Case Study:

Monitoring Low Impact Development at the IMAX demonstration site

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Building Confidence in Green Infrastructure

Green infrastructure, including low impact development (LID), is gaining traction as an approach to enhance stormwater management within existing urban areas to reduce stress on aging infrastructure. LID has been found to build resiliency, improve watershed health and the local economy, and optimize water and wastewater treatment costs by filtering and storing stormwater. LID can also contribute to cost savings. A recent report estimates that the annual savings to the United States in terms of flood losses avoided in the year 2040 could range from $63 to $136 million if green infrastructure practices were more widely adopted in new development and redevelopment[i].

In addition to the built environment, the natural environment is also facing stressors. Some of the challenges facing the Great Lakes, especially nearshore ecosystems, include stresses from a fast-growing population that is exacerbated by the influences of climate change. One such stress is the insufficiently treated urban runoff releasing excess phosphorus and other contaminants into the Great Lakes nearshore. High levels of nutrients (including phosphorus) in nearshore water can lead to excess algae growth and potential impairment of our drinking water source and valuable aquatic habitat.

> To reduce nutrient and pollutant loading to the Great Lakes, new approaches and technologies for the reduction of phosphorus from storm water discharge, and other urban sources should be developed and implemented.
> *2012 Great Lakes Water Quality Agreement*

LID technologies are designed to mimic the natural movement of water in the environment. They are engineered landscape features that infiltrate, filter and store stormwater runoff. They also provide surfaces for evaporation to occur. By emulating natural or pre-development conditions at a site, LID technologies help reduce the volume of runoff and help reduce pollutants of greatest concern. LID technologies can also restore groundwater and stream flows, protect our fisheries and wildlife habitats, and enhance human well-being.

These technologies are even more important when incorporated into industrial/commercial (IC) properties. IC land use zones typically occupy a considerable portion of urban areas. 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 areas and they typically have high impervious cover. Because of this, IC lands can generate the large runoff volumes per unit area. IC lands can also contribute to increased flooding, erosion, water quality issues, and are a major source of chloride loading.

Monitoring of LID features not only increases the knowledge of stormwater and LID practices through scientific research and reporting, but also through the promotion of advanced technologies through the implementation of innovative stormwater and LID practices in the region. This also provides a platform for public outreach and engagement for local communities and promotes responsible and sustainable environmental stewardship through knowledge sharing.

Reducing Risk through LID Monitoring

IMAX is just one of the many projects implemented and monitored by CVC as part of the Infrastructure Performance and Risk Assessment (IPRA) program. IPRA is a multi-year stormwater monitoring program focused on gathering detailed information to evaluate stormwater facility performance in various land use types, climate conditions and development stages. The IPRA program also evaluates the effectiveness of stormwater facilities in flood control, erosion protection, nutrient removal, cold climate performance and the maintenance of pre-development water balance.

Figure 1: Staff accessing monitoring equipment

The monitoring program is based around a set of objectives that have been developed with an advisory committee consisting of municipalities, provincial and federal environmental agencies, academia, and engineering professionals. Several of these objectives have scoped the monitoring program at IMAX, such as:

- Evaluate how a site with multiple LID practices treats and manages stormwater runoff;
- Evaluate the long-term maintenance needs and impact of maintenance on performance;
- Assess the quality and quantity performance of LID designs in clay or low infiltration soils.

Project Description and Site Design

A number of innovative stormwater management retrofits on both public and private properties have been implemented across the Credit Valley Conservation (CVC) watershed. 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 IMAX parking lot retrofit is a unique demonstration site where comprehensive infrastructure performance and risk assessment is being conducted. The LID features that are utilized at the site promote infiltration, retention and the slow release of treated stormwater runoff.

The parking lot was expanded and retrofitted with a combination of traditional asphalt and permeable pavement. The asphalt runoff drains to one of three vegetated bioretention units. The permeable pavement section is divided into three catchments with differing subsurface materials. The parking lot runoff is collected, absorbed and filtered by these LID practices before entering a wetland adjacent to the parking lot. Discharge then enters Sheridan Creek, which outlets to Rattray Marsh, a Provincially Significant Wetland and Provincial Area of Natural and Scientific Interest. The water then flows into Lake Ontario, the drinking water source for much of Ontario. The monitoring includes hydrology, water level measurements and water quality for some monitoring stations (see Monitoring Methodology below).

Figure 2: IMAX parking lot traditional asphalt drainage pre-retrofit (left) and LID treatment post-retrofit with permeable pavement indicated in blue and asphalt to bioretention indicated in green (right)

Bioretention Systems

Three side-by-side bioretention practices were integrated into the front of the parking lot retrofit including two treatment trains and a standalone bioswale (IX-4). In the first treatment train, asphalt generated runoff flows to the bioretention cell and then to a Sorbtive Vault for further polishing (IX-2). The Sorbtive media is designed to retain nutrients such as phosphorus. In the second, asphalt generated runoff drains to a Jellyfish Filter for pre-treatment before flowing into the bioretention cell (IX-3). The Jellyfish Filter is a membrane technology designed to remove a variety of stormwater pollutants, including oil, grease and suspended solids. The main function of the bioretention systems is to improve runoff water quality. Each system has its own perforated underdrain and outlet monitoring location.

Figure 3: Control bioswale

Figure 4: Sorbtive media vault

Figure 5: Jellfyfish reservoir and filters

Permeable Pavement Systems

In addition, three permeable pavement systems were implemented into the retrofit at the rear of the parking lot. The same permeable pavers were used on the surface of each system; however two different types of aggregate were used: granular “O” (IX-5) and ¾ inch clear stone (IX-6). The third system uses ¾ inch clear stone aggregate with an impermeable liner (IX-7). The ¾ inch clear stone aggregate differs from granular “O” in that it has been washed of its fine material, providing void spaces for water storage. The lined system may be used to evaluate its design and its application in groundwater sensitive areas, particularly with respect to providing protection from contaminants such as constituents of road salt. Each system has its own perforated underdrain and outlet monitoring location.

Figure 6: Granular “O” (left) and ¾ inch clear stone (right) base material

Figure 7: Geosynthetic clay liner and ¾ inch clear stone aggregate

Table 1 below summarizes some of the key sizing and design information for the LID features at IMAX.

