce the risk of LIDs clogging and thereby reduce LID maintenance and improve LID performance. The Environmental Technology Verification program of Canada have tested the removal efficiency of similar Stormceptors® to those used within Wychwood. Verification results revealed particulate removal efficiency was highly dependent on the particulate size, as finer particles require much longer detention time then larger particles (ETV Canada, 2020). The monitoring program at Wychwood was not designed to challenge the claims made by the proprietor but rather monitoring the removal efficiency of the combinations of LIDs implemented onsite.

During extreme events, conveyance is provided by the features to a receiving ditch along Churchville Road. A capacity analysis of the conveyance ditch was completed by the design consultant at two separate sections downstream of the outlet from the subdivision. From this, the ditch was estimated to have the capacity to manage outflows from a 100-year design storm. (TMIG, 2012).

3.3 Site Design

The site is divided up into two separate drainage areas, each with its own LID features. Figure 3-3 shows both drainage areas and the stormwater features within each catchment.

Figure 3-3: Western and Eastern Catchment Area

3.3.1 Western Catchment

The western section of the site is designed with three stormwater control features which capture runoff from the impervious surfaces and excess runoff from the lots. Runoff drains via traditional curb and gutters towards infiltration grass swales, rain gardens or a Stormceptor® unit providing first flush treatment within the western section of the site. Flows pre-treated by one of the above controls are directed to the infiltration trench located beneath the grass swales. A perforated pipe installed at the invert of the infiltration trench collects all treated stormwater and directs flows towards the municipal stormwater system. Stormwater leaving the subdivision flows into the Churchville Tributary and eventually into the Credit River. By using a treatment train approach with lot level and road right-of-way LID measures along with the infiltration trench, the western drainage system will offer increased runoff retention and decrease the lifecycle maintenance costs of each control. This approach will also provide erosion and flood control for storm events, as all flows are filtered by the infiltration trench and then released at a controlled rate through 25 mm orifices spread 50 mm apart along a perforated pipe. The perforated pipe and trench are wrapped in geotextile fabric to reduce the probability of fine particulates migrating into the infiltration trench, obstructing flows and reducing storage potential (TMIG, 2012).

3.3.2 Eastern Catchment

Within the eastern portion of the subdivision all minor and major runoff flows are controlled by a bioswale, which provides water quantity and quality control as well as erosion controls through the bioswale itself and the infiltration trench component beneath. The first flush portion of runoff events from impervious surfaces is treated by filtering through the bioswale and allowing for some fines to settle. Additionally, a single catch basin located on Honour Oak Crescent will provide runoff pre-treatment through the installed Stormceptor® for a small portion of the impervious surface. Similar to the infiltration trench in the western drainage system, there is a perforated pipe wrapped in geotextile fabric with a downstream orifice designed to allow a controlled release of stormwater so that the storage capacity of the bioswale may be fully utilized. The perforated pipe is located at the bottom of the feature invert of the infiltration trench and is sloped towards the downstream section of the trench to provide positive drainage towards the bioswale outlet. Figure 3-4 presents the flow path through the subdivision and identifies the sewer monitoring locations.

Figure 3-4: Flow Direction and Monitoring Locations

In addition to the above listed management features, residential lots were fitted with permeable paver driveways with available sub-base storage. In addition, lots, right-of-ways (ROW) and buffer landscape areas were constructed with additional topsoil to manage rooftop runoff within the lots. Finally, it should be noted that due to the high groundwater levels observed within the pre-development groundwater study within the site, (Terraprobe, 2010) a separate system of foundation drain collectors is installed within the subdivision municipal infrastructure to manage seasonally high groundwater levels. These drains outlet to the municipal stormwater system and contribute to baseflow levels measured at the outlet of the subdivision.

3.3.3 Stormwater Design Criteria

The site was designed for the following stormwater criteria:

- Water quality control – Enhanced water quality treatment per the MOE Stormwater Management Planning and Design Manual, i.e. long-term removal of 80 per cent suspended solids
- Erosion control – Manage, detain or reuse all rainfall events up to the 15 mm storm event over the entire site
- Water quantity control – Reduce the 2 to 100-year post development flows to pre development levels
- Water balance – Retain the average annual infiltration depth to pre development levels.

The above design criteria is used in comparison with post-development models and onsite monitoring data to assess the overall performance of Wychwood stormwater features. Modelling has been used as an evaluation tool for water quantity control and water balance criteria but has also been used to check monitoring results and inflow estimation. A separate modelling report has been prepared and included as **Appendix J**.

3.3.4 LID Features Details

Oil and Grit Separator (OGS): Stormceptor® STC 300 OGS units (Figure 3-5) are installed in all but two catch basins within the subdivision and are used to remove oil, grease and sediments from runoff. Stormwater flows treated by the OGS system are then conveyed to the perforated pipe within the infiltration trenches (TMIG, 2012).

Figure 3-5: Stormceptor

Enhanced Dry Grass Swales and Rain Gardens: The western drainage area that does not drain into the OGS units is pre-treated via enhanced swales and rain gardens. Curb inlets to the swales and the rain gardens are located at low points within the western ROW. Runoff will filter through the media in the swales/rain gardens and enter into the infiltration trenches below. Surface ponding within the grass swales and rain gardens over periods greater than 24 hours is not expected because stormwater should infiltrate into the infiltration trench. Overflow catch basins have been installed downstream of each rain garden inlet but not within the infiltration swale within the ROW (TMIG, 2012).

Figure 3-6: Rain Garden

Figure 3-7: Infiltration Grass Swale

Perforated Infiltration Trench System: A perforated pipe within an infiltration trench (7) is located within the boulevard of the eastern ROW on Fairmount Close. The trench receives, and stores stormwater runoff generated from the impervious surfaces and any excess runoff from the lots. Roadway runoff is pre-treated via the OGS units, enhanced swales and rain gardens where sediments will be captured and removed prior to entering the infiltration trench. The pre-treatment is essential in preventing clogging of the infiltration trench (TMIG, 2012)

The infiltration trench serves multiple functions: it serves as storage for erosion control and provides opportunities for infiltration to satisfy the water balance and water quality requirements. It also provides detention of runoff through the controlled flow outlet structures at the end of the system. The infiltration trench system has an estimated total storage volume of 191 m^3 (Figure 3-8: Cross section of Infiltration Trench System (TMIG, 2010)

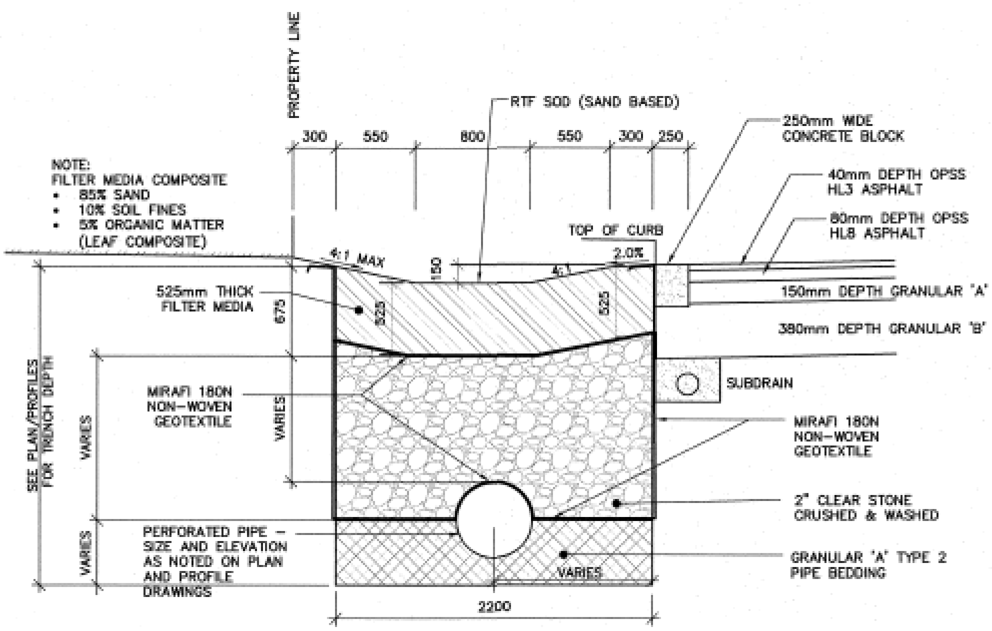

Figure 3-8: Cross section of Infiltration Trench System (TMIG, 2010)

Bioswale and Perforated Pipe Infiltration System: A linear bioswale is installed within the buffer area adjacent to the rail line (Figure 3-9). The bioswale has an engineered soil media largely made of fine and course sand material. Underneath the bioswale is a layer of high-performance pipe bedding clear stone with an infiltration trench and perforated pipe system (Figure 3-10). The perforated pipe increases in size from 375 mm to 450 mm to 525 mm as cumulative flows infiltrate through the bioswale and ultimately flow through the outlet. The bioswale has an estimated total storage volume of 703 m^3 (TMIG, 2012).

Figure 3-9: Bioswale

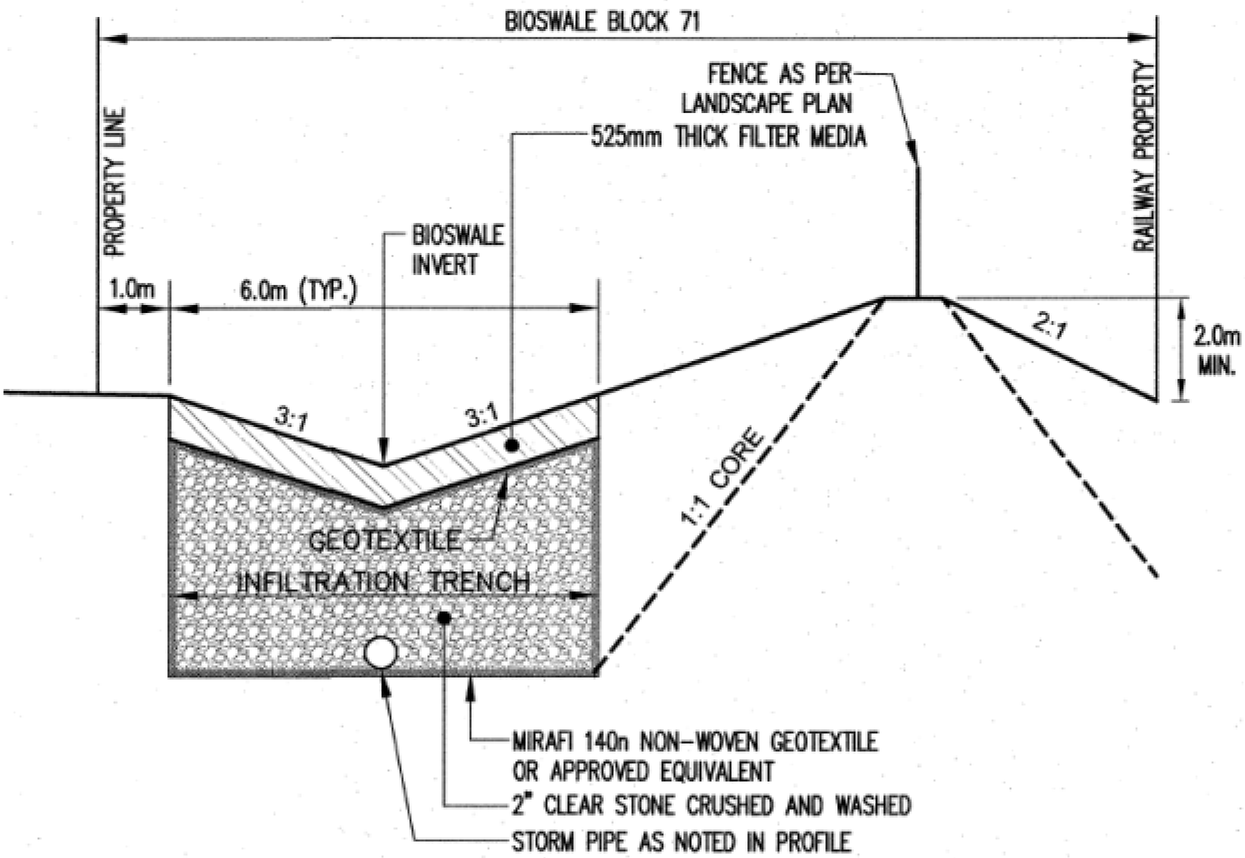

Figure 3-10: Cross section of Bioswale (TMIG, 2010)

Permeable Pavers: All lot driveways have been constructed with permeable pavers to reduce site imperviousness and the infiltration storage beneath each driveway will serve as storage for water quality and erosion control (TMIG, 2012).

Roof Leaders and Increased Topsoil Depth: Roof leaders are directed to the areas within the lots where there is increased topsoil depth and will eliminate rooftop runoff area for all events up to 25 mm. By allowing rooftop runoff to drain onto lot level permeable areas, it reduces the directly connected imperviousness of the site. The increased soil depths provide extra storage and increases infiltration evapotranspiration opportunities (TMIG, 2012).

3.3.5 Downstream Receiver

Once the storage capacity of the LID features has been reached, the residual runoff is piped through underground stormwater conveyance and discharged into the roadside ditch along Churchville road. Figure 3-11 presents a google map of the subdivision, direction of flow and location of the receiver in proximity to the subdivision. A photo of the stormwater outfall headwall and receiving ditch is provided in Figure 3-12. Downstream of the roadside ditch outfall, residual flows are combined with runoff from surrounding catchments and are discharged into the Credit River.

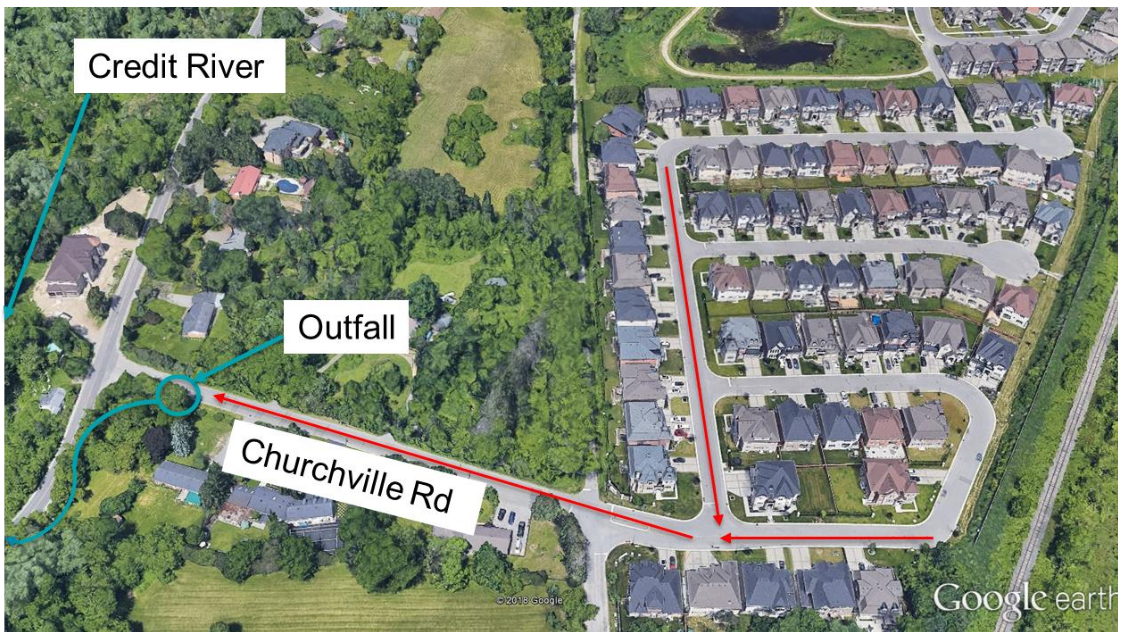

Figure 3-11: Wychwood Subdivision flow direction and location of conveyance ditch outfall (Google, 2018)

(red arrows indicate underground infrastructure; green arrows indicate above ground infrastructure)

Figure 3-12: Outfall headwall and downstream receiver

The design consultant completed an analysis of the receiving ditch and determined the capacity of the ditch could manage peak flows from the 100yr design storm of 1.13m^3/s (TMIG, 2012). Additionally, the vegetation within the ditch will provide an added water quality benefit prior to discharging flows into the Credit River.

3.3.6 Precipitation

Precipitation at Wychwood has been monitored continuously from September 2015 to August 2016 using a climate station installed and maintained by the Region of Peel. On August 9 2016, a meteorological station including a heated tipping-bucket rain gauge and air temperature sensor was installed on the roof of Churchville Public School (PS), located within 1 km of the Wychwood LID monitoring site. The approximate location of both meteorological stations is provided in Figure 3-13. The Churchville PS station has now become the primary precipitation gauge for Wychwood. Additional gauges maintained by the Region of Peel are used to validate data from the primary gauge and in the event of any data gaps. In addition, a HOBO event logger was installed alongside the tipping bucket on May 12, 2017 to ensure continuous data collection and account for fluctuations in precipitation logged by the nearby Region of Peel and CVC gauges. An Environment and Climate Change Canada gauge located at Toronto Pearson International Airport (about 22 km east of the Wychwood catchment), with a long-term record, is used to provide an understanding of regional “normal” or average precipitation values. Regional climate norms provide support in characterizing the events to be expected at Wychwood and the distribution in southern Ontario but should not be relied upon for determining site hydrology for individual events.

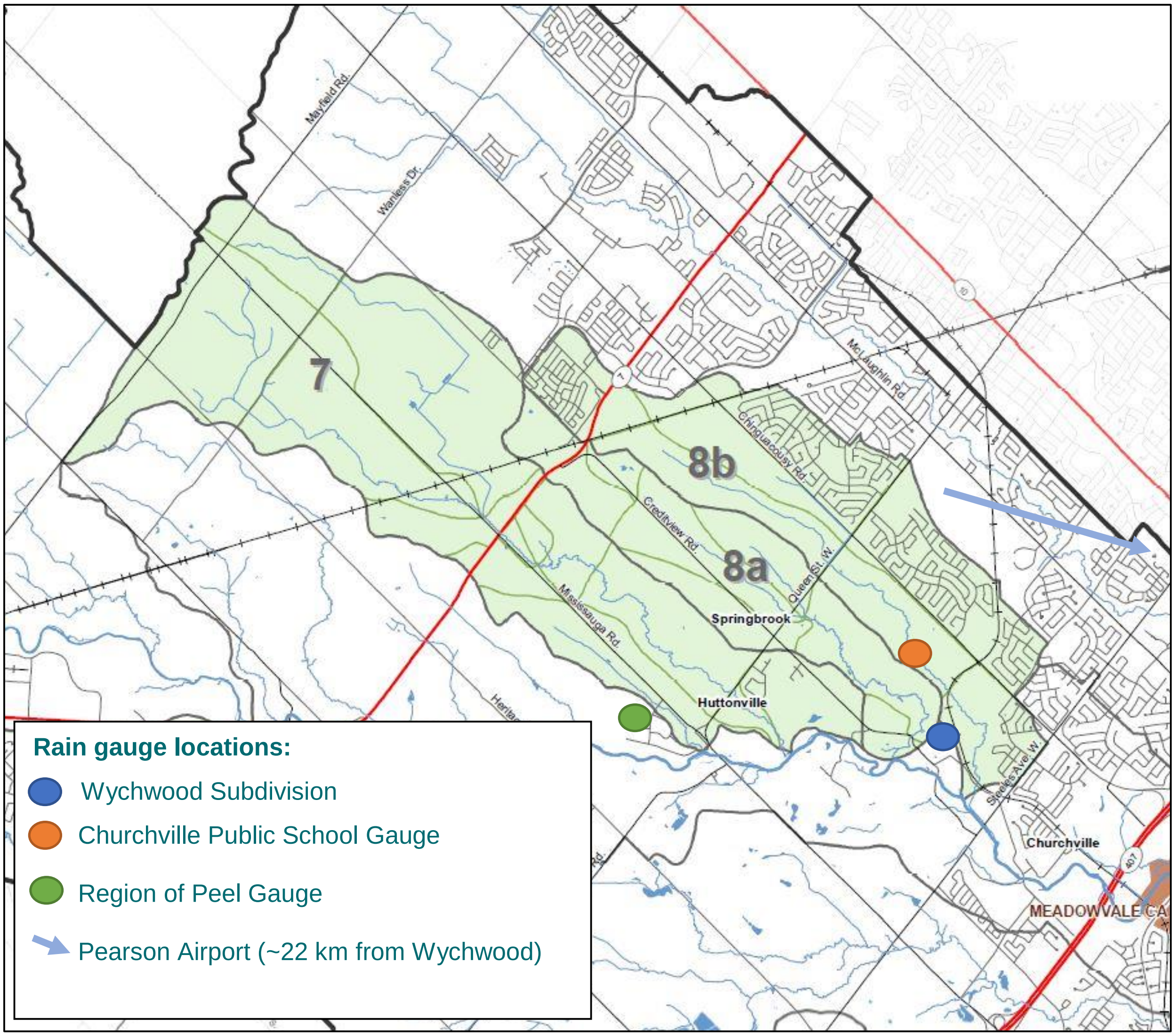

Figure 3-13: Selected rain gauges in reference to the Wychwood Subdivision

4.0 MONITORING RESULTS AND INTERPRETATIONS

This section provides results from the analysis of monitoring data collected from the two years of onsite stormwater monitoring from January 2016 through December 2017. The monitoring program for the Wychwood Subdivision includes the collection of precipitation and flow data, as well as outflow water temperature and water quality data from the LID sites installed within the east catchment and west catchment. Figure 4-1 and Table 4-1Error! Reference source not found. summarize the monitoring locations and equipment within the Wychwood Subdivision study area. The outflows from the east catchment are measured at the WW-1 station, and the outflow from the entire site, except for a 0.23 ha sub-area along the southern subdivision boundary, is measured at the WW-2 station. The WW-2 whole-site monitoring station was selected based on safety and accessibility to the storm sewer network. It was not possible to have a location that only measures the outflow of the entire Wychwood subdivision. Additionally, the WW-2 monitoring location avoids most of the lot level foundation drain collectors (FDC) pipes discharging excess subsurface water near the foundations into the storm sewer. The lots where the inclusion of FDC flows could not be avoided due to manhole access constraints, are highlighted in Figure 4-1. During the modelling and the stormwater monitoring process, CVC reviewed and re-analyzed the catchment area footprint of the Wychwood subdivision. Arc hydro Geographical Information software and Lidar analysis were used to delineate the discrete catchment area for each LID feature. A new total site catchment area of 4.09 hectares was determined to be more accurate for estimating runoff from the site. This catchment area is used to determine inflows for determining overall stormwater management performance. Further information on the monitoring protocols and data management and analysis methods is provided in **Appendix C.**

WW-1 receives inflow from the eastern catchment area as sheet flow and interflow (which is difficult to measure) WW-2 receives inflow from both the eastern and western catchment area and measures the full site performance of all stormwater control features within the Wychwood Subdivision, with the exception of a 0.23 ha catchment area in the extreme southern part of the western drainage area.

WW-1 is located within a manhole collecting outlet flows from the bioswale along the eastern perimeter of the site. WW-2 is located within a manhole where outlet flows from both the Western and Eastern catchment LIDs converge, to assess the performance of all the features combined. The monitoring data used for analysis was collected from January 2016 to December 2017. This data set represents the first two years of monitoring at Wychwood.

