IMAX

Low Impact Development Infrastructure Performance and Risk Assessment

July 2015

Technical Report

Business and Multi-Residential

IMAX CORPORATION, CITY OF MISSISSAUGA

LOW IMPACT DEVELOPMENT INFRASTRUCTURE PERFORMANCE AND RISK ASSESSMENT

TECHNICAL REPORT (2012 – 2013)

CREDIT VALLEY CONSERVATION

July 2015

NOTICE

Acknowledgments

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CVC Watershed Knowledge Team

University of Guelph

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The success of CVC's LID program is attributed to the leadership, vision, and commitment of:

- Showcasing water Innovation (MOE)
- Facilities Management, IMAX Corporation
- City of Mississauga
- CVC Board of Directions
- Region of Peel

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Message from – President of IMAX Theatres: Mark Welton

In February 2015, IMAX Corporation and Credit Valley Conservation (CVC) received a Minister's Award for Environmental Excellence from the Honourable Glen Murray, Minister of Environment and Climate Change, for using innovative approaches and new technologies to protect the Great Lakes and the environment. IMAX takes great pride in this achievement. We believe that receiving this award reinforces our vision of supporting environmentally-friendly approaches to building and maintaining our facilities. We look forward to continued collaboration with CVC.

In 2012, we partnered with CVC to retrofit the parking lot at our head office in Mississauga, Ontario. Innovative green technologies called low impact development (LID) were installed. CVC has been monitoring the performance of these technologies since. IMAX continues to collaborate and support CVC with their infrastructure performance and risk assessment program.

LID is part of our stormwater management solution at IMAX. The project provides significant water quantity and quality improvements as detailed in this report. In addition to treating stormwater, the parking lot also provides cost savings due to the increased lifespan of permeable pavers and the potential offset to anticipate stormwater utility credits. In addition, the permeable pavers and the bio-swale plantings enhanced the aesthetics of our site.

We are protecting the environment and expanding the parking lot at the same time. As a result, we've received positive feedback from our employees.. This is a true win-win scenario for CVC, IMAX, and the Great Lakes Protection Act that we are proud to be a part of.

This report details the performance of the IMAX parking lot retrofit.

Sincerely,

Mark Welton, President of IMAX Theatres, IMAX Corporation

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

Figure 4-2: 2013 Precipitation events

LIST OF ACRONYMS AND ABBREVIATIONS

ANSI	Provincial Area of Natural and Scientific Interest
ASTM	American Society for Testing and Materials
BMP	Best Management Practice
BMPDB	International Stormwater Best Management Practices Database
CCA	Canadian Council of Academics
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
Cl^-	Chloride
Cu	Copper
CVC	Credit Valley Conservation
DO	Dissolved Oxygen
EC	Environment Canada
EMC	Event Mean Concentration
Fe	Iron
FCM	Federation of Canadian Municipalities
g	Gram
GGH	Greater Golden Horseshoe
GTA	Greater Toronto Area
hr	Hour
IBC	Insurance Bureau of Canada
IC	Industrial/Commercial
IPRA	Infrastructure Performance & Risk Assessment
kg	Kilogram

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
Mg/L	Milligram per Litre
µg/L	Micrograms per Litre
min	Minute
mm	Millimetre
Mm/hr	Millimetres per hour
MOI	Ministry of Infrastructure
MTO	Ministry of Transportation of Ontario
N	Nitrogen
NH_3	Un-ionized Ammonia
Ni	Nickel
NSQD	National Stormwater Quality Database
$NO_2 + NO_3$	Nitrite + Nitrate
MOE	Ontario Ministry of the Environment
O&M	Operation and Maintenance
OP	Orthophosphate
P	Phosphorus
PAH	Polycyclic aromatic hydrocarbon
Pb	Lead

PoC	Parameters of Concern
PSW	Provincially Significant Wetland
PWQO	Provincial Water Quality Objective
RL	Reporting Limit
s	Second
SWM	Stormwater Management
SWMM	Stormwater Management Model (EPA SWMM)
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TRCA	Toronto Region Conservation Authority
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
WPCP	Water Pollution Control Plant
WSIB	Workplace Safety and Insurance Board
yr	Year
Zn	Zinc

EXECUTIVE SUMMARY

Stormwater management (SWM) has recently made headline news due to flooding in Alberta and the Greater Toronto Area (GTA). Canada has an estimated $171.8 billion infrastructure deficit (CCA et. al., 2012). This includes roads, water, wastewater and stormwater. Ontario's share of the deficit is estimated to be $100 billion (MOI, 2006). This deficit does not account for land costs which can be 3-4 times infrastructure costs within the Greater Golden Horseshoe (GGH) and does not consider new infrastructure needed to service areas without flood control to current standards (Reinthaler, Partner, Schaeffers & Associates, Ltd., 2012). Only 17% of the City of Mississauga has water quality treatment and only 25% has flood control (City of Mississauga, 2013). Bringing older areas to current standards will cost an additional $56.6 billion nation-wide (FCM, 2007).The question remains as to whether our current standards will provide the protection needed to safeguard our communities from frequent localized high-intensity storms such as the one experienced in the GTA on July 8th, 2013. Flood control is not the primary purpose of LID but when LID is combined with existing stormwater infrastructure, it does provide resilience. LID has the ability to reduce runoff volumes, reduce or delay water from entering stressed stormwater infrastructure and better protect assets from extreme precipitation events

Industrial/Commercial (IC) land use zones typically occupy 20-30% of urban area. IC land use can be described as buildings with large roof areas, large paved surfaces (parking, lots, and service roads) with little open space or green area. They typically have impervious cover ranging from 75-95% of total drainage area. Because of this, IC lands can generate the largest runoff volumes per unit area of all the urban land-use categories. IC lands contribute the following pollutant loads to surface waters: Total Suspended Solids (12-16%); Total Phosphorous (17-22%); Copper (62-75%); and Zinc (26-45%).

IC lands can also contribute to increased flooding, erosion, water quality issues, habitat degradation, fishery impacts, loss of base flow to streams, reduced infiltration and groundwater recharge and recreational disturbances (beach closures etc) and are a major source of chloride loading.

The Ministry of the Environment (MOE), City of Mississauga and Credit Valley Conservation Authority (CVC) have partnered with 18 public and private sector organizations to implement 10 innovative SWM retrofit sites on public and private properties. One of these retrofit sites is the IMAX corporate office that is located in the Sheridan Business Park, a highly industrial area in the headwaters of the Sheridan Creek Watershed. The project provides a unique demonstration site where comprehensive infrastructure performance and risk assessment is being conducted. The low impact development (LID) features that are utilized at the site promote infiltration, retention and the slow release of treated stormwater runoff. Permeable pavement areas and bioretention cell treatment train systems to control runoff volume and remove pollutants will be compared to a traditional asphalt-to-catchbasin practice.

Construction of the parking lot retrofit at IMAX began in October 2012 and finished in October 2013, due to weather delays. Performance assessment monitoring partially began in April of 2013 as construction completed and deficiencies were being addressed, and most stations came online by the end of 2013. The monitoring includes hydrology, water level measurements and water quality for some monitoring stations. An agreement exists between CVC and IMAX that provides assurance for long term monitoring and access to the demonstration site.

The IMAX parking lot retrofit is the first of its kind in Ontario and CVC will compare performance data from the site with performance data from the National Stormwater Quality Database (NSQD) and International Best Management Practice Database (BMPDB). This will allow Ontario practitioners to compare local site results to other LID sites in North America to build confidence in sizing and approving SWM infrastructure in Ontario.

In 2013, the site reduced the cumulative runoff volume (based on 58 events between April and December 2013) by 82% with a total retention volume of over 2.4 million litres of storm water. In other words, 82% of the annual runoff volume generated by the site was absorbed by the permeable pavement and bioretention; this volume would otherwise have entered the municipal sewer system and been conveyed to Sheridan Creek, Rattray Marsh and Lake Ontario.

Preliminary performance data for various low impact development demonstration sites undertaken by CVC suggest that wide-spread adoption of LID significantly benefits receiving streams and the Great Lakes. The results of the IMAX project will provide municipalities and business owners with tools to optimize costs of infrastructure upgrades and address pressures of growth, infill, and redevelopment while protecting and enhancing the environment. These actions will support the goals set out in the Ministry of Environment's Great Lakes Protection Act, Ministry of Infrastructure's Municipal Infrastructure Strategy, and the Ministry of Municipal Affairs and Housing's Go Green: Ontario's Action Plan on Climate Change.

1 BACKGROUND INFORMATION

This section describes for how infrastructure performance and risk assessment (field monitoring) can support asset management by developing targets and indicators that further support accountability, minimize risk and liability and infrastructure sizing in Ontario.

1.1 State of Stormwater Infrastructure in Ontario

Only 15% of the City of Mississauga receives stormwater quality treatment and 20 of the 30 watersheds under its jurisdiction have no flood control (AECOM, 2013), with a SWM infrastructure deficit of $23 Billion (excluding land acquisition costs) (McBean & Schuster, 2008).

With the recent 2013 floods in southern Alberta and Greater Toronto, attention has been put on Canada's aging infrastructure in need of rapid repair and replacement, a total cost mounting to $170 billion for water supply, wastewater, stormwater and road infrastructure stock. Ontario accounts for almost 60% of that amount, needed to replace existing water supply, wastewater, stormwater and road infrastructure stock (of which stormwater represents 23%). The stormwater management (SWM) infrastructure deficit in Ontario is estimated to be $23 billion (MOI, 2006). Many municipalities have large urban areas that were built prior to flood and water quality requirements. Growth pressures and extreme weather place greater strain on aging infrastructure and maintenance costs. A large part of the City of Mississauga was built before 1970, prior to modern flood and water quality controls. The lack of SWM infrastructure is concerning because of the more frequent and intense precipitation events being observed in Ontario with three 100-year storms and five 50-year storms occurring in Southern Ontario in the last eight years alone. Flooding events in Peterborough, Mississauga, and Toronto have caused over $260 million in damages to public and private property (Sandink, 2013). Water damage is the largest single component of insured loss with claims tallying at $1.7 billion/year (IBC, 2013a).

Figure 1-1: The July 8 2013 precipitation event caused mall evacuation and closure (SOURCE: Mississauga news)

Modern and reliable infrastructure drives our economy. It contributes to our province's wealth and productivity, and it helps us attract investment and create jobs. (http://www.moi.gov.on.ca/en/infrastructure/building_together_mis/index.asp)

In July of 2013 the GTA experienced two extreme weather events in one month. The July 8th storm saw 125 mm (5") fall in a two-hour period. This is the most extreme storm since Hurricane Hazel in 1954. The resulting flooding stranded commuters, extensively damaged infrastructure, disrupted businesses and cause power outages to more than 300,000 people. The total cost of damages is expected to be more than $850 million (IBC, 2013b).

Traditional approaches to SWM are costly within existing urban areas as land costs within the GTA can be 3-4 times that of stormwater infrastructure costs (Reinthaler, Partner, Schaeffers & Associates, Ltd., 2012). This makes expropriation of land for SWM costly. A new solution is needed to build cost-effective resiliency.

More than six Ontario municipalities have already implemented or are implementing stormwater utilities or flat rates where property owners will pay based on the amount of stormwater generated by the site?

In the USA, Europe and Australia the adoption of LID source and conveyance controls has grown over the last 20 years. These controls can be adopted within existing urban environments with little to no land needs that can easily be implemented in infill, redevelopment and Greenfield sites to meet SWM Guidelines. Commercial and industrial land uses often have high percentage of impermeable surfaces including rooftops, parking lots, laneways and roads. These surfaces generate large amounts of runoff that need to be collected and managed by costly stormwater infrastructure. The runoff contains pollutants that enter downstream ponds, creeks and streams. Poor SWM can put the environment, infrastructure and human safety at risk.

Figure 1-2: Large roof area and asphalt pavement that account towards impervious area in a typical industrial/commercial setting.

To address stormwater infrastructure costs, some Ontario municipalities are introducing a stormwater utilities program similar to the City of Kitchener and the City of Waterloo. The City of Mississauga conducted a stormwater financing study and determined stormwater utilities to be a viable option. The general idea is that properties putting more strain on municipal stormwater infrastructure pay a higher monthly fee. The user fee that the property owner pays to the municipality is either based on total impervious area or land use and property size.

Land owners who retrofit their property with LID could qualify for a rebate of up to 45%. Source: City of Kitchener (2013). Stormwater Credit Policy: http://www.kitchener.ca/en/livinginkitchener/Stormwater_Credit_Policy.asp

To encourage property owners and managers to reduce runoff quantity and improve stormwater quality from their properties, stormwater utilities programs often have credit programs. The credit programs offer reductions in monthly stormwater utility fees if the property owner implements onsite practices that divert water from the municipal storm sewer system and/or improve its quality. Industrial and commercial businesses can set up programs to educate employees on SWM and will qualify for more fee reductions. Each municipality with an incentive program will have different criteria for allocating stormwater credits.

1.2 Need for Long-Term Performance Assessment of Low Impact Development (LID) Techniques in Ontario

1.2.1 Address Knowledge Gaps

Currently LID technologies are facing challenges with public and industry acceptance, selection, design, approval and construction. The Industrial/Commercial/Institutional (ICI) sector lacks guidance, functional example projects, and confidence in anticipated long-term, in-situ performance. These challenges in turn have created a technology gap between the local design and construction industry and market capacity, preventing widespread acceptance.

The challenge with developing LID technology in Ontario is providing performance evaluation information to support the wide scale implementation of LID technologies. Early adopters of LID technologies require additional considerations and increased analysis to account for performance in cold climates. Another barrier is the limited local long term performance data to complete the life-cycle analysis required for asset management. The lack of data makes it difficult for designers to size stormwater infrastructure and for approval agencies to permit these techniques in different land-use applications.

The IMAX Corporation showed their commitment to green infrastructure by implementing LID practices in their employee parking lot. This provides a unique opportunity to evaluate the performance of LID technologies individually as well as a collective system. The performance monitoring results will address the above mentioned knowledge gaps and accelerate acceptance of LID technologies.

1.2.2 Risk Reduction

Taking steps to better manage stormwater on commercial property can also reduce risks faced during day-to-day operations. Some of these risks include:

- Rising costs of managing your property; this can include water, wastewater, stormwater, electricity, natural gas, maintenance and repair of facility buildings and grounds. *For example, due to inadequate parking lot drainage there can be challenges such as power outages within the building that can disrupting everyday business and add to maintenance and repair* costs.
- Costs of Slips and Falls; these can cost up to $22,000 for employees for WSIB claims. *Permeable pavement can withstand cracking or heaving from ground movement or frost hence reducing the chances of slips and falls. Permeable pavement allows snow to infiltrate through the gravel subbase which in turn reduces "black ice" formation.*
- Staying ahead of emerging regulations; in order to better evaluate asset protection, it is important to consider both current and future water regulations that can impact the owner's business operation and property. *For example, impacts include higher compliance costs, reduced ability to service your clients, increased taxes/stormwater utilities, reducing your time* spent understanding new regulations or even costs relating to potential fines and penalties.
- Remaining competitive in a marketplace where green business practices are a competitive advantage. *By initiating such projects, businesses can green their brand through the implementation of innovative technologies and reducing their water footprint.*

Flood control is not the primary purpose of LID but when LID is combined with existing stormwater infrastructure, it does provide resilience. LID has the ability to reduce runoff volumes, reduce or delay water from entering stressed stormwater infrastructure and better protect assets from extreme precipitation events.

1.2.3 Asset Management

Asset management is an integrated, lifecycle approach to maximize benefits, manage risk and provide satisfactory levels of service to the public in a sustainable and environmentally responsible manner. The United States Environmental Protection Agency (USEPA) defines asset management as maintaining a desired level of service for what you want your assets to provide at the lowest life-cycle cost. The lowest life-cycle generally refers costs associated with rehabilitating, repairing or replacing an asset. USEPA defines asset management as a framework that is being widely adopted to pursue and achieve sustainable infrastructure. It is the practice of managing infrastructure capital assets to minimize the total cost of owing and operating them while delivering the desired service levels.

Among the many benefits of asset management, USEPA as outlined some notable outcomes that include:

- Prolonging asset life and aiding in rehabilitation, repair and replacement decisions through efficient and focused operations and maintenance activities.
- Budgeting focused on activities critical to sustained performance
- Meeting service expectations and regulatory requirements
- Improving responses to emergencies
- Improving the security and safety of assets
- Reducing overall costs for both operations and capital expenditures

1.2.4 Water Opportunities Act and Great Lakes Protection Act

Performance data supports the guidelines outlined in the Province of Ontario's Water Opportunities Act by providing information on innovative water management technologies. The knowledge gained through performance evaluation will strengthen existing tools and be used to create new tools to support the promotion of voluntary efforts. This provides elected officials, municipal engineering and operations personnel, developers, contractors, consultants and businesses and residential landowners with the tools they need to successfully implement LID in their communities.

"The Water Opportunities Act, 2010 will help make Ontario a North American leader in developing water technologies and services, offering our expertise to the world through the Water Technology Acceleration Project (TAP) - a technology hub that brings together industry, academics, and government to develop and promote the sector. To complement this, the Showcasing Water Innovation program is highlighting new and innovative approaches and technologies for managing drinking water, wastewater and stormwater systems."