Table 1: Drainage areas and system design

	Area 2 (IX-2)	Area 3 (IX-3)	Area 4 (IX-4)	Area 5 (IX-5)	Area 6 (IX-6)	Area 7 (IX-7)
LID System Description	Asphalt to Bioretention to Sorbtive Vault	Asphalt to Jellyfish Filter to Bioretention	Asphalt to stand-alone bioretention cell	Permeable Pavement with Granular "O" aggregate	Permeable Pavement with ¾" Clear stone aggregate	Permeable Pavement with ¾" Clear stone aggregate lined with a geosynthetic clay liner
Drainage Area* (m^2)	1169	1457	2709	1862	1302	419
Imperviousness* %	83	98	86	-	-	-
BMP Surface Area (m^2)	41	63	72	1634	1165	380
Underdrain Details	200 mm ø perforated HDPE main collection pipe 25 mm above base	200 mm ø perforated HDPE main collection pipe 25 mm above base	200 mm ø perforated HDPE main collection pipe 25 mm above base	200 mm ø perforated HDPE main collection pipe 150 mm ø perforated HDPE Laterals 25 mm above base	200 mm ø perforated HDPE main collection pipe 25 mm above base	200 mm ø perforated HDPE main collection pipe 25 mm above base
Specification	Media Depth 675 mm Sand (2.0 to 0.005 mm Ø) 85-88% Organic Matter 3-5% Fines (<0.05 mm Ø) 8-12% % by weight			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)		

*Based on as built post-construction survey

Monitoring Methodology at IMAX

Construction of the parking lot retrofit at IMAX was completed in October 2013. 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. Performance assessment involves continuously monitoring precipitation, amount and quality of discharge from the six stations, and water temperature. Staff conduct bi-weekly visits to conduct regular equipment downloads. An overview of the site layout and monitoring locations can be found in Figure 8.

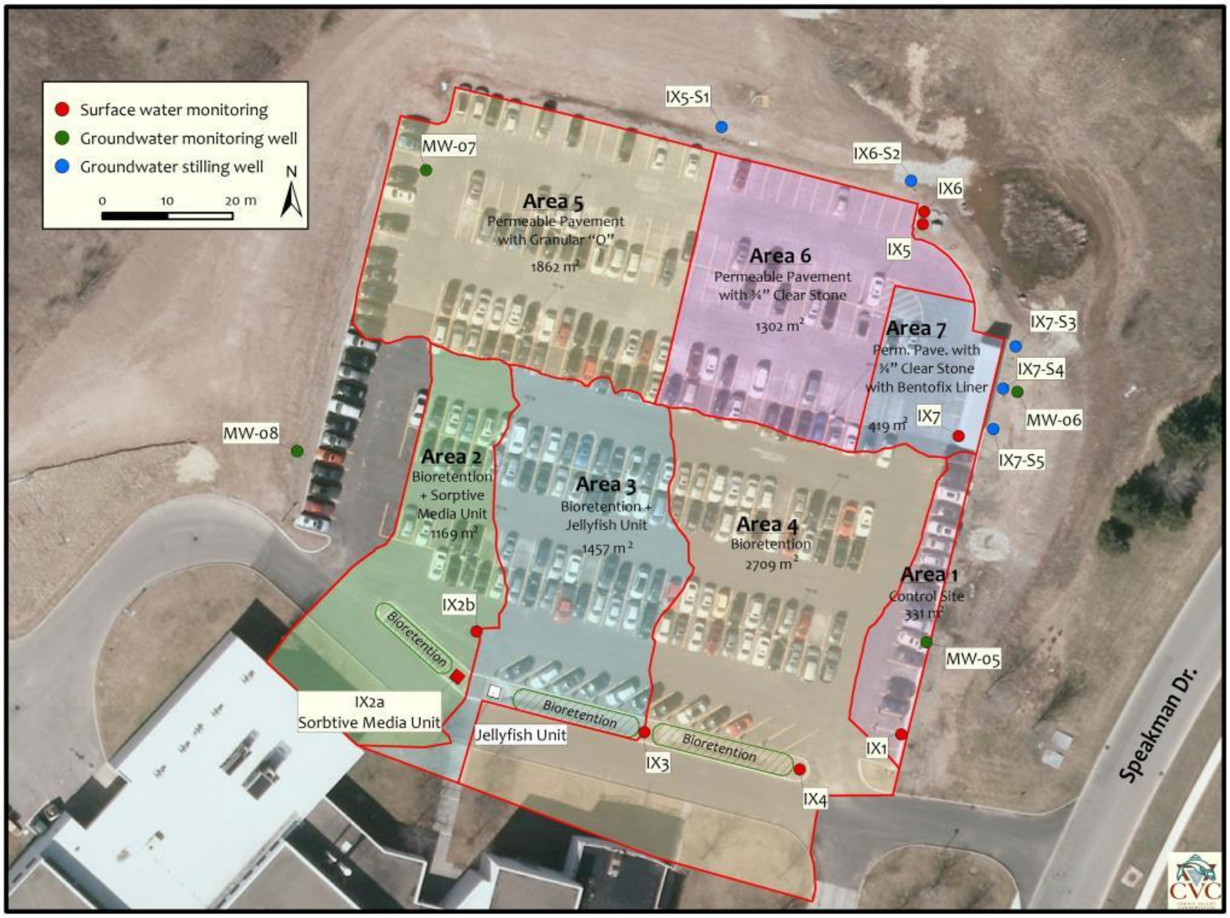

Figure 8: IMAX site layout, catchment areas and monitoring stations

Precipitation Monitoring

- Staff maintain a heated tipping bucket rain gauge on-site to provide local and reliable precipitation data.
- This data undergoes QA/QC with nearby municipal rain gauges and is calibrated twice annually to provide accurate data.

Water Quantity Monitoring

- The manhole at the outlet of each sub-catchment houses a v-notch weir, level probe, flow logger.
- The level probes are installed upstream of the weirs to ensure accurate water level measurements, which are validated with manual water level measurements.
- The flow loggers' record water level measured by the probes and calculate flow based on the height of water over each weir and the associated weir rating curve.
- Runoff is received as sheet flow making it difficult to measure inflow at one central location, so inflow is estimated for each sub-catchment using the Simple Method. The Simple Method transforms precipitation depth into flow and volume based on the catchment characteristics and impervious cover.