The analysis includes an examination of the hydrologic responses for events of various magnitudes at each monitoring location. Performance is assessed, based on peak flow reduction, lag time and an emphasis of the estimated runoff volume reduction. A full event summary for the entire monitoring year with highlighted performance of selected events is presented to demonstrate performance of the LID features at Wychwood. Finally, a combination of collected monitoring data and a calibrated Stormwater Management Model (SWMM) is used to compare estimated post-development design performance listed in section 3.3.3 of this report with post-development observed performance.

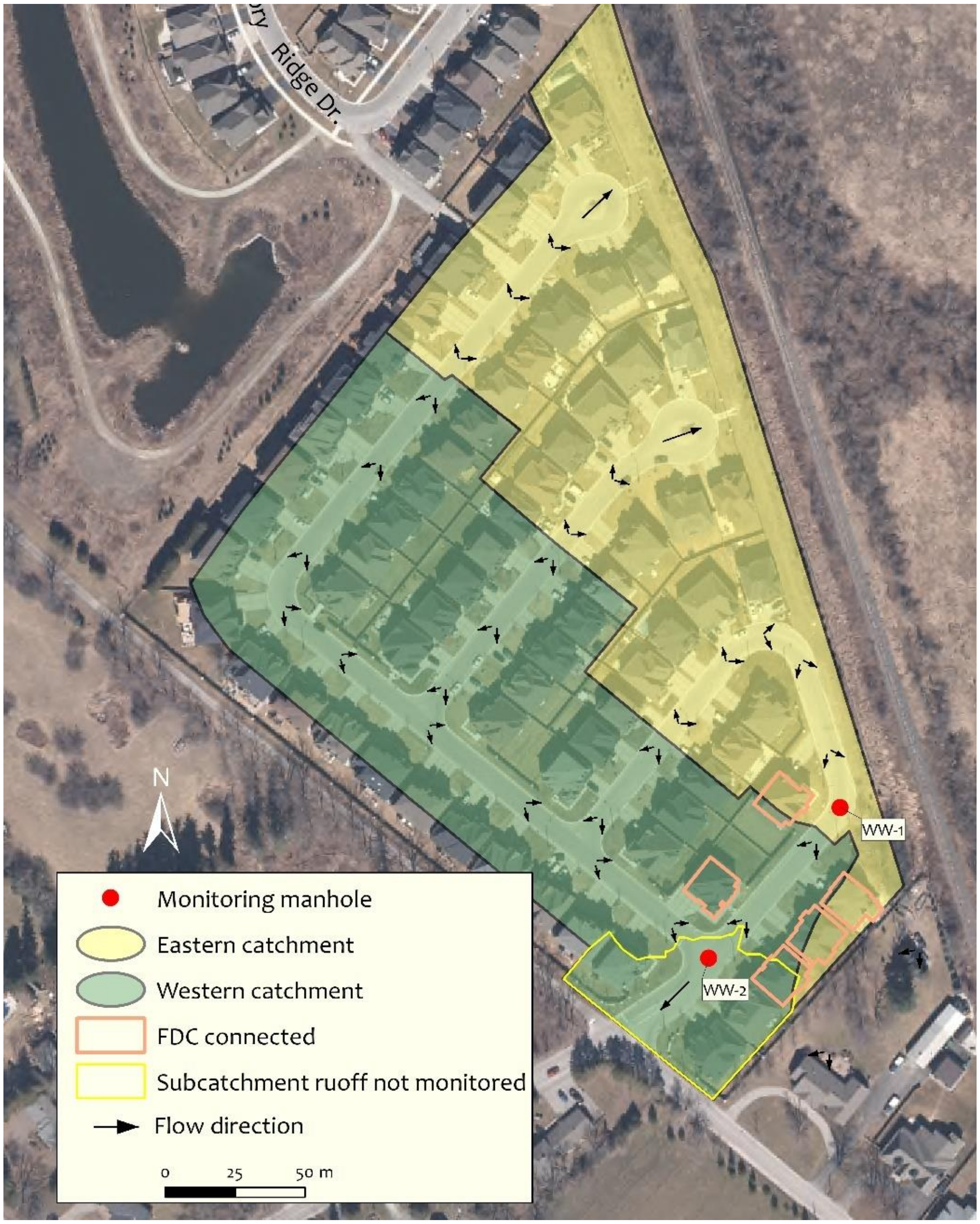

Figure 4-1: Continuous data collection monitoring locations

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

Measurement type	Monitoring equipment	Location/description
Construction Inspection-Condition of LID features	Camera	Entire Subdivision
Flow	Custom Compound Weir by Thompson Flow Investigations ISCO 2150 Flow Logger (water level meter)	WW-1 Outlet Manhole from Eastern Drainage Area WW-2 Total Site Outlet Manhole from Western Drainage Area
Rainfall depth and intensity	Hydrological Services TB3 Tipping Bucket Rain Gauge	Roof of Churchville Public School (approx. 1.3 km from Wychwood monitoring stations)
Water quality sampling	ISCO 6712 Automatic Sampler	WW-1 Outlet Manhole from Eastern Drainage Area WW-2 Total Site Outlet Manhole
Water Temperature	HOBO UA-002-64K	WW-1 Outlet Manhole from Eastern Drainage Area WW-2 Total Site Outlet Manhole WW-Inflow Runoff Temperature Collected within Inlet Catch basin

4.1 Environmental Compliance Approval #9879-8P6Q2S

During the 2016-2017 monitoring period, CVC completed all required monitoring components for the first two years of monitoring. These include:

- Implementing a monitoring program commencing at the completion of construction works for a minimum of two years after 90 per cent of homes within the subdivision are occupied
- Three grab samples have been collected from MH101for events where 15 mm of rainfall have occurred within the previous 24 hrs. Two of these samples were collected between the May to September time period. Samples collected on August 16, 2016, November 3, 2016 and May 5, 2017. Additional grab samples were collected in 2018.
- Work was completed per the "Procedures for Sampling and Analysis Requirements for Municipal and Private Sewage Treatment Works" (MECP, 2019)
- Samples were submitted to the MECP laboratory for analysis at 125 Resources Road, Toronto, Ontario for analysis of Total Suspended Solids.
- If requested by MECP, sampling and site inspection results can be made available per ECA requirements
- Inspections and mass accumulation of sediment, oil/grit and or vegetation within the Oil Grit Separators was documented by the land owner and can be provided to the MECP if requested.
- Inspection of the features has been completed regularly and have been placed in a database for maintenance tracking and life-cycle costing analysis

4.2 Construction Observations

During construction, representatives from Credit Valley Conservation visited the Wychwood Subdivision with an aim to ensure proper construction of the LID features (bioswales, rain gardens, permeable pavers) and to preserve their infiltration capacity by identifying protection measures needed during the construction phase. Additionally, with in-pipe performance monitoring occurring once the development reached 90 per cent completion, CVC can evaluate the impact adjacent construction activities had on the infiltration features through water quality and quantity performance results.

During site observation visits, existing areas of concern were documented and written notice of CVC's concerns were provided to Sequoia Grove Homes. After construction was completed, site observations documented during this phase were presented to City of Brampton in October 2016. The following table outlines the most common areas of concern observed during site visits.

Table 4-2: Construction Observation Summary

Observations	Photo Documentation
1) Bioswale Inlet Contamination • 1-2" of fine construction sediment was found in the areas near the cul-de-sac inlet and at the downstream end of the bioswale Correction Notice Provided: May 23rd 2014 • A sediment trap (OPSD 219.220) with a geotextile filter sock in the space between the inlet and bioswale	
2) Material Storage • Stockpile (on lot 64&65) is not isolated and stabilized per the plans Correction Notice Provided: May 23rd 2014 • Stockpiles shall be surrounded with sedimentation control fencing. All piles which are stocked for more than 30 days shall be seeded.	

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3) Grass Sod Installation

- Clay based sod used within invert of bioswale

Correction Notice Provided: September 8th 2014

- Removal of sod for the entire length of the base of the bioswale, removal of any sediment within the bioswale prior to scouring of bioretention media
- Scouring of bioretention soil media to rehabilitate any compacted media
- Seeding of bioswale with grass seed and adding compost on top will encourage rapid germination.

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4)Staging Area

- Bioswale used as a staging area. Stockpiles, debris, and gasoline/oil/chemicals were being stored directly on top of the bioswale.

Corrective Notice Provided: May 27th 2015

- Staging area should be determined pre-construction for material storage away from infiltration features to avoid compaction

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5) Finished Inlet Grades • Finished sod and soil grade higher than runoff inlet grade Corrective Notice Provided: September 2015 • Recommended re-grading to design grades to allow runoff to enter the LID feature • Grade drop will ensure positive drainage into the LID features. If there is insufficient grade drop, runoff bypassing or blockage could occur.	

Due in part to CVC's construction observations, testing, and partnership with the developer Sequoia Grove Homes, the bioswale was remediated to improve infiltration throughout the bioswale post-construction (Figure 4-2 and 4-3).

Figure 4-2: Remediation of Downstream Bioswale

Figure 4-3: Bioswale feature remediated post-construction

4.2.1 Construction Inspection and Assumption

CVC has found that one of the critical steps in ensuring LIDs function per design is to monitor and inspect the site during construction to ensure the feature is built as designed. This process requires constant communication between the designer and contractor to address any inconsistencies with the design and with actual site conditions. For LIDs to properly function, stormwater must flow freely into and through the feature. For this to occur, appropriately installed and maintained erosion and sediment controls (ESC) are necessary to protect the feature when adjacent properties are being built. If any of the LID components are contaminated or clogged with sediment, or over compacted due to improper material storage, the feature will not perform as designed. For Wychwood, site inspection and documentation on a frequent basis during construction helped to identify the issues presented in Table 4-2. If concerns with construction practices and ESCs had not been identified during inspection, the bioswale may not have been remediated.

With several construction projects ongoing across Brampton and the Region of Peel, integrating a performance and site condition standard for LIDs into the site assumption process may help to reduce the frequency of site inspection. Assumption of the feature could also be tied to the release of development securities to provide added incentive to ensure features are constructed and performing as designed. This process would require performance monitoring for some LID and stormwater ponds under construction to first develop a performance standard, but would reduce the risk and liability for the municipality to assume sites that under perform.

4.3 Precipitation Trends

Based on the climate norms at Pearson, the months of May through September are typically the rainiest months, each exceeding 70 mm of precipitation. 2016, however, was both a hot and dry year at Pearson, with ten of the twelve months falling in the upper 25th percentile for temperature (Figure 4-4) with August 2016 being warmer than any Pearson climate normal from 1981 to 2010 (hence not appearing in Figure 4-4 below). In addition, the months of May, June, July, October, and November were all in the driest quartile. Similar results were seen at the Wychwood climate station (Table 4-4), as the months from May through

November were all drier than the climate norms. The total 2016 precipitation at Wychwood of 699.7 mm was only 89 per cent of the Pearson climate norms' annual average of 785.9 mm.

In 2017 however, seven of the twelve months fell into the upper 25th percentile for temperature with February 2017 being warmer than any Pearson climate normal from 1981 to 2010 (Figure 4-5). Compared to 2016, where May, June and October fell into the driest quartile, in 2017, May, June and October fell into the wettest quartile. Similar results were seen at the Wychwood climate station (Table 4-2)**,** where May and June experienced greater rainfall than that of the climate norms. In addition, the total 2017 precipitation at Wychwood of 778.6 mm was 99 per cent of the Pearson climate norms' annual average of 785.9 mm, which is 10 per cent more than 2016.

Figure 4-4*:* Percentiles of 2016 and 2017 monthly climate data at Pearson International Airport relative to the 1981-2010 norms. August 2016 is not pictured as it exceeds the maximum 1981-2010 August temperature value, and it is at the 58 per cent precipitation percentile. February 2017 is not pictured as it exceeds the maximum 1981-2010 February temperature value, and it is at the 64 per cent precipitation percentile.

4.3.1 Precipitation Results

Understanding the relative contributions of events of different sizes to annual rainfall is important for interpreting performance results. Precipitation events are defined as periods of precipitation with a depth ≥2 mm. Figure 4-5 illustrates the typical annual rainfall distribution for the Pearson weather station for 2016 and 2017 combined and the actual number of precipitation events that were recorded at Wychwood during the monitoring period of January to December 2016 and 2017. The comparison suggests that the frequency of events of various sizes at Wychwood during both monitoring years combined were somewhat similar to the long-term regional frequency of occurrence.

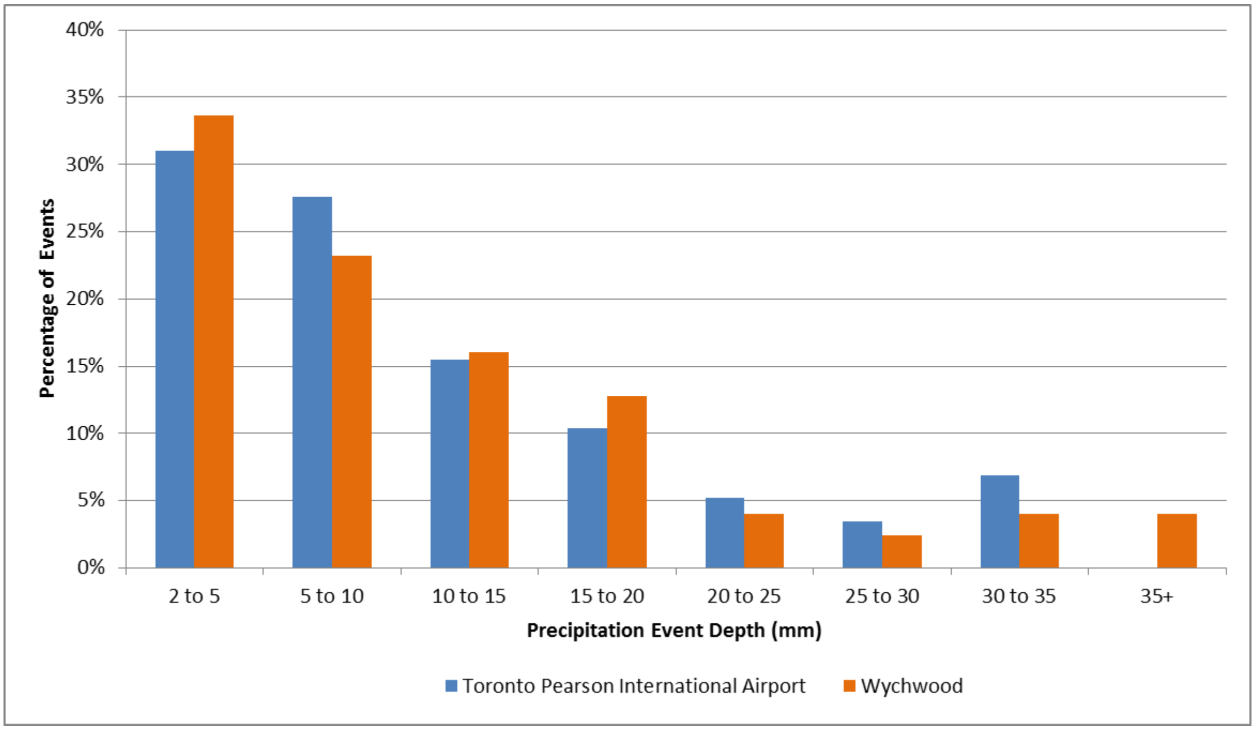

Figure 4-5: Rainfall frequency distribution graph between Environment Canada Toronto Pearson International Airport (1960-2012) and Wychwood (January 2016–December 2017).

Of the total number of events (125) observed during the 2016 and 2017 monitoring period combined that were considered for the hydrologic analysis, 112 had a precipitation depth less than 25 mm. As a result, events less than 25 mm make up 90 per cent of all precipitation events for the 2016 and 2017 monitoring period at Wychwood, which compares well with the long-term average of 95 per cent at Pearson Airport. Because events up to 25 mm in magnitude occur much more frequently and contribute a large proportion of the average annual precipitation, their management is particularly important for water balance objectives. Events in this size range are also responsible for transporting a large proportion of the annual contaminant mass delivered to receiving waters. Therefore, their management is also critical to achieve water quality objectives. For flood control objectives it is the large events, which occur less frequently, that are important.

Table 4-3: Monthly precipitation at Wychwood Toronto Pearson International Airport

Toronto Pearson International Airport													
	Precipitation (mm)												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
1981-2010	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
Wychwood													
2016	41.75	50.1	98.8	77.6	58.4	51.6	29.8	69.0	43.4	41.6	62.8	74.8	699.7
2017	78.0	39.6	62.2	107.8	125.8	83.0	34.6	70.4	29.2	63.4	65.2	19.4	778.6

(*Toronto Pearson International Airport data source:* ***http://climate.weather.gc.ca/index_e.html****)*.

** monitoring data not included in this report*

4.4 Summary of Measured Events

Table 4-4 and Table 4-5 present the hydrologic summary for events monitored at each of the stations between January 2016 and December 2017. The flow events are defined as having an inter-event duration of 6 hours or more, additionally events included in this analysis are those greater than 2 mm of precipitation or producing outflow. Wychwood's LIDs have multiple inflow points into the practice making inflow monitoring difficult to achieve using available monitoring equipment. Instead, influent estimations were determined using the simple method described in detail in **Appendix C**.

During the 2016 monitoring year, the weir located at the WW-2 monitoring location required repeated patching as leaks were observed at various times throughout the year. This is represented within the smaller data set as only 90 events at WW-2 have been reviewed compared to 125 events at WW-1. Events where a degree of uncertainty regarding the accuracy of the monitoring equipment and/or corresponding infrastructure was observed have not been included in analysis, to ensure the data set represents actual site conditions during an event.

Volume reduction is achieved by retaining water (through infiltration or evapotranspiration) such that it does not contribute to outflow from the site. It is important for groundwater recharge and water balance objectives as well as water quality objectives. In addition, retention of stormwater and reducing peak flow rates is an effective means of meeting erosion control objectives and reducing the load on the stormwater network. Results presented demonstrate the performance of LID features in providing significant volume reduction for a wide range of event flows.

Volume reductions for different precipitation event size bins for WW-1 and WW-2 are presented in Figure 4-6 and Figure 4-7. The total volume reduction from all measured events at WW-2, which represents outflow from 85 per cent of the subdivision catchment, was 73 per cent. For events under 25 mm, WW-2 detains 77 per cent of all runoff. The total volume reduction at WW-1, which measures outflow of the bioswale managing the eastern catchment is 97 per cent, and the volume reduction for events under 25 mm is also 97 per cent. Furthermore, result statistics summarized in Table 4-4 and Table 4-5 present high mean and median volume reduction results for both WW-1 and WW-2, demonstrating volume reductions the LID features have provided across a wide range of event flows.

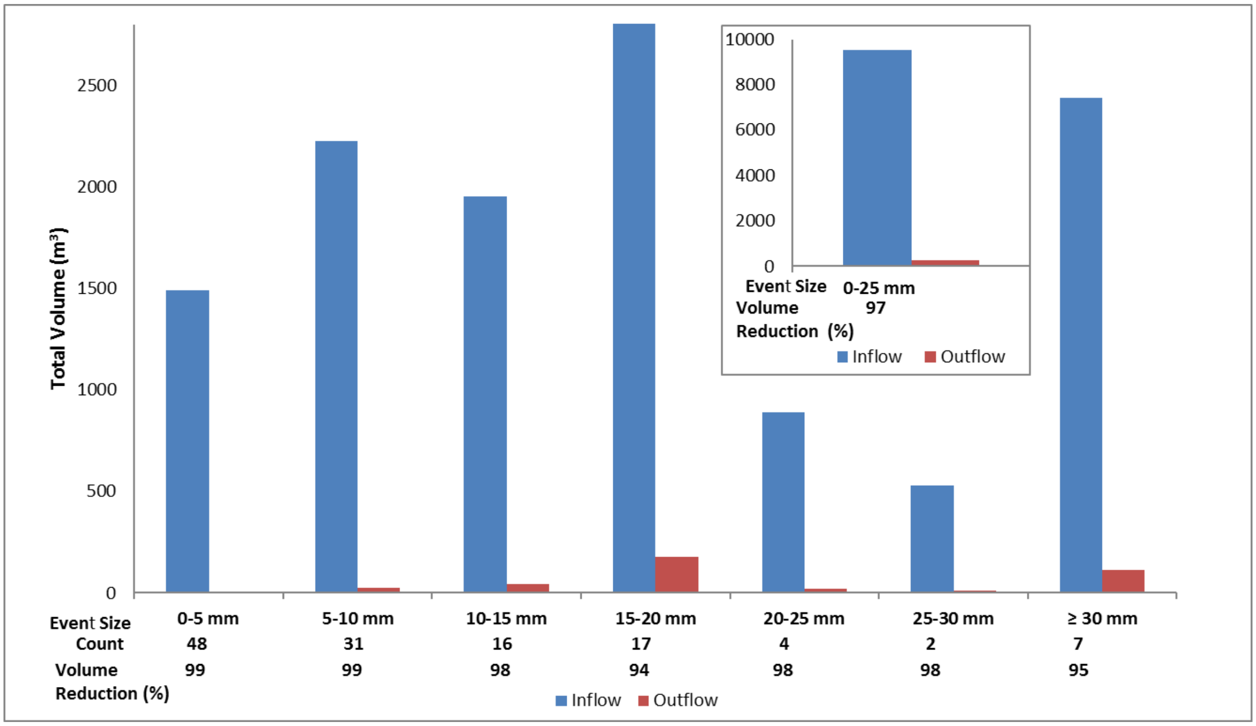

Figure 4-6: Runoff Volume Reductions measured at WW-1

The bioswale in the eastern catchment is very effective at infiltrating stormwater, as only 3 per cent of the calculated volume leaves and is measured as outflow (Figure 4-2). For large events with a precipitation depth of greater than 30 mm, the volume reduction at WW-1 was 95 per cent. These results demonstrate the bioswales performance in limiting overland flooding from large, long duration events.