Source - Building Together: Guide for Municipal Asset Management Plans, Ministry of Infrastructure

1.2.5 Infrastructure Performance and Risk Assessment

In an effort to build confidence in sizing stormwater infrastructure and long-term performance, CVC and its partners have implemented a series of demonstration sites within various land-use settings and are

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

delivering a 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 maintaining pre-development water balance. This program will produce performance data to address the knowledge gaps and stakeholder objectives identified in CVC's SWM Monitoring Strategy. In Section 2, seven overarching objectives are identified specifically for the IMAX project. They relate to the broader 18 objectives and stakeholder priorities identified in CVC's SWM Monitoring Strategy.

Table 1 below summarizes the Provincial Water Quality Objectives (PWQO) for many of the parameters being monitored at the IMAX site. Although these objectives were not specifically developed for stormwater discharges, it has long been recognized by the USEPA, MOE and EC that urban stormwater is a major contributor of pollutant loading to our creeks, rivers and Great Lakes. The PWQO guidelines listed in the Table 1-1 provide context for planning and water resource management. These parameters of concern will be assessed for SWM performance of LID practices in the sections ahead.

Table 1-1: Provincial Water Quality Objectives (PWQOs) for Selected Metals, Nutrients and Other Parameters of Interest

Parameter	Unit	PWQO
Metals		
Cadmium (Cd)	µg/L	0.2
Copper (Cu)	µg/L	5
Iron (Fe)	µg/L	300
Lead (Pb)	µg/L	1 – 5 depending on hardness (Interim)
Nickel (Ni)	µg/L	25
Zinc (Zn)	µg/L	20 (Interim revised)
Nutrients		
Total Phosphorus (TP)	µg/L	30
Nitrate-Nitrogen (NO_3-N)	mg/L	3.0 (CCME)
Nitrite + Nitrate (NO_2/NO_3)	mg/L	N/A
Un-ionized Ammonia (as NH_3)	µg/L	20
Other		
Dissolved Oxygen (DO)	mg/L	Temperature Dependent
Temperature	Deg. C	Narrative standard, with some numeric components
Total Suspended Solids (TSS)	mg/L	25(CCME)
Chloride (Cl^-)	mg/L	120 (CCME)
Source: 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		

To build confidence in the monitoring data obtained from CVC's monitoring program, CVC has opted to input performance data into the NSQD and BMPDB. This database allows Ontario practitioners with an opportunity to evaluate the performance of our local

For more information on CVC's LID sites, performance data and Show Casing Water Innovation Project checkout - www.creditvalleyca.ca/low-impact-development/showcasing-water-innovation-2/

sites in comparison to other cold weather climates in North America in order to build confidence in sizing and approving SWM infrastructure, long-term performance and maintenance requirements.

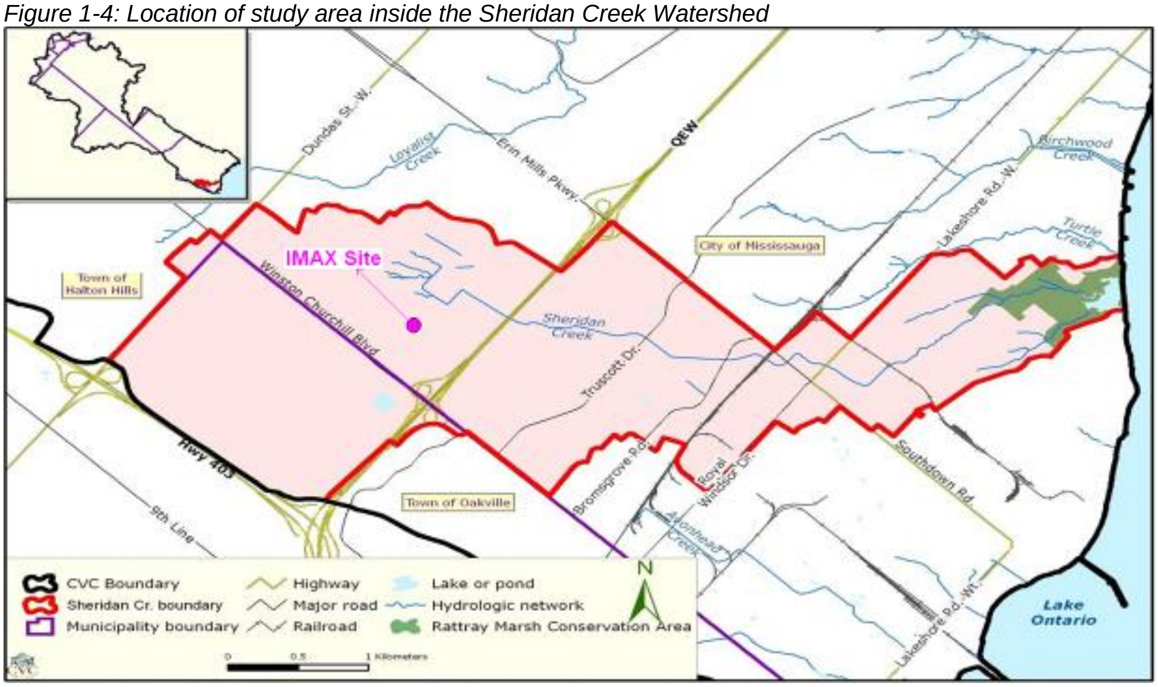
1.3 IMAX Parking Lot Retrofit – Green Infrastructure Design

The IMAX Headquarters head office is located at 2525 Speakman Drive, Mississauga. This location is at the headwaters of the Sheridan Creek Subwatershed as shown in Figure 1-3. The Sheridan Creek Watershed is a long, narrow, fully urbanized watershed located on the west side of the City of Mississauga. The subwatershed drains an area of approximately 1,035 hectares (ha) and outlets to Rattray Marsh. Rattray Marsh is a Provincially Significant Wetland (PSW) and Provincial Area of Natural and Scientific Interest (ANSI). The water then flows into Lake Ontario which is the drinking water supply for millions of Canadians (see Figure1- 3).

Figure 1-3: Sheridan Creek, Rattray marsh and Lake Ontario

The IMAX parking lot retrofit collects, absorbs and filters pollutants from stormwater runoff before it is discharged into Sheridan Creek. Figure 1-4 shows the location of the IMAX site within the Sheridan Creek Watershed in the Credit Valley Jurisdiction.

Figure 1-4: Location of study area inside the Sheridan Creek Watershed



The parking lot was expanded and retrofitted with permeable pavement s and bioretention cells with enhanced water filtration systems. The retrofit includes the practices listed below in **Table 2**.

These innovative practices store and filter stormwater before it enters the Sheridan Creek and Lake Ontario. **Figure 1-5** and **Figure 1-6** show the drainage patterns of the parking lot before and after construction.

Table 1-2: LID practices implemented at IMAX

LID Practice/Description	Graphic
Bioretention cells: are a SWM technique that uses the chemical, biological, and physical properties of plants and soils to treat stormwater runoff. They are designed to mimic natural conditions promoting retention (infiltration, evapotranspiration), and the slow release of stormwater runoff.	
Permeable pavement: an alternative paving system. This allows stormwater to drain through the surface and into a stone reservoir where it can be temporarily detained and infiltrated into the underlying native soil.	
Sorbtive® Vault: an oxide-coated, high surface area reactive engineered media that sorbs and retains large phosphorus loads; used as a post-treatment in conjunction with a bioretention cell at IMAX.	
Jellyfish® Filter: a membrane filtration technology capable of removing a high proportion and wide variety of stormwater pollutants; used as a pre-treatment in conjunction with a bioretention cell at IMAX	

Figure 1-5: Before Retrofit – Drainage from the IMAX parking lot

Figure 1-6: Post- Construction – Drainage from the IMAX parking lot with LID

Some of the Key Drivers for the Implementation of LID at IMAX

- Provide a better functioning parking lot with enhanced aesthetic value.
- Expand parking lot to accommodate IMAX's projected employee growth.
- Lowered operational costs.
- Reduce IMAX's potential stormwater utility cost should the City of Mississauga decide to implement a stormwater utility.
- Upgrade the existing parking lot surface with modern LID techniques which provide stormwater quantity and quality control.
- Position and brand IMAX as an environmentally sustainable company.
- Elevate the IMAX brand as a sustainability leader who consistently show superior performance and favorable risk/return profiles.
- Reduce likelihood of flooding and associated liability issues.
- Reduce carbon footprint with potential for carbon offsets.

2 LID MONITORING OBJECTIVES

2.1 Experimental Design - Study Objectives

An experimental design template was developed in 2012. The experimental design template outlines the seven overarching objectives defined as part of the Experimental Design development for the IMAX project (Drake et al. 2012) are listed below:

1. Apply and demonstrate LID systems within an urban community in the GTA;
2. Evaluate the behaviour of LID technologies as individual and collective systems relative to a traditional asphalt-to-catchbasin system;
3. Assess designs of permeable pavement systems to meet multiple environmental and non-environmental objectives ;
4. Evaluate the potential of in-series LID systems (Jellyfish® to Bioretention and Bioretention to Sorbtive® Vault) to maximize water quality improvements;
5. Investigate long-term performance of LID systems and the implications to receiving surface and groundwater systems;
6. Monitor and assess the operational and maintenance needs of LID systems and the subsequent effects on performance;
7. Refine and customize guidelines for LIDs (design, construction and O&M) to suit various Ontario conditions (e.g. high groundwater sensitivity, commercial/industrial land use, low permeability soils, cold weather climate, etc.).

2.2 Addressing Stakeholder Objectives

The CVC Stormwater Management Monitoring Strategy was developed in 2013 which defines 18 objectives identified by a multi-stakeholder group. Out of these, our stakeholders rated the top 5 objectives based on priorities and concerns. This section describes how IMAX's overarching objectives relate to these top 5 stakeholder objectives which are:

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

Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance (Objective 6);

- Questions and concerns regarding operation and maintenance (O&M) are largely unanswered impeding the use of LID systems. As new technologies emerge, development, testing and refinement of O&M practices is needed.
- Performance data collected through the monitoring program will be used to plan and adapt maintenance activities at IMAX.
- All maintenance activities performed and their associated costs will be documented. In the first year, the main goal is to start the O&M procedures, document activities and

begin to gather data. More intensive analysis will be done when enough data is collected in a few years.

Determine the life cycle costs for LID practices (Objective 6)

- Site inspections are performed on a biweekly basis and to collect maintenance data, ongoing communication with maintenance staff is needed.
- CVC will communicate with IMAX facilities management to determine O&M activities and associated costs and develop a data sharing system/protocol including log sheets, photos, videos, invoices etc.
- Cost data will support life cycle costing tool development for low impact development. This exercise will define the life cycle maintenance and costs needs in Southern Ontario. Furthermore, as the maintenance data set grows, an evaluation can be performed on the optimum design and management strategies that reduce maintenance and life cycles costs.

Assess the water quality and quantity performance of LID design in clay or low infiltration soils relative to those that do not use infiltration (Objective 2)

- Local performance data is needed to better understand the impact of LID on stormwater flows and water quality within the Credit River watershed. Performance of full-sized LID systems has not been widely studied and some of the LID designs in this project have never been tested in field installations.
- Long term performance will demonstrate how LID systems perform with respect to water quality and quantity in clay soils.

Evaluate how a site with multiple LID practices treats stormwater runoff and manages stormwater quantity as a whole (Objective 2)

- Monitoring studies tend to be limited to individual installations of single LID technologies. Integrated designs, like IMAX, frequently use several LID systems on a single lot. Evaluating the performance of collective systems versus individual systems will help inform designers and watershed managers. It will allow them to compare the environmental benefits of these technologies when used together as compared to traditional asphalt-to-catchbasin systems. Demonstration of multiple LID practices will inform practitioners on the potential for flood control under various types of precipitation events and also to building infrastructure resilience which one technology cannot provide alone.

Evaluate whether LID SWM systems are providing flood control, erosion control, water quality, recharge, and natural heritage protection as per the design standard (Objectives 1, 2, 3, 4 and 5)

- CVC's goal is to foster awareness and understanding of innovative SWM practices. The IMAX parking lot is a demonstration site of LID for industrial/commercial applications.
- As more monitoring data becomes available for IMAX, performance will be evaluated for CVC's greenfield SWM criteria. This is a tool for providing flood control, erosion control, water quality, recharge and natural heritage protection.

To assess these objectives, CVC has developed comprehensive meteorological, hydrologic and water quality assessment protocols. These can be found in Appendix A and B. A detailed rationale for the approaches recommended for IMAX can be found in the Experimental Design Report (Drake et al., 2012).

3 SITE DESIGN

The total drainage area for the site is 0.93 ha (9,268 m^2) based on 2013 as-built survey results, see Appendix E for details. The IMAX parking lot retrofit applies LID designs to a SWM system that is customized to suit local hydrology and geology conditions. The layout of the parking lot is shown in **Figure 3-1** below which outlines the locations of the different SWM technologies. The main source of runoff to the LID systems is from the parking lot and entrance driveways. The parking lot has been divided through the upper third with permeable pavement on the north end and asphalt draining into a series of LID treatment trains on the south end.

Figure 3-1: IMAX retrofit design concept

3.1 Innovative Technology Controls

3.1.1 Treatment Train

The integration of proprietary products such as oil-and-grit separators in a treatment train setting with low impact development practices have not been extensively implemented nor monitored. Side-by-side monitoring of bioretention cells demonstrate the unique attributes of each technology as well as the advantages of in-series design to create a treatment-train. Through monitoring, the performance results gathered for these treatment train scenarios will demonstrate potential for resilience that one technology can not provide alone. For example, if a large storm of large intensity occurs producing flow rates that overwhelm the Jellyfish® filter, the bioswale downstream will still provide some level of effluent treatment. Similarly, for the other treatment train, if the bioswale is overwhelmed during an intense storm, the overflow/bypass will received some level of treatment through the Sorbtive® Vault unit. These in-series LID combinations are the first of their kind in Ontario. The treatment trains implemented at IMAX and the components of the design are shown in **Figure 3-2** and **Figure 3-3** below. Treatment train #1 drains asphalt generated runoff to a Jellyfish® Filter for pre-treatment and then outlets to a bioretention for secondary treatment. Treatment train #2 drains asphalt generated runoff to a bioretention for pre-treatment and then to a Sorbtive® Vault for further polishing and secondary treatment. As shown in **Table 3-1** under Section 3.3, treatment train #1 drains 1256 m^2 of contributing drainage and treatment train #2 drains 1110 m^2.

Figure 3-2: Asphalt to Jellyfish® filter to Bioretention (Treatment Train #1)