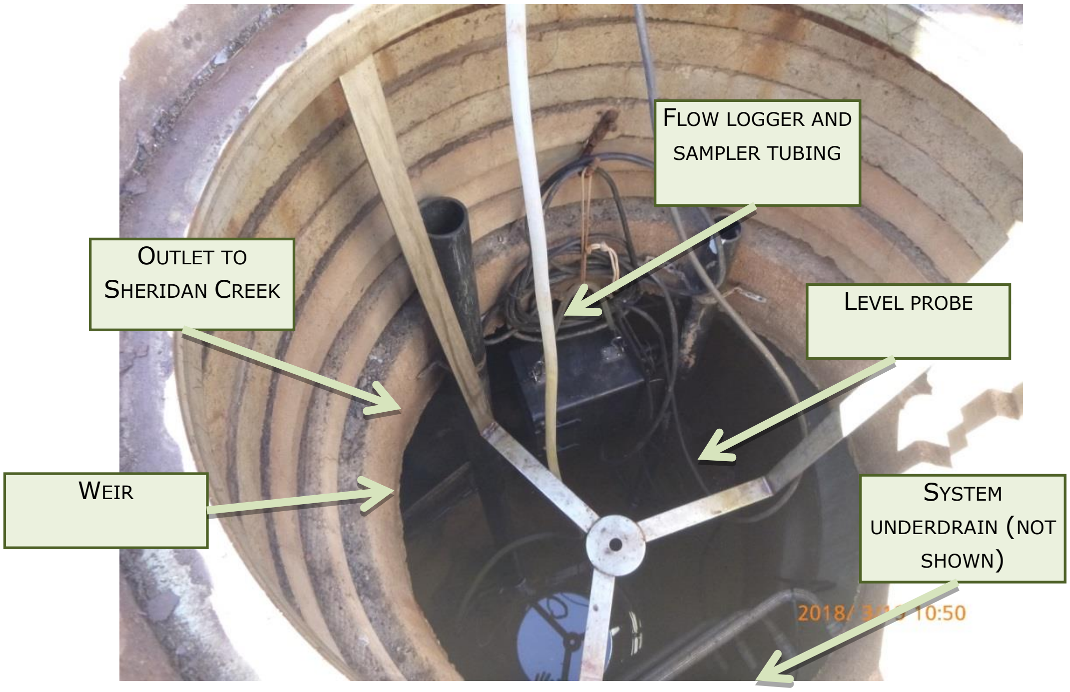

Figure 9: IMAX outlet monitoring manhole and equipment

Water Quality Monitoring

Automatic Sampler

- Each outlet manhole or customized equipment box contains an automatic sampler with a 24 1-litre bottle configuration to capture composite water quality samples from events producing discharge.
- The samplers are programmed to collect discharge based on a fixed time interval, which varies depending on the anticipated event magnitude and duration.
- Bottles that were filled while discharge was observed are used to generate flow-weighted composite samples. This ensures that the samples are representative of the events and provide adequate sample volume to perform lab analyses.
- The samples are analysed for a broad spectrum of parameters including total suspended solids, nutrients and metals.
- In addition, a continuous conductivity probes are installed at two of the permeable pavement stations (IX-5 and 7). Grab samples are collected along the hydrograph for discrete chloride and conductivity. These values are used to calibrate the conductivity loggers installed at both locations and to create a conductivity and chloride relationship.

Figure 10: Autosampler base with 24 1-litre bottle configuration

Figure 11: Staff collecting a composite water quality sample

Water Temperature

- Outlet water temperature is monitored with a pendant-style logger installed in each outlet manhole.
- An additional water temperature logger is located in the Jellyfish Filter reservoir for an inlet comparison.

Infiltration and Groundwater Monitoring

- Observation wells equipped with level loggers are used to monitor changes in water level within the bioretention soil median and aggregate bases for both the bioswales and permeable pavement areas.
- Each bioswale has a well that extends to the base of the bioswale in addition to a shallow well which is used to record information related to duration of ponding and infiltration.
- Four groundwater monitoring wells are located around the parking lot to continuously record water level. Water quality samples are submitted twice a year for lab analysis.

Soil Monitoring

Soil Quality Monitoring

- Soil samples have been collected from the bioretention media in 2013, 2014 and 2016 as a method of pollutant tracking.
- Samples have been collected from the upstream and downstream ends of each bioswale at two depths, shallow and deep, relative to the depth of the bioretention media.

Soil Moisture and Temperature Monitoring

- Recently, a soil moisture monitoring pilot project was added to the monitoring activities at IMAX (see Soil Moisture Monitoring below).
- Soil moisture and temperature sensors, and data loggers were installed in two of the three bioretention swales.

- The pilot project aims to continue and further integrate winter monitoring data into CVC's analysis of LID features.

Monitoring Outcomes

Performance monitoring at IMAX has provided valuable data to address many of the gaps and barriers associated with wide LID implementation. This information has been instrumental in scoping and refining the monitoring activities at IMAX, as well as within CVC's LID monitoring program.

Water Quantity

By providing storage, LID practices are expected to provide a delay in outflow, and a reduction of peak flows during less frequent events. The cumulative storage that can be provided by extensive LID implementation has the potential to reduce flooding as well. Volume reduction is achieved by retaining water (through infiltration or evapotranspiration) such that it does not contribute to outflow from the site. It is important for groundwater recharge and water balance objectives as well as water quality objectives.

Bioretention

Although the main purpose of the bioretention is to provide water quality control, this is typically achieved through volume reduction. Figure 12 presents the inflow and outflow volumes, normalized per unit drainage area, for the bioretention systems for events less than 25 mm between 2014 and 2016. The inflow volumes were estimated for each sub-catchment using the Simple Method. For this range of events, the percent volume reductions achieved by IX-2, IX-3 and IX-4 were 88%, 75% and 66%, respectively. For larger events (not graphed), the percent volume reduction declines; however the LID systems are reducing the volumes during these larger events, thereby alleviating pressure on the stormwater network.

The lower percent volume reduction at IX-4 for events less than 25 mm is attributed to the size of the catchment area. At twice the size of the IX-2 and IX-3 catchments, the IX-4 control bioswale is still performing relatively well. This suggests that the IX-4 bioswale is undersized for its catchment area.