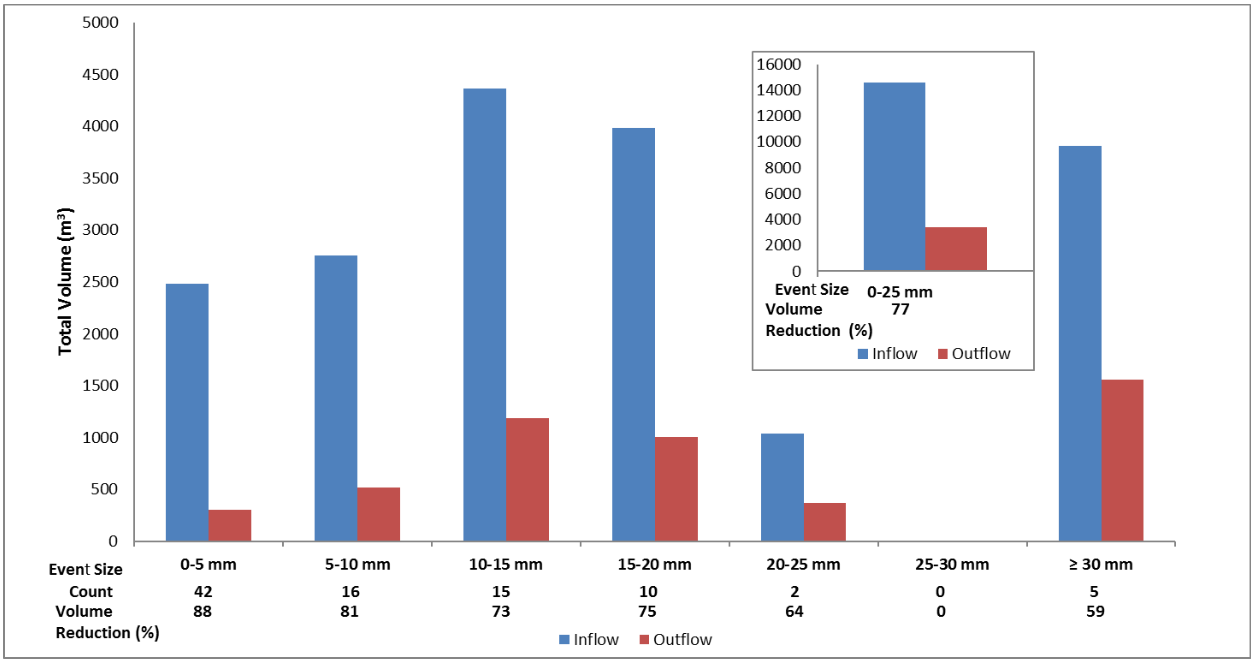

Figure 4-7: Runoff Volume Reduction measured at WW-2

Table 4-4: WW-1 Event precipitation, flow, and volume statistics: January 2016 to December 2017

Statistic	Antecedent Dry Period (Days)	Event Duration (min)	Peak Intensity (mm/h)	Precipitation Depth (mm)	Peak Effluent Flow (L/s)	Influent Volume (L)	Effluent Volume (L)	Estimated Volume Reduction (%)	Estimated Peak Flow Reduction (%)
Total Events	125.0	125.0	124.0	124.0	125.0	124.0	125.0	124.0	124.0
Mean	4.5	524.2	11.2	10.1	0.7	100653.2	3187.8	98%	97%
25 Percentile	1.4	155.0	3.6	3.8	0.0	37425.0	0.0	99%	98%
Median	3.1	385.0	6.0	7.1	0.0	70858.0	0.0	100%	100%
75 Percentile	6.1	755.0	13.5	14.2	0.8	141217.2	1372.5	100%	100%
Max	16.4	3430.0	64.8	39.6	13.8	395208.0	97275.9	100%	100%

Table 4-5: WW-2 Event precipitation, flow, and volume statistics: January 2016 to December 2017

Statistic	Antecedent Dry Period (Days)	Event Duration (min)	Peak Intensity (mm/h)	Precipitation Depth (mm)	Peak Effluent Flow (L/s)	Influent Volume (L)	Effluent Volume (L)	Estimated Volume Reduction (%)	Estimated Peak Flow Reduction (%)
Total Events	89.0	90.0	89.0	89.0	90.0	89.0	90.0	89.0	89.0
Mean	4.3	1121.4	9.5	9.1	11.2	207033.6	54851.3	81%	83%
25 Percentile	1.1	350.0	2.4	3.0	1.3	68295.0	3745.6	72%	76%
Median	2.4	642.5	4.8	6.6	4.2	150249.0	16563.7	86%	87%
75 Percentile	5.4	1603.8	12.0	13.8	12.4	314157.0	68310.4	93%	95%
Max	21.7	4405.0	50.4	37.6	98.6	855964.1	413158.3	100%	100%

Table 4-4 and 4-5 Notes: 1. Peak intensity is the peak volume of precipitation occurring over an hour frequency. 2. All influent calculations were determined using the simple method described in detail in appendix C. Note: Total number of events vary by one as precipitation was not measured for one event included in the analysis.

The volume storage provided by the LID features can help to reduce peak flows during less frequent events or high intensity events, which helps to prevent surcharging of downstream pipe infrastructure. The cumulative storage that can be provided by extensive LID implementation may contribute to the reduction of watercourse flooding as well. Median peak flow reductions presented in Table 4-4 and Table 4-5 for WW-1 and WW-2 monitoring locations are 100 per cent and 87 per cent respectively. Average peak flow reductions for both monitoring locations are presented in Figure 4-8 and Figure 4-9. During the monitoring period, 85 events measured at WW-2 (summarized in Figure 4-9) had magnitudes of 25 mm or less. For these events, an average peak flow reduction of 82 per cent was provided by the LID features. For large events greater than 30 mm, peak flows were reduced by at least 74 per cent. A comparison of peak flows observed at the WW-1 station against those calculated from the Simple Method (summarized in Figure 4-8) indicate a peak flow reduction of 98 per cent provided by the bioswale for 116 events within the 25 mm or less range and 93 per cent for events greater than 30 mm.

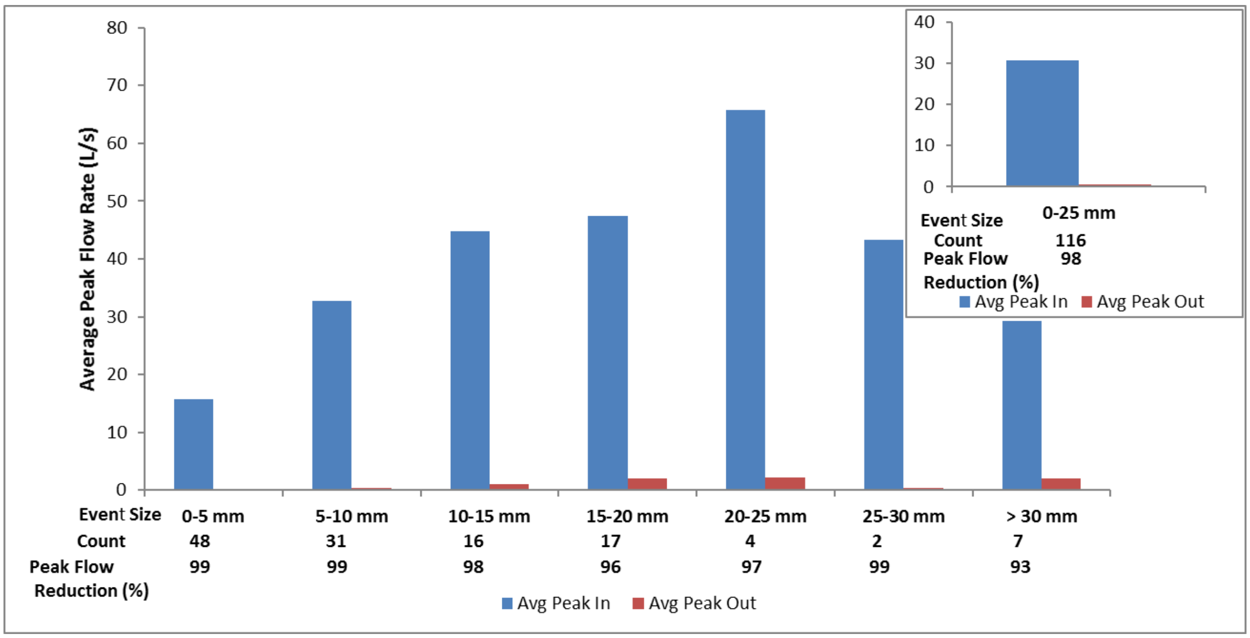

Figure 4-8: Mean peak flow reductions measured at WW-1

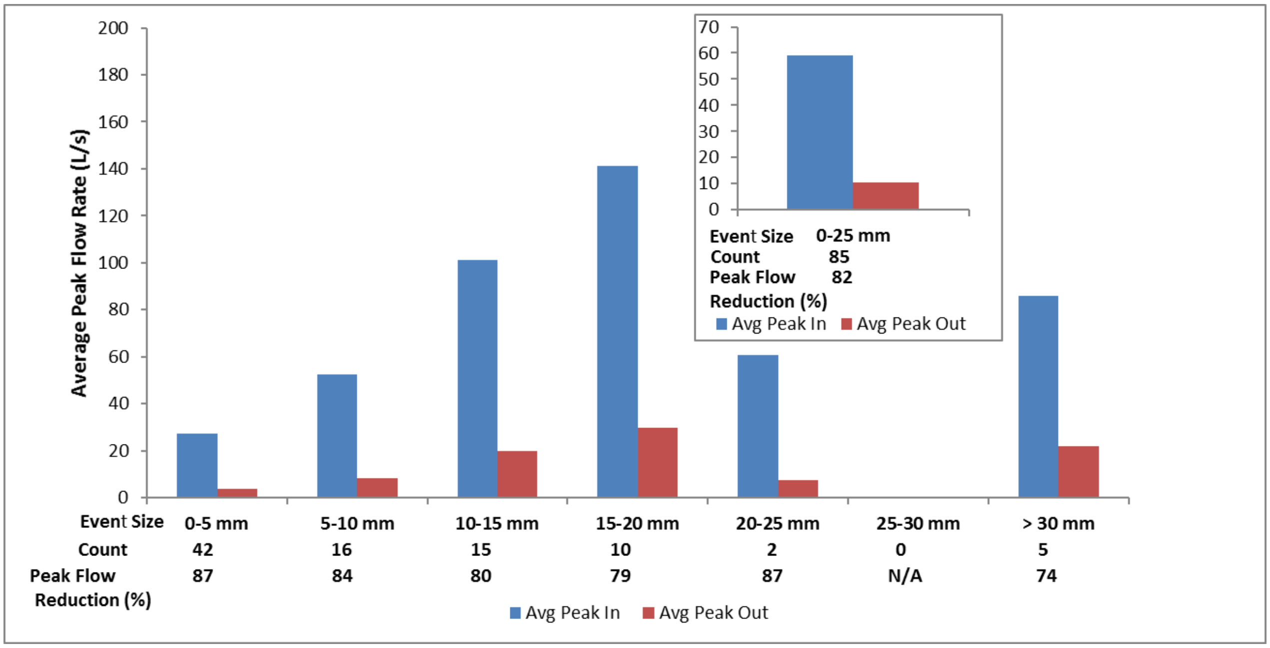

Figure 4-9: Mean peak flow reductions measured at WW-2

By reducing volume and peak flow using the bioretention systems and permeable pavers implemented at Wychwood, the runoff frequency and volume rates are significantly reduced across all events. This is expected to reduce stress loads on downstream stormwater conveyance systems by reducing the frequency of potentially damaging surcharge events. Volume and peak flow reduction can also reduce the frequency of maintenance activities and extend the lifespan of stormwater infrastructure. It is anticipated that due to climate change, the frequency of high intensity events will increase, indicating the benefits of volume and peak flow reduction provided by green infrastructure will have a lasting positive impact.

4.4.1 Hydrologic Response to Selected Events

Infrastructure resiliency is provided by reducing or delaying the hydrologic response of the event. This is particularly important for municipalities with aging infrastructure during events with high intensities. Although LIDs are designed for most moderate magnitude events, the detention storage provided by these systems is what drives the reduction in peak flows during large events. To demonstrate the degree in which the LID features at Wychwood detain flows, hydrologic responses for selected events are presented.

Figure 4-10 presents the hydrograph for a 34.6 mm event in November 2016 at WW-1. Outflow was only observed for the second half of the event, and the site provided a 94 per cent peak flow and total volume reduction. Additionally, a lag time of 13 hours after the start of rain, and a lag time for peak flow of just over an hour was observed at WW-1.

Figure 4-11 shows a hydrograph for the same 34.6 mm event at WW-2. Overall, this site achieved a 66 per cent volume reduction and an 80 per cent peak flow reduction for this event. These results are typical for events >30 mm at the WW-2 monitoring station.

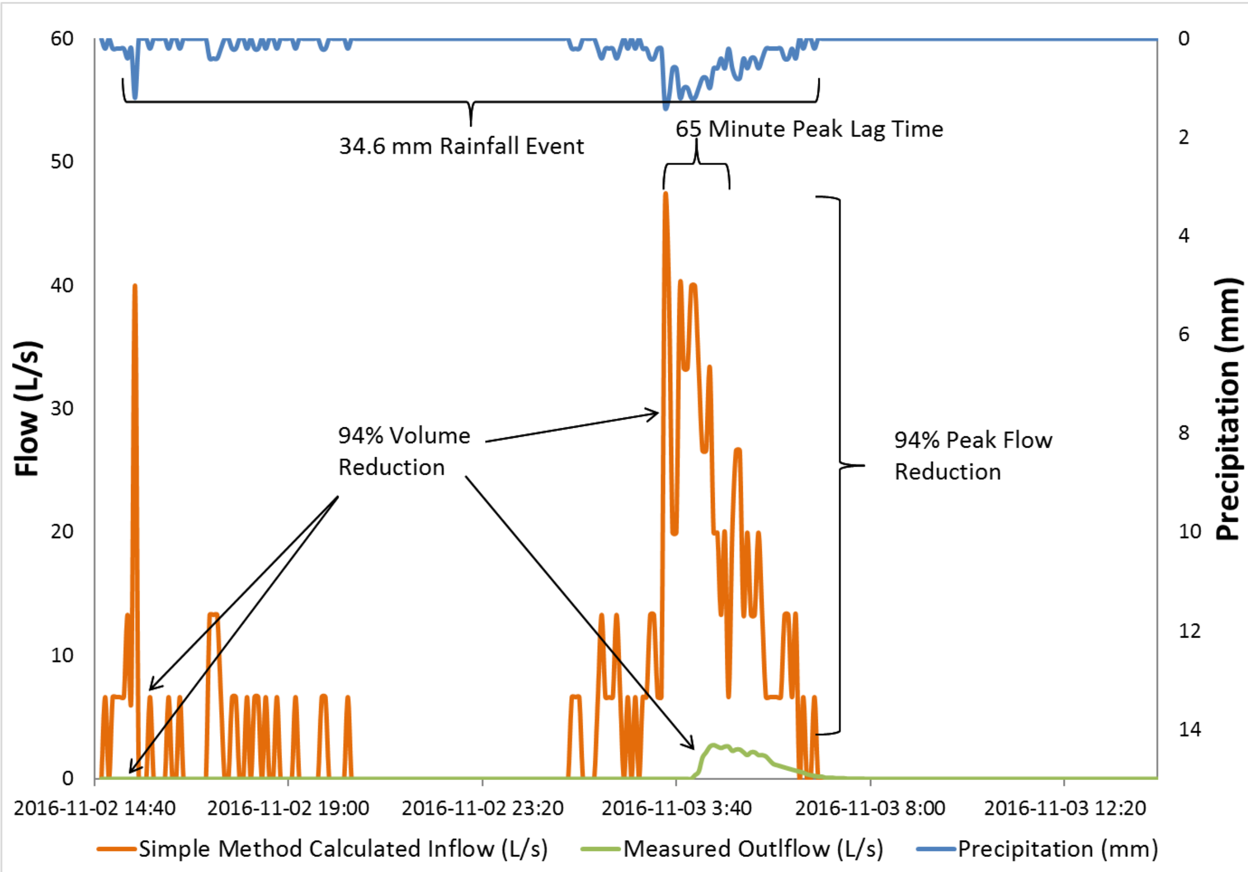

Figure 4-10: Hydrologic summary of the November 2nd-3rd 2016 rain event at WW-1 (34.6 mm)

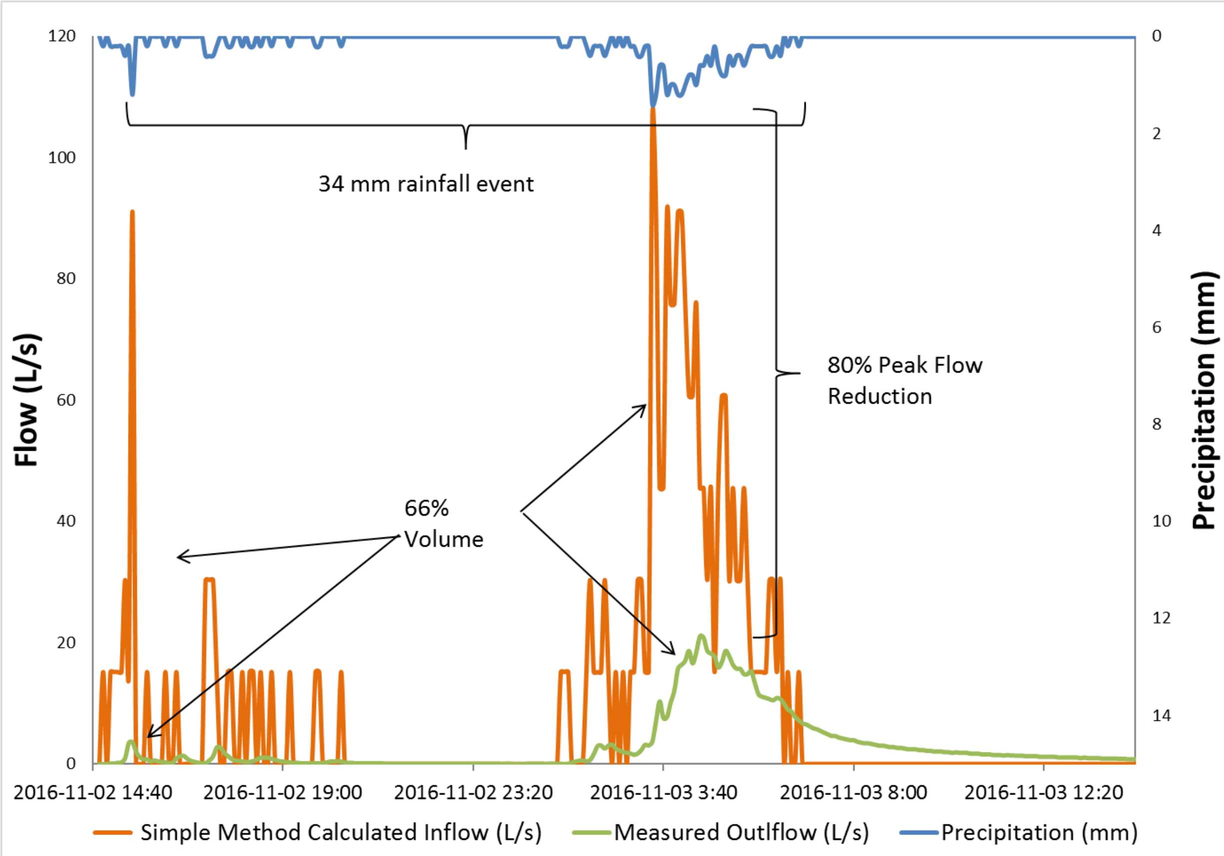

Figure 4-11: Hydrologic summary of the November 2nd-3rd 2016 rain event at WW-2 (34.6 mm)

As is apparent from the above results, hydrologic results measured at the WW-1 monitoring location provide better results than those at WW-2. This is likely because catch basin inlets within the western catchment provide preferred conveyance for inflow from the roadway directly into the underdrain within the infiltration trench. This design reduces the lag-time from the start of rain fall to observed outflow at WW-2 for large events or events with high intensity. Further, flow contribution from the high groundwater table affects the western catchment of the site. This additional flow contribution is removed during analysis using baseflow separation techniques, but with this added flow contribution, significant portions of the storage area within the infiltration trench become saturated and during events the storage area within the trench is reduced. These results in comparison to WW-2 for the same event indicate the impact that observed higher groundwater levels within the western catchment have on overall site volume and peak flow reduction. Further, inlet design has a significant impact on whether the full features' runoff storage capacity is used in that the bioswale in the eastern catchment (WW-1) receives most of its runoff through wide curb-cuts and a long-rolled curb inlet (Figure 4-12). This design better utilizes the storage volume on the surface of the swale and enhances its performance, resulting in greater lag-time between peaks and increased volume and peak flow reduction. Although the enhanced swales within the western catchment also have rolled curb inlets, the sod layer was installed slightly higher than the rolled curb, allowing runoff to flow along the edge of the sod directly into the catch-basins (Figure 4-13). This bypass is often observed during the growing season.

Figure 4-12: Curb-cut and Rolled Curb Inlets to Bioswale

Figure 4-13: Rolled Curb Inlets to enhanced swale and catch-basin location

Events with high intensity precipitation have the potential to cause localized flooding as well as cause significant erosion impacting runoff water quality. The response of the LID controls during a short duration high intensity event measured at WW-1 and WW-2 are provided in Figure 4-14 and Figure 4-15. This August event had a total rainfall depth of 15.2 mm, with almost half of that depth occurring in one 20-minute period, which produced a short lag-time between rain fall and observed outlet flow. The LIDs collectively produced a 94 per cent peak flow and 85 per cent total flow reduction observed at the WW-2 monitoring station (Figure 4-15). Observed flows at WW-1 indicate that a significant portion of flow was managed by the bioswale for this intense event, limiting the peak flow and total outlet flow to 1 per cent of estimated inlet flow.