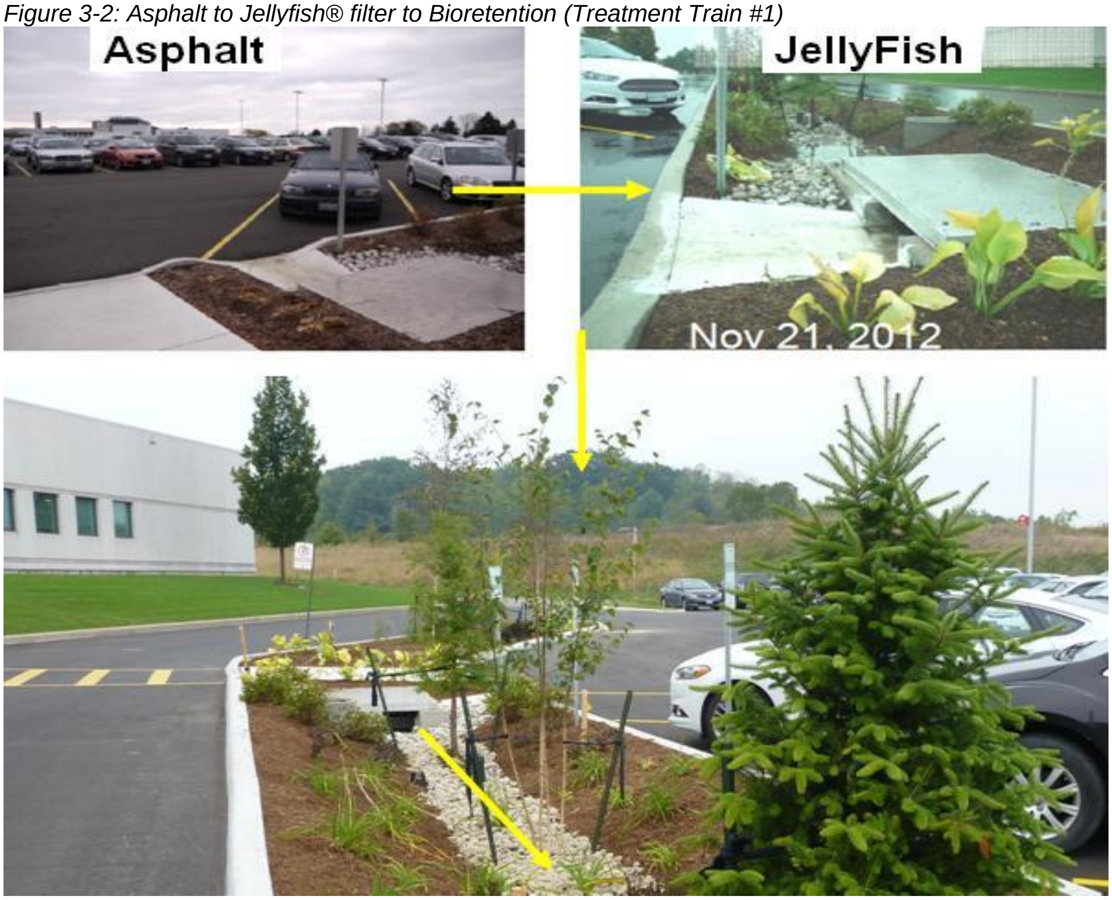
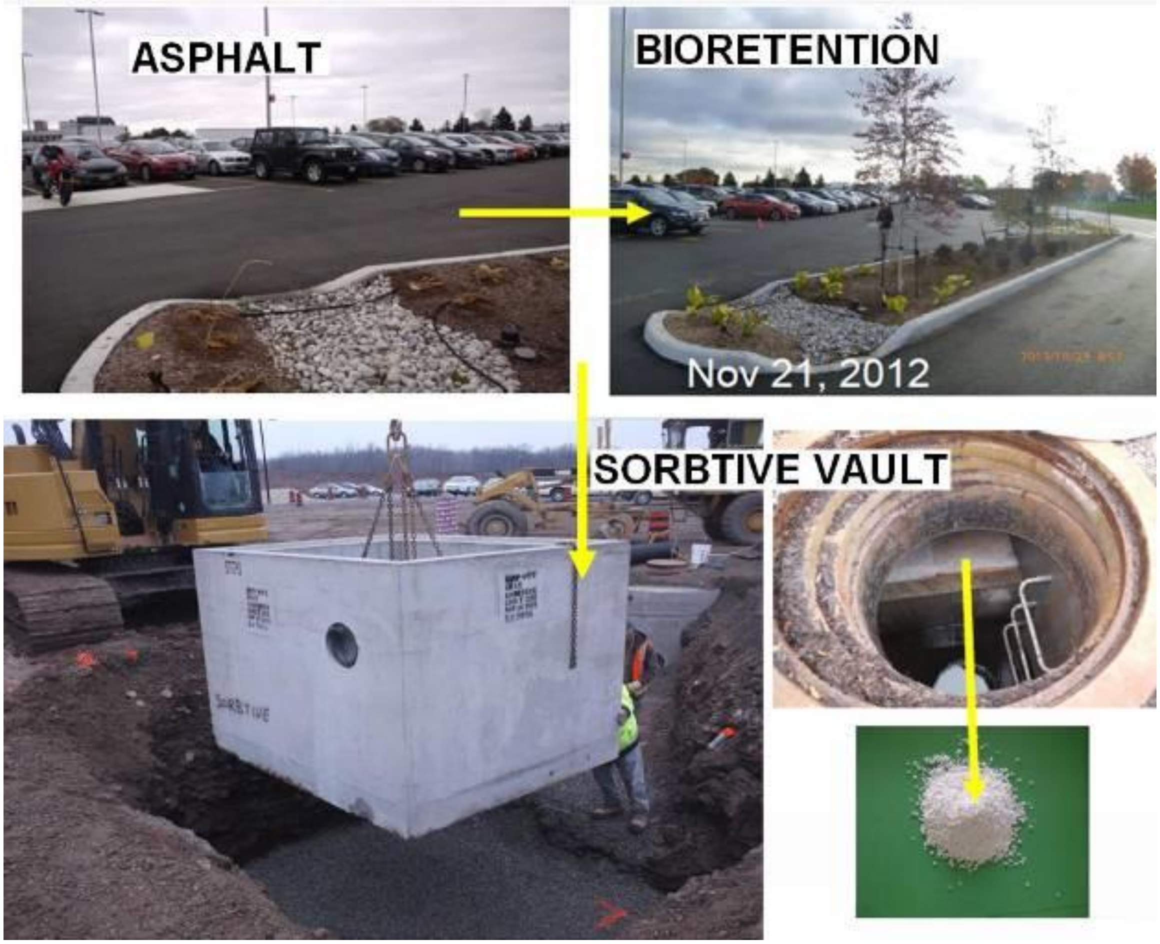


Figure 3-3: Asphalt to bioretention to Sorbtive® Vault (Treatment Train #2)



3.1.2 Subbase Aggregate Materials

As part of the experimental design, the permeable pavement parking lot was separated into two sections to include different aggregate materials to investigate permeable pavement design. These sections are hydraulically separated with an impermeable liner. Each section is designed to have an independent underdrain system so performance comparisons are possible. **Figure 3-7** shows the permeable pavement lot has three distinct catchments; Area 5, Area 6 and Area 7. Area 5 has been constructed with a granular "O" base. Areas 6 and 7 have been constructed with a 20 mm clear stone base. Infiltrating stormwater from these catchments will be routed to manholes IX-5, IX-6 and IX-7, respectively. Stormwater from IX-5 and IX-6 discharge to the constructed wetland that is adjacent to the IMAX property. IX-7 drains to the municipal sewer. As outlined in **Table 3-1** under section 3.3, the contributing drainage areas for IX-5 and IX-6 are 1915 m^2 and 1328 m^2, respectively.

Clear stone is recommended for permeable pavement systems because it does not include fines and has large void spaces that provide storage for infiltrating stormwater. The lack of fines means that larger aggregate depth is required to meet structural requirements for traffic loadings. Aggregate 'O' is readily available in Southern Ontario and requires less aggregate depth to meet structural requirements. This study tests Aggregate 'O' as an alternative base material which may offer better balance between structural and environmental objectives.

Figure 3-4: Granular "O" (left) and 3/4" Clearstone (right)

3.1.3 Impermeable Liner

The risk to groundwater systems from LID is unknown. Fully lined and underdrained permeable pavements are not anticipated to pose a significant risk if all infiltrating stormwater is routed to a conventional storm sewer system (Area 7). The IMAX property is a good location to test and monitor a lined permeable pavement system as it is not an area of groundwater sensitivity. The monitoring data can be used to assess lined infiltration systems in groundwater sensitive areas such as CVC’s upper watershed and across Southern Ontario. The subcatchment has sampling ports beneath the liner that connects to an observation well. This well can be used to check for leakage when performing an annual dye test. As outlined in **Table 3-1** under section 3.3, the contributing drainage area for IX-7 is 478 m^2.

Figure 3-5: Geosynthetic Clay Liner

3.2 Monitoring Catchment Areas

The parking lot has been divided into seven subcatchments, defined by the drainage area entering each SWM system. There are seven monitoring stations where stormwater flows are monitored and sampled. Soil conditions are unsuitable for complete stormwater infiltration so the bioretention cells and permeable pavements are designed as underdrained systems. This means that infiltrated stormwater will be collected through buried perforated pipes. The underdrains are dual purpose, providing access points to measure and sample infiltrated stormwater while simultaneously conveying excess stormwater to the receiving municipal stormwater system.

3.2.1 Control Site

Field research commonly monitors runoff from traditional asphalt catchment near an LID installation (e.g. Drake et al., 2012, TRCA 2008, Collins et al. 2008). This allows for direct comparisons between the two systems. Side-by-side testing ensures that systems are exposed to climatic, geologic, and pollutant conditions which are as similar as possible in a field installation. The control site allows for more confidence in the interpretation of the benefits of LID systems. **Figure 3-7** shows that Area 1 drains stormwater from asphalt entrance laneways to a traditional catchbasin collection system which serves as a control for the site. As outlined in **Table 3-1** under Section 3.3, the control site has a contributing drainage area of 815 m^2 with an imperviousness of 92%.

3.2.2 Control Bioretention

As described in section 3.1.1, the performance data from the treatment train systems will be used to evaluate SWM technologies in-series versus each technology on its own. As shown in **Figure 3-7**, a "control" bioretention cell has been implemented which standards "on its own". This analysis can be used to determine if bioretention systems design can be optimized when used in conjunction with additional treatment units. It will also be used to analyze costs and benefits of in-series LID systems. As outlined in **Table 3-1** under Section 3.3, the control site has a contributing drainage area of 2367 m^2 with an imperviousness of 92%.

Figure 3-67: Asphalt to bioretention

Figure 3-7: Catchment Areas and monitoring stations

Table 3-1: Drainage Area characteristics

Design Criteria	Area 1- IX1	Area 2 - IX2	Area 3 - IX3	Area 4 - IX4	Area 5 - IX5	Area 6 - IX6	Area 7 - IX7
Area Description	Asphalt to catch basin system (Control site)	Asphalt to Bioretention (primary treatment) and Sorbtive® Vault (secondary treatment)	Asphalt to Jellyfish® Filter (pre-treatment) and Bioretention (secondary treatment)	Asphalt to stand- alone bioretention cell	Permeable Pavement with Granular "O" aggregate.	Permeable Pavement with ¾" Clearstone aggregate.	Permeable Pavement with ¾" Clearstone aggregate lined with a geosynthetic clay liner.
Drainage Area	815 m^2	1110 m^2	1256 m^2	2367 m^2	1915 m^2	1328 m^2	478 m^2
Weighted Imperviousness %	92	76	92	92	-	-	-
Water Quality Storage Volume Requirement*	43 m^3/ha	37 m^3/ha	43 m^3/ha	43 m^3/ha	-	-	-
Required Water Quality Storage Volume**	3.50 m^3	4.107 m^3	5.401 m^3	10.178 m^3	-	-	-
Provided Water Quality Storage Volume	0	27.3 m^3	36.6 m^3	41.6 m^3	141 m^3	222 m^3	125 m^3
Bioretention Filter Mix Specification	Depth 675 mm Sand (2.0 to 0.005 mm Ø) 85-88% (by weight) Organic Matter 3-5% Fines (<0.05 mm Ø) 8-12%				80 mm – Eco Optiloc(R) by Unilock Bedding 50 mm of No.8 angular chip stone (5-7 mm ø) Woven multi-layered geotextile (Tencate's RS380i)		
Water Quality Design Estimation	Enhanced treatment is provided (80% TSS removal)						
* Extrapolated from Table 3.2 of the 2003 Stormwater Management Planning and Design Manual. **Storage volume is estimated as void space below the under drain. Additional storage (temporary) above the under drain (void spaces and on the surface of the cells) provides additional storage capacity.							

4 ASSESSMENT RESULTS AND INTERPRETATIONS

The Project Team has developed a comprehensive data management and analysis program for CVC's LID monitoring sites. To add to the robustness of the analyses for the water quantity and quality data, numerous water quality guidelines, performance, and contaminant references are included in the analyses as described in sections below. The size of the dataset will dictate the types of analytical methods that can be applied for data analysis and, as additional data are collected, it may become feasible to apply different or additional analytical/statistical techniques.

As summarized in Table 4-1 below, the performance of LID systems will be evaluated by monitoring climate conditions (precipitation, temperature etc.) by using a heated tipping bucket rain gauge that is installed on site. The hydrologic response will be measured by flow equipment such as weirs and flow loggers to evaluate inflow/run-on, water level/moisture, and outflow. Furthermore, parameters of concern have been identified and water samples will be collected for analysis by using a standard automatic sampler. Ground water levels and surface ponding or saturation levels will also be monitored through the use of level and barometric pressure loggers.

Table 4-1: A summary of the measurement type, monitoring equipment and monitoring location currently being utilized at the IMAX monitoring site

Measurement Type	Equipment	Location/Description
Flow	Custom V-notch Weir & Flow Logger (water level meter)	Manhole downstream of permeable pavement, bioretention treatment trains and the control site.
Rainfall Depth and Intensity	Heated Tipping Bucket Rain Gauge	On IMAX property
Water Quality Samples	Standard Automatic Sampler	Manhole downstream of permeable pavement, bioretention treatment trains and the control site.
Ground Water Level	Level and Barometric Pressure logger	Observation wells at four locations across the parking lot
Practice Saturation/Moisture Level	Level and Barometric Pressure logger	Deep and Shallow observation wells within bioretention.

Note: Specific protocols for each measurement type can be found in Appendix A

4.1 Meteorological Review

Precipitation at IMAX has been monitored by CVC on site since April 3rd, 2013. Prior to this, data was obtained from a secondary onsite rain gauge, installed on the IMAX property in July 2012 which is now used as a quality control rain gauge for comparisons. A local Mississauga network rain gauge located just over 1 km from the IMAX property is used as a 'back-up'. A summary of the meteorological behavior observed to date has been provided below in order to give context to the hydrological and water quality results. Additionally, a comparison of the meteorological data with respect to local climate norms has been included to provide perspective for the performance assessment.

Understanding the event sizes that contribute to the majority of annual rainfall is important for interpreting performance results. An example of the frequency of precipitation events in Ontario relative to event size is presented below in **Figure 4-1**. This figure presents hourly weather records from 1950-2005 for the

Toronto Lester B. Pearson International Airport weather station. The analysis was completed using WQ-COSM, software which is designed for modeling water quality (CVC 2013). The analysis indicates that 92% of all precipitation events were 25 mm or smaller. **Figure 4-2** below indicates the number rainfall events that were recorded at IMAX from February to December 2013. Precipitation events are defined as periods of precipitation with a depth of 2 mm or greater. Sixty-two (62) events were observed during this monitoring period (February to December 2013); of these, fifty-five (55) had a precipitation depth smaller than 25 mm. This is equivalent to 89% of the total precipitation events observed during the monitoring period, which is consistent with the average precipitation patterns observed in Southern Ontario.

Figure 4-1: Event size related to the frequency of occurrence (Source: CVC 2013)

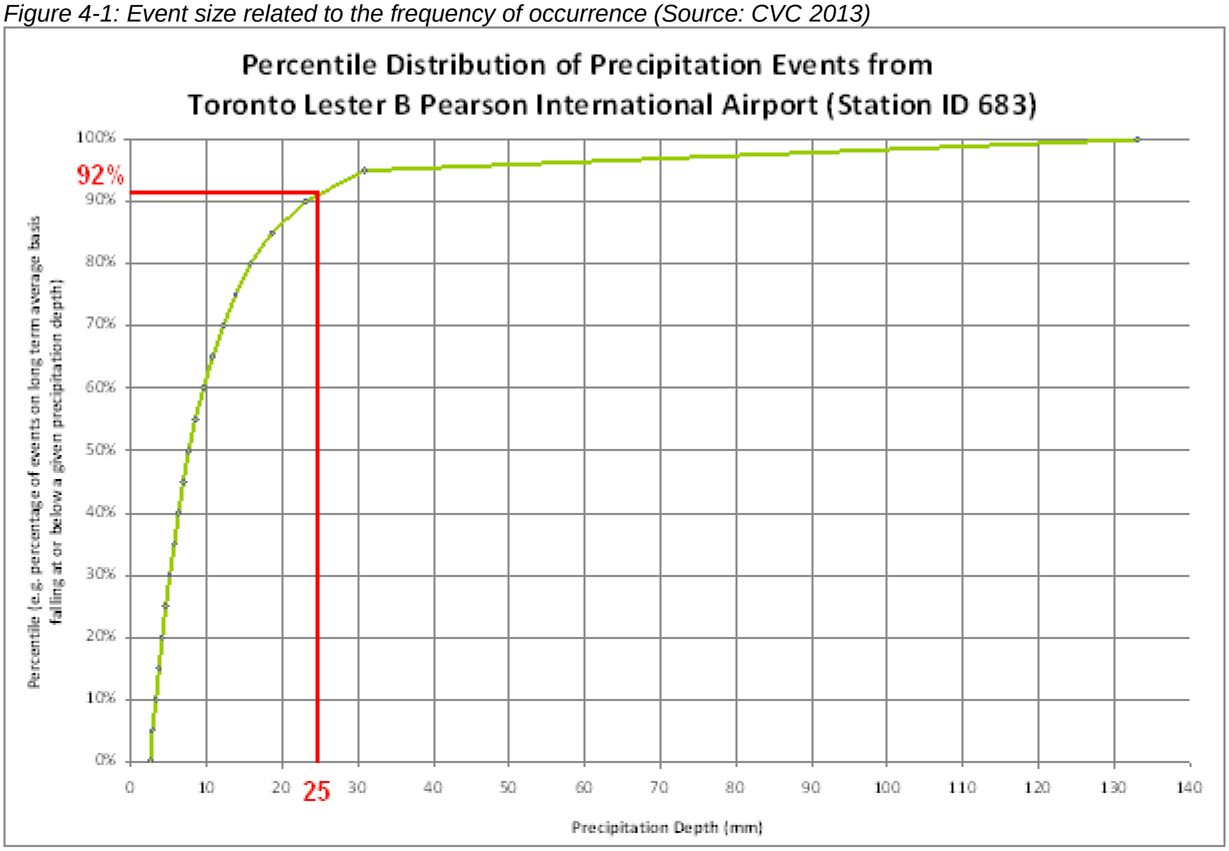


Figure 4-2: 2013 Precipitation events

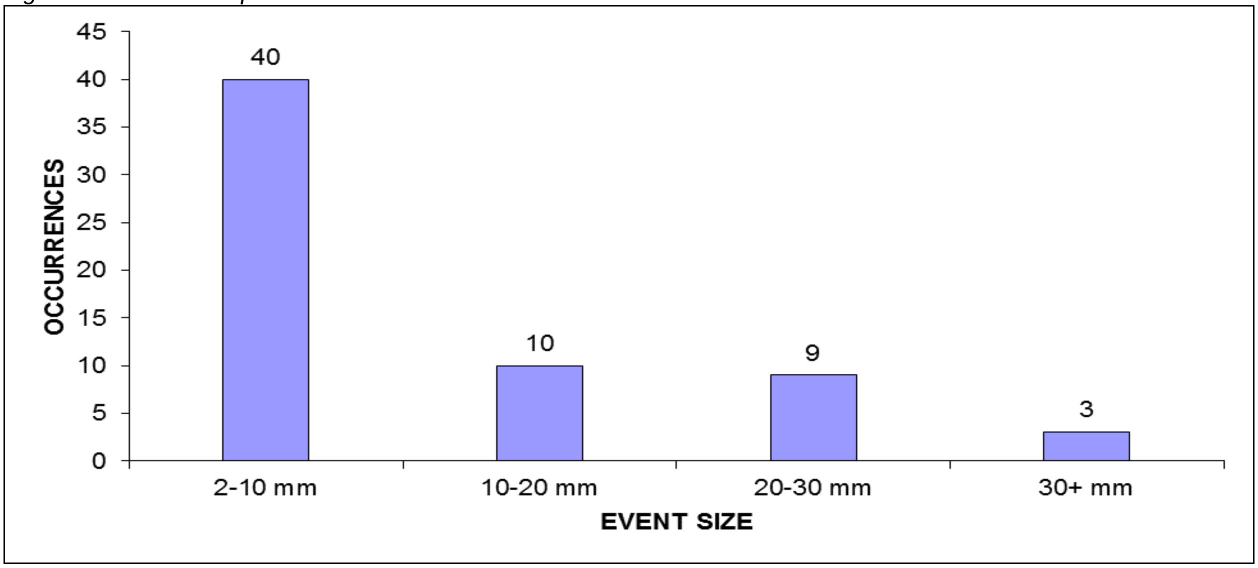


Table 4-2 contains the historical monthly and annual precipitation data observed at the Oakville Southeast WPCP (Meteorological Service of Canada Climate ID 615N745) from 1971-2000, and at the Toronto Lester B. Pearson International Airport (Meteorological Service of Canada Climate ID 6158733) from 1981-2010. The Oakville WPCP and Lester B. Pearson stations are located approximately 4 km and 18 km, respectively, from the IMAX site.