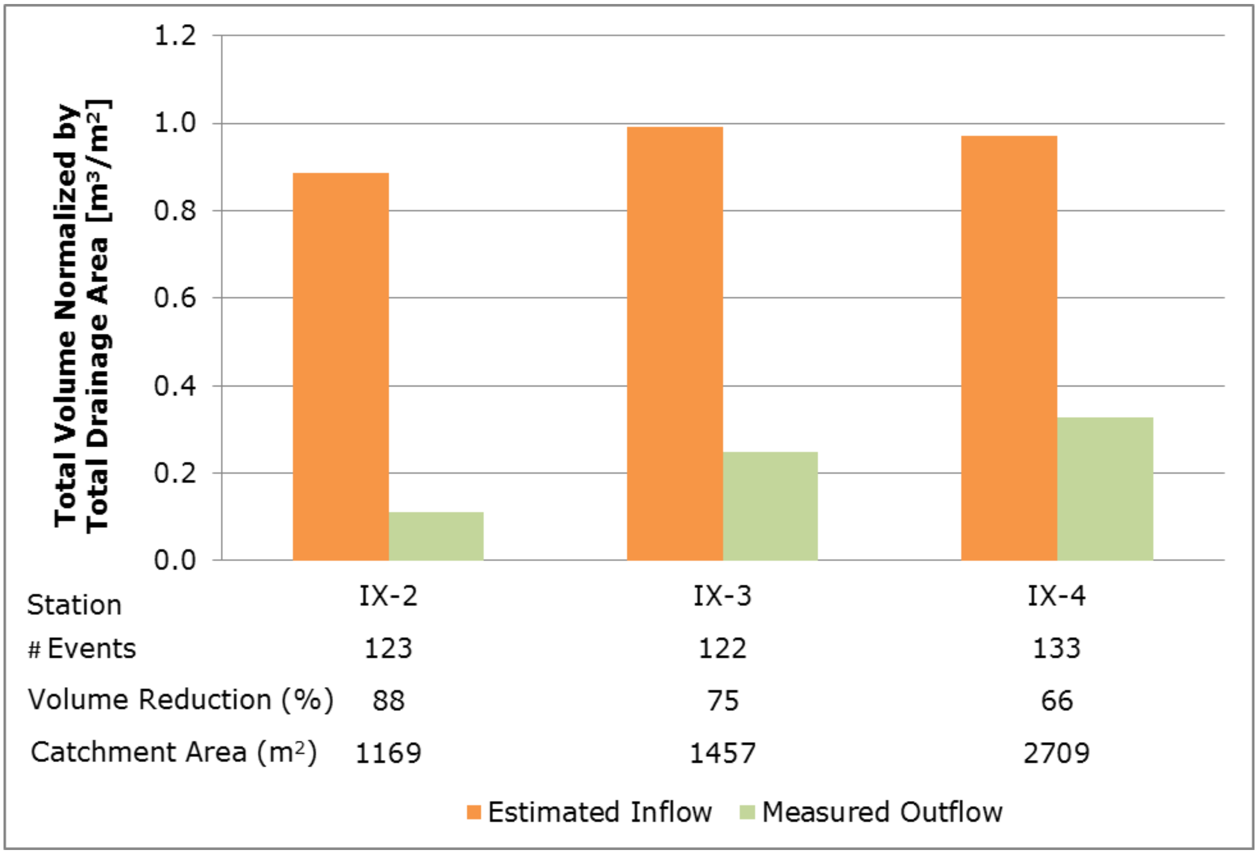

Figure 12: Volume reduction for bioretention systems for events <25 mm

The systems were also found to reduce peak flows during larger, less frequent events, helping to prevent surcharging of downstream pipe infrastructure. For events greater than 25 mm, peak flow is reduced by at least 46% and up to 85% for IX-2, 36% to 78% for IX-3, and 34% to 81% for IX-4.

Soil Moisture and Temperature Monitoring

Continuous soil moisture and temperature monitoring initiated in 2017 at IMAX with the installation of eight soil moisture sensors in two of the bioretention swales. The purpose of this pilot project is to continue and further integrate winter monitoring data into CVC's analysis of LID features. Based on discussions with CVC's LID advisory committee and the challenges with collecting accurate input water balance data, soil moisture is an important parameter that should be monitored to provide a better understanding of performance on a seasonal basis.

Figure 13: Soil moisture data logger installed in a swale

Objectives of the pilot project also include:

- Provide evidence of infiltration during an event, and combined with temperature data offer insight into the conditions in the cells when they freeze;
- Confirm if snowmelt is infiltrating through the feature,
- Confirm the soil conditions throughout the feature during by-pass events,
- Confirm if the feature freezes completely and if infiltration can occur with frozen soil,
- Determine the types of conditions that lead to freezing that might inhibit infiltration,
- Determine the types of weather events that lead to high or low infiltration

The sensors were installed in two bioretention swales, IX-2 and IX-4. Each swale has two data loggers, eight soil moisture sensors, and 8 soil temperature sensors (Figure 14). In each swale, the soil moisture and temperature sensors are installed in both upstream and downstream locations, at both shallow (~0.1 m) and deep (~0.3 m) depths relative to the swale surface. The data loggers are installed between the soil moisture sensor monitoring locations in each swale to reduce the number of data loggers required. The loggers are attached to wooden stakes and the sensor cables are covered in a protective plastic casing to prevent damage.

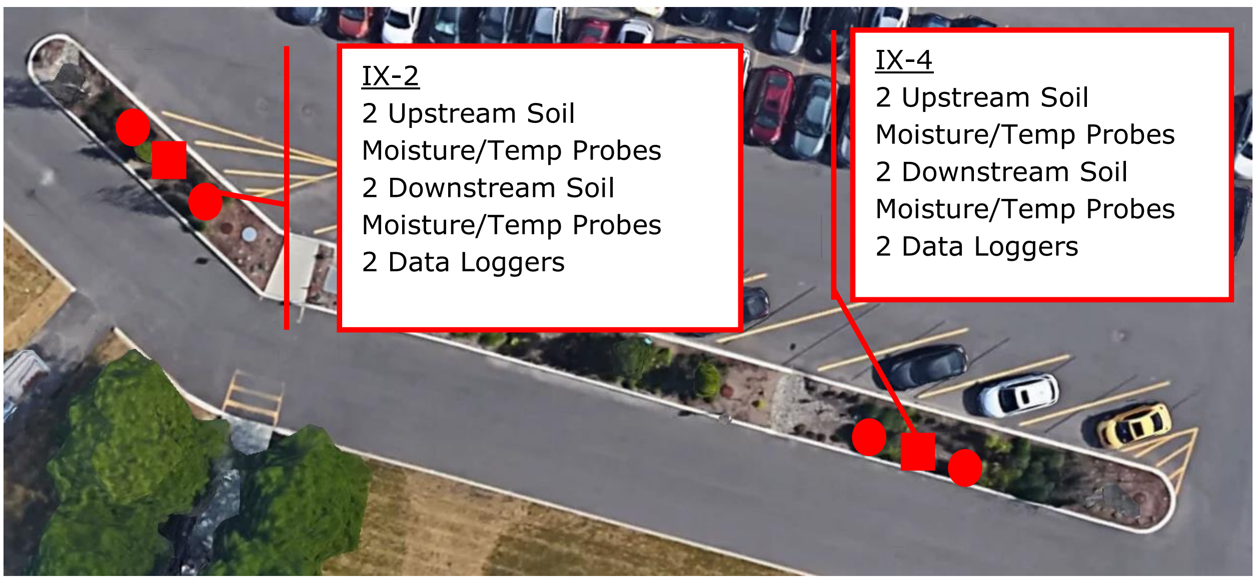

Figure 14: Soil moisture sensor monitoring locations

Installing equipment at different swales allows a comparison in performance between the two swales, which can be related to the different infiltration rates and volume reductions observed in the swales. In addition, if there is any equipment malfunction or unforeseen problem in one of the swales, installing equipment in two swales adds redundancy to the monitoring program. CVC will continue the soil moisture pilot project through 2018 to gain further insight into this type of monitoring and the data outcomes.