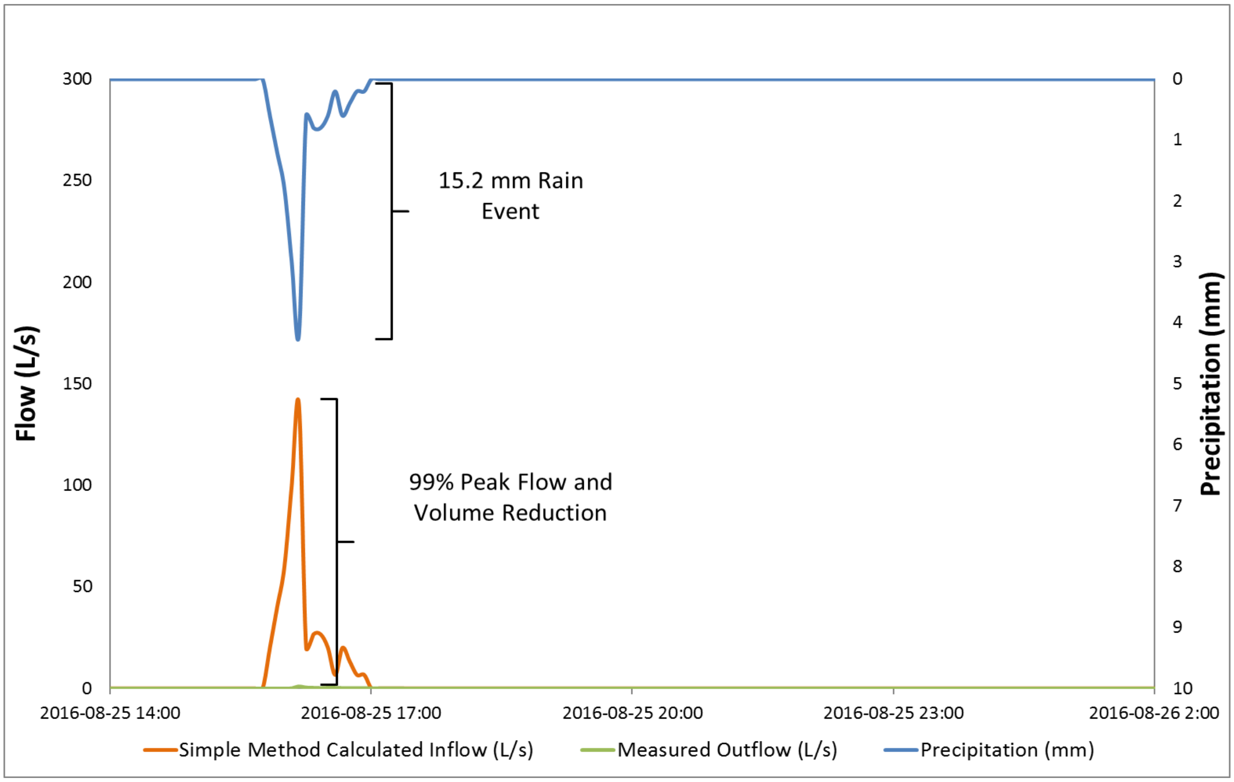

Figure 4-14: Hydrologic summary of the August 25th 2016 rain event at WW-1 (15.2 mm)

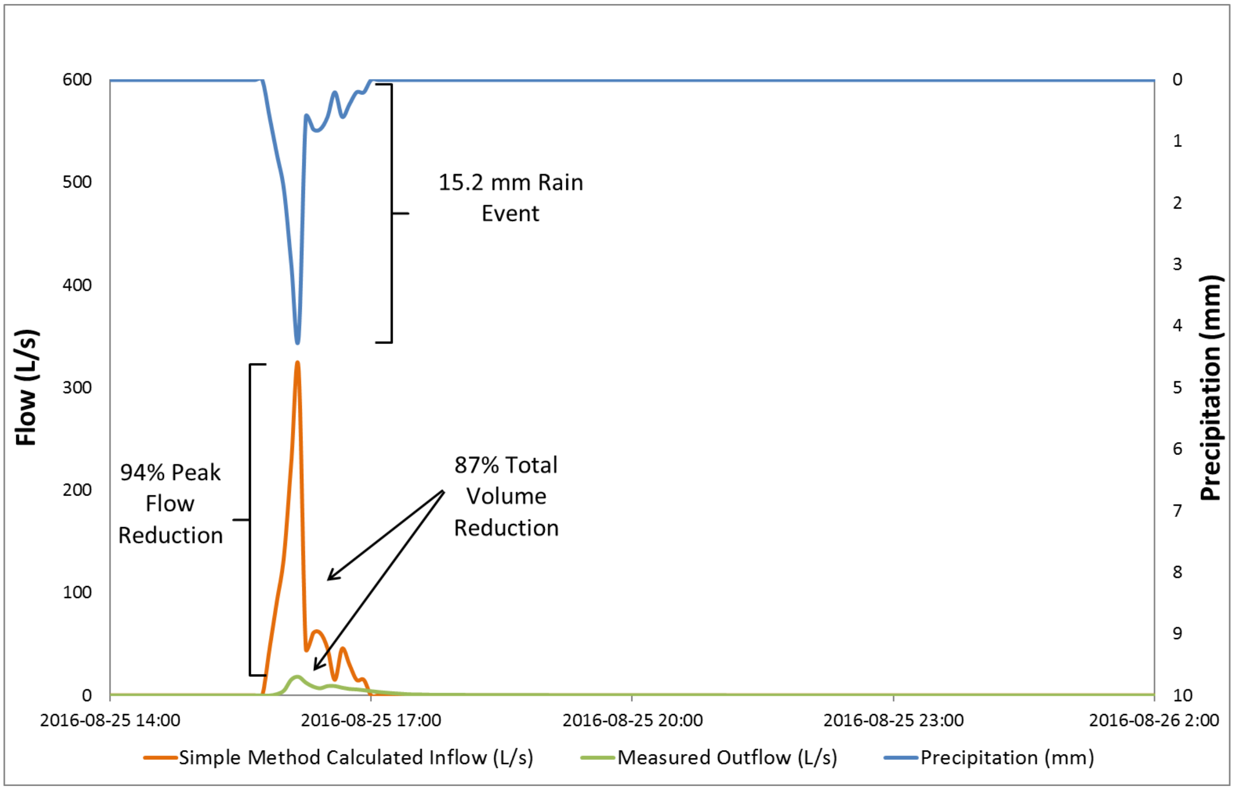

Figure 4-15: Hydrologic summary of the August 25th 2016 rain event at WW-2 (15.2 mm)

During the two-year monitoring period, CVC has recorded initial volume and peak flow performance results for a range of event sizes and intensities. These results not only provide initial performance indicators but also will be used as a baseline to assess performance over time, as the site continues to stabilize and responds to lot level landscape changes implemented by home owners. Additionally, this data will be used to further refine an inflow model by guiding granular refinements to improve inflow volume estimations as the site catchment characteristics change. CVCs monitoring group will continue to monitor hydrological conditions over the course of the subdivisions life-cycle to assess long-term performance and enhance design and construction techniques of LID features for future development.

4.4.2 Long-Term Monitoring for Asset Management

Typically, a feature's best performance is observed in the early stages of its life-cycle. As the feature ages, performance is expected to decline but the rate of decline is unknown and unique to the feature's design and catchment area. Long-term monitoring is the most effective way to identify stages in performance decline and to determine when maintenance and rehabilitation is required. Additionally, long-term monitoring is necessary to inform the municipalities asset management program. Now that baseline water quantity performance data has been collected from Wychwood, CVC can advise the City of Brampton on when site maintenance is required if monitoring were approved to continue beyond the five-year program. Monitoring could be adjusted temporality to focus on tracking the core components of site performance, then scaled back up if issues identified need further investigating. Since asset management is now a requirement to access provincial funding, long-term monitoring can track and document stormwater assets and help the City make the case for provincial funding support (MMAH, 2019).

4.4.3 Water Levels and Ponding Depths

As part of the monitoring plan prepared by CVC, continuous infiltration and ponding depth monitoring was to be implemented within the bioswale and grass swales above the infiltration trench. This monitoring would involve installing deep and shallow wells with continuous water level loggers to determine infiltration rates and ponding depths over time. This monitoring technique would also inform infiltration performance of the feature during cold winter temperatures when the soil layers are thought to be frozen and infiltration is potentially limited. However, the monitoring team did not proceed with this phase of the project as support for the installation of shallow and deep wells within the features was not provided by the developer pre-assumption, citing concerns with disrupting the LID features' underlining components. Figure 4-16 provides a visual graphic of the approximate depth each type of well would need to be installed to monitor infiltration rates and frequency of ponding.

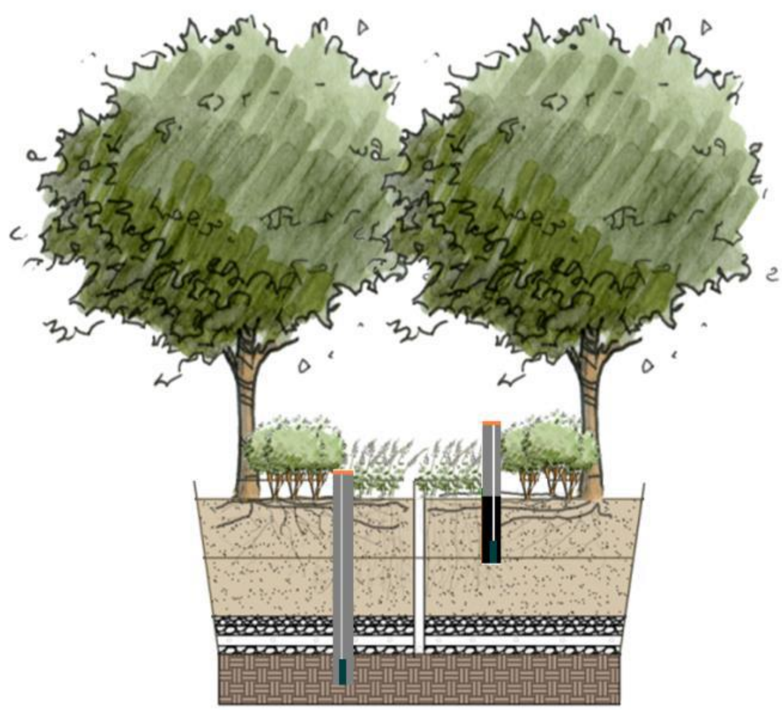

Figure 4-16: Example bioretention cell cross section with monitoring wells

Monitoring infiltration rates continuously within the features is not an ECA monitoring requirement. In the absence of continuous infiltration monitoring, CVC has been collecting photos of the condition of the features before, during, and after precipitation events. To date, CVC has yet to observe any residual precipitation ponding within the infiltration features 24-hours after a precipitation event. The 24-hour maximum surface ponding time is less than the time required for one mosquito breeding cycle and is a standard guideline for indicating if any maintenance or remediations are required.

4.5 Water Quality

Installing stormwater quality controls is important so that development or urbanization does not degrade the water quality of receiving water bodies. CVC's Stormwater Management Criteria (CVC, 2012) stipulates that all watercourses and water bodies such as Lake Ontario within CVC's jurisdiction are classified as requiring, at a minimum, an enhanced level of protection with 80 per cent TSS removal.

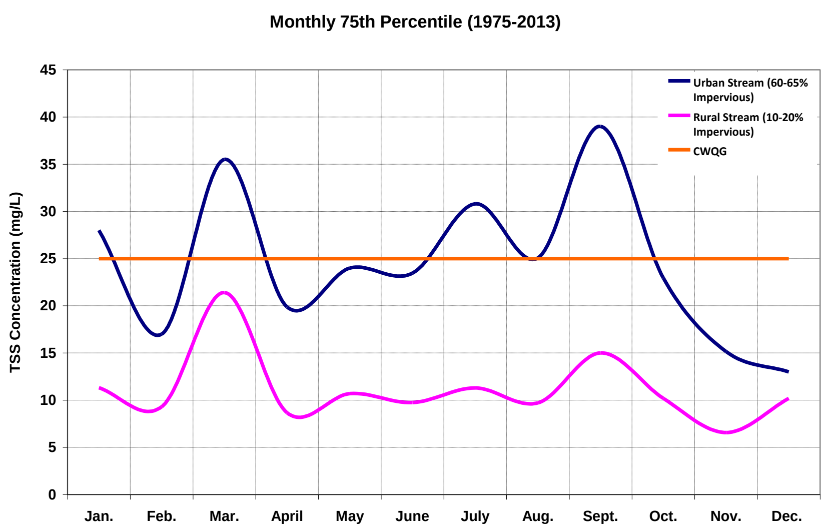

Figure 4-17*:* Monthly 75th percentile total suspended solids concentration compared at an urban vs rural catchment area

For the last three decades, Ontario stormwater practitioners have been achieving enhanced water quality control by constructing end-of-pipe wet facilities (i.e. wet ponds, wetlands and hybrid ponds). In conventional end-of-pipe wet stormwater management infrastructure, the main treatment mechanism for reduction of particulates is through settling. This mechanism is less effective in removing smaller particles for shorter time frames. Similarly, dissolved pollutants often go untreated through conventional stormwater infrastructure. Nutrients as well as many hydrocarbons are often associated with fine particles (**Appendix D**).

The 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. 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 per cent suspended solids, the typical removal efficiency for total phosphorus is 40-50 per cent.

Figure 4-17 shows the difference in TSS concentration between an urban (impervious cover between 60-65 per cent) stream that receives stormwater from upland developments (with conventional end-of-pipe wet facilities) as the dark blue line and a rural stream (pink line) with 10-20 per cent impervious cover during dry ambient conditions in the Credit River Watershed. The comparison demonstrates 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 result is due to the lack of water quality control in the stormwater management ponds. To further support these conclusions, a USGS study (USGS 2008) conducted in Wisconsin, showed that during a seven year period of study, LID on average yielded 20 per cent less sediment per acre (39 lb/acre) when compared to a conventional development with a traditional stormwater management basin (49 lb/acre).

CVC’s Water Quality Strategy (CVC, 2009) further identifies parameters of concern (PoC) that must meet the respective provincial or federal water quality objectives. Table 4-6***: Provincial Water Quality Objectives (PWQOs) for selected parameters of interest*** summarizes PWQOs for many of the parameters that are being monitored at Wychwood. Although these objectives were not specifically developed for stormwater discharges, Environment Canada, MECP, and the U.S. EPA have long recognized that urban stormwater is a major contributor to pollutant loading to our creeks, rivers and Great Lakes. The guidelines listed in the table provide context for planning and water resource management. These guidelines will be used as a basis for assessing water quality performance of LID practices and indicate which pollutants are particularly well controlled. Implementing best management practices such as treatment trains that incorporate LID can help achieve control, so the quality of the receiving water bodies is protected or improved.

Table 4-6: Provincial Water Quality Objectives (PWQOs) for selected parameters of interest

Sources: Water Management Policies, Guidelines, Provincial Water Quality Objectives of the Ministry of the Environment (July 1994, Reprinted February 1999); Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. (2015).

Parameter	Unit	PWQO	CCME
Water Quality			
Aluminum (Al)	µg/L	75 for pH between >6.5 and 9	100 if pH >=6.5
Cadmium (Cd)	µg/L	0.1 to 0.5 depending on hardness (Interim)	0.09
Chloride (Cl)	mg/L	N/A	120 (640 short term)
Copper (Cu)	µg/L	1 – 5 depending on hardness (Interim)	2 – 4 depending on hardness
Iron (Fe)	µg/L	300	300
Lead (Pb)	µg/L	1 – 5 depending on hardness (Interim)	1 – 7 depending on hardness
Nickel (Ni)	µg/L	25	25 – 150 depending on hardness
Zinc (Zn)	µg/L	20 (Interim)	30
Total Phosphorus (TP)	mg/L	0.02 (Interim value to eliminate nuisance concentrations of algae in lakes)	<4 to >100 depending on existing conditions
Nitrate (NO_3)	mg/L	N/A	13 (3 mg/L as NO_3-N)
Nitrite + Nitrate (NO_2 + NO_3)	mg/L	N/A	N/A
Total Suspended Solids (TSS)	mg/L	N/A	For clear flows, maximum increase of 25 mg/L from background levels for any short-term exposure (e.g., 24-h period). Maximum average increase of 5 mg/L from background levels for longer term exposures (e.g., inputs lasting between 24 h and 30 d).
Other			
Temperature	°C	Narrative standard, with some numeric components	Narrative standard

Water quality control of LID practices is best measured as load reduction, which considers all volume and pollutant reduction mechanisms. Load reduction in LID practices is influenced by several mechanisms: volume reduction (e.g., infiltration and evapotranspiration), filtration, settling, and adsorption. While infiltration decreases pollutant loadings to surface water, it provides a pathway for water-soluble pollutants (e.g., nitrates and chlorides) to reach groundwater. Filtration, settling, and adsorption removes pollutants from surface water by retaining them in the filter media.

Event mean concentrations (EMCs) are the flow-proportional average concentrations of water quality parameters during a storm event.

The EMCs and the runoff volume determine the pollutant loads from a site and are representative of average pollutant concentrations over a runoff event.

4.5.1 Pollutant Load Reduction

Pollutant load is calculated by multiplying the event volume of stormwater by the event-mean concentration (EMC) of the parameter of interest. EMCs are flow-proportional average concentrations of water quality parameters during a storm event, and when multiplied by the total runoff volume they give the total mass load of the parameter being conveyed by the event. The load reduction for the LID features at Wychwood was calculated by comparing the estimated influent load with the measured effluent load. The LID features at Wychwood were designed to meet the enhanced water quality treatment guideline of 80 per cent total suspended solids (TSS) removal (TMIG, 2012).

Due to the nature of the LID features at this site, it is impossible to directly measure the influent volumes and concentrations as there is no single inlet to the features. The influent volumes were estimated using the simple method described in **Appendix C**. As there was no water quality control site located at Wychwood, the median EMC values from CVC's monitoring site LV-1 (Lakeview Neighbourhood) were used as estimated influent concentrations. This site is located in Mississauga, about 17.5 km south-east of Wychwood, and has traditional curb and gutter to inlet and storm sewer pipe systems. LV-1 has a lower percent imperviousness (28 per cent) compared to WW-1 (45 per cent) and WW-2 (48 per cent), as it's an older neighbourhood with smaller houses and driveways relative to the size of the lots. Results are presented to provide a comparison between two residential neighbourhoods similar in size and vehicle traffic. From 2012 to 2015, 49 water quality EMC samples were collected at LV-1 using the same techniques used at Wychwood. A comparison of monitoring projects with both similar and dissimilar components is a common way to present data results simply for comparison in other published studies (Hasse et all, 2018)

For events with measured precipitation and estimated inflow but no effluent volume was observed (i.e. outflow volume was equal to 0), the estimated pollutant load reduction was 100 per cent. For events where, effluent discharge was recorded but no water quality sample was collected, loads were computed with the median effluent value from the collected samples at WW-1 and WW-2 separately. The influent and effluent loads for 2016 and 2017 for sampled events, unsampled events, zero-outflow events, and the load reduction for all events for the parameters of concern at WW-1 and WW-2 are presented in Table 4-7 and Table 4-8, respectively.

Results for cadmium, lead, and nickel are not presented due to the large number of non-detects in the effluent data at both sites, and chloride results are not presented due to the seasonality of the results and the limited number of sampled winter events.

Table 4-7: WW-1 estimated water quality treatment performance summary for 2016-2017

Parameter (g)	Sampled Events (n = 20[a])		Unsampled Events (n = 34[b])		Zero-outflow events (n = 71)		All events (n = 125)
	Total Estimated Influent Load (g)	Total Measured Effluent Load (g)	Total Estimated Influent Load (g)	Total Estimated Effluent Load (g)	Total Estimated Influent Load (g)	Total Effluent Load (g)	Total load reduction (%)
TSS	182025	5641	194007	2479	198093	0	99%
TP	1023	84	1102	30	1120	0	96%
PO_4	472	72	509	20	517	0	94%
NO_2+NO_3	1220	129	1314	39	1335	0	96%
Al	1075	87	1230	33	1214	0	97%
Cu	61	5	70	2	69	0	97%
Fe	2066	118	2365	48	2334	0	98%
Zn	263	7	301	3	297	0	99%

[a] 22 sampled events for TSS
[b] 32 unsampled events for TSS

Table 4-8: WW-2 estimated water quality treatment performance summary for 2016-2017

Parameter (g)	Sampled Events (n = 18)		Unsampled Events (n = 66)		Zero-outflow events (n = 6)		All events (n = 90)
	Total Estimated Influent Load (g)	Total Measured Effluent Load (g)	Total Estimated Influent Load (g)	Total Estimated Effluent Load (g)	Total Estimated Influent Load (g)	Total Effluent Load (g)	Total load reduction (%)
TSS	288082	55376	507730	83245	51784	0	84%
TP	1628	275	2870	457	293	0	85%
PO_4	752	203	1325	227	135	0	81%
NO_2+NO_3	1941	1377	3422	2505	349	0	32%
Al	1766	573	3113	983	317	0	70%
Cu	100	24	177	44	18	0	77%
Fe	3394	699	5982	1235	610	0	81%
Zn	431	53	760	98	78	0	88%

Based on representative influent data from LV-1, WW-2 achieved a total load reduction for TSS of 84 per cent, and WW-1 achieved a total estimated load reduction for TSS of 99 per cent. Overall, the Wychwood subdivision exceeds the target of 80 per cent TSS removal, and the eastern catchment and bioswale greatly exceed the target. WW-2 had a load reduction of at least 70 per cent for each of the parameters of concern with the exception of nitrate + nitrite. This may be due to a combination of most nitrate salts being water soluble, and thus not being captured with the filtration of particulate bound pollutants, and the possible addition of nutrients from the plants in the bioswale feature or fertilizers added to residential landscaping. WW-1 had a much higher load reduction for all parameters, largely due to a higher volume reduction as the bioswales storage capacity is not impacted by the seasonal fluctuations in groundwater levels.

4.5.2 Event Mean Concentrations

While loading comparisons are preferred, EMCs also demonstrate the reduction in concentration with treatment of the LID system. As many pollutants are particulate bound, TSS concentrations are often used as a surrogate for general stormwater quality. A boxplot comparing the range of TSS values found at Wychwood with the TSS values seen at a number of control sites is presented in Figure 4-18. The control sites used are LV-1 representing traditional curb and gutter infrastructure, LV-2, which is a traditional grass swale located in the Lakeview neighbourhood, and median values from the National Stormwater Quality Database (NSQD). Water quality sampling at LV-2 was carried out using the same methods as WW-1, WW-2, and LV-1, and the NSQD values were filtered for USEPA Rain Zone 1 and residential primary land use.

The median effluent EMC information for TSS and other parameters of concern for sampled events at Wychwood are provided in Table 4-9 along with the median values at LV-1, LV-2, and the filtered NSQD median values. The PWQOs and CCME guidelines are also presented for comparison.