- Oakville WPCP station data indicates that July, August, and September are historically the months with the greatest amount of precipitation in the local area, contributing a total of 229.8 mm of precipitation (28% of annual precipitation) during this time on average over the 30 year period. In 2013, 231 mm of precipitation was recorded from July through September at IMAX (29% of annual precipitation).

- IMAX rain gauge recorded April as the highest precipitation month in 2013 contributing 111.6 mm which was 65% than recordings at Oakville WPCP station of 67.6 mm.

- Total annual precipitation observed at IMAX was 872 mm which is similar to 786 mm and 809 mm recorded at Toronto Pearson and Oakville stations, respectively. .

Table 4-2: Climate Normals 1971-2000

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
Station: Oakville Southeast WPCP													
Rainfall (mm)	30.6	27.7	46.6	65	70.3	71.3	72.9	78.4	78.5	68.8	68.8	47	725.9
Snowfall (cm)	28.1	16.5	15.3	2.6	0	0	0	0	0	0	2.7	17.6	82.8
Precipitation (mm)	58.8	44.2	61.9	67.6	70.3	71.3	72.9	78.4	78.5	68.8	71.5	64.6	808.7
Station: Toronto Lester B. Pearson International Airport													
Rainfall (mm)	25.1	24.3	32.6	63	74.3	71.5	75.7	78.1	74.5	60.6	68	34	681.6
Snowfall (cm)	29.5	24	17.7	4.5	0	0	0	0	0	0.4	7.5	24.9	108.5
Precipitation (mm)	51.8	47.7	49.8	68.5	74.3	71.5	75.7	78.1	74.5	61.1	75.1	57.9	785.9
2013 Precipitation at IMAX[1,2]													
Precipitation (mm)	77.41	77.42	20.82	111.6	69.4	79	80.8	69.2	81	99.6	39.2	66.8	872.2

1. Precipitation data obtained from the Aquafor Beech back-up rain gauge located on the IMAX property
2. Precipitation data obtained from the local Mississauga rain gauge (S09 Truscott) located just over 1 km from the IMAX property

4.2 Site Hydrology

The IMAX retrofit attenuated a total of 1,859 m^3 of runoff in 2013 which is equivalent to 13,676 bathtubs.

The hydrology of a receiving water body is affected by changes in the land use practices of its catchment area. Urban watersheds respond more quickly to precipitation events, produce larger runoff volumes, have higher runoff peak flowrates, and have a greater energy to transport contaminants than undeveloped watersheds. Implementing stormwater quantity control practices (including LID techniques) into developed areas help restore the predevelopment conditions of an urbanized (or urbanizing) catchment. The following section presents the hydrologic performance results for the 2013 monitoring period of the IMAX system, which is an example of an urban development that has been retrofitted to include a variety of LID practices for stormwater quantity control.

A summary of the hydrological results for monitoring stations IX-2b, IX-3, and IX-5 are provided below in **Table 4-3**, **Table 4-4**, and **Table 4-5**, respectively. Full data sets showing the results for the individual precipitation events are contained in **Appendix C**.

- Forty-nine (49) precipitation events occurring between March 12, 2013 and December 28, 2013 have been included in the data set for IX-2b. The monitoring equipment was removed from this catchment between June 20, 2013 and September 3, 2013 and, therefore, flow data is not available during this time.
- Sixty-one (61) precipitation events in total were observed between March 12, 2013 and December 28, all of which have been included in the data set for IX-3.
- Forty-six (46) precipitation events between April 24, 2013 and December 14, 2013 make up the hydrological data set for IX-5.

Some variation in the duration, intensity, and total depth of precipitation events was observed throughout the 2013 study period for the different monitoring stations. This variation is due to how a precipitation event is defined, which is dependent on both the precipitation and outflow from the LID system. Precipitation events are separated by a minimum of a 6 hour period during which there is no precipitation and no change in flow. Due to the differing storage capacities of the LID systems there is some variation in the timing of outflows from the different systems, which caused some monitoring station to be identified as experiencing more precipitation events than others during the same monitoring period.

The results for IX-2b and IX-3 presented to date are to be interpreted with caution. Construction was fully completed for these catchments on October 23rd 2013 while troubleshooting carried on until December 9th, 2013. Data collected up to this date may contain inaccuracies.

Peak inflow for the bioretention cells (IX-2b and IX-3) was calculated using the Rational Method for the contributing areas. This method uses precipitation intensity, catchment area, and a runoff coefficient based on impervious cover to determine the peak flow that is generated within a catchment. A runoff coefficient of 0.9 was used to represent the imperviousness of IX-2b and IX-3. As surface water runoff is not generated on permeable pavement the Rational Method is not an appropriate approach to estimate peak inflow from these areas. Peak inflow for IX-5 was assumed to be equal to the peak precipitation intensity.

Hydrological data is not available for the time frame reported at this time for the control site (IX-1) due to construction and troubleshooting delays. The deficiencies were recently addressed in December 2013 and monitoring has since commenced. Furthermore, the bioretention cell in IX-4 needs to be regraded to provide sufficient storage and these changes were completed in spring 2014. Monitoring results for these catchments will be reported later in 2014.

Table 4-3: Summary of hydrological results for IX-2b (Area 2, drains asphalt to bioswale and Sorbtive® Vault)

Event Type	Storm Date	Antecedent Dry Period (days)	Event Duration (min)	Peak Precipitation Intensity (mm/hr)	Peak Inflow (L/s)	Total Precipitation (mm)	Inflow Volume (L)	Peak Discharge (L/s)	Outflow Volume (L)	Runoff Volume Reduction (%)	Peak Runoff Reduction (%)
Largest Precipitation Event (rain only) and Highest Intensity Precipitation event	2013-09-20	5.00	1100.00	30.00	8.33	43.00	47708	1.59	8195	83%	81%
Smallest Precipitation Event to Produce Outflow	2013-11-02	1.15	440.00	3.60	1.00	3.20	3550	0.02	22	99%	98%
Minimum Intensity to Produce Outflow	2013-10-21	1.95	300.00	3.60	1.00	8.40	9320	0.04	150	98%	96%
Largest No Flow Event	2013-06-02	1.10	1010.00	12.00	3.33	10.60	11761	0.00	0	100%	100%
Highest Intensity Event to Produce No Outflow	2013-06-02	1.10	1010.00	12.00	3.33	10.60	11761	0.00	0	100%	100%
Lowest Volume Reduction	2013-04-11	0.29	780.00	13.20	3.66	27.40	30400	3.37	23407	23%	8%
Lowest Peak Flow Reduction	2013-04-11	0.29	780.00	13.20	3.66	27.40	30400	3.37	23407	23%	8%

Note: Full data set and performance analysis for individual precipitation events for IX-2b can be found in **Appendix C**.

Table 4-4: Summary of hydrological results for IX-3 (Area 3, drains asphalt to Jellyfish ® filter and bioswale)

Event Type	Storm Date	Antecedent Dry Period (days)	Event Duration (min)	Peak Precipitation Intensity (mm/hr)	Peak Inflow (L/s)	Total Precipitation (mm)	Inflow Volume (L)	Peak Discharge (L/s)	Outflow Volume (L)	Runoff Volume Reduction (%)	Peak Runoff Reduction (%)
Largest Precipitation Event (rain only)	2013-09-20	5.00	1100.00	30.00	9.43	43.00	54018	2.84	13769	75%	70%
Highest Intensity Precipitation event	2013-08-27	1.18	390.00	66.00	20.74	22.20	27888	8.33	14724	47%	60%
Smallest Precipitation Event to Produce Outflow	2013-03-31	12.83	60.00	7.20	2.26	2.20	2764	0.00	10	100%	100%
Minimum Intensity to Produce Outflow	2013-03-18	5.52	160.00	0.40	0.13	3.40	4271	0.00	6	100%	97%
Largest No Flow Event	2013-05-23	1.13	310.00	2.40	0.75	3.40	4271	0.00	0	100%	100%
Highest Intensity Event to Produce No Outflow	2013-05-22	1.69	20.00	12.00	3.77	2.60	3266	0.00	0	100%	100%
Lowest Volume Reduction	2013-08-27	1.18	390.00	66.00	20.74	22.20	27888	8.33	14724	47%	60%
Lowest Peak Flow Reduction	2013-08-27	1.18	390.00	66.00	20.74	22.20	27888	8.33	14724	47%	60%

Note: Full data set and performance analysis for individual precipitation events for IX-3 can be found in **Appendix C**.

Table 4-5: Summary of hydrological results for IX-5 (Permeable Pavement with Granular "O")

Event Type	Storm Date	Antecedent Dry Period (days)	Event Duration (min)	Peak Precipitation Intensity (mm/hr)	Peak Inflow (L/s)	Total Precipitation (mm)	Inflow Volume (L)	Peak Discharge (L/s)	Outflow Volume (L)	Runoff Volume Reduction (%)	Peak Runoff Reduction (%)	Inflow Time to Centroid (min)	Outflow Time to Centroid (min)	Lag Time (min)
Largest Precipitation Event (rain only)	2013-09-20	5.00	1100.00	30.00	15.95	43.00	82327	1.00	28464	65%	94%	527	879	352
Highest Intensity Precipitation event	2013-08-27	1.18	1240.00	66.00	35.10	22.40	42886	3.02	15417	64%	91%	199	334	135
Smallest Precipitation Event to Produce Outflow	2013-11-06	4.07	450.00	3.60	1.91	6.40	12253	0.01	179	99%	100%	160	1057	897
Minimum Intensity to Produce Outflow	2013-11-21	3.16	1050.00	2.40	1.28	7.20	13785	0.01	148	99%	100%	296	1182	886
Largest No Flow Event	2013-06-02	1.10	1010.00	12.00	6.38	10.60	20294	0.00	0	100%	100%	-	-	-
Highest Intensity Event to Produce No Outflow	2013-06-02	1.10	1010.00	12.00	6.38	10.60	20294	0.00	0	100%	100%	-	-	-
Lowest Volume Reduction	2013-07-19	10.76	540.00	42.00	22.34	23.20	44418	3.02	26342	41%	86%	136	447	311
Lowest Peak Flow Reduction	2013-07-05	0.90	500.00	37.20	19.78	23.40	44801	4.53	10965	76%	77%	386	533	148

Note: Full data set and performance analysis for individual precipitation events for IX-5 can be found in **Appendix C**.

Summaries of the overall runoff volume reduction achieved by IX-2b, IX-3, and IX-5 are provided below in Figure 4-3, Figure 4-4, and Figure 4-5, respectively.

Figure 4-3: Runoff volume reduction from IX-2b for different event ranges

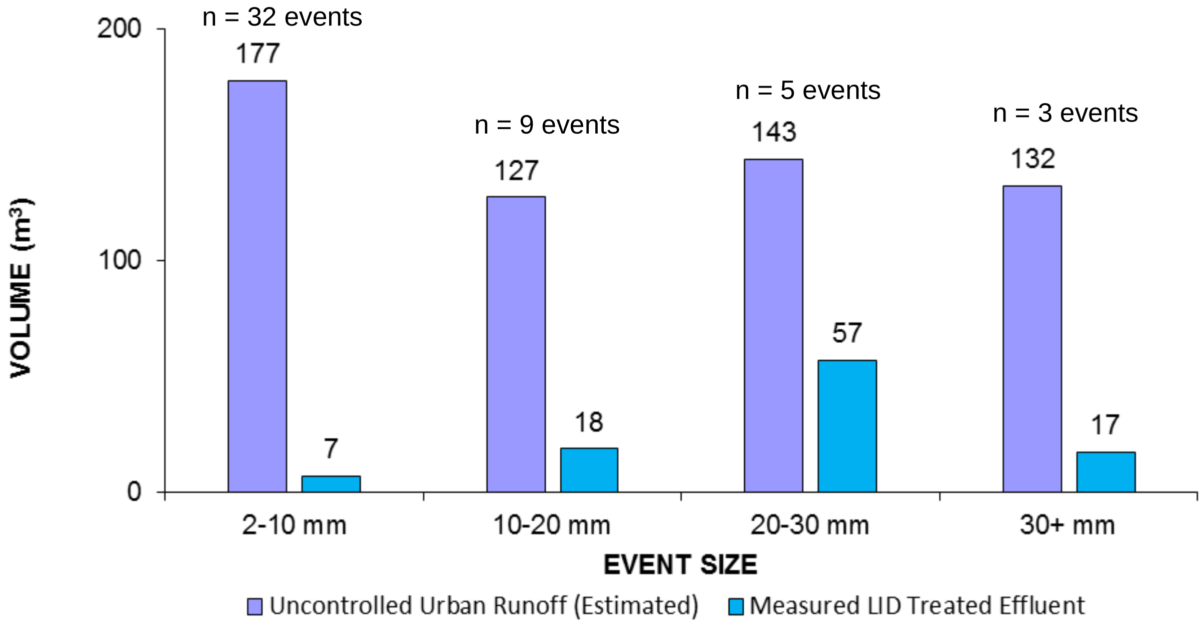


Figure 4-4: Runoff volume reduction from IX-3 for different event ranges

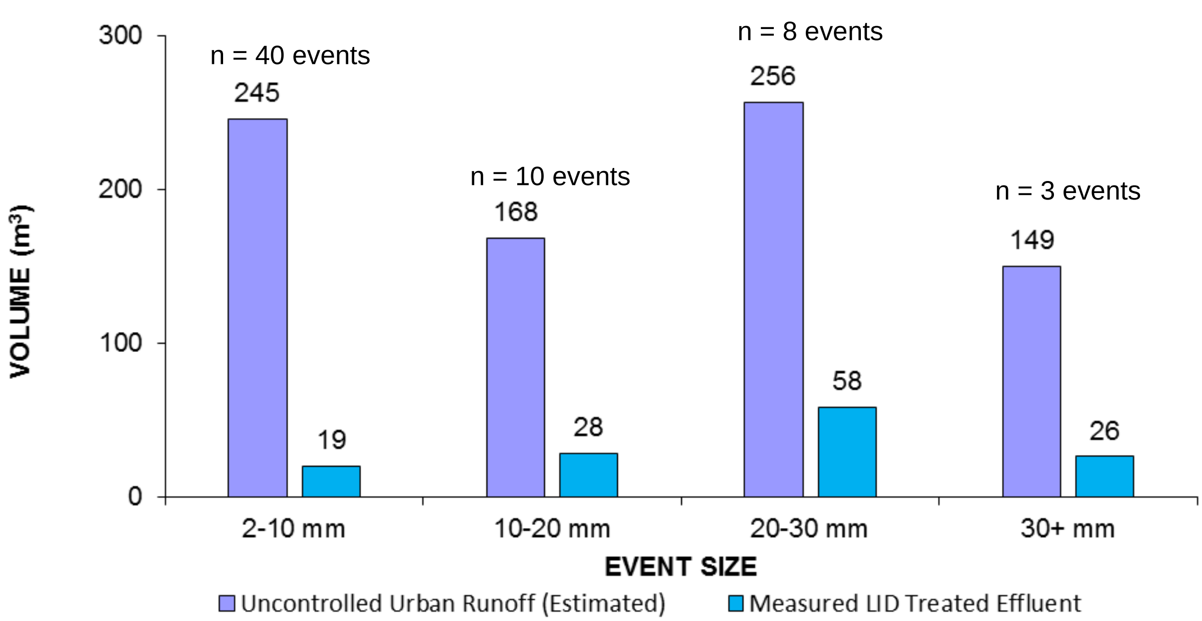
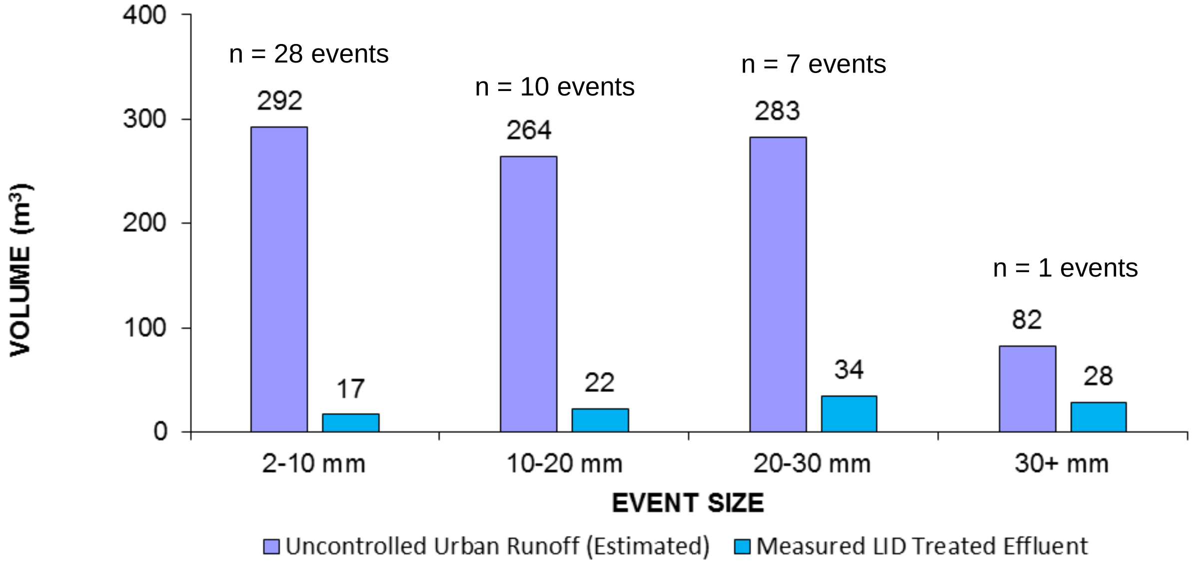