Permeable Pavement

Volume reduction was also assessed for the permeable pavement systems. Figure 15 presents the inflow and outflow volumes, normalized per unit drainage area, for the permeable pavement systems for events less than 25 mm between 204 and 2016. For this range of events, the percent volume reductions achieved by IX-5, IX-6 and IX-7 were 61%, 99% and 95%, respectively. These high volume reductions are closely mimicking the natural hydrology and water balance.

The lower volume reduction achieved at IX-5, relative to IX-6 and IX-7, may be caused in part by the lack of a hydraulically separated catchment. The subsurface storage of IX-5 is not lined or separate from the surrounding area. This includes the adjacent greenspace and hill, which could potentially cause run-on to the IX-5 catchment, or subsurface seepage, generating more outflow. During construction, a geosynthetic clay liner was placed between IX-5 and IX-6 to hydraulically separate the areas, since they have different aggregate bases; IX-5 has granular “O”, where IX-6 and IX-7 have ¾ inch clear stone. Granular “O” still has fines attached to it, which may be occupying storage space compared to the clear stone which has been washed of fine material. Unlike the other two permeable pavement systems, IX-5 has 150 mm lateral pipes throughout its storage layer that are connected to the underdrain. These may also help runoff enter the underdrain through a more direct path. In comparison, both IX-6 and IX-7 have relatively high volume reductions. This is likely due to the aggregate material. In the case of IX-7, it may be possible that a leak is present in the liner, since the underdrain is located near the base of the feature and little water is observed discharging from the system.

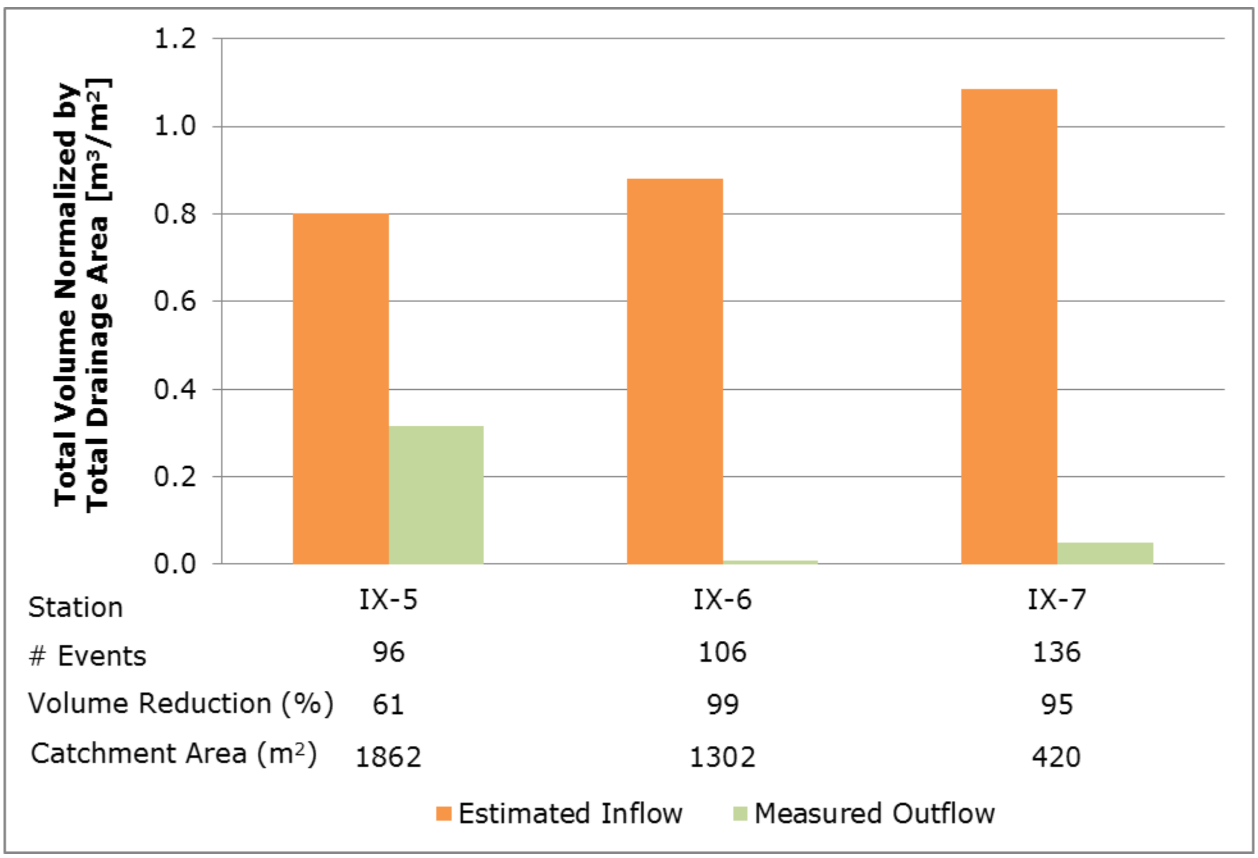

Figure 15: Volume reduction for permeable pavement systems for events <25 mm

The permeable pavement systems were also found to reduce peak flows during less frequent events, helping to prevent surcharging of downstream pipe infrastructure. For events greater than 25 mm, peak flow is reduced by at least 39% and up to 84% for IX-5, 31% to 100% for IX-6, and 66% to 92% for IX-7.

Water Quality

The inflow loads for both the bioretention and permeable pavement systems were calculated using median event mean concentrations (EMCs) from the National Stormwater Quality Database (NSQD), filtered for commercial, industrial and institutional land uses, and the estimated inflow using the Simple Method. To calculate outflow loads, the EMCs for a particular event were used if the event was sampled and analyzed. If no lab analyses were available for a particular event, the median EMC for each station and parameter were used. For precipitation events that did not produce outflow, the load reduction was 100%. The total estimated influent and effluent loads were obtained by summing the results for all events from all seasons.