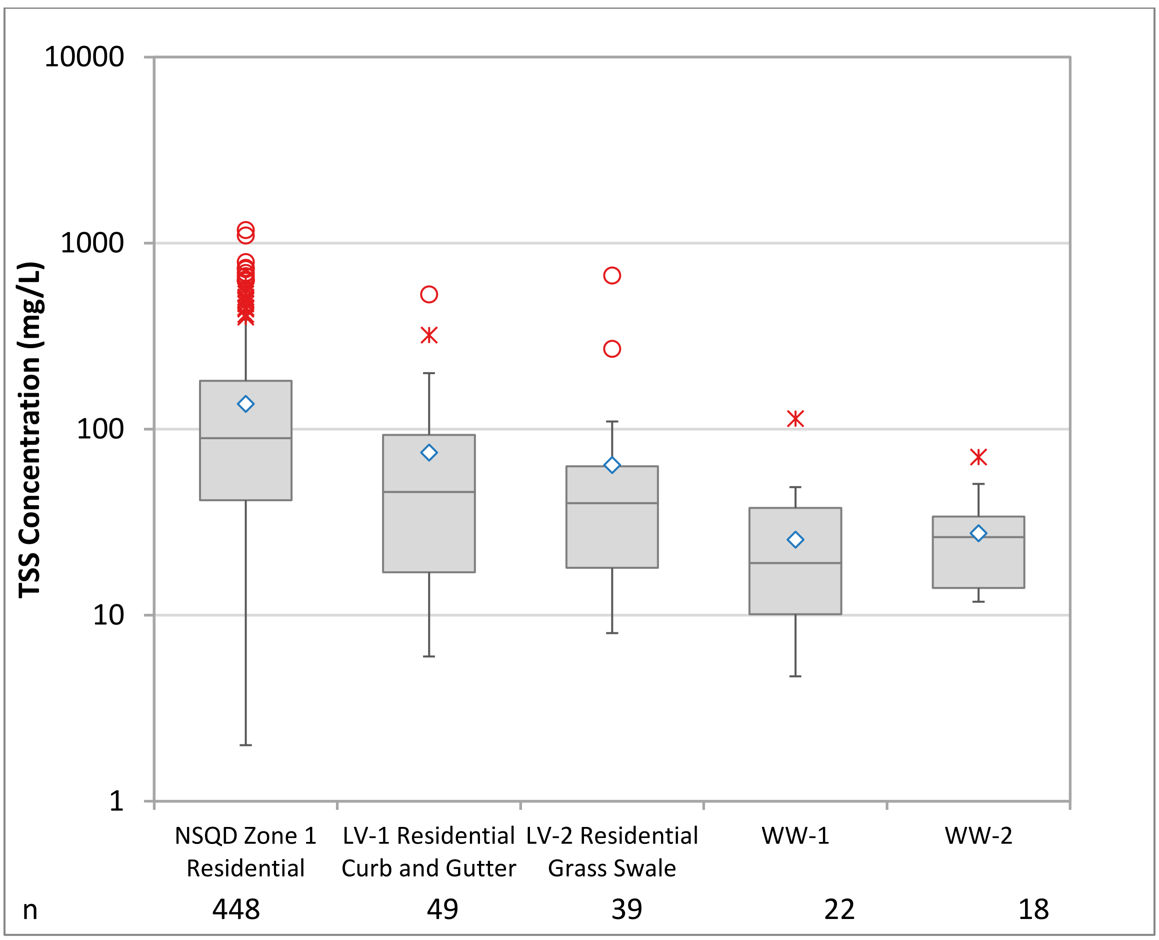

Figure 4-18: Box plot of Wychwood TSS results compared with residential control sites, road ROW values, and NSQD values

Table 4-9: Wychwood Effluent EMC results compared to control locations and guidelines

Parameter	Units	NSQD	LV-1	LV-2	PWQO	CCME	WW-1	WW-2
TSS	mg/L	89.5	44.5	40	N/A	N/A[a]	19.1	26.25
TP	mg/L	0.627	0.255	0.25	0.03[b]	N/A	0.232	0.144
PO_4	mg/L	0.3	0.125	0.15	N/A	N/A	0.156	0.072
NO_2+NO_3	mg/L	0.07	0.305	0.57	N/A	3[c]	0.302	0.79
Al	µg/L	N/A	282	333	75[d]	100[d]	252	310
Cu	µg/L	20	15.7	17.7	5	2[e]	12.35	14.0
Fe	µg/L	N/A	537.5	441	300	N/A	368	389.5
Zn	µg/L	111	67.5	47.3	20[f]	30	25.7	30.8

[a] CCME guidelines for TSS are based off an increase from background levels. For clear flows, the limit is an increase of 25 mg/L for short-term exposure and 5 mg/L for long term exposure, for high flows the limit is an increase of the higher of 25 mg/L or 10% the background concentrations

[b] Interim value to eliminate excessive plant growth

[c] Guideline is for Nitrate

[d] Guidelines for pH values above 6.5

[e] Ranges based on hardness, most conservative value used based on the observed hardness at WW

[f] Interim value

Note: WW and LV are effluent results

PWQO and CCME guidelines presented are for receiving waters

The mean, median, lower quartile, upper quartile, and maximum TSS EMCs are lower for Wychwood than all of the control sites, indicating that it's very likely that the LIDs installed at Wychwood lower the concentration of suspended sediment in the stormwater it treats. These low values are despite the large amount of private landscaping works observed at the site, which may be contributing a lot of sediment. The median EMCs at Wychwood are lower than the LV-1 and NSQD concentrations for all parameters other than NO_2+NO_3 and PO_4 for WW-2. While the major benefit for LID features with respect to water quality is the load reductions, these results demonstrate that these features are also likely lowering the concentration of most of the parameters of concern.

Both WW-1 and WW-2 exceed guideline values for TP, copper, iron and zinc. As most of the parameters are lower than the estimated influent values, it is likely these exceedances would be even greater if not for the presence of the LID features. In addition, the PWQOs and CCME guidelines were developed for freshwater waterbodies and not specifically for stormwater discharges.

Over the monitoring periods, there were many landscape alterations made by residents to the front and rear portions of their properties. This involved the movement of sod and installation of landscaping material such as gravel and impervious pavers to extend walkways, driveways, add tree boxes and increase the overall impervious cover. The movement and storage of landscape materials could be the source of additional nutrients and metals increasing the concentration within the samples. The presence of baseflow at this site may also influence the EMC concentrations, although for most events the volume of the stormflow is much higher than the baseflow. Water chemistry testing of this baseflow has been budgeted for the 2019 monitoring year to help quantify any potential contribution to the effluent.

Overall, the Wychwood water quality analyses indicates that the LID performance is improving water quality by reducing the total load of parameters of concern entering the local stormwater system and ultimately the Credit River. In addition, there is an estimated reduction in concentration of most of the parameters. Other summaries and comparisons including time series plots and graphical statistical summary plots can be found in **Appendix D**.

4.5.3 Water Quality Response to Selected Events

The ECA for the subdivision required that two grab samples be taken each year in a catch basin downstream of WW-2 during storm events after a minimum of 15 mm of rain had fallen. In 2016, effluent grab samples were taken on August 16 and November 3. These results, along with the effluent composite EMC results for WW-1 and WW-2 for those events, are displayed in Table 4-10. A grab sample collected in May of 2017 is also included but due to equipment failure during this event no composite sample was collected at either WW-1 or WW-2 monitoring stations. A graph showing the outflow for the November 3 event and when the grab and composite samples were taken is shown in Figure 4-19.

Table 4-10: Wychwood Effluent EMC results from storm events on 2016-08-16 and 2016-11-03

Date	Site	TSS (mg/L)	TP (mg/L)	PO4 (mg/L)	NO2+NO3 (mg/L)	Al (µg/L)	Cu (µg/L)	Fe (µg/L)	Zn (µg/L)
2016-08-16	WW-1	4.7	0.044	0.0174	0.302	83.3	7.45	76.8	37.8
	WW-2	26.5	0.142	0.0764	0.488	358	10.8	386	32.3
	WW-Grab	4.6	0.09	0.0665	0.698	185	6.53	207	29.3
2016-11-03	WW-1	16.2	0.254	0.214	0.848	311	14.6	398	17.4
	WW-2	32.3	0.176	0.213	0.665	347	15.2	411	24.8
	WW-Grab	7.9	0.147	0.127	1.62	223	7.14	161	24.5
2017-05-05	WW-Grab	5.6	0.09	0.0772	1.14	216	6.56	173	17.1

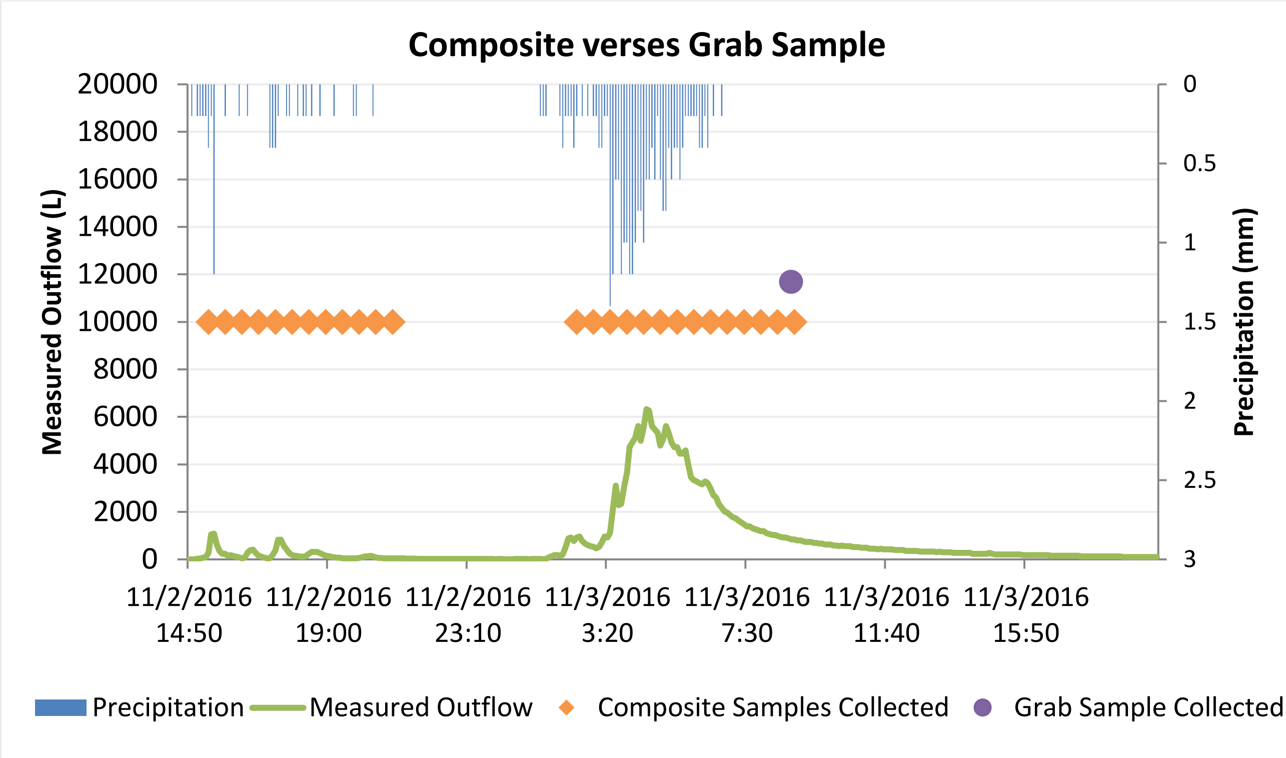

Figure 4-19: Outflow during rain event on November 2nd to 3rd 2016, timing of composite sample collection verses timing of grab sample collection.

The grab sample concentrations are lower than most of the EMC values at both sites, with the exception of nitrate + nitrite. The TSS grab sample concentrations are at least 75 per cent lower than the WW-2 EMC, which is located just upstream, for both events. This may be due to the timing of the grab samples, occurring later in the events after most of the precipitation had fallen. For many parameters, the highest concentration is often during the first flush, the period at the beginning of the event where the stormwater collects contaminants that have built up over the previous dry period. Figure 4-19 shows how the samples collected to create the composite EMC were during all parts of the event: the lower flows at the beginning due to the first few millimeters of rain, the rising limb of the hydrograph response to the bulk of the rain, the peak of the hydrograph, and the falling limb of lower flows after the rain has stopped. The grab sample, however, only represents a particular moment during the falling limb. The results of these events display why a grab sample may not be a representative method for determining parameter concentration for an event, especially if it's taken after a large amount of rain has already fallen (as directed by the ECA for Wychwood).

4.5.4 OGS Sediment Samples

In July 2017, the sediment in four of the OGS units at Wychwood was sampled for soil chemistry, and the results are presented in Table 4-11. OGS-1, OGS-3, and OGS-5 capture and treat stormwater before discharging it to the entrance of the subdivision (where it is then measured at WW-2). OGS-7 is within the catch basin inlet to the bioswale (Figure 3-3) located on the east side of Honour Oak Crescent. Outflows from the OGS-7 unit are measured as part of the WW-1 monitoring station. As the OGS results are from sediment that has collected through the lifetime of the feature, they cannot directly be compared to the EMC concentrations. OGS-units were placed online in spring of 2015 with an estimated 90 events occurring from spring 2015 to time of sediment sample collection in December of 2016. However, since the site was not assumed at this time, the frequency of OGS maintenance and sump sediment removal is unknown. Based on limited maintenance records attained by CVC from the consultant, each OGS unit was cleaned out at least once between spring of 2015 and December 2016. Sediment in the OGS units is removed and disposed of at a local landfill. Prior to disposal, the contents within the OGS sump are tested for hydrocarbons to determine the appropriate waste class and cost for disposal. Although these results cannot be directly compared to EMCs and total pollutant loads discussed in section 4.4.1 and 4.4.2, the results show high concentrations of aluminum, iron and phosphorus within the sump material.

Table 4-11: OGS sediment sample results

Parameter	Unit	OGS-1	OGS-3	OGS-5	OGS-7
Acid Extractable Aluminum (Al)	µg/g	6600	7000	6700	5600
Acid Extractable Cadmium (Cd)	µg/g	0.16	0.25	0.3	0.23
Acid Extractable Copper (Cu)	µg/g	40	44	42	27
Acid Extractable Iron (Fe)	µg/g	12000	14000	12000	11000
Acid Extractable Lead (Pb)	µg/g	14	16	23	16
Acid Extractable Nickel (Ni)	µg/g	14	14	17	11
Acid Extractable Phosphorus (P)	µg/g	720	720	870	700
Acid Extractable Zinc (Zn)	µg/g	170	180	200	140

Although many of these parameters are known to be sediment bound, results indicate the importance of using OGS units and/or specially designed catch basins to trap sediment and improve water quality. Another sample will be collected near the end of the monitoring term and analysis of the trends in water chemistry will provide further information on the effectiveness of the OGS units in stormwater pre-treatment and the impact maintenance has on the removal efficiency of parameters of concern.

4.6 Stormwater Design Criteria: Post-Development Assessment

As part of CVCs performance monitoring assessment of the stormwater control features at Wychwood, monitoring results and a post development performance model was developed and used to determine the site stormwater management performance in comparison to pre-development design criteria provided in section 3.4.3.

CVC has developed a site model using the Environmental Protection Agency's Stormwater Management Model Version 5 (SWMM) calibrated with monitoring data collected over the course of the study period. SWMM was used for the model comparison as it has an enhanced LID module component and more effectively considers the process in which LIDs infiltrate runoff and how the LIDs can continue to absorb further runoff as storage capacity becomes available. For this reason, SWMM was used instead of Visual OttoHymo, which was used by the design consultant for design estimations for peak flows and water balance. A full technical report was prepared to provide details on the techniques used for the model as well as interpretation of the results. This report can be found in **Appendix J**. For the purposes of this report the results pertaining to the design criteria from section 3 are provided.

- Water quality control – Enhanced water quality treatment per the MOE Stormwater Management Planning and Design Manual, i.e. long-term removal of 80 per cent suspended solids (MOE, 2003)

Estimated pollutant loading results for both sampled and unsampled events collected during the monitoring period are presented in Table 4-12. The table includes results collected through onsite monitoring over the two-year study period and results produced through a calibrated SWMM model. The results from both methodologies suggest the site is meeting the enhanced water quality objectives (long term 80 per cent TSS reduction) at the WW-2 total site monitoring station.

There is some variation in the results between modelled and monitored results for total loads presented. This is to be expected as modelled load in and out are direct outputs from SWMM and are calculated at each time step and summed over the observed period of flow. Conversely, monitored influent loads are calculated for each precipitation event using the simple method and monitored effluent loads are calculated by multiplying the volume of stormwater by the EMC results. According to a published review comparing the accuracy of modelling techniques and measured flow data, a 10 per cent difference in results is considered a “Very good” comparison (Morias, et al, 2007). Given the results presented in Table 4-12 are within this range, this demonstrates a degree of confidence in the accuracy of measured and modelled results.

Table 4-12: TSS and TP SWMM Model and Monitored result comparison during January 2016-December 2017 study period

Water Quality Analysis Comparison				
	Monitored Results		SWMM Model Results	
Parameter	TSS	TP	TSS	TP
Total Influent load (kg)	847.6	4.8	894.4	5.1
Total Effluent load (kg)	138.6	0.7	159.4	1.3
Load reduction (mass)	709.0	4.1	735.0	3.8
Load reduction (%)	84%	85%	82%	75%

More detailed information on total modelled loads in comparison with monitored load reduction is provided in the Wychwood Modelling report in Appendix J.

- Erosion control – Manage, detain or reuse all rainfall events up to 15 mm storm event over the entire site

A summary of selected events where approximately 15 mm of rainfall had accumulated at Wychwood is provided in Table 4-13. Outflow and lag time results from the total site monitoring station (WW-2) for selected events indicates the site does not completely meet the erosion control criteria to manage, detain or reuse all runoff from a 15 mm event. For erosion control measures to be effective, a reduction in peak flows and runoff flow lag-time are necessary to limit erosion and stress on downstream infrastructure. However, during monitoring site visits and maintenance inspections no evidence of extensive erosion was observed within the site or in the downstream receiver within the roadside ditch on Churchville road (Figure 3-12).

Table 4-13: Observed Event Flows from a 15 mm event

Date	Rainfall depth (mm)	Rain Duration (hrs)	Antecedent Dry Period (Days)	Observed Runoff Volume (m3)	Observed peak flow (lps)	Lag Time (min)
2016-08-16	14.6	11.5	20.7	97.25	11.31	355
2017-06-29	14.8	62	4	120.52	67.65	5
2017-08-17	13.8	13	2.4	59.18	25.14	5
2017-08-22	16.2	4.5	4.2	76.72	50.2	20
2017-09-04	10.4	7.7	9.8	38.85	31.38	10

Another way to observe the performance of the site during events producing ~15 mm of precipitation is by converting measured total outflow volumes at the monitoring station to precipitation depth. Figure 4-20 presents event depth results to compare millimeters of precipitation depth stored within the site to precipitation depth measured at the climate station for the same event. For events within this range, the event depth retained within the site varies but does not reach 15 mm. CVC calculates a median depth of 12.9 mm (86 per cent) of measured precipitation is stored within the features for events producing approximately 15 mm.

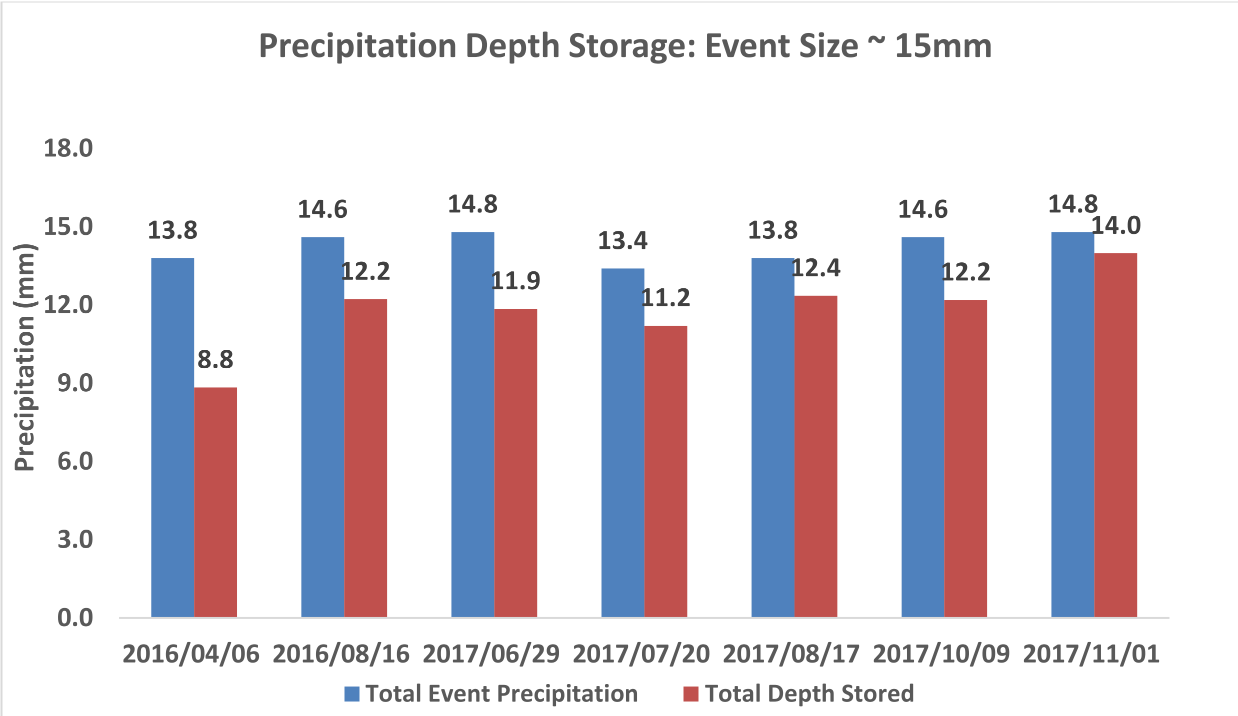

Figure 4-20: Precipitation Depth Stored for events producing approximately 15 mm

The results indicate that for most events of approximately 15 mm in size, a significant portion of the precipitation is retained and managed by the LID features onsite. In reviewing the post-development observed data set, site condition, design assumptions and pre-development site conditions, there are several explanations as to why the site does not successfully reuse runoff from all 15 mm events:

I. The pre-construction groundwater study (Terraprobe, 2010) and monitoring observations at WW-2 indicate a high groundwater table within the western section of the development block. The presence of flow between events indicates that a portion of the infiltration trench may already be saturated (with groundwater), reducing the storage capacity of the feature and its ability to allow stormwater to infiltrate into the surrounding soil.

   During the planning approval stages, CVCs development review staff requested the buffer between the base of the infiltration trench and the observed seasonally high groundwater table to be 1 meter. The design consultant settled on a 0.5 meter buffer which was the depth difference between the designed base of the infiltration trench and the seasonally high groundwater level according to the pre-development hydrogeological study. The study reported a surficial sand layer within the site overlying the glacial till, forming a perched water table identifying a potential source of observed baseflow (Terraprobe, 2010). If the infiltration trench had been constructed with an additional 0.5 meter buffer, the impact of observed high groundwater levels on the performance of the infiltration trench may have been reduced.

II. During the monitoring period, CVC observed significant landscape changes to approximately half of the lots throughout the subdivision. Residents have increased the impervious footprint across the subdivision by expanding driveways and walkways which may or may not have been constructed with a 30 mm sub-base for runoff storage included as part of the original driveway design. Additionally, rear and front yards have been enhanced with interlocking stone patios and poured concrete forms. These lot level alterations have limited available runoff storage volume within the added topsoil provided at construction. When implementing lot level runoff storage features, an anticipated loss of storage is expected as residents have no legal obligation at Wychwood to refrain from altering or removing these features within their property limits. Although built in runoff storage redundancies were part of the site design to limit the risk of extended ponding and flooding, these site alterations are increasing the impervious ratio across the subdivision contributing to increased runoff.

III. Antecedent conditions between events will have a significant impact on the volume of outflow and are not necessarily dependent on accumulated rainfall depth or rain intensity. For three of the selected 15 mm events in Table 4-13, there is a relatively short lag-time between events (2 to 4 days). Given the size of the subdivision catchment area and the tight soils observed within the western block during the pre-development study (Terraprobe, 2010), the site is expected to have an extended residual runoff infiltration period for feature storage space to be completely void. Unfortunately, the groundwater wells installed for pre-development hydrogeological monitoring had been damaged and removed during construction. Continued groundwater monitoring would have assisted in verifying these conditions after the development. The land owner has not granted CVC consent to install additional wells to observe groundwater condition and infiltration rates during the first two years of monitoring.

In the case of Wychwood, the capacity of the downstream swale along Churchville Road where outflows from Wychwood are received (3.35 Downstream Receiver) and density of the vegetation within the receiver provides additional peak flow and water quality controls to manage residual stormwater effluent from the site. The added redundancy of this feature to overall stormwater performance was not measured in this study, however it is estimated based on its size capacity to manage a 100-year storm event at a flow rate of 1.12m^3/second (TMIG, 2012). Although the swale will discharge flows and alleviate pressure within the stormwater system, it will not improve the performance of onsite features measured at the monitoring locations to the standard of the design criteria.

Finally, there could be many interpretations of the erosion control criteria to manage, detain or reuse all 15 mm events, CVCs interpretation is the site should reuse or retain all rainfall from a 15 mm event. Based on this interpretation of the erosion criteria, the performance results indicate the criteria is not being met. However, event precipitation depth for a range of event sizes presented in Figure 4-20 shows the site does manage and detain most of the event precipitation. Monitoring activities are ongoing at Wychwood and additional observation contributing to the sites limitations in retaining a 15 mm event will be documented for further review.