Figure 4-5: Runoff volume reduction from IX-5 for different event ranges



Hydrographs for a low and high intensity precipitation event during which IX-2b, IX-3, and IX-5 were monitored are provided below in **Figure 4-6** and **Figure 4-7**, respectively. As hydrological data is not available at this time for the control site (IX-1) the runoff hydrograph was estimated using the Rational Method, assuming a runoff coefficient of 0.9. Additionally, the hydrographs for the control site, IX-2b, IX-3, and IX-5 were normalized by dividing the hydrograph volumes by the contributing catchment areas.

Figure 4-6: Normalized hydrograph for low intensity event – April 28, 2013

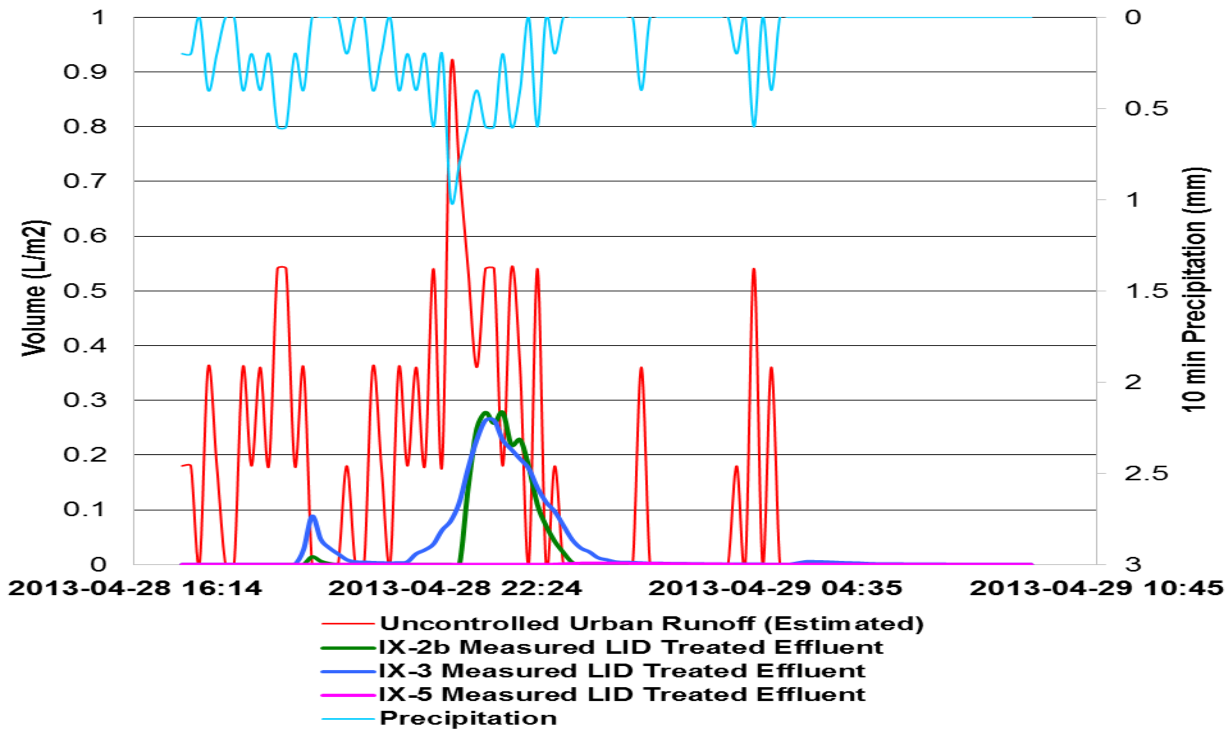
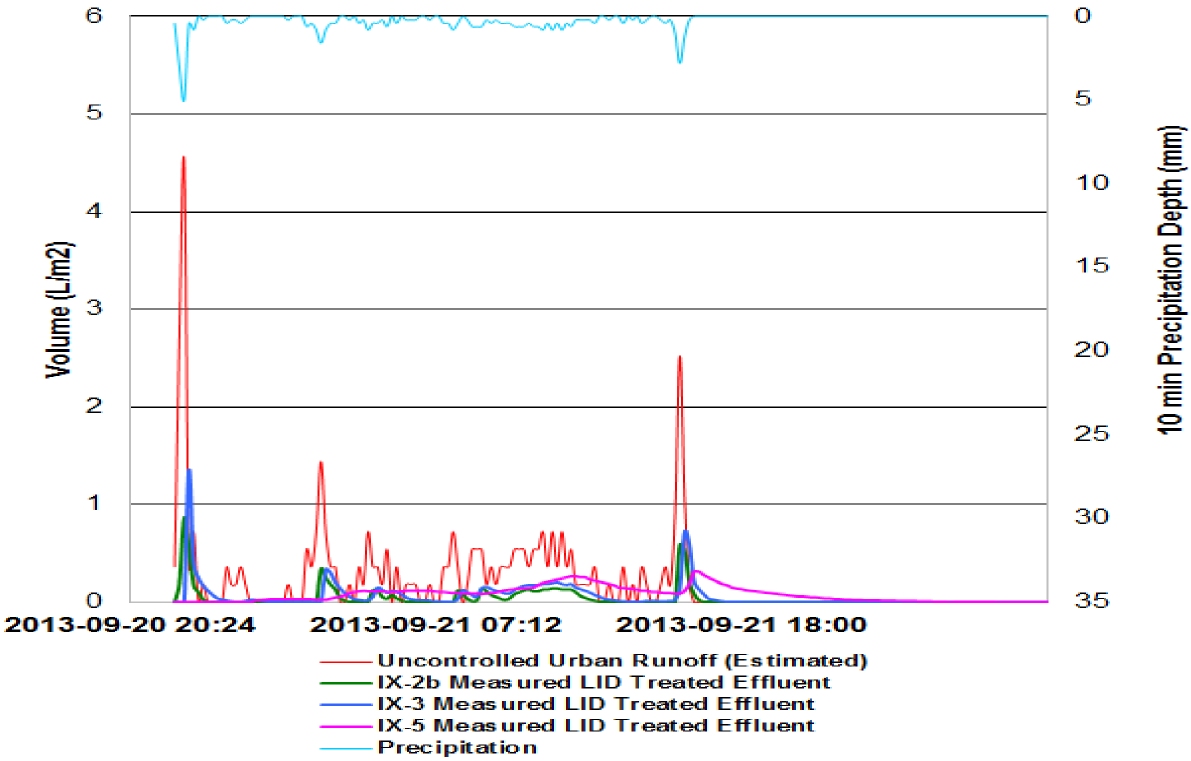


Figure 4-7: Normalized hydrograph for high intensity event – September 20, 2013



4.2.1 IX-2b Performance

IX-2b achieved an average volume reduction of 91% for the forty-nine (49) precipitation events observed at this location during the 2013 monitoring period. 100% volume reduction was observed at IX-2b for nineteen (19) precipitation events, the largest of which had a total precipitation depth of 10.6 mm. This event (the IX-2b "no flow" event) occurred on June 2, 2013.

The largest precipitation event (rain only) observed at IX-2b occurred on September 20, 2013, with a total precipitation depth of 43 mm and an instantaneous peak intensity of 30 mm/hr. An 83% volume reduction was achieved for this event. The lowest volume reduction observed at IX-2b of 23% occurred for an event on April 11, 2013 that had a total precipitation amount of 27.4 mm and a peak rainfall intensity of 13.2 mm/hr. This event also achieved the lowest observed peak flow reduction of 8%. At the time of the April 11 storm the IX-2 bioretention cell had not yet been planted and the surface grading had not been adjusted, both of which likely affected the performance. Additionally, this was the second event to occur on this day and the short antecedent dry period of 7 hours which likely contributed to its poor performance. Construction at IX-2 was complete by the September 20th storm and, therefore, the performance observed during this event is more representative of the system's capability.

4.2.2 IX-3 Performance

IX-3 achieved an average volume reduction of 90% for the sixty-one (61) precipitation events observed at this location during the 2013 monitoring period. 100% volume reduction was observed at IX-3 for twelve (12) precipitation events, the largest of which had a total precipitation depth of 3.4 mm. This event (the IX-3 "no flow" event) occurred on May 23, 2013.

The largest precipitation event observed at IX-3 occurred on September 20th, 2013, with a total precipitation depth of 43 mm and a peak rainfall intensity of 30 mm/hr. A 75% volume reduction was achieved for this event. The lowest volume reduction observed at IX-3 of 47% occurred during a high intensity storm on August 27, 2013 that had a total precipitation amount of 22.2 mm and a peak rainfall intensity of 66 mm/hr. As discussed previously for IX-2b, precipitation intensity drives reduction of total runoff and now the total precipitation volume. The bioretention system in IX-3 is less effective at reducing total runoff volume for high intensity events. Note that this event was not recorded at IX-2b as equipment had been removed during this period due to follow up construction activities.

4.2.3 IX-5 Performance

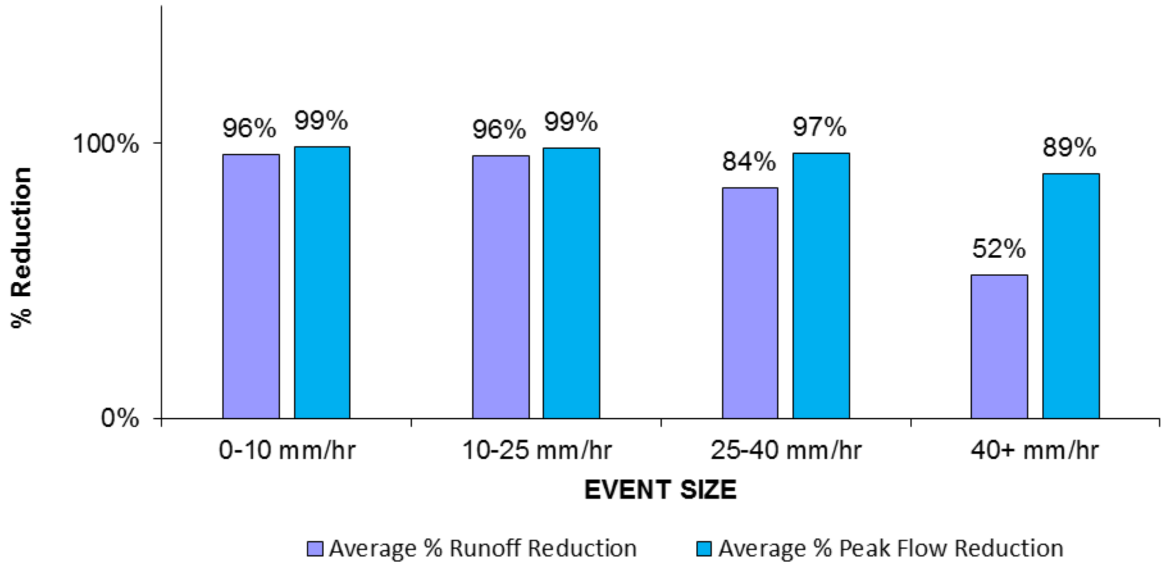
IX-5 achieved an average volume reduction of 92% for the forty-six (46) precipitation events observed at this location during the 2013 monitoring period. 100% volume reduction was observed at IX-5 for eighteen (18) precipitation events, the largest of which had a total precipitation depth of 10.6 mm. This event (the IX-5 “no flow” event) occurred on June 2, 2013.

The largest precipitation event observed at IX-5 occurred on September 20, 2013, with a total precipitation depth of 43 mm and a peak rainfall intensity of 30 mm/hr. This precipitation event achieved a 65% volume reduction, which is below the average volume reduction, but not the lowest volume reduction that was observed for the current data set. The lowest volume reduction of 41% occurred for a precipitation event on July 19, 2013 that had a total precipitation amount of 23 mm and a peak rainfall intensity of 42 mm/hr, which was the second highest observed rainfall intensity. The highest observed rainfall intensity of 66 mm/hr occurred on August 27, 2014, with a total precipitation depth of 22 mm. This storm event achieved a 64% volume reduction. The low volume reductions of these high intensity storm events indicates that it is not the total precipitation amount that affects the ability of the permeable pavement systems to reduce the total runoff volume, but the intensity of the precipitation event. The permeable pavement system in IX-5 is less effective at reducing total runoff volume for high intensity events. This is further supported by comparing precipitation events to the IX-5 “no flow” event. Precipitation events with total precipitations depths smaller than 11 mm but with large peak intensities were able to generate outflow. The July 27, 2013 precipitation event, for example, had a total depth of 7.2 mm and a peak rainfall intensity of 28.8 mm/hr. This event produced outflow, achieving only a 53% volume reduction. Additionally, the lower volume reduction achieved during the July 19 storm when compared to the higher intensity storm on August 27 indicates that the storm distribution also affects the performance of the permeable pavement system in IX-5. The majority of precipitation fell during the beginning of the August 27 storm, whereas there was a pulse of precipitation near the end of the July 19 storm when the system would have already been saturated. This is the suspected cause of the low volume reduction for the July 19 storm event.

IX-5 achieved an average peak flow reduction of 98%. The lowest peak flow reduction observed at IX-5 of 77% occurred during a storm on July 5, 2013. This precipitation event had a total precipitation depth of 23.4 mm and a peak rainfall intensity of 37.2 mm/hr; however, IX-5 was able to achieve a greater peak flow reduction for precipitation events of both greater intensity and total depth. During the September 20, 2013 storm (precipitation depth of 43 mm and a peak rainfall intensity of 30 mm/hr), for example, a 94% peak flow reduction was observed at IX-5. It is suspected that the shorter antecedent dry period of 21.6 hours was responsible for the low peak flow reduction on July 5, 2013 when compared to the larger precipitation event on September 20, 2013, which had an antecedent dry period of 5 days.