Bioretention

Table 2 provides the load reduction results for the bioretention systems for six parameters of interest for events between 2014 and 2016. Boxplots of the sampled EMCs for total phosphorus (TP), orthophosphate (OP), and total suspended solids (TSS) are displayed in Figures 16-18. The bioretention swales are performing well with respect to reducing contaminant loads from the sub-catchments to downstream watercourses. Load reductions ranged from 37% to 98%, depending on the parameter and station. The degree of load reduction is influenced by the size of each sub-catchment area. As discussed above, the catchment for IX-4 is larger than that of IX-2 and IX-3, and receives more runoff which may lower the load reductions.

Both IX-2 and IX-3 feature proprietary units working in conjunction with the bioswales to provide water quality treatment. At IX-2, treatment is provided by the bioswale followed by a Sorbtive Media Vault. The Sorbtive Media is designed to polish runoff and provide nutrient removal, with a focus on dissolved phosphorus. IX-3 provides treatment through first entering a series of Jellyfish Filters, followed by the bioswale. The Jellyfish Filters are designed to remove a variety of pollutants, including suspended solids, oils and greases.

IX-2 achieved the greatest TP reduction at 87%, compared to IX-3 and IX-4 at 56% and 37%, respectively. As shown in Figures 16 and 17, the EMCs of TP and OP were lower at IX-2 than the two other swales. The high TP reduction and lower TP and OP EMCs indicate that the Sorbtive Media is functioning well to remove both TP and dissolved phosphorus.

While each bioswale achieved a high TSS reduction (97%, 98% and 94% for IX-2, IX-3 and IX-4, respectively), IX-3 attained both the greatest TSS load reduction and event mean concentrations (Figure 18), demonstrating that the Jellyfish Filter pre-treatment is more effective at removing TSS than the other monitored systems.

Table 2: Load reductions for the bioretention systems

System	IX-2	IX-3	IX-4
# composite samples, # events	42, 136	33, 138	38, 147
Parameter (units)	Estimated Load Reduction (%)		
Total Suspended Solids	97	98	94
Total Phosphorous	87	56	37
Total Kjeldahl Nitrogen	89	76	65
Nitrate + Nitrite	87	60	43
Copper	91	86	73
Zinc	98	97	95

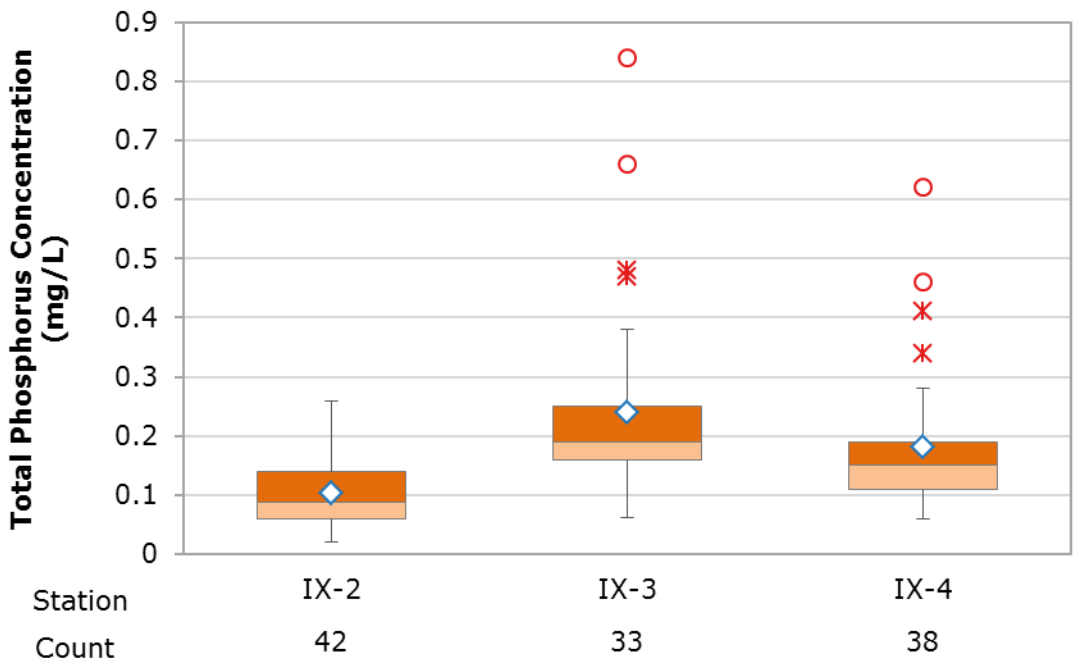

Figure 16: Box and whisker plots of effluent total phosphorus event mean concentrations in the bioretention systems

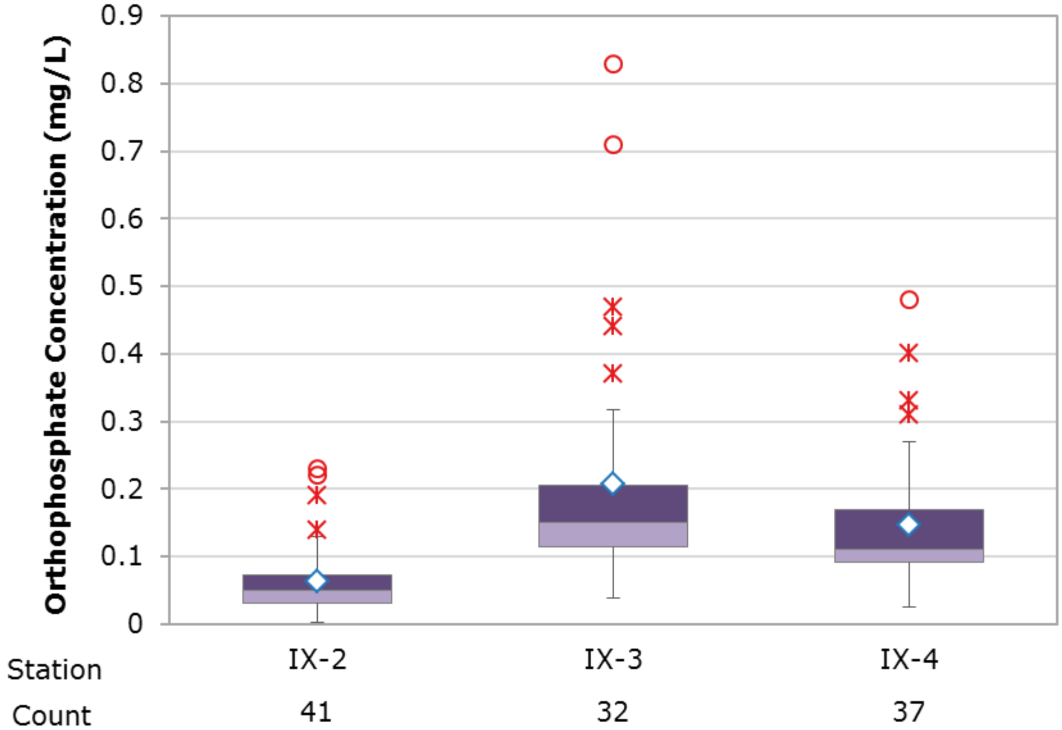

Figure 17: Box and whisker plots of effluent orthophosphate event mean concentrations in the bioretention systems