- Water quantity control – Reduce the 2 to 100 year post development flows to pre development levels

Short-duration high-intensity design storm events are helpful in estimating performance of these systems during convective storm events (thunderstorms). Pre and post development peak flow comparisons using SWMM are provided in Table 4-14. The post-development estimates for peak-flow rates prepared during the design of the site are also provided for comparison.

Table 4-14: Pre and Post development peak flow estimates by SWMM model

Return period	Rainfall depth (mm)	Peak flow out (cms)		Difference (pre/post SWMM)
		Pre (SWMM)	Post (SWMM)	
2	50	0.155	0.115	26%
5	68	0.233	0.173	26%
10	83	0.306	0.252	18%
25	95	0.369	0.336	9%
50	107	0.432	0.422	2%
100	119	0.513	0.566	-10%

CVC's pre-development SWMM model incorporates pre-development site condition including soil characteristic, land use and slope to determine estimated pre-development peak flows. The post-development model is calibrated using data collected over the monitoring period. Results from the post-development model indicate the site is not meeting flow targets for less frequent events (100yr). The increase in peak flow rates are still well under the capacity of the downstream swale receiver (1.13 m^3/s) and is not a major flood concern based on the model. The increase in estimated peak flow could be the result of increased impervious cover from added impervious landscaping. Additionally, when 100-year storms occur, rain intensity is often too high for pervious sections of the site to absorb runoff adding additional runoff that impacts peak flow estimations (Hortonian overland flow). Differences in CVCs SWMM pre and post model peak flow volume is considered low for a 100 year storm given the variability in outflow volume that would occur depending on the storm intensity and antecedent conditions. For more frequent events (2-25yr) the model presents a peak flow reduction in pre to post development results, indicating the site provides a modeled over-control of peak flows within this range.

Marginal differences in modelled and monitored results are allocated to estimated baseflow removal interpretations by the user. Additionally, the version of SWMM used did not allow for routing of catchments directing runoff into the LID features underdrain bypassing infiltration zones. This scenario occurs for one of the OGS units within Wychwood where the OGS outlet is connected to the underdrain within the bioswale. A 10 per cent range in peak flow estimations is still within the acceptable limits for modelled results and indicates the post-development model is well calibrated (Morias, et al, 2007). CVC Wychwood Modelling report (**Appendix J**) provides additional event results on the pre and post development SWMM model, as well as additional detail on of how to improve the SWMM calibrations.

- Water balance – Retain the average annual infiltration depth to pre-development levels.

Water balance is another stormwater management criterion that is critical to design of stormwater management features. Typically, it has to do with maintaining pre-development infiltration rates. Table 4-15 summarizes water balance estimated for pre and post development conditions by the SWMM model.

The pre and post SWMM model comparison indicates the annual infiltration depths are retained and are enhanced through the LID features. While the evapotranspiration (ET) rate has been reduced from 432 mm in pre-development condition, the infiltration rate has increased in post-development from 229 to 277 mm annually to help offset loss in ET. However, overall annual runoff has increased across the site from 24 per cent to 30 per cent indicating the site deficiencies discussed in the erosion control criteria analysis above may impact annual water balance performance over the lifecycle of the subdivision. Since the criteria is to retain the average annual infiltration rates, this design criteria is achieved by the LID features.

Table 4-15: Pre and Post development water balance comparison between SWMM model

Model	Area (ha)	Precip (mm)	Evapotranspiration (mm)	ET/ precip	Infiltration (mm)	Inf/ precip	Runoff (mm)	Runoff/ precip
Pre Dev SWMM	4.09	789	432.0	54%	229.4	29%	190.7	24%
Post Dev SWMM	4.09	789	324.1	41%	277.6	35%	234.0	30%

4.7 Thermal Mitigation

When precipitation events occur on warm sunny days, the stormwater flows over hot roads, sidewalks and rooftops, and absorbs the heat stored within the impervious surface through conduction. This stormwater becomes warmer and, in most cases, flows into the nearest stormwater sewer system followed by the local receiving body. The sudden increase in temperature caused by the stormwater runoff in these stream reaches can have significant negative impacts on freshwater habitat, including the growth and survival rates of aquatic species, and concentrations of oxygen, nutrients, and pollutants dissolved in the water.

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.

4.7.1 Background

Peer-reviewed studies have provided evidence that LID is capable of reducing thermal pollution from stormwater runoff (Hester and Bouman, 2013; Wardynski et al., 2013; Jones et al., 2012; Sabouri et al., 2013; Natatajan et al., 2010). These studies compelled CVC to instigate a thermal monitoring program at local sites to see if similar thermal performance could be achieved by LID sites in Ontario. CVC initiated a thermal monitoring study in the spring of 2013 and 2015 at Elm Drive and IMAX LID treatment train sites in Mississauga, Ontario. Results collected at Elm Drive and IMAX have prompted interest to monitor the thermal loading reduction potential of the LID features at Wychwood.

The Wychwood LID facility design incorporates features used in previous studies for reducing thermal impacts from stormwater runoff. Figure 4-21 illustrates the inlet and outlet temperature monitoring locations in the western and eastern catchment areas, respectively. Monitoring at the outlet began in March 2016 and the inlet in August 2016. Monitoring at the inflow location was delayed due to equipment failure and as a result did not start until late summer. CVC has been able to use this smaller data set to explore the thermal mitigation performance of the LID sites at Wychwood on a preliminary basis.

4.7.2 Methodology

The bioswale at Wychwood is being evaluated for thermal mitigation potential by developing event mean temperatures (EMTs) and thermal loads of inflows and outflows. EMT is the flow weighted average temperature of water flowing in and out of the LID facility during an event, whereas thermal load is the amount of energy introduced to the LID facility from heat transferred to stormwater from surface runoff. In order to assess thermal mitigation and calculate EMTs, HOBO pendant temperature loggers were deployed at the inflow catch basin at Fairmont Close and Honour Oak Crescent, and at the bioswale outflow manhole located at WW-1 as indicated in Figure 4-21. Both loggers are set to record temperatures at five-minute intervals. Refer to **Appendix G** for further details of the methodology and analyses used for determining thermal mitigation through the LID. It is important to note that monitoring station WW-1 was chosen for the thermal analysis as WW-2 has baseflow present, which would add complexities to the analysis. Thus, the results discussed in this section cannot be generalized for the entire subdivision.

Figure 4-21: Overview of the Wychwood LID subdivision and location of the inlet and outlet temperature loggers as well as the WW-1 and WW-2 monitoring manholes.

4.7.3 Results

The focus of the thermal monitoring is inclusive to the warmest months of the calendar year, May to September, when the impacts of thermal loading from stormwater runoff are the greatest in urban streams. CVC has been monitoring stormwater outflow temperatures at WW-1 since March 30, 2016 and inflow temperatures since August 25, 2016. In order to effectively assess EMT and thermal load reductions, both inlet and outlet temperatures for the same precipitation event need to be available. Since both loggers were not logging data at the same time, until August 25, 2016, a limited number of precipitation events are available to report on. However, the preliminary data already suggests that the bioswale significantly improves thermal loading impacts for events less than 25 mm. CVC has found similar bioretention thermal loading reductions at the Elm Drive and IMAX treatment train sites, whereby a thorough analysis for each site can be found in the respective technical reports. Due to the small monitoring window at WW-1, minimal data is presently available to determine if larger precipitation events experience the same thermal load reduction, but CVC seeks to explore larger events when more data becomes available.

Figure 4-22 illustrates the average thermal load reduction for all storm events divided into 10 mm increments. The decrease in effluent volume through runoff storage within the LID facility is the leading factor in producing high thermal and temperature reductions at WW-1. Additionally, any effluent produced must pass through the bioswale, which spans the entire eastern length of the subdivision, where thermal energy is transferred. Runoff from the small portion of impervious surface is also pre-treated by the Stormceptor®, further reducing temperatures. The treatment train provides high thermal reduction in all event ranges and nearly 100 per cent reduction during smaller more frequent events.

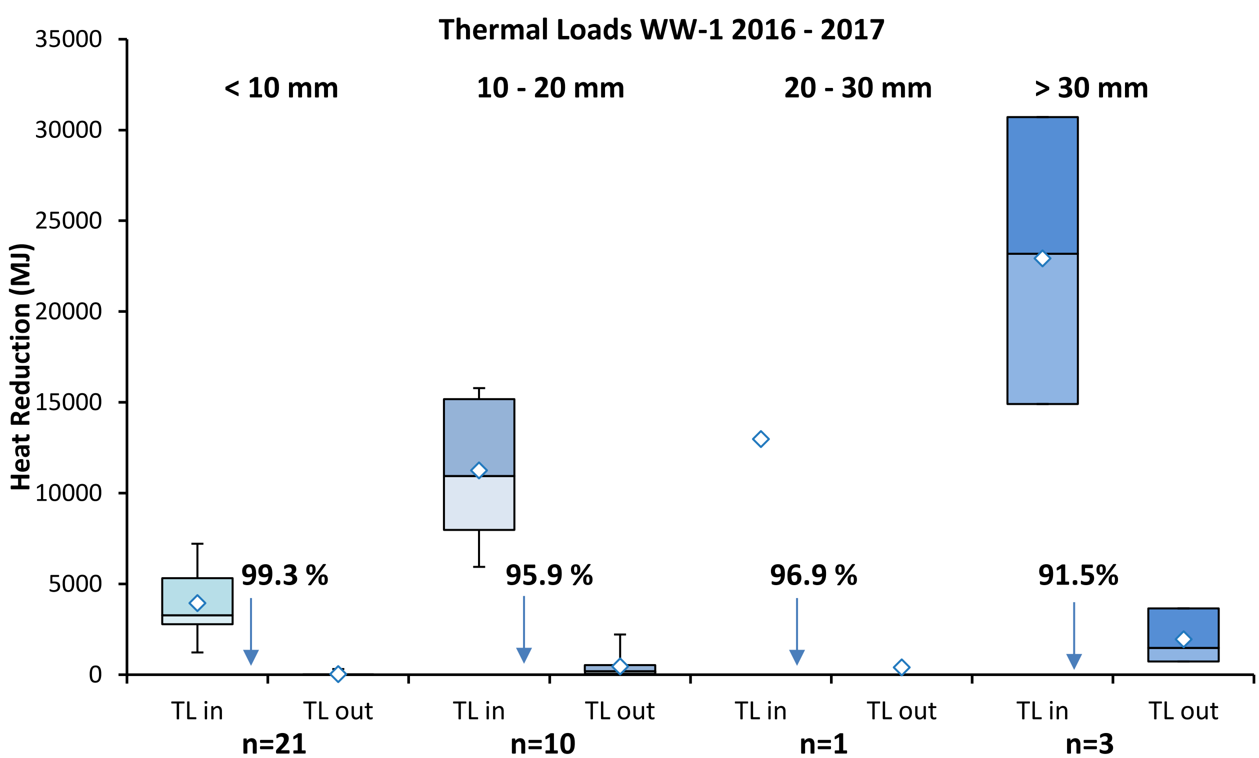

Figure 4-22: Thermal loading results for all event sizes at WW-1 2016-2017

Figure 4-23 and Figure 4-24 illustrate the thermal loading at WW-1 for two different events documented during 2016. The September 7th, 2016 results depicted in Figure 4-23 demonstrates the effectiveness of catch basins in relation to directing runoff into the infiltration trench quickly. These results further demonstrate that when shorter, more intense precipitation events like this occur, there is not enough time for the heated runoff to infiltrate through the bioswale, resulting in inlet and outlet EMTs remaining approximately the same or warmer EMT outlet results compared to the inlet. Still, even when the inlet and outlet EMTs are similar, there is a thermal benefit whereby a portion of the volume is stored in the bioswale reducing the effluent volume of heated runoff, therefore having limited impacts on in-stream temperature conditions.

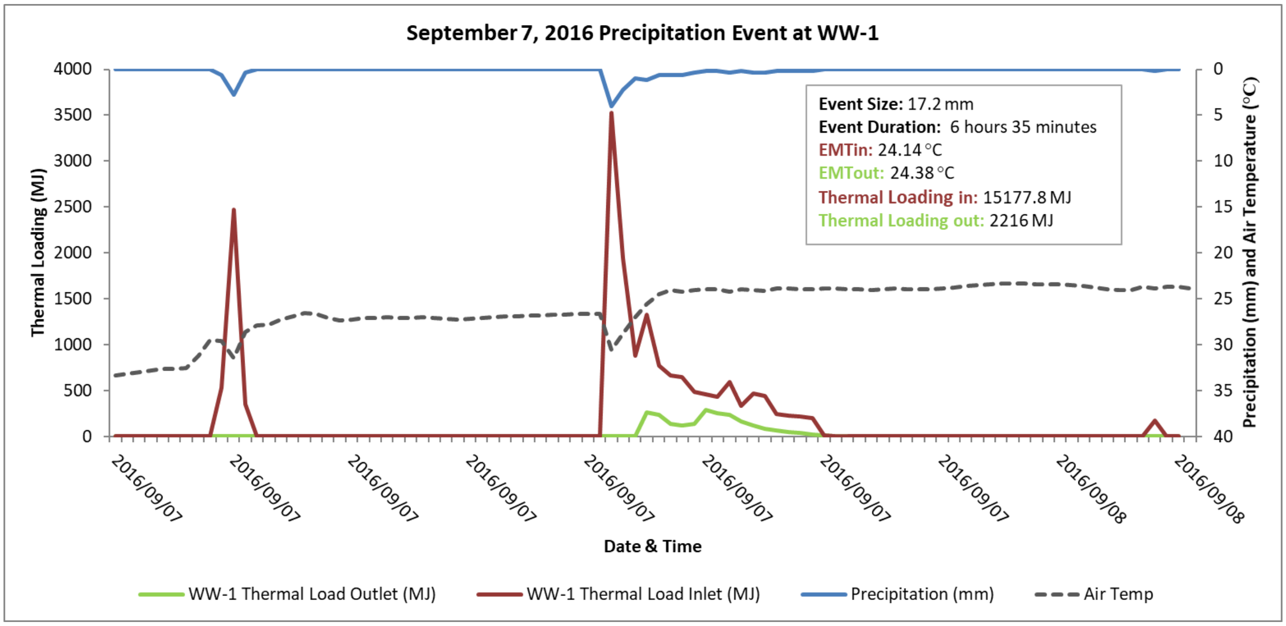

Figure 4-23: Thermal loading results from September 7, 2016 event of 17.2mm.

Nearly 100 per cent thermal reductions occurred during the smaller events such as the one that took place on September 17th, 2016 with a total of 7 mm of rainfall. This event is depicted in Figure 4-24. The event lasted a duration of 11 hours and 25 minutes and was much less intense in comparison to the larger September 7th event. This longer and less intense event likely provided sufficient time and opportunity for the runoff to infiltrate through the bioswale and effectively reduce the outlet EMT.

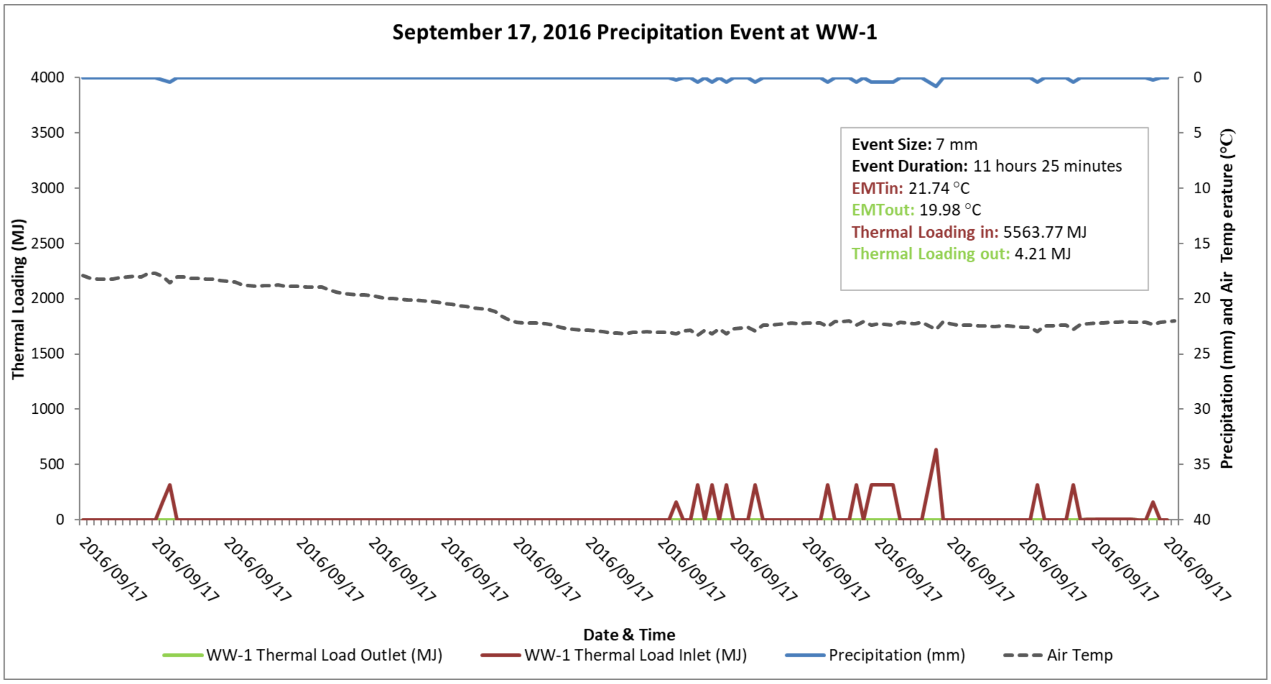

Figure 4-24: Thermal loading results from September 17, 2016 event of 7mm.

To demonstrate how the treatment train provides thermal reduction specifically during events which generate outflows, Figure 4-25 provides EMT results for all outflow events during the two-year monitoring period. CVC intends to continue the thermal monitoring program at WW-1 to build a larger data set and develop greater insight into the thermal reduction potential of larger precipitation events as more data becomes available for analysis.

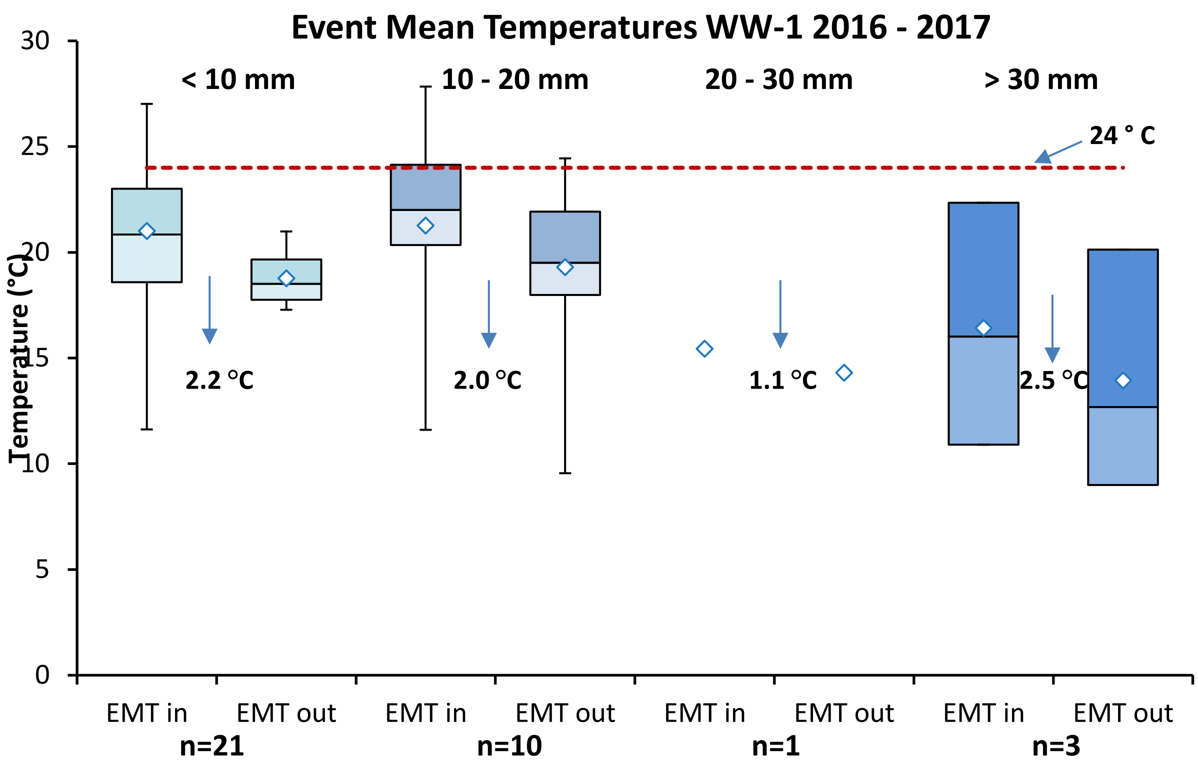

Figure 4-25: *Event mean temperature results for all event sizes at WW-1 2016-2017.*

Furthermore, the Ministry of Natural Resources and Forestry (MNRF) has developed guidelines for stormwater management facilities whereby discharge temperatures must be less than 24°C and events less than 15 mm cannot produce stormwater runoff (MNRF, 2011). These guidelines are protective of sensitive Redside Dace habitats as they are presently an endangered coldwater fish species (MNRF, 2011). Consistent EMT reductions below the 24°C threshold at WW-1 provided by the LID features, as indicated by the red dotted line in Figure 4-25, demonstrates the need to continue to implement LID designs upstream of known sensitive stream habitats. In addition, it can be concluded that similar LID technologies can be used to continue to meet the MNRF's requirements in protecting species such as Redside Dace.

4.8 Soil Analysis

The LID approach at Wychwood aims to minimize runoff and pollutants through the combination of permeable pavement and bioretention material. Rainwater alone contains trace amounts of pollutants; however, stormwater runoff plays a key role in contaminant transport. This is particularly evident in winter as a result of winter road maintenance activities when anthropogenic sources of soluble salts (de-icing salt constituents) are transported to soils. Bioretention features use plants and engineered filter media to chemically, physically and biologically treat pollutants. Soil sampling will help track contaminants and aid in evaluating the frequency of maintenance activities such as filter media replacement. The complete soil sampling methodology is provided in **Appendix C**.

4.8.1 Soil Sampling Results

The concentrations of the soil quality parameters that correspond to the defined water quality parameters of interest are summarized in Table 4-16. Results for all parameters can be found in Appendix F. Table 4-17 illustrates the changes in concentration between shallow and deep soil samples taken from the same location. The shallow sample is a reference point therefore if the value is positive (↑) the shallow sample had a higher concentration than the deeper sample and the concentration decreases with depth. If the value is negative (↓) the deep sample had a higher concentration than the shallow sample and the concentration increases with depth. All results fell below the applicable CCME, 2014 and MOE, 2011 soil condition standards for parameters that had guidelines available.