The performance of IX-5 based on peak precipitation intensity is provided in **Figure 4-8** below:

Figure 4-8: IX-5 performance based on peak precipitation intensity

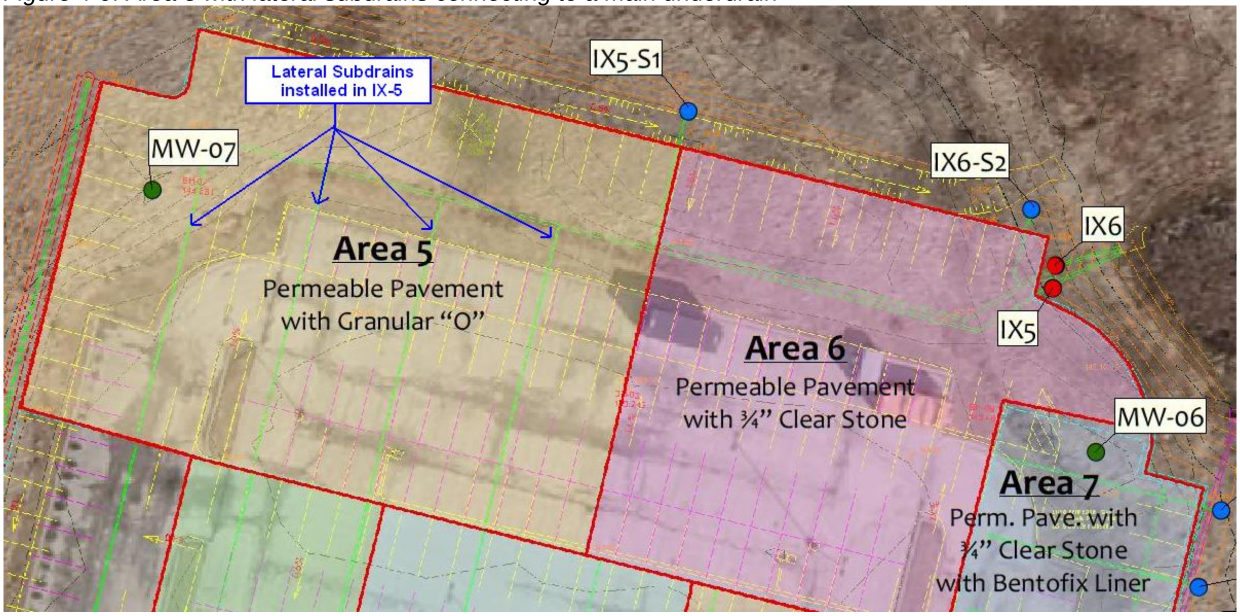


Lag times at IX-5 ranged from negative 19 min to positive 911 min, with an average of 372 min. The negative 19 min lag time occurred for the May 28, 2013 storm event, and indicates that the LID outflow time to centroid occurred 19 min before the inflow time to centroid. All other lag times were positive values, indicating that the peak outflow occurred after the peak inflow for the majority of the storm events. The longest lag time of 911 min occurred for the July 27, 2013 storm event.

4.2.4 IX-6 Performance

Catchment IX-6 has achieved 100% volume reduction for all storms observed to date. A water test for this catchment was performed in the summer of 2013 to determine whether this is due to its actual performance, or as a result of a construction deficiency. The results of the water test confirmed that IX-6 is operating as designed. It is suspected that outflow has been observed from IX-5 and not from IX-6 due to the presence of lateral subdrains in IX-5 to provide free draining of the system as opposed to the difference in subbase materials between the two catchments. As shown in **Figure 4-9**, the lateral subdrains in subcatchment IX-5 promote drainage from the entire catchment area towards the IX-5 monitoring station, whereas more infiltration is able to occur across subcatchment IX-6 as there are no lateral subdrains to intercept the flow through the pavement structure. No further analysis for IX-6 is required at this time; however, it will continue to be monitored to assess future performance.

Figure 4-9: Area 5 with lateral subdrains connecting to a main underdrain



4.3 Water Quality

Stormwater quality controls are important in order to prevent the degradation of the water quality of receiving water bodies in developed or urbanizing area. The CVC's Stormwater Management Criteria (CVC 2012) stipulates that all watercourses and water bodies (e.g. Lake Ontario) within CVC's jurisdiction are classified as requiring, at a minimum, an enhanced level of protection (80% TSS removal). The CVC's Water Quality Strategy (CVC 2009) further identifies parameters of concern (PoC) that need to pass their respective Provincial Water Quality Objectives (MOE 2004) or Canadian Council of Ministers of the Environment (CCME 2002) guidelines in the watercourses (**Table 4-3**). Therefore, CVC proposes stringent measures to control discharges of PoCs to the watercourses by implementing best management practices (BMPs).The Sheridan Creek watershed was developed prior to the implementation of stormwater management controls. As the watershed is now fully developed, there is limited space to add end-of-pipe facilities such as stormwater management ponds. The City of Mississauga has studied the watershed in detail and is commencing an aggressive plan to implement stormwater management where feasible. Furthermore, implementing LID facilities for providing water quality control at the source is an option that could help contribute to meeting the water quality objectives laid out in CVC's Stormwater Management Criteria. The following section presents the water quality performance results for the IMAX system, which is an example of an industrial/commercial LID retrofit located within in the Sheridan Creek watershed.

Water quality control is influenced by contaminant removal within the LID practices, which affects effluent concentrations but also by volume reduction which plays a substantial role in reducing the mass loading of stormwater contaminants to receiving waters. The water quality control of LID practices, expressed as load reduction, takes into account both mechanisms. In the case of IMAX, preliminary results show that effluent volume reduction is very important to load reduction. This is in contrast to conventional BMPs such as retention ponds that do not provide substantial volume reduction and therefore, depend upon contaminant removal to achieve mass load reductions.

Composite water quality samples were collected for twenty-one (21) of the forty-six (46) precipitation events observed for IX-5, of which fifteen (15) had no errors. Composite water quality events were collected for one (1) precipitation event for IX-2b and three (3) precipitation events for IX-3, all of which were taken after construction of these catchments was complete. A summary of the effluent Event Mean Concentration (EMC) and load reduction results for monitoring stations IX-2b and IX-3 can be found in **Table 4-6** and **Table 4-7**, respectively. A summary of the effluent EMC results for IX-5 can be found in **Table 4-8**, and the IX-5 load reduction results can be found in **Table 4-9**. Full data sets showing the results for the individual precipitation events are contained in **Appendix C**.

As outlined in the Experimental Design, the CVC *Impact Monitoring Program* summarized current conditions in the Credit River watershed and identified several key water quality issues and parameters or concern. These include:

1. Chloride: Road salting practices have led to contamination of both the creek and groundwater. Chloride levels within Sheridan Creek remain above the CCME objective during snow-free and dry weather conditions.
2. Nutrients: High nutrient levels are contributing to excessive algal growth within the creek. Total phosphorus concentrations exceed PWQO during wet weather particularly during the first flush. Nitrate concentrations meet the CCME objectives and are not currently a concern.
3. Metals: Levels of metals (indicated by zinc concentrations), which exceed the PWQO, occur in Sheridan Creek. The highest levels are associated with first flush from industrial land-uses.
4. Total Suspended Sediments: PWQO are exceeded during wet weather conditions, with TSS concentrations increasing downstream.

Water quality data is not available at this time for the control site (IX-1) or catchment IX-4 due to construction and troubleshooting delays. Additionally, a water test was performed for the lined permeable pavement system (IX-7) in the summer of 2013. The results of this test were inconclusive as to whether a leak is present in the system's impermeable liner. Analysis intended to evaluate risk to groundwater systems cannot be completed at this time. A necessary dye test will be performed in spring 2014 to identify leakage, if any. This dye test can be performed on a yearly basis to detect potential leakage overtime, if at all.

As no outflow from IX-6 has been observed to date no water quality samples are available for this catchment. The 100% volume reduction observed at IX-6 indicates that there is no contaminant mass leaving this system via the underdrains. Similarly, all precipitation events that achieved 100% volume reduction at IX-2b, IX-3, and IX-5 (19, 12, and 17 precipitation events, respectively) have no contaminant mass leaving the systems by the surface water pathway.

From a concentration perspective, the outflow from the IMAX LID systems was compared to parameters of concerns that are defined for watercourses to meet PWQO. Red highlighted cells in **Table 4-6** through **Figure 4-8** indicate values above the objective for the particular parameter.

As water quality data is not available for the control site (IX-1), water quality results for IX-2b, IX-3, and IX-5 were compared to typical EMC values for commercial properties for this analysis. The typical EMC values for commercial properties were obtained from the City of Toronto Wet Weather Flow Management Master Plan, Study Area 5-Highland Creek, Rouge River and Waterfront Area (Aquafor Beech, 2003) for Total Suspended Solids (TSS), Total Phosphorus (TP), Nitrate + Nitrite (NO_2 + NO_3), Total Kjehldahl Nitrogen (TKN), Copper (Cu), and Zinc (Zn), and from The National Stormwater Quality Database, Version 1.1 (U.S. EPA, 2005) for Cd, Pb, Ni. The typical commercial value for Orthophosphate (OP) was estimated using the median value for commercial properties found in Table 4-7 of the Elm Drive report (CVC, 2013). As limited data is available for Fe, the median value for industrial properties found in Table 4-6 of the Elm Drive report (CVC, 2013) was used as the typical commercial value for this analysis. These typical commercial EMC values were used to estimate the influent contaminant load based on the recorded volume of inflow to the systems.

The results are also compared to typical EMC achieved by other similar LIDs, as per the BMPDB. The BMPDB values for both the bioretention cells and permeable pavement systems were obtained from the Elm Drive report (CVC, 2013). These values represent LIDs that are used to treat stormwater runoff from a broad range of land uses, not just those found in commercial settings. Yellow highlighted cells indicate values above the BMPDB value for the LID technique.

Table 4-6: Summary of effluent EMC and load reduction results for IX-2b

Parameter	Units	Objective	Typical Commercial Concentration	BMPDB Bioretention Cell	2013-10-31	
					Effluent EMC	Load Reduction (%)
Total Suspended Solids (TSS)	mg/L	25	70	8.42	7	99%
Total Phosphorous (TP)	mg/L	0.03	0.25	0.142	0.02	100%
Orthophosphate (OP)	mg/L	1	0.15	0.0573	0.042	98%
Nitrate + Nitrite (NO_2 + NO_3)	mg/L	13.06	0.67	0.225	0.26	98%
Total Kjehldahl Nitrogen (TKN)	mg/L	1	0.71	0.64	0.29	98%
Cadmium (Cd)	ug/L	0.2	0.96	0.789	0.06	100%
Copper (Cu)	ug/L	5	22	9.6	5.1	99%
Iron (Fe)	ug/L	300	2000	1030	78	100%
Lead (Pb)	ug/L	5	18	1.98	3.97	99%
Nickel (Ni)	ug/L	25	7	5.3	0.8	99%
Zinc (Zn)	ug/L	20	127	19.6	6.3	100%

NOTE: These results are based on one sample only. More data are needed to provide solid results and will be reported on in Spring 2014.

RED – Above Provincial Water Quality Objectives

YELLOW – Above BMPDB performance

Table 4-7: Summary of effluent EMC and load reduction results for IX-3

Parameter	Units	Objective	Typical Commercial Concentration	BMPDB Bioretention Cell	2013-10-26		2013-10-31		2013-11-06	
					Effluent EMC	Load Reduction (%)	Effluent EMC	Load Reduction (%)	Effluent EMC	Load Reduction (%)
Total Suspended Solids (TSS)	mg/L	25	70	8.42	2	100%	4	99%	5	100%
Total Phosphorous (TP)	mg/L	0.03	0.25	0.142	0.14	98%	0.24	91%	0.13	99%
Orthophosphate (OP)	mg/L	1	0.15	0.0573	0.14	97%	0.21	87%	0.14	98%
Nitrate + Nitrite (NO_2 + NO_3)	mg/L	13.06	0.67	0.225	0.23	99%	0.35	95%	0.29	99%
Total Kjehldahl Nitrogen (TKN)	mg/L	1	0.71	0.64	0.46	98%	0.93	88%	0.46	99%
Cadmium (Cd)	ug/L	0.2	0.96	0.789	0.11	100%	0.09	99%	0.04	100%
Copper (Cu)	ug/L	5	22	9.6	2.9	100%	8.8	96%	1.9	100%
Iron (Fe)	ug/L	300	2000	1030	64	100%	61	100%	31	100%
Lead (Pb)	ug/L	5	18	1.98	3.72	99%	4.86	97%	2.91	100%
Nickel (Ni)	ug/L	25	7	5.3	0.6	100%	0.7	99%	0.6	100%
Zinc (Zn)	ug/L	20	127	19.6	15.5	100%	11.7	99%	7.2	100%

NOTE: These results are based on three samples only. More data are needed to provide solid results and will be reported on in Spring 2014.

RED – Above Provincial Water Quality Objectives

YELLOW – Above BMPDB performance

Table 4-8: Summary of effluent EMC results for IX-5

Parameter	Units	Objective	Typical Commercial Concentration	BMPDB Permeable Pavement	2013-04-29	2013-05-28	2013-06-10	2013-07-19	2013-08-01	2013-08-26	2013-09-11	2013-09-21	2013-10-04	2013-10-07	2013-10-13	2013-10-16	2013-10-17	2013-10-19	2013-10-21	2013-10-26	2013-11-07	2013-11-17	Average
Total Suspended Solids (TSS)	mg/L	25	70	15.8	3	2	2	140	25	3	3	19	1	6	2	1	6	8	4	4	<1	18	15
Total Phosphorous (TP)	mg/L	0.03	0.25	0.09	0.01	0.02	0.027	0.31	<0.10	0.027	0.012	0.021	0.006	0.011	0.01	0.01	0.018	0.004	0.024	0.007	0.007	0.018	0.032
Orthophosphate (OP)	mg/L	1	0.15	0.0823	0.007	<0.002	0.023	0.15	0.002	0.016	0.035	0.014	0.011	0.019	0.004	0.004	0.02	0.019	0.015	0.031	0.016	0.019	0.024
Nitrate + Nitrite (NO_2 + NO_3)	mg/L	13.06	0.67	1.42	0.62	0.86	0.75	0.58	0.72	0.55	0.59	0.49	0.41	0.39	0.44	0.46	0.45	0.43	0.37	0.42	1.4	0.29	0.57
Total Kjehldahl Nitrogen (TKN)	mg/L	1	0.71	0.957	0.28	0.53	0.66	1.1	0.45	0.35	0.29	0.46	0.4	0.88	0.27	0.16	2.9	0.29	0.5	0.32	0.29	1.8	0.7
Cadmium (Cd)	ug/L	0.2	0.96	0.231	0.1	0.12	<0.05	0.43	0.07	0.25	0.12	0.16	0.08	0.13	0.13	<0.05	0.07	0.21	0.12	0.04	0.1	0.04	0.14
Copper (Cu)	ug/L	5	22	8.28	8	6	6.1	12	5.9	4.5	5.5	5.1	7.3	8.3	2.5	2.5	3.8	5.2	5.8	4.6	5.3	9.6	6
Iron (Fe)	ug/L	300	2000	N/A	<50	49	<25	3180	864	<25	33	454	<10	98	<25	47	320	236	415	389	<10	627	559
Lead (Pb)	ug/L	5	18	0.05	4.8	3.29	2.25	6.8	3.85	3.1	1.5	2.8	1.8	2.2	1.3	1.49	2.38	1.9	2.4	2.3	1.2	2.8	2.7
Nickel (Ni)	ug/L	25	7	1.71	10	4.4	3.3	6.8	4.4	3.1	1.9	2.3	1.7	1.8	1	1	1.3	1.4	1.3	1.2	1	1.5	2.7
Zinc (Zn)	ug/L	20	127	14.8	19	39	17.8	34	32	40	29	35	27	26	27.1	25.7	28.3	26.5	29	27	26	27	29

RED – Above Provincial Water Quality Objectives

YELLOW – Above BMPDB performance

Table 4-9: Load reduction results for IX-5

Parameter	2013-04-29	2013-05-28	2013-06-10	2013-07-19	2013-08-01	2013-08-26	2013-09-11	2013-09-21	2013-10-04	2013-10-07	2013-10-13	2013-10-16	2013-10-17	2013-10-19	2013-10-21	2013-10-26	2013-11-07	2013-11-17	Overall
Total Suspended Solids (TSS)	100%	100%	100%	98%	83%	99%	99%	73%	100%	99%	100%	100%	96%	99%	100%	99%	100%	95%	94%
Total Phosphorous (TP)	100%	100%	100%	0%	100%	98%	99%	92%	100%	100%	100%	100%	97%	100%	100%	100%	100%	99%	98%
Orthophosphate (OP)	100%	100%	100%	0%	99%	98%	95%	91%	99%	99%	100%	100%	94%	99%	100%	98%	100%	98%	98%
Nitrate + Nitrite (NO_2 + NO_3)	100%	98%	99%	0%	48%	83%	82%	27%	95%	95%	97%	96%	68%	97%	98%	95%	97%	92%	78%
Total Kjehldahl Nitrogen (TKN)	100%	99%	99%	0%	69%	90%	92%	35%	95%	90%	98%	99%	-97%	98%	98%	96%	99%	51%	77%
Cadmium (Cd)	100%	100%	100%	0%	96%	95%	97%	83%	99%	99%	99%	100%	96%	99%	100%	100%	100%	99%	96%
Copper (Cu)	100%	100%	100%	0%	87%	96%	95%	77%	97%	97%	99%	99%	92%	99%	99%	98%	100%	91%	93%
Iron (Fe)	100%	100%	100%	0%	79%	100%	100%	77%	100%	100%	100%	100%	92%	99%	99%	98%	100%	94%	94%
Lead (Pb)	100%	100%	100%	0%	90%	96%	98%	84%	99%	99%	100%	99%	94%	99%	100%	99%	100%	97%	96%
Nickel (Ni)	100%	99%	100%	0%	69%	91%	94%	67%	98%	98%	99%	99%	91%	99%	99%	98%	100%	96%	90%
Zinc (Zn)	100%	100%	100%	0%	88%	93%	95%	72%	98%	98%	99%	99%	89%	99%	99%	98%	100%	96%	93%

4.3.1 IX-2b Performance

The single water quality sample collected for the bioretention cell system in IX-2 returned only Cu as in exceedance of the PWQO. NO_2 + NO_3 and Pb both exceeded the BMPDB value for bioretention cells. All other parameters were within the acceptable limits.

Assuming an influent concentration of 70 mg/L, a 99% TSS load reduction was observed for the October 31, 2013 sample event. Loadings for other particulate bound contaminants (including metals) were also reduced considerably; assuming an influent concentration of 127 mg/L for zinc, for example, a 99% load reduction was also observed for the October 31 storm event.