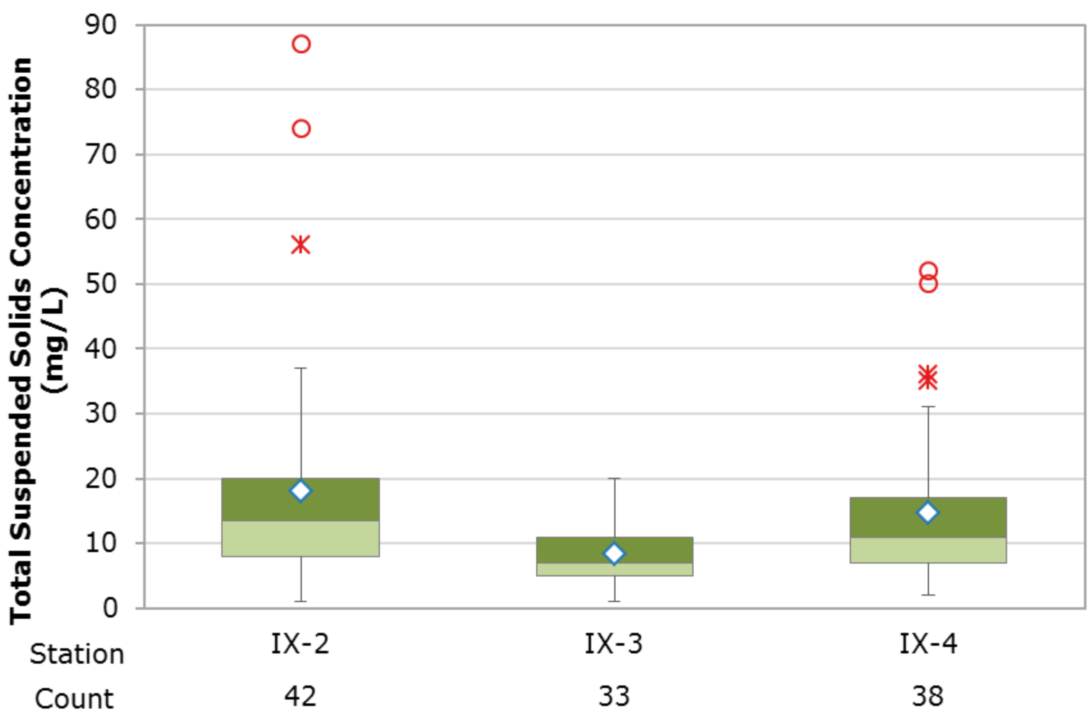

Figure 18: Box and whisker plots of effluent total suspended solids event mean concentrations in the bioretention systems

Permeable Pavement

Table 3 provides the load reduction results for the bioretention systems for six parameters of interest for events between 2014 and 2016. Load reductions ranged from 41% to 99%, depending on the parameter and station. Load reductions were greatest at IX-6, which is likely due to the extremely high volume reductions observed.

Table 3: Load reductions for the permeable pavement systems

System	IX-5	IX-6	IX-7
# composite samples, # events	25, 111	11, 117	33, 149
Parameter (units)	Estimated Load Reduction (%)		
Total Suspended Solids	92	99	96
Total Phosphorous	80	98	97
Total Kjeldahl Nitrogen	78	98	96
Nitrate + Nitrite	41	94	92
Copper	79	98	96
Zinc	90	99	98

Thermal Mitigation

The LID performance sites at IMAX are being evaluated for thermal mitigation potential by developing event mean temperatures and thermal loads of influent and effluent. Event mean temperature is the average temperature of water flowing in and out of the LID facility during an event whereas thermal load is the amount of energy in mega joules (MJ) introduced to the LID facility from heat transferred to stormwater from surface runoff. In order to assess thermal mitigation and calculate event mean temperatures, temperature loggers were deployed within the effluent manhole of each LID performance site and the influent Jellyfish reservoir at IX-3. The influent temperature collected from IX-3 was used to analyze thermal reduction potential at each site. These inlet temperature readings where assumed to be equivalent to runoff temperatures throughout the entire parking lot.

Figures 19 and 20 present the thermal load reductions for the bioretention systems and permeable pavement systems, respectively. These graphs focus on events less than 25 mm between May and September in 2015 and 2016.

The thermal mitigation analysis at IMAX has found:

- The number of events analyzed varies for each station since each station has a different size catchment area which influences the inflow volume required to generate flows from site to site.

- IX-5 generates long extended flows after large events. These flows are further extended when a subsequent precipitation event occurs while flows are slowly receding.
- For the bioretention systems, thermal load reductions range from 73% to 86%, with the lowest reduction observed at IX-4 where the catchment area is the greatest compared to the catchments of IX-2 and IX-3.
- For the permeable pavement systems, the reduction is greater at IX-7 than IX-5 due to the higher volume reduction through storage. IX-6 was not included in this analysis, since few outflow events were produced in the <25 mm range

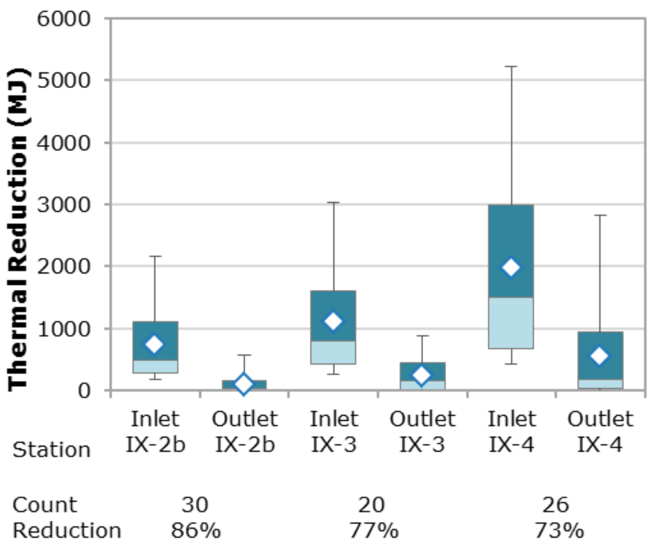

Figure 19: Thermal load results for events the bioretention systems for events <25mm, 2015-2016