Since these results are from the first year of soil sampling at Wychwood there are no annual trends to compare. CCME and MOE guidelines are provided where applicable for comparison. These guidelines are set at levels where risk to human health is a concern suggesting additional comparison be included to track soil condition. Similar to the water quality EMC comparison in section 5.3, median results are provided from CVCs monitoring project of the Lakeview Neighbourhood. Lakeview, as a residential neighbourhood with bioswales, provides additional context to the soil sampling results from Wychwood. Median results comparison is provided in Table 4-16. With the exception of the deep sample results for total kjeldahl nitrogen and copper, results from Wychwood indicate smaller pollutant burdens then those from Lakeview. Sodium Absorption Ratio (SAR) is a measure of the sodium concentration relative to the amount of calcium and magnesium released from the soil when the soil is saturated. When SAR values increase, infiltration rates through the soil material typically decrease as increase SAR values impact electric-conductivity properties, increases soil dispersion and leads to soil erosion (Aboukarima., et al, 2018). Currently, SAR levels provided in Table 4-16, are below guidelines and are no cause for concern. As the study period continues at Wychwood, additional soil sampling will be conducted to provide further insight on the changes in concentrations with time. There is no specific quality guidance on when bioretention soil would need to be changed as it is a function of the type of catchment area and the volume of events the soil is treating. Currently, prolonged ponding greater than 48 hours after a storm event is the only threshold used for replacing or maintaining soil media (TRCA, 2010).

Table 4-16: Soil Sampling Results for Wychwood, 2016 and Comparison with Lakeview Neighbourhood Medians

Parameter	Units	Detection Limit	Guideline		Rain Garden Shallow	Rain Garden Deep	Grass Swale Shallow	Grass Swale Deep	Bioswale 1 Shallow	Bioswale 1 (Deep)	Bioswale 2 (Shallow)	Bioswale 2 (Deep)	Lakeview Shallow Median	Wychwood Shallow Median	Lakeview Deep Median	Wychwood Deep Median
			CCME [a]	MOE Guideline	WW-RG-1-S	WW-RG-1-D	WW-GS-1-S	WW-GS-1-D	WW-BS-1-S	WW-BS-1-D	WW-BS-2-S	WW-BS-2-D				
Orthophosphate (P)	ug/g	0.2	[c]	[c]	18	6.9	7.5	8.8	3/3.2 [e]	1.2	6.5	7.9	10	6.5	9	7.9
Nitrate + Nitrite (N)	ug/g	3	[c]	[c]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
Aluminum (Al)	ug/g	50	[c]	[c]	1900	1700	2000	1800	7400	4300	1900	1700	2500	2000	2500	1800
Copper (Cu)	ug/g	2	63	140	8.5	6.8	7.5	11	20	14	8.9	11	11	8.5	11	11
Iron (Fe)	ug/g	50	[c]	*	4800	4600	5300	4500	12000	9100	4800	4700	5200	5300	8800	4600
Zinc (Zn)	ug/g	5	200	340	17	14	17	21	43	20	15	20	25	17	24	20
Sodium Adsorption Ratio	N/A	0	[c]	5	0.26	0.26	0.34	0.2	0.59	0.97	0.56	0.23	N/A	0.34	N/A	0.26
Total Kjeldahl Nitrogen	ug/g	10	[c]	[c]	1650	1950	2800	2700	1090	190	1960	2010	2040	1960	1730	2010

[a] Residential/Parkland

[b] Shallow Soil, Not Potable, Residential/Parkland/Institutional, Coarse Texture

[c] Indicates no guideline available

[d] Indicates result below the detection limit

[e] Lab duplicate for specific parameter

Table 4-17: Trends in Soil Sampling Results (Shallow vs. Deep)

Sample Location	Metals			Nutrients			Other		
	Parameter	Change (µg/g)	Trend	Parameter	Change (µg/g)	Trend	Parameter	Change	Trend
Rain Garden in front of 11 Fairmont Close (Shallow and Deep)	Aluminum (Al)	200	↑	Orthophosphate (P)	11.1	↑	Sodium Adsorption Ratio	0	=
	Copper (Cu)	1.7	↑	Nitrate + Nitrite (N)	a	a			
	Iron (Fe)	200	↑	Total Kjeldahl Nitrogen	-300	↓			
	Zinc (Zn)	200	↑						
Grass Swale (Shallow and Deep)	Aluminum (Al)	200	↑	Orthophosphate (P)	-1.3	↓	Sodium Adsorption Ratio	0.14	↑
	Copper (Cu)	-3.5	↓	Nitrate + Nitrite (N)	a	a			
	Iron (Fe)	800	↑	Total Kjeldahl Nitrogen	100	↑			
	Zinc (Zn)	-4	↓						
Bioswale 1 (Shallow and Deep)	Aluminum (Al)	3100	↑	Orthophosphate (P)	12.9 b	↑	Sodium Adsorption Ratio	-0.38	↓
	Copper (Cu)	6	↑	Nitrate + Nitrite (N)	a	a			
	Iron (Fe)	2900	↑	Total Kjeldahl Nitrogen	900	↑			
	Zinc (Zn)	23	↑						
Bioswale 2 (Shallow and Deep)	Aluminum (Al)	200	↑	Orthophosphate (P)	-1.4	↓	Sodium Adsorption Ratio	0.33	↑
	Copper (Cu)	-2.1	↓	Nitrate + Nitrite (N)	a	a			
	Iron (Fe)	100	↑	Total Kjeldahl Nitrogen	-50	↓			
	Zinc (Zn)	-5	↓						

Notes:

a - Indicates result below the detection limit

b - The average of both samples was used for Bioswale 1 (Shallow)

↑ - Concentration is higher in the shallow soil sample than the deep soil sample
↓ - Concentration is lower in the shallow soil sample than the deep soil sample

4.9 Site Inspection and Maintenance

The stormwater facilities at Wychwood are designed to trap debris, sediments and other stormwater pollutants that will accumulate and will require periodic removal and maintenance. Landscaping and healthy vegetation are also important features of LIDs as the plants absorb many stormwater pollutants. This requires maintenance for both aesthetic reasons and to promote optimal performance.

The City of Brampton, the developer (Sequoia Grove Homes), and individual home owners are responsible for different aspects of the overall site maintenance. Although a resident is not required legally to maintain the permeable driveways or lot level permeability, the original home buyers guide provided details on how the site was designed to manage runoff through LIDs. Maintenance criteria was not included in the home buyers package but the need for maintaining the permeable pavers has been communicated to residents by CVC staff during site inspections and interviews.

Scheduled maintenance duties that are performed by the City of Brampton include:

- Snow removal from roadways
- Trash and debris removal from the bioswale
- Cutting the grass along the bioswale
- Inspection and clean out of the oil-grit separators (OGS) post-assumption (once the stormwater infrastructure had been assumed by the City of Brampton which occurred in fall 2017)

Scheduled maintenance duties that are performed by the developer include:

- Inspection and clean out of the oil-grit separators (OGS) pre-assumption (up until the City of Brampton assumed the stormwater infrastructure which occurred in fall 2017)

Maintenance duties that are performed by the individual home owner:

- Trash, debris, and snow removal from the permeable pavement
- Maintenance of the rain gardens (pruning and weeding)
- Maintenance of the grass swales (cutting, re-seeding/sodding, etc.)

CVC monitoring staff have been collecting data on maintenance activities performed and inspecting conditions of the bioretention features, OGS, and permeable pavement at Wychwood at a minimum on a seasonal basis. For the permeable pavement LID feature, the size of the site (70 homes) restricts how many can be inspected during the monthly visit. CVC inspects a total of 12 driveways during each monthly inspection. Six of those 12 driveways remain the same and are the “Permanent Permeable Pavement – Driveways”. The remaining six driveways rotate among the remaining 64 houses within the subdivision, the results are under the “Rotating Permeable Pavement – Driveways”. A standard site inspection checklist has been created and is used by staff during each site visit (**Appendix E**).

4.9.1 Analysis and Results

The analysis of the maintenance inspection results is for the 2016 and 2017 calendar years. CVC tries to conduct the maintenance inspections each month or seasonally depending on the scope of the project. The initial inspection for Wychwood was conducted in April 2016 and total of ten inspections were conducted of LID features from April 2016 to December 2017. Figure 3-3 in Section 3 illustrates the location of the LID features that are inspected regularly. Features are ranked visually based using the following criteria.

Examples for each ranking:

Good: Little to no sediment accumulation on the road, permeable pavement and in the bioretention cells; few weeds present in the bioretention cell; little to no trash or debris is present in the bioretention cells or surrounding area; and the bioretention cell inlets are clear and are able to accept runoff.

Mild: Some sediment is present on the road or permeable pavement; some weeds are present in the bioretention cells; some trash is present in the bioretention cell or drainage area.

Moderate: Sediment is accumulating on the permeable pavement or in the bioretention cells; a fair amount of weeds or dense vegetation is present in the bioretention cells; trash or debris are present in the bioretention cell and may be starting to impede runoff from entering the system; maintenance is required.

Severe: Sediment is clogging the permeable pavement and not allowing runoff to infiltrate; vegetation or weeds have overgrown the area and need to be trimmed back; large amounts of trash or debris are captured in the bioretention cells or surrounding area; incoming runoff has caused erosion in the bioretention cell; maintenance is required and/or overdue.

For further guidance, a visual legend is included in Appendix E

4.9.1.1 Permeable Pavement Inspection Results

For the rotating permeable pavement driveways there was more variation in the average category ranking, ranging from “Good” (sediment) to “Mild” (sediment). The rotating permeable pavement had only three occasions identified as clogged during the inspection period.

For the permanent permeable pavement driveways the average category ranking was “Mild” for all categories. The permanent permeable pavement was not identified as clogged during the inspection period.

Table 4-18: Permeable Pavement Maintenance Survey Results

Feature	Attribute	No	Yes
Rotating Permeable Pavement - Driveways	Clogging	45	3
	Structural Damage	47	1
Permanent Permeable Pavement - Driveways	Clogging	57	0
	Structural Damage	48	10

***Examples for each ranking; a visual legend is included in Appendix E**

If a driveway contained a broken or chipped paving stone it would most likely be flagged as structural damage, however, a few stones in this condition would not likely impact the function of the feature. Clogging, as well, would most likely only apply to a select area of a permeable pavement driveway and therefore is not expected to impair the overall function of the feature. Since some of the rotating inspection locations have only been visited once it is important to continue collecting the inspection results for future analysis. It is important to note that if the rotating inspection locations show significant deterioration in condition it would be weighed heavily in comparison to the permanent stations as they offer a wider view of what is happening throughout the entire subdivision. Summary tables within **Appendix E** contain a more detailed breakdown of the inspection results.

As permeable pavers become more common, greater emphases needs to be placed on educating residents and contractors on proper material storage and appropriate maintenance techniques to return the greatest performance benefit over the features life-cycle.

During the maintenance inspections it was observed that several properties had ongoing landscaping and construction projects. Construction materials (sand, flagstone, etc.) were observed to be staged on the permeable pavement during some of these projects (Figure 4-26). A close up of permeable pavement is shown in Figure 4-27 prior to being used for material storage. Staging these materials on the permeable pavement reduces the infiltration capacity as it blocks that surface area footprint from accepting infiltration. Construction materials such as sand can also run off these piles during rain events and clog the joints in-between the paving stones which further reduces the infiltration capacity of the permeable pavement (Figure 4-28). To prevent these issues in the future home owners can inform landscape and construction contractors of the permeable pavement function and they may be able to stage construction materials in a better location or at minimum lay down a surface cover such as plywood to prevent the pavement from becoming clogged (Figure 4-29). Vegetation growing through permeable pavement stones can be seen in Figure 4-30, which, can also reduce the infiltration provided by these LID features. Sunken paving stones were also observed during the maintenance inspections which may be due to contractors not compacting the granular bed material prior to the installation of the paving stones. These deficiencies reduce the water quality and quantity performance of these features.

Figure 4-26: Improper material storage

Figure 4-27: Prior to material storage, free of Impediments

Figure 4-28: Close-up of Permeable Pavement Blockage, July 2017

Figure 4-29: Permeable Pavement Blocked with Construction Materials in July 2016

Figure 4-30: Permeable Pavement Partially Blocked with Weeds in August 2017

4.9.1.2 Bioretention Inspection Results

The bioretention inspection results refer to both the bioswale and the grass swale as they function in a similar manner. The results for both the bioswales and grass swale have been split up into three sections as these features are long.

Bioswale section 1 ranged from “Good” (sediment and trash and debris) to “Mild” (bare soil and erosion). Bioswale section 2 ranged from “Good” (trash/debris) to “Mild” (bare soil, erosion and sediment). Most of bioswale section 2 had an average category of “Mild”. Bioswale Section 3 ranged from “Good” (bare soil) to “Mild” (erosion, sediment and trash/debris). The outlet remained clear during the inspections for Bioswale Section 1 and 2, whereas Bioswale Section 3 had one occurrence where the outlet was blocked and unable to release flow. The table within **Appendix E** contains a more detailed breakdown of the inspection results.

All three of the grass swale sections had an average category of “Good” for all attributes except for sediment which had an average condition of “Mild”. The inlets were identified as clear and able to accept flow during each of the maintenance inspections. The table within **Appendix E** contains a more detailed breakdown of the inspection results.

The difference between the bioswale and the grass swale may be due to the impact of the home owners. The bioswale is fenced off from the adjacent homeowner’s properties and is maintained by a City of Brampton subcontractor. The grass swales are located adjacent to the houses along Fairmont Close and there is no barrier so these home owners take responsibility for maintaining this feature (i.e. removing trash, cutting grass, etc.). The home owners are invested in maintaining the appearance of their property therefore the grass swale feature may be benefiting from this relationship. Figure 4-31 presents a location overview of each inspected section of the bioswale and grass swale.

Figure 4-31: Location of each section of the grass swale and bioswale features as inspected

The results are displayed in Table 4-19 and Table 4-20 below.

Table 4-19: Bioswale Maintenance Survey Results

Feature	Attribute	Yes	No
Bioswale Section 1	Outlet Clear and able to Accept Overflow	10	0
	Structural Damage	0	10
Bioswale Section 2	Outlet Clear and able to Accept Overflow	10	0
	Structural Damage	0	10
Bioswale Section 3	Inlet Structural Damage	0	10
	Outlet Clear and able to Accept Overflow	8	1
	Outlet Structural Damage	1	8

***Examples for each ranking; a visual legend is included in Appendix E**

Table 4-20: Grass Swale Maintenance Survey Results

Feature	Attribute	Yes	No
Grass Swale Section 1	Inlet Clear and able to Accept Flow	10	0
	Structural Damage	1	9
Grass Swale Section 2	Inlet Clear and able to Accept Flow	10	0
	Structural Damage	0	10
Grass Swale Section 3	Inlet Clear and able to Accept Flow	10	0
	Structural Damage	0	10

***Examples for each ranking; a visual legend is included in Appendix E**

It was occasionally observed that the bioswale inlets were obstructed by sediment and debris accumulations (Figure 4-33 to Figure 4-32). Since the bioswale is located along the eastern property boundary and separated from the individual properties by a fence, this barrier may reduce the impact residents can have on the condition of the bioswale. The inlets to the bioswale (section 1 and 2) are curb cuts from Fairmont Close and Coach House Court which are prone to sediment accumulation and should be inspected seasonally to ensure runoff can freely flow into the feature. The inlet into the bioswale receiving runoff from Honour Oak Crescent is a rolled curb design and is not protected by a fence and as a result is accessible to residents and contractors. This design allows maintenance contractors to access the entire bioswale to mow the lawn and remove garbage and debris. However, during one maintenance inspection at Wychwood signs of truck washout were observed within the subdivision (see Figures 4-35 and 4-36). Truck washout may allow sediment to travel from the roadway into the bioswale which could reduce its efficiency by clogging the filter media. This activity should be avoided and could be eliminated if a designated washout and material storage station were provided during construction and landscaping activities. Street sweeping at least twice a year may help reduce the sediment and residual construction debris on the roadway making it less likely that it will be transported into the bioswale. During one occasion soil material was observed to be stored in one of the grass swales (see Figure 4-37).

Figure 4-33

Figure 4-34

Figure 4-32

Figure 4-33 to Figure 4-32: Bioswale Inlet (with sediment accumulation) in September 2016 and October 2016 and Bioswale Inlet (with sediment accumulation and vegetation growth) in December 2017.


Figure 4-35 and Figure 4-36: Truck washout near rolled curb and overflow catch basin June, 2016 and signs of possible truck washout near catch basin in December 2017.

Figure 4-37: Excess soil material left in grass swale in August 2017

4.9.1.3 Rain Garden Inspection Results

The results of the rain gardens ranged from "Good" (trash/debris, vegetation) to "Moderate" (sediment and vegetation cover). The majority of the vegetation components were either ranked as "Good" or "Mild". Rain Garden 1 was clear and able to accept flow during half of the inspections. The inspections identified that for Rain Garden 2 the inlet was not clear and unable to accept flow on three occasions during the inspection period. The results are displayed in Table 4-21 below.

Table 4-21: Rain Gardens Maintenance Survey Results

Feature	Attribute	Yes	No
Rain Garden 1	Inlet Clear and able to Accept Flow	5	5
	Inlet Structural Damage	0	10
	Overflow Clear and able to Accept Flow	10	0
	Overflow Structural Damage	1	9
Rain Garden 2	Inlet Clear and able to Accept Flow	3	7
	Inlet Structural Damage	3	7
	Overflow Clear and able to Accept Flow	10	0
	Overflow Structural Damage	0	10

***Examples for each ranking; a visual legend is included in Appendix E**

The results illustrate that the residents are taking care of the appearance of the rain garden by pruning and trimming vegetation and removing trash and debris since these attributes were usually in the "Good" or "Mild" categories. However, some of the attributes related to the functionality of the feature such as sediment and erosion had average categories identified as "Moderate" and "Mild". Tables within **Appendix E** contain a more detailed breakdown of the inspection results.

Wychwood residents can impact the appearance and the performance of the rain gardens by clearing debris from the features inlet (Figure 4-38 and 4-39). Due to the proximity of the two rain gardens to residential properties, site inspections have recorded changes to the rain garden plantings and soil mixture completed by the two property owners directly adjacent to the rain gardens. One of the rain garden's original plantings has been completely replaced with non-native ornamental plants after the property owner moved into the house. Additionally, the same property owner has installed gravel within the inlet blocking runoff from entering the feature (Figure 4-38 Although the full impact of these modifications to the feature is still unknown (infiltration rate, water quality, etc) observing the home owners taking ownership over the feature is encouraging.

Figure 4-38 and Figure 4-39: Rain Garden Inlet (with debris and sediment accumulation and without impediments) in July 2016 and November 2016.

Figure 4-40 and Figure 4-41: Rain Garden Inlet (clogged with sediment prior to gravel installation and inlet modified by home owner) in July 2017 and September 2017.

4.9.1.4 OGS Inspection Results

The results of the maintenance surveys for the OGS ranged between “Moderate” and “Good” for sediment and trash and debris. Based on the visual inspections only one occurrence of structural damage was observed during the inspection period.

Table 4-22: OGS Maintenance Survey Results

Feature	Attribute	Yes	No
OGS 2	Structural Damage	0	5
OGS 3	Structural Damage	1	9
OGS 4	Structural Damage	0	9
OGS 5	Structural Damage	0	3
OGS 6	Structural Damage	0	3
OGS 7	Structural Damage	0	10

***Examples for each ranking; a visual legend is included in Appendix E**

The OGS units were inspected or maintained twice annually by the developer during the 2016 calendar year. The developer has also provided the service reports for each OGS clean out completed in 2015. The clean out is triggered when nine inches of sediment accumulates in the OGS. A stormwater service contractor is hired to clean out the OGS. The volume of material pumped-out is measured by visual inspection through the hatch opening of the vacuum truck. A unique dipstick called a sludge judge is used to measure the volume of sump material prior to disposal. A percentage ratio comparison of solids to liquids is completed prior to disposal by way of centrifugation. The amount of volume removed is then reported back to the developer in a service report (Minotaur, 2016). Although maintained by the developer CVC monitoring staff does include the OGS in the monthly inspection. Tables provided within **Appendix E** contain a more detailed breakdown of the inspection results.

Residents can affect the performance and maintenance of the OGS units. Nothing should be purposely dumped into catch basins however, based on observations, at least one catch basin appeared to have grass clippings dumped into it (Figure 4-42). Debris such as trash, leaves, and grass clippings should be collected from individual home owner properties so it does not eventually make its way into the OGS. Figure 4-43 shows leaf litter accumulated within the OGS unit. Once an OGS is clogged with debris, untreated stormwater will by-pass the settling basin at the bottom of the OGS and flow directly into the outlet.

Figure 4-42: OGS clogged with sediment and grass clippings in June 2016

Figure 4-43: OGS with leaf litter in December 2017

Another element related to the maintenance inspections is tracking, where possible, individual property owner's changes that affect the total impervious area of the subdivision (Figure 4-44 to Figure 4-46). Based on the maintenance inspections, over time, additional impervious areas were constructed (additional walkways or patio enlargements). These changes reduce the overall permeable area therefore increasing stormwater runoff. Individual home owners are allowed to modify their property (in accordance with applicable regulations) and since CVC only conducts the inspections on public land these changes in the drainage area may go unnoticed.

Figure 4-44

Figure 4-45

Figure 4-46

Figure 4-44 to Figure 4-46: Changes to the impervious area of individual homeowner's properties

The continued collection of information on maintenance activity will help CVC guide the municipality's determination of maintenance requirements and lifecycle costs of LID features. These observations also speak to the importance of understanding the land use and choosing the best suited BMP for the area.

4.9.2 Site Assumption Protocols

As LID features become more commonly used, municipalities and property owners need methods to verify that these features have been designed and constructed properly. Assumption inspection protocols ensure that knowledgeable personnel such as third-party inspectors, design engineers or permitting agencies, evaluate whether LID features have been installed properly before the contractor is released of responsibility. Thorough assumption inspection protocols reduce the risk to the owner and will save money in the short and long term.

For all construction projects including LID, the pace and extent of construction may preclude assumption inspections from ensuring critical design elements are properly built. Assumption of the LID feature should take place when all construction activities have been completed and drainage areas have stabilized. Assumption protocols are the last opportunity to identify issues related to improper design, improper construction, and/or unforeseen site condition issues. LID assumption inspection protocols ensure that the property manager receives a feature that is functioning properly and will not require costly near- or long-term repairs. These protocols are not only for LID projects but are part of many construction projects. They are similar to many regular construction inspections or warranty periods.

4.9.2.1 Tools to Assess Performance Prior to Assumption

The tools for assessing performance prior to assumption are outlined in the CVC document: “Low Impact Development Assumption Inspection Protocols: Bioretention Practices” (CVC, 2017). As a general overview the following four levels are included within the protocol:

Level 1 – Visual Inspection

Level 1 uses visual inspections as an initial assessment tool for all stormwater treatment practices. The person conducting the inspection looks for evidence of a malfunction or deviation from the design plan. By attending the site in various conditions (i.e. dry and wet weather) the inspector will be able to see the features respond in various weather conditions. Visual inspections were conducted at Wychwood and memos outlining the results were prepared for the City of Brampton. More detailed information regarding the visual inspections during the construction period is presented in Section 3.2.

Level 2 – Capacity Testing

Level 2 moves beyond the visual inspection, and actual testing and measurements are conducted. Soil sampling and testing may be conducted to confirm that the filter media meet the design specification. In addition, infiltration testing may be performed to confirm drawdown times. Elevation surveys can also be conducted to confirm drainage areas, depths, heights and storage volumes are per the design. Infiltration testing was completed at Wychwood during the construction period and is presented in Section 3.2.