As more water quality data for IX-2b becomes available an assessment of the effectiveness of the treatment train utilized by this system will be made relative to stand alone bioretention cells.

4.3.2 IX-3 Performance

The PWQO for TP was exceeded for all three (3) sampling events at IX-3. Additionally, Cu was in exceedance for the October 31, 2013 event. This is the same event for which the objective for Cu was exceeded at IX-2b as well. OP, Pb, and NO_2 + NO_3 exceeded the BMPDB value for bioretention cells for all three (3) sample events, and TKN exceeded the BMPDB value during the October 31 event only.

Assuming an influent concentration of 70 mg/L, 100% TSS mass removal was observed for the October 26, 2013 and November 6, 2013 events, and 99% TSS mass removal was achieved for the October 31, 2013 storm. Significant reductions in other particulate bound contaminants (including metals) were also observed; assuming an influent concentration of 127 mg/L for zinc, for example, a 99% load reduction was also observed for the October 31 storm event.

As more water quality data for IX-3 becomes available an assessment of the effectiveness of the treatment train utilized by this system will be made relative to stand alone bioretention cells.

4.3.3 IX-5 Performance

TKN was in exceedance of the PWQO for three (3) of the eighteen (18) sample events, TP for one (1) event, and TSS for one (1). The July 19, 2013 storm event was responsible for the TP, TSS, and one of the TKN exceedances. All other general and nutrient parameters were below the PWQO for all precipitation events. TSS exceeded the BMPDB value for permeable pavement for three (3) sampling events, and OP was in exceedance of the BMPDB value for one (1) event.

The metals were more commonly outside of the acceptable range of concentration. The concentration of Cu exceeded the objective for thirteen (13) of the eighteen (18) precipitation events, Cd for three (3), Fe for seven (7), Zn for sixteen (16), and Pb for one (1). Pb exceeded the BMPDB value for permeable pavement for all of the other sampling events, Ni for eight (8), and Zn for nine (9).

4.4 Surface Water Infiltration Results

Infiltration testing was completed for the permeable pavement systems (subcatchments IX-5, IX-6, and IX-7) on June 14th, 2013 and August 2nd, 2013. Testing was performed at eighteen (18) locations on each day, for a total of thirty-six (36) testing locations. The combined data set was used for analysis. The permeable pavement testing locations are shown in **Figure 4-10** below.

Average infiltration rates and ranges of infiltration rates based on the subbase material and the location within the parking area are provided below in Table 4-10 and Table 4-11, respectively.

Table 4-10: Permeable pavement sub-base material infiltration results

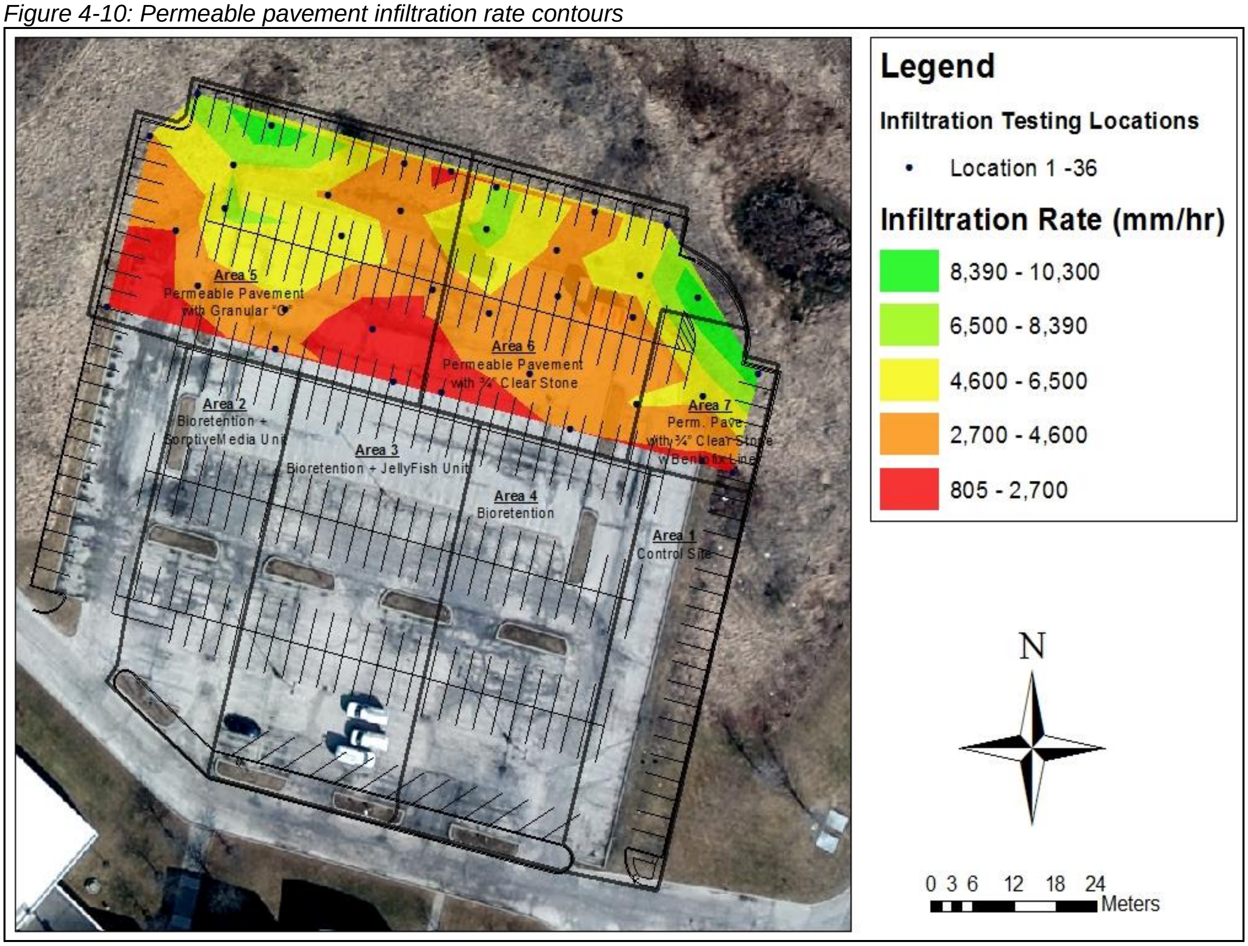
Catchment	Average	Range
IX-5	4,190 mm/hr	800 – 10,140 mm/hr
IX-6/IX-7	4,840 mm/hr	1,980 – 10,290 mm/hr

Table 4-11: Permeable pavement parking lot location infiltration results

Location	Average	Range
Laneways	4,500 mm/hr	800 – 10,290 mm/hr
Parking Spaces	5,330 mm/hr	1170 – 10,140 mm/hr
Paint Lines	3,740 mm/hr	1980 – 6,850 mm/hr

Figure 4-10 below provides a contour image describing the spatial distribution of infiltration rates across the permeable pavement parking area.

Figure 4-10: Permeable pavement infiltration rate contours



The findings from the infiltration testing events are discussed below based on two (2) main criteria: subbase material and location within parking area.

There are two (2) different kinds of subbase material used in the permeable pavements systems at the IMAX property: Granular O in IX-5 and ¾" clear stone in IX-6 and IX-7. As IX-6 and IX-7 share the same granular material they are assessed as one area when comparing infiltration rates based on subbase material.

Infiltration testing was performed for three (3) different types of locations throughout the parking area: laneways, parking spaces, and along paint lines between parking spaces. Averages provided based on location are for the entire parking area (i.e. include both types of subbase material).

The total average infiltration rates for IX-5 and IX-6/IX-7 are 4,190 mm/hr and 4,840 mm/hr, respectively. The clear stone subbase material in IX-6 and IX-7 has a more uniform grain size than the Granular O used in IX-5 and is expected to have a higher hydraulic conductivity. It is possible that this influences the surface infiltration rates. Infiltration rates range from 800 mm/hr to 10,140 mm/hr for IX-5 and from 1,980 mm/hr to 10,290 mm/hr for IX-6 and IX-7. The infiltration rates observed for both types of subbase material are within the typical range for new permeable pavement systems.

High traffic areas within permeable pavement parking lots, such as laneways, typically have lower infiltration rates than low traffic areas, such as parking stalls. The highest average infiltration rate based on parking area location was found, as expected, within the center of the parking stalls with an average of 5,330 mm/hr. The lowest average infiltration rate based on parking area location, however, is located on the lines dividing parking spaces. The average infiltration rate in these areas is 3,740 mm/hr. This is likely due to the build-up of sediment along the lines that washes off of vehicles within the parking spaces, as well as due to the accumulation of debris left in these areas by people entering or leaving their vehicles. The average infiltration rate for laneways fell between those for parking stalls and paint lines, with an average of 4,500 mm/hr. Infiltration rates within laneways, however, varied significantly; both the lowest (800 mm/hr) and highest (10,290 mm/hr) individual infiltration rates were found in laneways. The lower infiltration rates within the laneways are located in the entrances to the permeable pavement area as well as in the row closest to the entrance to the building. This reflects the areas of the parking lot that are most commonly used by IMAX staff.

Another area of importance is in the entrance to IX-5 (south-west corner of the permeable pavement area) where very low infiltration rates were observed. This corresponds to a recurring erosion and sediment control issue during construction; despite the use of barricades to prevent access, vehicles repeatedly drove through a pile of granular material that was placed on the impermeable surface just south of the entrance to the permeable pavement area, dragging the granular material onto the pavers and causing early clogging in this location.

The surface infiltration rate tests will be performed yearly on a seasonal basis. This will allow for changes and/or trends in infiltration rates due to seasonal changes and the age of the pavement to be measured over time. The infiltration rates will be paired with the performance monitoring results as well as any maintenance and operational issues. These tests will assist in addressing Objective 6, which is to *monitor and assess the operational and maintenance needs of LID systems and the subsequent effects on performance*. This in turn will also aid in achieving two (2) of the top stakeholder priorities outlined in Section 2: 1) Evaluate long-term maintenance needs and maintenance programs, and the impact of maintenance on performance and, 2) Determine the life cycle costs for LID practices.

5 CONSTRUCTION ISSUES AND OBSERVATIONS

With such a sophisticated infrastructure performance assessment, a number of barriers and challenges had to be addressed. These barriers and challenges include:

- Need for a control site
- Missed rain events
- Grading to ensure sufficient ponding depth

Need for a control site

Following the onset of construction, modifications had to be made to the control site location to ensure proper representation of the frequently used employee parking lot. Originally, the control site was located as such that it would receive runoff from external areas including the truck loading/unloading area and bypass from surrounding areas. To properly isolate the control site drainage area, a twin-catch basin was added where the runoff can be monitored separate of any external waters.

To accommodate the new control site, negotiations with IMAX representatives and the contractor to relocate the monitoring location was required. The need for a control site and the critical part it plays in performance assessment was iterated to and acknowledged by IMAX. Ultimately, the new site location was agreed to and terms were negotiated such that construction costs did not increase and IMAX was satisfied with the aesthetics of the new location.

Missed flow events

On several occasions, during the early stages of the monitoring program, flow was observed at some monitoring locations and not others. Although potentially attributed to a number of different factors including the variances between individual LID practices and configurations, the observations were consistent for a number of rainfall events with various magnitudes and frequencies. Looking closer at the data for the sites of concern, water levels were observed to decrease behind the weirs indicating what would seem to be a leak in the system.

As a result, a number of water and pressure tests were performed to identify and rectify the defects. As a lesson learned, anomalies within monitoring data of LID practices can assist the deficiencies items contractors are to address as part of construction. Traditional methods of verifying the work quality such as visual inspections may have overlooked the deficiency.

Grading to ensure sufficient ponding depth

As with traditional stormwater management ponds, determining adequate ponding depth can be critical to the success of the practice. Similarly, it is also important with LID design to consider ponding depth to capture maximum runoff volumes and provide enough contact time for infiltration. Pond depth errors documented by CVC for LID project sites cause major issues as illustrated in the following photo. The second coat of asphalt was delayed due to winter weather and the heights of the overflow pipes set too high. Subsequent snowfall followed by heavy rain led to large runoff volumes and backflow into the parking lot. The heights of the overflow pipes were temporarily reduced just below

Ponding depth within LID with overflow not cut to proper grade

inlet grade to stop backflow onto parking lot and reinstated when the asphalt paving was completed the following spring. When designing, ensure LID pond depth accounts for the grades of inlets, outlets, overflow pipe, and ground surface to avoid issues backflow or insufficient ponding depth.

Related to grading, the bioswales were fine graded to the final elevations prior to the bioretention mix, plant and mulch material being installed. This resulted in a higher final grade of the ground surface limiting surface ponding capacity. This was identified through visual inspections and flow monitoring which indicated that the LID system had outflow for events as small as 4 mm. As a result, the bioswale grades were adjusted to increase surface ponding capacity and the excess bioretention mix was reapplied elsewhere on site.

Surface ponding capacity increased

6 DISCUSSION – MONITORING OBJECTIVE ASSESSMENT

To advance the use of LID designs and practices, CVC has worked with partners and stakeholders to address their questions about performance, operations, implementation and maintenance. As outlined in Section 2, the research objectives and stakeholder priorities are to be addressed to help maximize the benefits of investments in LID, and provide the data needed to develop long-term solutions for stormwater management plans. In efforts to develop and implement a robust monitoring program to better understand LID performance and address information gaps, the IMAX monitoring program will directly assess these objectives.

1. Apply and demonstrate LID systems within an urban community in the GTA.

   - Parking lot retrofit construction was officially completed in October 2013.
   - Education and demonstration initiatives took place at the IMAX parking lot through tours and presentations.

2. Evaluate the behaviour of LID technologies as individual and collective systems relative to a traditional asphalt-to-catchbasin system.

   - Control site (IX-1) monitoring data is not available at this time and will be reported on in spring 2014. Troubleshooting took place for most part of the year and deficiencies were rectified in October 2013.
   - Bioretention to Sorbtive® Vault (IX-2b) has achieved an average 91% volume reduction (for 49 storm events), Jellyfish® to Bioretention (IX-3) has achieved an average 90% volume reduction (for 61 storm events), and permeable pavement with granular "O" (IX-5) has achieved an average 92% volume reduction during the 2013 monitoring period (for 46 storm events). Volume reductions for all systems appear to be governed by storm intensity rather than total precipitation depth.
   - Bioretention to Sorbtive® Vault (IX-2b) has achieved an average 86% peak flow reduction (for 49 storm events), Jellyfish® to Bioretention (IX-3) has achieved an average 87% peak flow reduction (for 61 storm events), and permeable pavement with granular "O" (IX-5) has achieved an average 98% peak flow reduction (for 46 storm events) during the 2013 monitoring period.
   - For IX-5, water quality analysis shows overall load reductions of 94% for TSS, 98% for TP reduction, 77% for TKN reduction, and 78% for NO_2 + NO_3 during the 2013 monitoring period. These load reductions are based on eighteen (18) samples and are preliminary. Long-term monitoring is needed to develop a representative annual pollutant load reduction for all water quality parameters to satisfy MOE definition of enhanced quality performance.
   - For IX-5, lag times at IX-5 from negative 19 min to positive 911 min, with an average of 372 min. Only one storm event experienced a negative lag time, which indicates that the LID outflow time to centroid occurred before the inflow time to centroid. All other lag times were positive values, indicating that the peak outflow occurred after the peak inflow for the majority of the storm events. For a large precipitation event of 43 mm, the lag time is estimated to be approximately 6 hours. For the highest intensity event of 66 mm/hr, the lag time is approximately 2.5 hours.
   - For IX-2b and IX-5, the maximum observed rainfall intensity to produce no outfall was 12 mm/hr, which occurred during a storm on June 2, 2013 with a total precipitation depth of 10.6 mm/hr (based on 49 and 46 storm events, respectively). For IX-3, the maximum

observed rainfall intensity to produce no outfall was also 12 mm/hr, however this occurred during a storm on May 22, 2013 with a total precipitation depth of 2.6 mm/hr (based on 61 storm events). Storm events with higher precipitation depths and lower rainfall intensities at IX-2b, IX-3, and IX-5 were able to achieve 100% volume reduction. Similarly, storm events with shorter antecedent dry periods but lower precipitation depths than the June 2 and May 22 events also produced runoff at IX-2b, IX-3, and IX-5. This indicates that the performance of these systems to achieve stormwater volume reduction is governed by rainfall intensity and antecedent conditions, rather than total precipitation depth.

3. Assess designs of permeable pavement systems to meet multiple environmental and non-environmental objectives.

   - During this reporting period, the permeable pavement underdrains were free flowing and the 90^{o} elbow has not been used to restrict outflow yet.

4. Evaluate the potential of in-series LID systems (Jellyfish® to Bioretention and Bioretention to Sorbtive® Vault) to maximize water quality improvements.

   - One (1) water quality sample has been collected from IX-2b after the installation of the Sorbtive® Vault, and three (3) water quality samples have been collected from IX-3 after the installation of the Jellyfish® cartridges. No water quality data is available at this time for IX-4. Additional water quality data is required to address this objective with confident results.

5. Investigate long-term performance of LID systems and the implications to receiving surface and groundwater systems.

   - A water test of the lined permeable pavement system (IX-7) was inconclusive as to whether a leak is present or not in the impermeable liner. A dye test will be performed in spring 2014 to provide further insight into the presence of a leak in the impermeable liner.
   - This is a long-term objective and cannot be completed at this time.