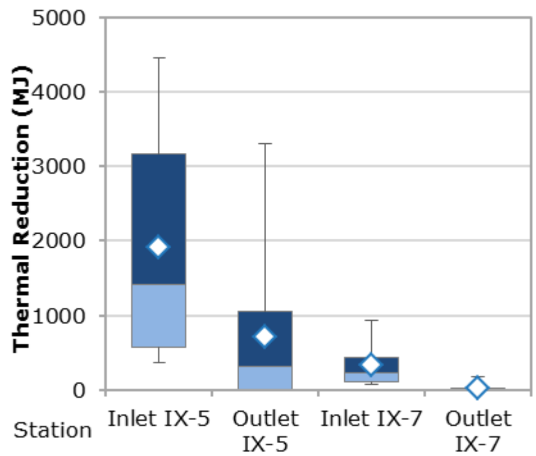

Figure 20: Thermal load results for events the permeable pavement systems for events <25mm, 2015-2016

Inspection and Maintenance

Since 2013, staff has been collecting data on maintenance activities performed, and inspecting conditions of the bioswales (IX-2, IX-3 and IX-4) and permeable pavement (IX-5, IX-6 and IX-7) at IMAX on a monthly basis. A standard site inspection checklist has been created and is used during each visit. A photo inventory is also maintained, documenting site conditions. This inspection along with interviews with property owners has led to the creation of a maintenance database, to track maintenance tasks and needs to help determine life-cycle costs.

From 2013 to 2017, 65 inspections have been completed at IMAX, providing valuable information on conditions within the LID features such as inlets, overflows and outlets, in addition to the surrounding catchment area.

Based on the site inspections the main reoccurring maintenance issues at IMAX include:

- Soil clogging the permeable pavement in the IX-5 catchment due to excavated soil being stored on the feature,
- Leaf debris collecting within the swales in the fall season,

- Difficulty establishing certain types of vegetation in the swales (i.e. trees and non-drought tolerant vegetation), and
- During the winter months the swale inlets to the bioswales have occasionally been blocked with snow.

Maintenance activities are organized and performed by IMAX staff. Based on an interview with IMAX staff, no maintenance activities have been performed on the permeable pavement to date. Ongoing maintenance activities are performed on the bioswales by a landscaping contractor. Activities typically include trash removal, clearing inlets, weeding and cutting back perennials, removing plant debris, pruning out unwanted vegetation, snow removal at inlets and outlets, and removal of mulch layer and raking the surface. It is estimated that it takes a team of 4-8 people 4-5 hours to complete the landscaping of the entire property. Of that total time it is estimated that the bioswales take approximately 40 minutes to maintain. Since the landscaper provides costs based on the entire property it is unknown how much it costs to maintain the bioswales.

The Jellyfish Filters are inspected yearly by a contractor and are either cleaned or replaced as needed. Typically, the filters are cleaned and rotated yearly, costing approximately $350 per year. In 2017, the Jellyfish Filters were replaced, the reservoir sump was cleaned out and the waste water disposed of. To date, there is no record of maintenance activities performed on the Sorbtive Media; however the fabric filter cloth was replaced in the Sorbtive Vault in 2017. The total cost of these maintenance activities for both the Jellyfish and Sorbtive units in 2017 was $8,150.

Adaptive Management

As part of adaptive management, stormwater management has evolved over time from flood control requirements, to water quality and erosion requirements, to water balance requirements. The cost and complexity of these engineered systems has increased. In light of the current spot light on climate change and aging infrastructure there is growing awareness that stormwater management has become more than just treating a storm event it's also about maintaining stream flows during dry weather periods for wastewater assimilation, fisheries, and water takings.

Results from IMAX and other similar performance studies will provide private land owners and municipalities with the knowledge they need to make informed decisions on the role of green infrastructure for stormwater management. They are essential to gain insights into preferred designs and advancements which may be needed to meet stormwater management and other objectives cost-effectively. This data can help inform the planning and implementation processes required for green infrastructure such as informing the credit application process for the City of Mississauga's stormwater charge. Studies such as IMAX are also providing the local, long-term performance data needed to conduct the integrated life-cycle analysis required for asset management, including tracking operations and maintenance activity need, frequency and cost.

Knowledge Transfer

One of the main objectives of CVC Stormwater monitoring program is to educate and communicate the performance outcomes to our partners and stakeholders about the effectiveness of LID at managing stormwater risks, reducing infrastructure costs and liability, and improving the resilience of our stormwater management systems. CVC communicates monitoring results through reports, presentations, site tours, and other public forums. To further share our monitoring knowledge and expertise, CVC has partnered with the Sustainable Technologies Evaluation Program (STEP). STEP was established as a multi-agency initiative to provide data, scientific evidence, analytical tools, and the expertise needed to support broader implementation of sustainable technologies and practices with a Canadian context. To better coordinate research activities and facilitate knowledge transfer related to urban runoff management, a memorandum of understanding is underway between TRCA, LSRCA and CVC to provide a framework for collaborative activities, such as professional training initiatives.

Through STEP, CVC has co-developed a monitoring training module to complement the existing design, construction, and inspection and maintenance modules focussing on stormwater and LID facilities. The module is offered in a variety of formats include half and full day workshops where participants have the opportunity to learn monitoring techniques, explore case studies and participate in activities including monitoring plan development and hands-on equipment sessions.

Next Steps

CVC will continue the monitoring activities at IMAX to inform our monitoring program and objectives, and deliver on our commitments to our partners. Moving forward, CVC is looking for partnership opportunities to grow and develop our monitoring program and address our core monitoring objectives. This may require modifying our monitoring methodology to explore new monitoring techniques, such as the soil moisture monitoring at IMAX.

Additional information on the performance of the LID features at IMAX and other projects can be found on our website at **http://www.cvc.ca/LID**.

Figure 25: IMAX bioswale

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- IMAX
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[i] Atkins. 2015. Flood Loss Avoidance Benefits of Green Infrastructure for Stormwater Management. Prepared for United States Environmental Protection Agency, December 2015. Available at URL: https://www.epa.gov/sites/production/files/2016-05/documents/flood-avoidance-green-infrastructure-12-14-2015.pdf.