Level 3 – Continuous Water Level Monitoring

Continuous water level monitoring is used to measure infiltration rates. Level monitoring is a cost-effective alternative and also allows for the evaluation of seasonal and winter variations in level. Although this is not currently conducted at Wychwood, it could have been done as part of the assumption process and would have allowed the City of Brampton to confirm that the storage capacity, infiltration, sedimentation rate and volume reduction are achieved prior to assuming the features.

Level 4 – Continuous flow and Water Quality Monitoring

If level 2 and 3 do not achieve the goals and further testing is required, then more intensive flow and quality monitoring should be considered. This type of monitoring represents the most comprehensive assessment technique and can document water volume reduction and peak flow reduction for most stormwater treatment practices by measuring discharge during runoff events. It can also be used to document new technology, different or challenging situations, or new stormwater facility designs. This is the most informative level of performance testing. CVC is currently conducting continuous flow and water quality monitoring at Wychwood and the preliminary results are presented throughout Section 4.

4.9.3 Pre-Assumption Recommendations

The overall recommendations would be to develop or adapt an existing assumption protocol that could be used for future LID features. Based on the pre-assumption protocol followed at other LID sites the following recommendations have been made for the Wychwood subdivision:

- Develop site specific assumption protocols for each LID or conveyance feature identified in CVC's document: "Low Impact Development Assumption Inspection Protocols: Bioretention Practices" (CVC, 2017) to assess the performance of the LID features prior to assumption.
- Redesign of the rain garden inlet. The current construction of inlet is at a 90° angle to the direction of flowing stormwater which causes a portion of the stormwater in the road to bypass the rain garden. If the inlet was wider, at less of an angle and had a rolled curb the inlet may channel more water through the rain garden.

Figure 4-47: Rain Garden 90-degree inlet, bypass observed

Figure 4-48: Example of wide curb cuts from bioswale

Figure 4-49: Rolled Curb

- Installation of shallow and deep monitoring wells (in the bioswale and grass swale) to allow for continuous monitoring of infiltration and ponding. Monitoring within these features would require written permission from the City of Brampton as both features are within the municipal property boundary. The home owners adjacent to the grass swales would also need to be consulted to ensure residents understand the purpose of the well and avoid damaging it while the lawn is being maintained

Figure 4-50 and Figure 4-51: Preferred Location for Shallow and Deep Well Installation

- Educating subdivision residents and their landscaping and construction contractors. By educating the residents, and subsequently their contractors, this would avoid situations such as storing sand or soil on permeable pavement (which can clog the feature). If the residents have a better understanding of how the features function, they can avoid situations that will contribute to the impairment of the feature.

Based on the Inspection and Monitoring information gathered from 2016 and 2017, CVC recommends a pre-assumption monitoring and inspection protocol be developed for future sites. An assumption protocol with detailed performance criteria would provided an added level of protection to the owner, ensuring any issues are remedied by the developer before the site is assumed by the municipality. An assumption performance criteria would prevent additional costs to the municipality and provide assurance that the feature is working as designed. Assumption performance requirements could be added to the release of development securities to add additional incentive to meet performance requirements.

5.0 DISCUSSION AND RECOMMENDATIONS

The unique LID stormwater management design implemented at Wychwood was first of its kind when the subdivision plans were first approved in 2011. Now that the construction is complete, and two years of performance data has been collected, an initial assessment of the stormwater performance in comparison with design can be completed to provide a baseline for future stormwater performance results collected at Wychwood. The results contained within the report can also be used to inform future implementation of low impact development stormwater systems, as landowners, designers and regulators enhance their knowledge of these systems. The stormwater management criteria for evaluating LID feature performance at Wychwood includes:

Table 5-1: Wychwood Stormwater Management Design Criteria

Stormwater Element	Design Criteria
Water quantity control	Reduce the 2 to 100-year post development flows to pre-development levels
Water quality control	Enhanced water quality treatment per the MOE Stormwater Management Planning and Design Manual, i.e. long-term removal of 80 per cent suspended solids
Water Balance	Retain the average annual infiltration depth to pre-development levels.
Erosion Control	Erosion control – Manage, detain or reuse all rainfall events up to 15 mm storm event over the entire site

Table 5-2 summarizes the results of CVCs 2-year monitoring assessment in comparison to the four, site specific, stormwater design criteria. Additionally, performance data is assessed within the context of the 13 monitoring objectives from the 2012 CVC stormwater management monitoring strategy (from section two of this report) identified for LID stormwater performance assessment at Wychwood.

Table 5-2: Assessment of Stormwater Design

Wychwood Stormwater Design Criteria (TMIG, 2012)	**Measured Performance**
Reduce the 2- to 100-year post development flows to pre-development levels	• Post development SWMM model results identified an over-control of peak flow for events within the 2-50 year return range. • The SWMM model estimates peak flows of 0.566m^3/s in comparison to the pre-development target of 0.513 m^3/s for a 100-year storm. • Although the onsite LID features do not manage post development peak flows from the 100-year design storm according to the SWMM model, the increase in peak flow rates are still well under the capacity of the downstream conveyance swale (1.13 m^3/s) (TMIG. 2012). • The capacity of the conveyance swale provides sufficient redundancy within the stormwater control system. • 10 per cent difference in modelled peak flow volume estimates compared to monitored results is considered low given the variability in outflow volumes for a storm measured at a 100-year magnitude. • Infill single dwelling lots are being developed along Churchville sideroad and construction material was observed to be discarded within the roadside swale. Inspection of the conveyance swale should continue to ensure the swale capacity does not change given further development pressures. If the capacity of the conveyance swale is impacted by added development, there may be a concern with the release of residual flow from Wychwood. • Additional monitoring data will be used to further calibrate the SWMM model and continue to verify the post development design storm results.
Enhanced water quality treatment per the MOE Stormwater Management Planning and Design Manual, i.e. long-term removal of 80 per cent suspended solids	• Total TSS load reduction was calculated as 84 per cent (monitored) and 82 per cent (modelled) over all events, exceeding Level 1 (enhanced) protection. • EMC of TSS sampled is consistently less then results collect from traditional or grey infrastructure.

Retain the average annual infiltration depth to pre-development levels	• Pre-development SWMM model results estimate total annual rainfall is managed by evapotranspiration (54 per cent) and infiltration (29 per cent). • Annual infiltration has increased across the subdivision from 29 per cent to 35 per cent exceeding the criteria of retaining the average annual infiltration depth to pre-development levels. • Estimated runoff on an annual basis has increased by 6 per cent in the post-development model. • Pre-development annual average infiltration rate is the design criteria of the LID site design. The goal of LID is to recover the treatment capacity available through evapotranspiration in the pre-development landscape through engineered infiltration. • SWMM model determined the site average annual infiltration rate have increased compared to pre-development estimates, meeting the site water balance design criteria of enhancing annual infiltration rates
Manage, detain or reuse all rainfall events up to 15 mm storm event over the entire site	• Stormwater outflows are observed for *all* 15 mm precipitation events indicating this design criteria is not being met across the entire site due to high groundwater table in the western section of the subdivision and changes in imperviousness in the catchment. • Volume and peak flow reduction are observed across all event sizes.
CVC Stormwater Management Criteria Guideline	**Observed Performance**
Evaluate whether LID SWM systems are providing flood control, erosion control, water quality, recharge, and natural heritage protection per the design standard *	• Total calculated TSS load reduction of 84 per cent was observed for 90 events. • Average 80 per cent peak flow and 73 per cent volume reduction was achieved for events with precipitation depths of 15 mm, reducing erosion concerns both locally and within downstream receivers. • Post development SWMM model results identify an over-control of peak flow events (2-50-year return); model estimates pre development 100-year storm peak flow target of 0.513m^3/s is not fully controlled by the stormwater features. SWMM model estimates post-development peak flow for 100-year storm at 0.566m^3/s. • The post development SWMM model estimates 80 per cent of annual precipitation is controlled through infiltration and evapotranspiration provided by the LID features.

**This Objective assesses site performance in the context of CVC Stormwater management criteria for planning and design SWM infrastructure, CVC, 2012, Also included as Objective 5 within monitoring objectives section 2*

Table 5-3: Assessment of Monitoring Objectives

CVC Stormwater Monitoring Objectives	Observed Performance

1. Evaluate how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity as a whole	• Full Site Results collected from 90 events:
	  ○ Both mean volume and peak flow reduction for all storm events were calculated as 81 per cent and 83 per cent
	  ○ The total volume reduction for storms with depths of 25 mm or less was 77 per cent
	• Eastern Catchment Results collected from 125 events:
	  ○ The mean volume and peak flow reduction for all storm events was calculated as 98 per cent and 97 per cent
	  ○ The total volume reduction for storm with depths of 25 mm or less was 97 per cent

2. Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance	• ~3 per cent (3 of 102 surveyed) of driveways appear to show signs of clogging after 1-2 years in service. • Maintenance of the bioswale is the responsibility of the municipality who have hired a landscape contractor to maintain the visual aesthetics of the feature. CVC inspections do not indicate any change is needed in the frequency of contractor maintenance. • Currently, the OGS units are inspected and cleaned ~ every 6 months by consultants based on measured sediment depths within the OGS sump. Based on CVCs routine inspection of the OGS units, a 6-month inspection frequency is sufficient in maintaining the treatment capacity of the OGS units. Observations from this monitoring study indicate all parties in the LID implementation process (designers, contractors, municipal inspectors and even residents) should be further educated on the functionality of LID to address the impacts of compaction, construction material storage and disposal of residual landscaping and construction material within the features.
3. Determine the life cycle costs for LID practices	• Data collected from resident interviews determine approximately $5/year spent on chip stone per driveway. However not all residents are maintaining their driveway. • The municipality spends $1500-2000/year to maintain the bioswale. • Oil Grit Separator maintenance for the Stormceptor STC-300 are ~ $300 for inspection and $3000 for cleaning excluding HST. • More interviews need to be completed across the subdivision to track cost over life-cycle.

6. 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)	• Nitrate is in a dissolved state and is partly sequestered in the shallow groundwater and could travel with the movement of groundwater. Monitoring results show a 35 per cent load reduction for nitrite + nitrate. Median results from the WW-2 monitoring station are higher then median results from Lakeview and NSQD but are still well below guidelines. • Observed use of fertilizers and high nutrient soils by residents for enhancing lot level landscapes is likely the main source of increased dissolved nutrients within the stormwater. An education program could be presented to residents on the impacts of fertilizers on downstream tributaries. This may also help reduce nutrient levels within the stormwater.
7. Demonstrate the degree to which LID mitigates urban thermal impacts on receiving waters	• Greater than 90 per cent thermal load reduction was achieved by the Bioswale for all events within the monitoring period. • Event mean outlet temperature of stormwater flows from the bioswale was consistently below the Ministry of Natural Resource and Forestry's 24 C° threshold for sensitive species habitats.
8. Assess the water quality and quantity performance of LID technologies	• Total calculated TSS load reduction of 84 per cent over all events, exceeds Level 1 (enhanced) protection. Results include analysis of 18 sampled events and 66 unsampled events. • EMC of TSS samples from Wychwood (19-26 mg/L) is consistently less than results collect from traditional or grey stormwater infrastructure results from Lakeview (40-44mg/L). • 86 per cent median volume reduction was achieved through the features. Volume reduction is the main driver for enhanced water quality. If outflows are reduced, pollutant load reductions increase. • Estimated median peak flow reduction provided by the features was 86 per cent. • Three grab samples where collected during the 2016-2017 monitoring period. More grab samples will be collected to continue to assess the water quality according to site environmental compliance approval.
11. Assess the potential for soil contamination for practices that infiltrate	• Soil quality sampling was conducted in the fall of 2016 where both a shallow and a deep sample was collected at 4 separate sampling locations • Sample concentrations were lower then available Guidelines from the CCME and MOE guidelines for select parameters of concern. • For the majority of soil parameters tested, higher concentrations were found within the shallow samples in comparison to the deep samples. With continued sampling CVC will track the pace in which concentrations migrate and produce a guideline for soil maintenance and rehabilitation for soil-based LIDs. • Soil sampling is scheduled for every 2 years within the LID features. Sampling results along with site inspection and infiltration testing will monitor the condition of the soil and its ability to infiltrate and filter runoff.

12. Evaluate effectiveness of soil amendments and increased topsoil depth for water balance and long-term reliability	• Enhancements to lot level landscaping, patios and walkways by the homeowners has reduced available topsoil for rooftop runoff volume control and increased the impervious area across the subdivision. • Changes to lot level perviousness increases rooftop runoff draining to the LID features impacting site feature performance compared to the erosion control 15 mm design criteria and post development peak flow control. Increased imperviousness will increase overall runoff and reduce opportunities for onsite infiltration.
13. Evaluate and refine construction methods and practices for LID projects	• Installing and maintaining erosion and sediment controls (ESC) around the perimeter of infiltration features during adjacent construction activities is critical to reduce rehabilitation costs and maintain design performance. • Observed deficiencies in ESCs were shared with the Wychwood developer and many concerns were addressed before site assumption. Inspection reports produced by CVC and shared with the developer and the City of Brampton have been provided in **Appendix M**. • Photo logs of construction activities were taken as the LID was installed and ongoing inspections and maintenance is occurring. • Construction observations where shared with the City of Brampton prior to assumption.
14. Develop and calibrate event mean concentrations (EMCs) for various land uses and pollutants	• Event Mean Concentration comparison in section 4.5 presents results from WW-1 (n=22) and WW-2 (n=18) with residential subdivision data from the NSQ database and from the Lakeview neighbourhood control site for 8 water quality parameters of concern.
18. Improve and refine the designs for individual LID practices	• The rain garden curb cut inlet design do not allow runoff to enter rain garden due to its narrow opening width. Runoff is unable to make the quick 90 degree turn into the rain garden. • Accumulated sediment within inlets also restricts inflows limiting potential runoff storage and filtration within the garden. Additionally, sediment accumulates within the inlets because of the location and size of vegetation at the base of the inlet. Redistributing vegetation, increasing inlet slope and width would allow runoff to enter the garden and improve overall site runoff control. • Infiltration trench underdrain was installed within 0.5 m of seasonally high groundwater level. CVC recommends 1 m buffer between water-table and bottom of proposed facility (CVC, 2012).

19. Assess the overall performance of LID technologies under winter conditions	• Winter maintenance inspections are completed through the winter months to observe and document feature functionality. • Winter events impact volume reduction results, as accumulated snow stored within the site melts during winter and spring precipitation with a rise in temperature. These conditions produce negative volume reductions at the total site monitoring station. Furthermore, accumulated snow is stored along the edge of the rolled curb inlets blocking melt and winter runoff from entering the features. • Snow removal operators could push accumulated snow beyond the edge of the rolled curb further into the bioswale and grass swales. This would allow melt and rain on snow precipitation to enter these features via the rolled curb and produce better winter runoff performance. • CVC is compiling winter data to analyze this dataset separately, to better quantify performance during the winter months.

5.1 Recommendations for Municipalities and Stormwater Practitioners:

CVC has provided the following recommendations for municipal staff responsible for reviewing both development and stormwater management designs, and for staff administering construction and LID condition inspections. These recommendations are intended to help refine the design, review and inspection process based on the performance monitoring and inspection data collected from the Wychwood subdivision.

5.1.1 Designers and Municipality:

- The presence of seasonally high groundwater within a development will impact the volume of runoff that can be managed by LIDs. The key advantage to using LID is to store runoff where it lands through infiltration. With available storage space being reduced due to high groundwater, runoff will need to be stored elsewhere, or performance criteria should be adjusted accordingly.
- When developing site specific design standards for peak flow, water balance, water quality and erosion control beyond what is required by the province, the wording must be clear. The erosion control criteria for Wychwood contains verbiage that could be interpreted differently depending on the background of the practitioner and level of experience. Manage, reuse and detain all 15 mm events across the entire site could have been limited to either manage or detain for example to improve the criteria's measurability with monitoring data.
- Home owners enhancing property landscaping resulting in an increase in lot level imperviousness will have an impact on the design performance of the LIDs. These practises increase runoff volumes and reduce available pervious area for infiltration. Stormwater management features should continue to be installed within municipally owned property wherever possible, with losses to imperviousness as a result of landscape alterations on private property considered in original designs. Considerations can also be made for municipal by-law processes when considering changes to imperviousness to private properties.
- Municipalities would benefit from a site assumption protocol that outlines performance criteria that ensures the municipality is assuming a feature constructed as designed and performing to the design standards. A measurable performance standard could be tied to the release of

development securities to ensure the municipality is assuming a feature constructed according to the approved design.

5.1.2 Construction Site Inspectors

- Keeping LID features clean and clear of construction debris and sedimentation is critical to the features' performance once being placed online. Frequent site inspections to document the LID feature conditions during construction and during adjacent construction activities to ensure it is protected by appropriate ESC controls cannot be overstated. Due to frequent site inspection at Wychwood, CVC was able to provide documentation of improper construction material storage, sedimentation and compaction within the bioswale to the developer and municipality. This led to the appropriate remediation of a section of the feature prior to site assumption.

5.1.3 Municipal By-Law Inspectors

- Post-construction, CVC staff observed landscaping activities within municipal property and within a section of the grass swale. In one case a walkway was constructed through the grass swale to connect a home owners' front door with the road way and in another case a basement entrance was added at the rear of a home. CVC staff spoke with a City of Brampton inspector while onsite and these activities were completed without a permit. Although home buyers were provided with information on the unique LID features onsite during home presentation by the developer, further education is needed to ensure all home owners are aware of the LID features and the City's by-laws for construction permitting.

- CVC recommends site inspection of the LID features be completed at a minimum frequency of every 6 months. Site inspection will document the condition of the features as they age and will help in tracking further lot level landscape changes to impervious cover across the subdivision. Additionally, site inspections are key to identifying when maintenance or site rehabilitation is needed.

6.0 CONCLUSION

The Infrastructure Performance and Risk Assessment monitoring program at CVC is focused on evaluating the long-term performance of stormwater management features in a variety of land use types across the watershed. Monitoring the performance of low impact development (LID) features in the Wychwood Subdivision provides detail on their effectiveness in providing food control, erosion protection, nutrient removal, cold-climate operation and maintaining pre-development water balance. This information will identify opportunities to reduce stormwater risks and provide data required for future infrastructure maintenance, investment and planning.

The Wychwood subdivision demonstrates the ability of LID to manage stormwater runoff from an entire subdivision. It utilizes permeable paver driveways, rain gardens, infiltration trenches and a bioswale to manage stormwater across the site. Runoff from the roadway is pre-treated for suspended solids by oil grit separators prior to directing flows into feature underdrains for further treatment and potential storage. Distributing these LID features throughout the subdivision allowed the designated pond block to be used for additional home development and added tax base to the municipality. The LIDs not only provide additional green space enhancing residential properties aesthetically, they also alleviate future liability of maintaining a stormwater pond.

This report focused on the monitoring and analyses of stormwater performance data, and construction and maintenance inspections collected from January 2016 to December 2017. This report, along with ongoing site monitoring and inspections, is intended to meet Wychwood's regulatory monitoring requirement as prescribed by the site Environmental Compliance Approval (ECA). It will inform future implementation of integrated stormwater management including design, operation and maintenance and lifecycle costs.

Of the total number of measured events (125) during the monitoring period, 112 had a precipitation depth less than 25 mm. These events make up 90 per cent of all precipitation events for the 2016 and 2017 monitoring period at Wychwood, which aligns with the long-term average of 95 per cent at Pearson Airport. Monitoring at the Wychwood Subdivision found a 77 per cent volume reduction and 83 per cent peak flow reduction is achieved by the site LID features for events less than 25 mm. Since these events occur most frequently, they are responsible for transporting a large proportion of the annual contaminant mass delivered to receiving waters. Therefore, their management is critical to achieve water quality objectives.

All watercourses and water bodies within CVC's jurisdiction require, at a minimum, an enhanced level of protection (i.e. 80 per cent TSS removal) (CVC, 2012). Observed performance for Total Suspended Solids (TSS) load reduction from the total site monitoring station is 84 per cent, with the bioswale achieving a total estimated load reduction of 99 per cent. Overall, the Wychwood Subdivision exceeds the target of 80 per cent TSS removal, and the bioswale alone greatly exceeds this target.

Event mean concentrations (EMCs) are also used to assess water quality performance of the features at Wychwood. Results are compared with water quality data collected from other long-term monitoring locations within the watershed. The comparison includes traditional grass swales and curb-and-gutter controls from the Lakeview Neighbourhood in southern Mississauga and median values from the National Stormwater Quality Database (NSQD). Summary statistics of TSS EMCs collected from Wychwood are lower than all comparisons, indicating that the LIDs at Wychwood reduce the concentration of suspended sediment in all treated stormwater.

Observed event performance data and a SWMM model simulation were used to assess site performance compared to the Stormwater Management Design Brief Criteria. The Wychwood Subdivision meets stormwater design criteria by removing 80 per cent TSS loading and achieving pre-development peak flow rates for the 2 to 50-year design storms. The SWMM model calculated a 6 per cent increase in annual runoff volume due to the changes in overall site imperviousness. However, the SWMM model determined the site average annual infiltration rate have increased compared to pre-development estimates, meeting the site water balance design criteria of enhancing annual infiltration rates.

Event monitoring during the study period has determined the erosion control criterion to manage, detain or reuse all events up to the 15 mm has not been achieved. A range of events producing ~15 mm of precipitation with varying intensities occurred during the monitoring period. These events produced outflows at the total site monitoring station. Design deficiencies have been identified as contributing factors in the performance reduction. Changes in lot-level pervious area, lag-time between events and limited infiltration rates due to a high groundwater table within the features have been identified as potential contributors to performance reduction. Despite this, there are no observed concerns regarding overall site water quantity erosion control, peak flow attenuation or water quality treatment.

Construction and site maintenance inspections are a critical part of monitoring the life-cycle and performance of stormwater management features. While Wychwood was under construction, CVC staff completed several site inspections to document feature conditions and ensure implementation of appropriate erosion and sediment controls. These inspections observed several deficiencies in sediment barrier controls protecting the LID features while under construction, including unprotected inlets to the bioswale and improper storage of concrete material within the bioswale. These deficiencies were addressed by the developer and the affected section of the bioswale was remediated.

Once the construction of the subdivision and LID features was completed, CVC staff conducted site inspections to visually document performance and maintenance across all seasons while the features are in service. Ten site inspections have been carried out during the monitoring period. These inspections documented the property alterations made by homeowners that increased the impervious ratio across the subdivision, contributing to greater runoff from the residential lots. These inspections have observed and tracked impervious modifications to lot level pervious area at nearly half of the lots. Site inspections will continue throughout the monitoring period as they are an effective technique in documenting changes within the site and feature that directly impact feature performance.

Monitoring at Wychwood (including the recommended addition of groundwater monitoring in 2020) will continue to assess the long-term performance of the LID features. The addition of groundwater monitoring wells will provide detail on the influence of high groundwater levels on runoff storage, infiltration and peak flow attenuation with corresponding surface flow monitoring information. Site inspections will continue to document changes to the site and help evaluate long-term performance and maintenance needs of the LID features with a goal of developing guidance on life-cycle costs and asset management. This comprehensive data set will provide further insight on the long-term performance of infiltration features in areas with site constraints such as high groundwater levels.

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