6. Monitor and assess the operational and maintenance needs of LID systems and the subsequent effects on performance.

   - As of late 2013, CVC monitoring staff have been collecting data on maintenance activities performed to date and keeping records of inspections of the LID practices on a biweekly basis. A site inspection checklist has been created and is used by staff during each site visit. Furthermore, maintenance activities are outlined for bioretentions, permeable pavement, Jellyfish® Filter and Sorbtive® Vault as outlined in **Appendix D**. No maintenance data is available for this reporting and will be provided later.
   - CVC is working with IMAX and their winter contractor in logging salt applications.
   - Permeable pavement infiltration tests were performed using a Single Ring infiltrometer. These tests will be performed on a seasonal basis to address maintenance and operational needs.
   - Pending further funding, CVC plans on continuing to monitoring IMAX to assess long term performance and maintenance requirements for the different LID practices. Currently, there is a 5 year agreement with IMAX and perhaps longer term observations will be needed to address maintenance asset management related questions.

7. Refine and customize guidelines for LIDs (design, construction, and O&M) to suit various Ontario conditions (e.g. high groundwater sensitivity, commercial/industrial land use, low permeability soils, cold weather climate, etc.).

    - Longer term monitoring data is needed to address this objective for any future refinements to LID guidelines.

7 CONCLUSIONS AND RECOMMENDATIONS

Stormwater has received media attention in 2013 with the Calgary and Toronto extreme precipitation events. Unlike Alberta, Ontario is fortunate to have implemented floodplain management in the mid-1950s; this minimized Ontario's flood damages in comparison to Alberta. In Ontario, costly flood damage was largely due to aging and deficit infrastructure estimated to be roughly $100 billion in Ontario (MOI, 2006). This estimate does not account for potential land acquisition costs associated with certain solutions such as construction of stormwater detention facilities. It also does not take into consideration the need for new infrastructure to service areas not yet receiving flood control to current standards. Approximately 60-75% of the GTA is without flood control (TRCA, 2013).

While the media is focused on extreme events, municipalities and provincial agencies are cognizant that frequent precipitation events in urban areas can also cause damage. Beach closures along the Greater Golden Horseshoe cost businesses an estimated $776-1.5 billion per year in lost revenue due to pollutant loading from urban stormwater (Marbek, 2010). Streets, sidewalks and driveways contribute 65 to 75% of total loadings of suspended solids, nutrients and heavy metals (Bannerman et. al., 1992).

Business owners need to realize that stormwater produced at their properties can have detrimental downstream impacts not just for their neighbors but for their watersheds as a whole. IMAX is leading by example by understanding and relating to their connection with the environment which drains to Sheridan Creek, Rattray Marsh and Lake Ontario, our drinking water supply. By implementing LID retrofits on a lot level basis, business owners like IMAX are protecting their assets and helping municipalities in eliminating costs associated with conventional stormwater management when land costs are considered. More infrastructure asset management comparisons can be found in *CVC's Grey to Green Road Retrofits.*

By incorporating LID within existing and new urban development, municipalities can build resiliency in keeping with provincial initiatives such as the *Ministry of Environment's Great Lakes Protection Act, the Ministry of Infrastructure's Municipal Infrastructure Strategy, and the Ministry of Municipal Affairs and Housing's Go Green: Ontario's Action Plan on Climate Change.*

Through the MOE's Showcasing Water Innovation Grant, CVC and partners are being recognized both provincially and internationally as a leader in LID. Local manufacturers are gaining profile and helping to build Ontario's local green economy through job creation in public and private sectors, while protecting our Great Lakes (our Great Lakes support 40% of our national economic activity are the source of drinking water source to 8.5 million Canadians (EC, 2013). CVC's comprehensive monitoring results of "In The Ground" sites, tools and "How To" guides will provide municipalities, agencies and professionals with the necessary information to make LID techniques mainstream.

In addition, MOE's SWI grant funded the implementation of nine LID demonstration sites in Mississauga, including IMAX Parking Lot Retrofit. With this grant, CVC has also implemented the LID Infrastructure Performance and Risk Assessment program. This project was initiated and constructed in 2012-2013 with performance monitoring starting in late 2013.

The IMAX parking lot retrofit with LID employs permeable pavement with two aggregate materials (granular "O" and ¾" clearstone) which drain to an isolated wetland. Furthermore, a portion of the permeable pavement with ¾" clearstone is lined with an impermeable liner to evaluate groundwater sensitivity. The remainder of the parking lot is traditional asphalt which drains to three separate bioretention cells out of which two are treatment trains in conjunction with Imbrium's Jellyfish® Filter and

Sorbtive® Vault. Prior to construction, this site drained directly into Sheridan Creek through the municipal sewer network with no opportunity for pre-treatment. By employing permeable pavement and bioretention cells within the IMAX system it will be able to relieve the local municipal sewers by providing stormwater quantity and quality control.

To build consensus on the performance of LID in Ontario, CVC created a technical and advisory committee (see Section 2 for more details). These working groups provided feedback on monitoring objectives for LID performance monitoring. The top five objectives focused on both short-term and long-term goals. The performance objectives goals include: water quantity and quality performance in tight soils, flood control, erosion control, recharge, natural heritage protection, maintenance needs and life cycle costs for LID practices. The findings of this report focus on the short-term performance assessment, while the ultimate goal is to continue monitoring and address long term performance and life-cycle cost objectives.

Listed below is a summary of the findings from the assessment conducted from the 2013 monitoring period (quantity, quality and maintenance):

7.1 Precipitation events Monitored

The precipitation events that occurred at IMAX matched well with the event frequency distribution determined using the Environment Canada's Toronto Lester B. Pearson International Airport station for Southern Ontario. Out of the total sixty-two (62) precipitation events captured in 2013, 65% were between 2-10mm, 16% were between 10-20mm, 14% were between 20-30 mm and 5% were larger than 30mm. Overall, 89% of the precipitation events observed during 2013 were 25 mm or less.

7.2 Water Quantity

The IMAX LID site was assessed for runoff volume reduction, peak flow reduction, and peak flow lag. The runoff volume reduction was estimated by finding the difference between the observed outflow from the LID site and the estimated runoff inflow to the LID systems. The analysis concluded that:

- Bioretention-to-Sorbtive® Vault treatment train (IX-2b) attenuated precipitation events less than or equal to 10.6 mm provided that the peak rainfall intensity was less than or equal to 12 mm/hr (based on 49 storm events).

- Jellyfish®-to-Bioretention treatment train (IX-3) attenuated precipitation events less than or equal to 3.4 mm given that the peak rainfall intensity was less than or equal to 12 mm/hr (based on 61 storm events). It is likely that the reason this site produced outflow during an event of this size is primarily due to surface grading issues, which were partially rectified in December 2013 and will be completed in spring 2014.

- Permeable pavement with granular "O" (IX-5) attenuated precipitation events less than or equal to 9 mm given that the peak rainfall intensity was less than or equal to 12 mm/hr (based on 46 storm events).

- Permeable pavement with ¾" clearstone (IX-6) attenuated all storms to date for a total of 728.6 mm (not including snowfall) which equates to 83% of total annual precipitation of 872.2 mm. The largest event observed was 43 mm and the largest intensity storm observed was 66 mm/hr, neither of which produced any outflow from the system.

- The cumulative total annual runoff volume reduction for all events (based on 54 events between April 2013 and mid-December, 2013) was 84%. This retention is expected to increase with improvements to bioretention grading.

- In other words, 84% of the annual runoff volume generated by the site was absorbed by the permeable pavement and bioretentions which would otherwise enter the municipal sewer system and flow into Sheridan Creek.

- LID performance for both runoff volume and peak flow reduction is governed primarily by the peak rainfall intensity and antecedent conditions, rather than by total precipitation amount.

- While the IMAX site was not designed for flood attenuation, event hydrographs show a considerable lag in time between the peak inflow and outflow, as well as a significant reduction in the peak flow rate between the measured LID effluent and the estimated uncontrolled urban runoff. The bioswales IX-2b and X-3 and permeable pavement IX-5 and IX6 achieved an average peak flow reductions of 86%, 87%, 98%, and 100% respectively.

- Monitoring results for permeable pavement show that there is significant lag time between inflow and the subsequent occurrence of outflow. For a large precipitation event of 43 mm, the lag time is estimated to be approximately 6 hours. For the highest intensity event of 66 mm/hr, the lag time is approximately 2.5 hours. The lag time plays a significant role in managing urban stormwater runoff, as it delays the time for runoff to reach the site outlet and, therefore, helps to provide relief within the receiving municipal sewer systems.

7.3 Water Quality

The IMAX LID site was assessed for water quality by calculating load reductions for a series of parameters including Total Suspended Solids (TSS), Total Phosphorous (TP), Orthophosphate (OP), Nitrate + Nitrite (NO_2 + NO_3), Total Kjehldahl Nitrogen (TKN), Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Nickel (Ni), and Zinc (Zn). The load reductions were estimated by finding the difference between the LID outflow event mean concentrations (EMC) and typical commercial land concentration. The analysis concluded that:

- Despite limited water quality data, results for the 2013 monitoring found that for precipitation events less than 3.4 mm (23% of the 62 total observed precipitation events), no pollutants entered Sheridan Creek (or consequently Lake Ontario) from the IMAX property. It is anticipated that this value will further improve following final re-grading of IX-3 which was found to be by-passing due to grading issues around the overflow structures in 2013. As a result, it is likely that the small "no flow" event for IX-3 was due to construction deficiencies rather than actual performance.

- The "no flow" event for both IX-2b and IX-5 is 10.6 mm (based on 49 and 46 events, respectively) which translates to 100% contaminant attenuation from these catchment areas for precipitation events up to this size. For IX-2b, however, this is based on a limited data set of three (3) samples.

- IX-6 has exceeded water quality expectations with its 100% volume reduction of all precipitation events to date, because as no runoff leaves the site from this catchment there is a corresponding 100% reduction of stormwater contaminants to the receiving water system.

- One of the major performance objectives of the IMAX LID site was to provide enhanced water quality treatment which is 80% TSS load reduction. Water quality performance assessment monitoring results show that the permeable pavement system in IX-5 is far exceeding these criteria by achieving an average of 97% TSS reduction for the eighteen (18) water quality sampling events in the 2013 monitoring period. Additional water quality data is required for the bioretention cells before conclusions can be made on their ability to provide TSS load reduction.

- Loadings for other particulate bound contaminants were also reduced considerably. Metal concentrations recorded average load reductions of up to 91% at IX-5 for the eighteen (18) water quality sampling events. Nutrient loadings from stormwater runoff are a concern as they feed algae growth which can in turn lead to beach closures. Total TP and NO_2 + NO_3 are typical nutrients that are monitored to assess the effectiveness of stormwater practices to reduce algae growth. Water quality performance assessment at IX-5 showed an average of 93% reduction in TP and an average 81% reduction in NO_2 + $NO_{3,}$ for the eighteen (18) sampling events.

A more detailed interpretation of water quality results will be possible in Phase 2 with sampling of more events, and as samples from other systems (such as the control catchment) become available. Early results from the IMAX site are within the range of results included in the International Stormwater BMPDB for similar LID practices. Moving forward, more detailed comparisons will be possible and the IMAX monitoring results will be included in the databases for use by practitioners internationally.

7.4 Maintenance - Surface Water Infiltration

Infiltration testing of the permeable pavement systems at the IMAX parking lot has revealed that catchments with ¾" clearstone (IX-6 and IX-7) have a higher surface infiltration rate than catchment with granular "O" (IX-5). The average infiltration rates for ¾" clearstone and granular "O" are 4840 mm/hr and 4190 mm/hr respectively. The clear stone subbase material in IX-6 and IX-7 has a more uniform grain size than the Granular O used in IX-5 and is expected to have a higher hydraulic conductivity. It is possible that this influences the surface infiltration rates. Additionally, the testing has revealed that the lowest infiltration rates across the permeable pavement parking area are located on the paint lines between parking spaces. This is likely due to the build-up of sediment along the lines that washes off of vehicles within the parking spaces, and accumulates as people enter or leave their vehicles. Laneways have the second lowest infiltration rates, and the fastest infiltration rates are located within the centre of the parking stalls. Overall, the infiltration rates tested overtime will be used to understand maintenance needs as the site matures.

7.5 Recommendations

- Short-term monitoring and LID design criteria: The substantial investment in the construction of the LID retrofit and the required infrastructure and instrumentation for monitoring is beginning to yield high quality data. In the near term, continued collection of water quantity and quality data will facilitate an evaluation of the hydrologic and water quality performance of the multiple systems installed in the IMAX retrofit project. Comparison of the results from the study systems as well as systems included in the BMPDB will provide information on specific design and operation parameters which contribute to improved (or poorer) performance. The results will contribute to filling the knowledge gap with respect to systems that employ a treatment train.
- Long term assessment goals: The existing databases contain insufficient information to provide answers to long term performance and maintenance questions. Most of the studies included in the databases were monitored for two to five years. However, infrastructure life-cycle cost estimates, lifetime performance, and long-term maintenance assessments over longer time periods are required. Therefore, it is important to pool resources in extending the infrastructure

assessment at IMAX and use the findings of this study to answer long-term questions on performance and maintenance of treatment train LID practices.

8 REFERENCES

AECOM. (2013). *City of Mississauga Stormwater Financing Study*. Kitchener.

Aquafor Beech Limited. (2011). *Geotechnical Investigation Report.* Kitchener: Aquafor Beech Limited.

Aquafor Beech Limited. (2012). *IMAX Infiltration / Groundwater Level Testing.* Kitchener: Aquafor Beech Limited.

ASTM. (2003). *ASTM D 3385 - 03 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer.* West Conshohocken: ASTM International.

ASTM. (2009). ASTM C 1701 Standard Test Method for Infiltration Rate of In Place Pervious Concrete. In *Annual Book of ASTM Standards* (Vol. 04.02). Conshohocken: American Society for Testng and Materials International.

Brown, R., & Hunt, W. (2011). Underdrain configuration to enhance bioretention exfiltration to reduce pollutant loads. *J. Environ. Eng., 197*(11), 1082-1091.

Canadian Construction Association (CCA), Canadian Public Works Association, Canadian Society for Civil Engineers and Federation of Canadian Municipalities. 2012. Municipal Roads and Water System. Volume 1.

City of Mississauga. 2013. Draft Mississauga Stormwater Quality Control Strategy Update.

Credit Valley Conservation (CVC) and Toronto and Region Conservation Authority (TRCA). (2010). Low Impact Development Stormwater Management Manual. Toronto: Credit Valley Conservation and Toronto and Region Conservation.

Chapman, C., & Horner, R. (2010). Performance assessment of a street-drainage bioretention system. *Water Environ. Res., 82*(2), 109-119.

Collins, K., Hunt, W., & Hathaway, J. (2008). Hydrologic comparison of four types of permeable pavement and standard asphalt in eastern North Carolina. *J. Hydrol. Eng., 13*(12), 1146-1157.

Drake, J., Bradford, A., & Van Seters, T. (2012). *Evaluation of Permeable Pavements in Cold Climates-Kortright Centre, Vaughan.* Toronto and Region Conservation Authority.

Drake, J., & Bradford, A. (2011). Assessing the Potential For Rehabilitation of surface permeability using regenerative air and vacuum sweeping trucks. *CHI Monograph*.

Drake, J., Bradford, A., James, P., Zimmer, C., Sebti, S., Tariq, A. 2012. Development of an Experimental Design Template for Performance Evaluation of Innovative Stormwater Management Practices. Credit Valley Conservation Authority.

Federation of Canadian Municipalities (FCM). 2007. Danger Ahead: The Coming Collapse of Canada's Municipal Infrastructure.

Geosyntec Consultants and Wright Water Engineers,Inc. (2009). *Urban Stormwater BMP Performance Monitoring.*

Insurance Bureau of Canada (IBC). 2013a. Facts of the property & casualty insurance industry in Canada. ISSN 1197 3404.

Insurance Bureau of Canada (IBC). 2013b. Media Release August 14, 2013

Marbek. (2010). *Assessing the Economic Value of Protecting the Great Lakes: Rouge River Case Study for Nutrient Reduction and Nearshore Health Protection Final Report*. November 2010.

McBean, E., and Schuster, C. "Aging Infrastructure, An Emerging Crisis". Water Down Under. 2008. PP 2539-2545.

Ontario Ministry of Infrastructure. 2006. ReNew Ontario: Progress report 2006. http://www.moi.gov.on.ca/pdf/en/renew2006/ReNewOntarioSummary.pdf

Ontario Ministry of Natural Resources (MNR). (2012, March 13). *Floods*. Retrieved August 31, 2012, from Ontario Ministry of Natural Resources: http://www.mnr.gov.on.ca/en/Business/Water/1ColumnSubPage/STEL02_165450.html

Personal Communication with Harold Reinthaler, Partner, Schaeffers & Associates, Ltd., Concord, Ontario. October 2012

Sandink, Dan. (February 2013). *Urban flooding in Canada Lot-side risk reduction through voluntary retrofit programs, code interpretation and by-laws*. Institute of Catastrophic Loss Reduction.

Toronto and Region Conservation Authority (TRCA). (2008). *Performance Evaluation of Permeable Pavement and a Bioretention Swale.* Sustainable Technologies Evaluation Program. Toronto: TRCA.